Indigenous Lands, Protected Areas, and Political Ecology: A GIS-Supported Analysis of Conservation and Land Rights in the Brazilian Amazon

By
Seth Greer
University of Colorado Boulder

A thesis submitted to the
University of Colorado Boulder
In partial fulfillment
Of the requirements to receive
Honors designation in
Environmental Studies

Defense date: October 19th, 2022

Thesis committee
Cassandra Brooks, Department of Environmental Studies, Primary Advisor
Colleen Scanlan Lyons, Department of Environmental Studies, Honors Council representative
Joe Bryan, Geography, Outside Reader

Table of Contents:

Abstract:

The Amazon Basin is viewed as an essential area for global conservation due to its biodiversity and larger impacts on climate and carbon cycling. Inidgenous Peoples in the Amazon represent a significant population, and have a relatively large amount of officially tenured land. These lands are often cited to be relatively ecologically healthy, drawing comparisons to governmental Protected Areas (PAs). In this project, I compared the effectiveness of National PAs, State PAs, and Indigenous Lands in preventing deforestation and mining on their lands using GIS analytics. Indigenous Lands had a difference of 8.7% between mean deforestation levels in areas inside of and outside of them. This difference in means for National PAs was found to be 7.3%, and 5.7% for State PAs. Indigenous Lands had 192,226 square kilometers of mined area within their boundaries, representing 16.18% of Indigenous Lands. A very small amount of this mining was found to be illegal, only National PAs displayed overlap with 92,226 square kilometers of mining operations, only 177.42 square kilometers, or .014% of Indigenous Lands. National PAs were found to overlap with 106,014 square kilometers of mining, around 15.27% of their land area. However, they also hosted 3,726 km2 of illegal mining operations, representing .055% of total lands in National PAs. State PAs had 96,837 km2 of mining, taking up 16.27% of their lands, but zero illegal mining, at least at the resolution of study. Indigenous Lands were therefore found to be relatively effective conservation units in the Amazon. The existence of these lands as sanctuaries from degradation is thanks to a combination of traditional land practices intertwined with Traditional Ecological Knowledge and deliberate social movements that have advocated for these lands over the past 50 years.

1: Introduction

Almost no region on Earth is as ecologically and socially rich as the Amazon Basin of South America. Covering about 8.4 million square kilometers, or 5.2 million square miles, approximately the size of the continental United States (Alves, 2022), the Basin spans a vast range of different ecosystems, cultures, and socioeconomic strata. Amazonia is recognized in the global conservation community as an area of particular focus. It contains the largest continuous stretch of rainforest on the planet, and is considered by many to be the most biodiverse region on Earth as well, containing around 10% of global biomass and productivity (Foley et al, 2007). The sheer mass of the basin has repercussions on global ecology as well. The Amazon's drainage of 7,381,000 cubic feet per second accounts for ⅕ of all freshwater on Earth, and the forests of the Amazon alone have the capacity to sequester up to 2 billion tons of CO_2, about 20% of the totals emitted from the burning of fossil fuels (Tigre, 2019).

However, the days of viewing conservation efforts through a solely ecological lens are in the past, and it is important to recognize the unique social realities of the area as well. The Amazon is home to around 33 million people spread across 9 countries, spanning a variety of social, economic, and political strata, including as many as 1.5 million Indigenous Peoples belonging to around 385 different tribes. (Vallejos et al, 2020). Indigenous Peoples in particular, through thousands of years of everyday realities, have developed a unique and irreplaceable knowledge and relationship with the land, commonly known as Traditional Ecological

Knowledge (TEK). In the last half a century, thanks to rural social movements and international support, Indigenous Peoples in the Amazon have been able to secure legal tenure over a portion of their rightful land, allowing more freedom to practice land relations inspired by TEK. This project will use GIS Analytics to assess the correlation of three different land protection regimes – Indigenous Lands (ILs), National Protected Areas (NPAs), and State Protected Areas (SPAs) – with protection from degradative land use change. It will then attempt to draw connections between these statistics and the political ecologies and histories of these different areas. While this analysis will be on an overall coarse level, it will demonstrate how GIS can be used in the Amazon and similar areas to bring into focus conservation efforts and contextualize them to the realities of the regions of study. Due to the Amazon's large size and variety of national government structures within this area. I will focus this particular study on the areas of the Amazon Basin that fall within the borders of Brazil. Brazil contains 61.9% of the Amazon's land area, and Brazilian policy and economic relations have significant effects on the region as a whole (Alves, 2022; Hecht & Cockburn, 2011). While studies of the Brazilian Amazon don't represent the entire area, they can act as suitable proxies for social and ecological phenomena of the Amazon Basin as a whole.

2: Background

Ecology of the Amazon Basin

For much of recorded history, the Amazon has presented a key focus for both economic projects and ecological research and sustainability efforts. But the Amazon has proven itself to be far from an ecological Eden to those who would both exploit its resources and attempt to preserve them. Reducing the Amazon to a simple homogenous rainforest region has proven foolish, and a vast variety of ecosystems cover its massive land area. These various ecoregions have proven not to be easily exploited by traditional European agriculture, but support a variety of localized small-scale economies that have supported rural populations for hundreds of years.

The Basin is bookended by the Guianan Shield formation to the North and The Brazilian Shield to the South, two of the oldest rock formations on Earth, and by the geologically young Andes Mountains to the West. Between these mountains, the Amazon and its thousands of tributaries crisscross the basin, creating a collage of floodplains in the low-elevation continental center that give way to rocky cataracts as the terrain gets rougher closer to the mountainous shields (Hecht & Cockburn, 2011).

The sedimentary content carried down from the highlands has wide-ranging effects on local ecosystems, and leads to categorization of river systems as *whitewater, blackwater* or *clearwater*. Whitewater river systems like the central channel, known in different areas as the Amazonas or Solimões River, contain incredibly high levels of dissolved minerals derived from the Andes. These clayey sediments are deposited on the banks en masse, forming large floodplains known locally as the *varzea,* where the low-pH river water can support various forms of pasture and animal husbandry (Araújo et al, 2017; Junk et al, 2015). Elsewhere, in blackwater watersheds, mainly the Rio Negro, humic acids stain the water ink-black and lead to poor soil quality and stunted forest growth (Hecht & Cockburn, 2011). Blackwater rivers create large interfluvial *igapós*, flooded forests commonly referred to as 'dead forests' due to the lack of ecological and economic productivity (Junk et al, 2015). Clearwater rivers like the Tapajós contain little suspended minerals, and hover in the middle of the pH scale. *Igapós* located in clearwater systems are much more productive than those of their blackwater counterparts (Araújo et al, 2017).

In addition to differences in water acidity and mineral content, the Amazon Basin can be categorized by seasonally flooded and non-flooded areas, presenting obvious differences in ecosystems and biotic productivity. Fig. 1 visualizes the mosaic of water composition and inundation in the Amazon basin. River colors were determined using base data on Amazon rivers cross-referenced with river color data (Venticinque et al, 2021; Junk et al. 2015) then manually reclassified in ArcMap 10.0. Seasonal Flooding data was extrapolated to an ecotone scale using global ecoregion data manually reclassified to flooded or dry areas using data regarding individual ecoregions and their inundation statuses ((Dinerstein et al, 2017); Schipper).

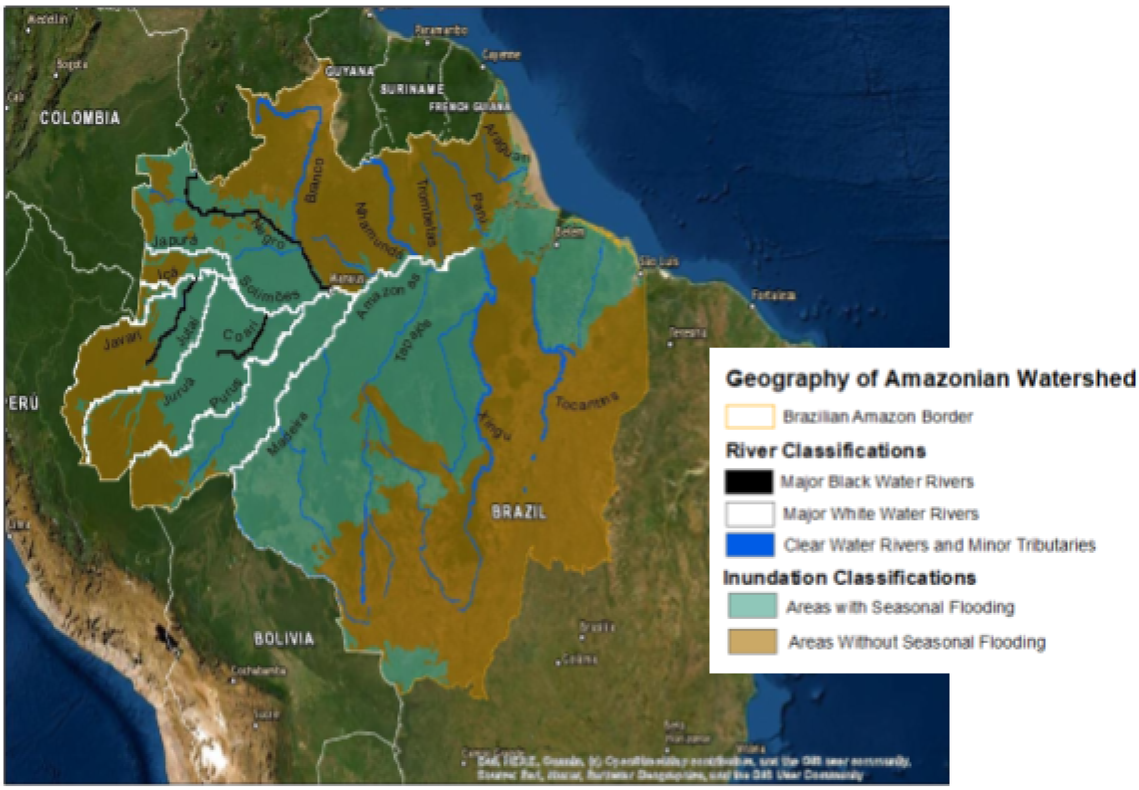


Fig. 1: Map delineating river classifications and inundation status in the Brazilian Amazon

These geomorphologic variables result in a mosaic of biomes within the Amazon Basin, and dramatic ecological variability between these zones, even over short distances. In the Manaus region of Brazil, forested plots as little as 50 miles apart share only about 1% of species makeup (Hecht & Cockburn, 2011). Overall, the Amazon, by some delineations, contains 30 separate ecotones, ranging from flooded *varzeas* and *igapós* to rocky *terre firme* highlands to vast areas of *cerrado* savanna (Hecht & Cockburn, 2011). Fig. 3 shows individual ecoregions of the Amazon based on global ecoregion information (Dinerstein et al, 2017).

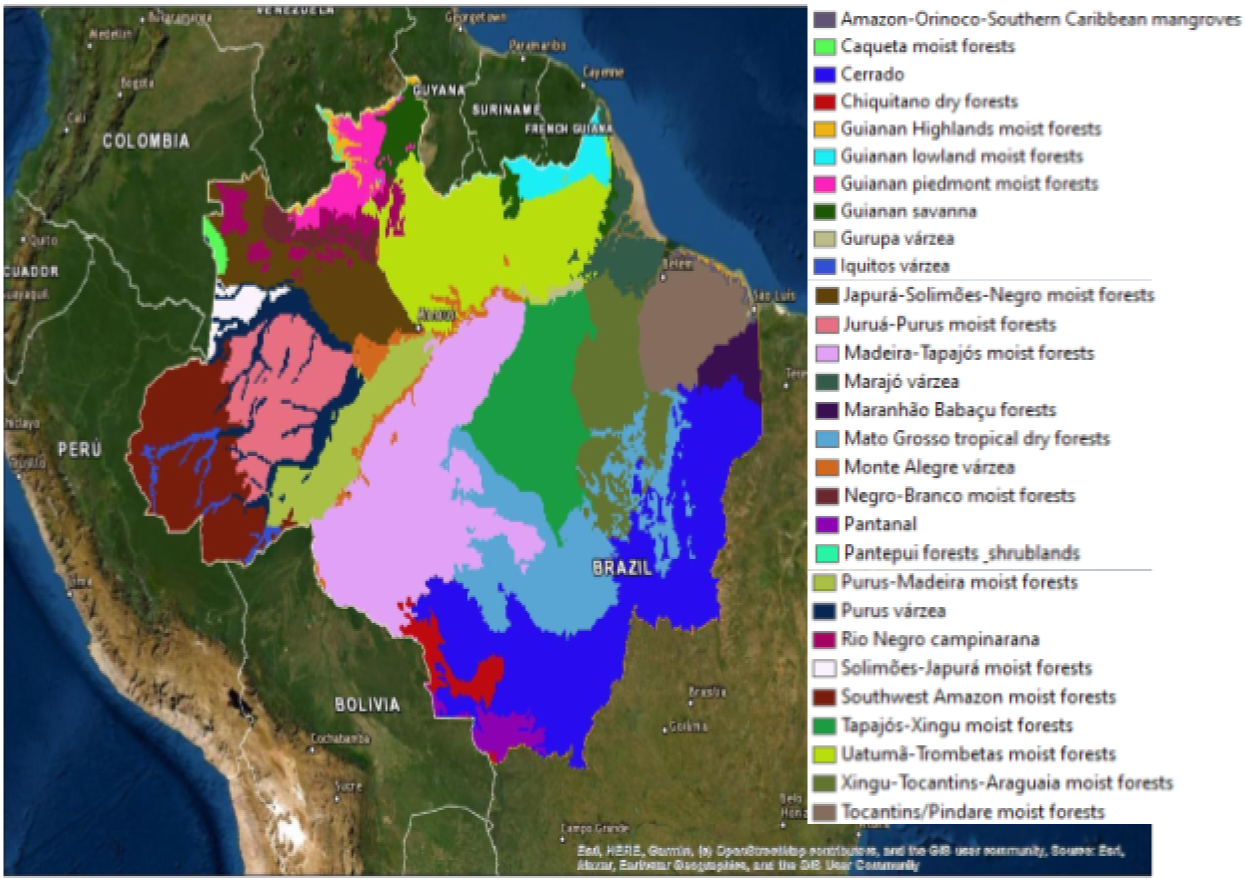


Fig. 2: Ecotones of the Brazilian Amazon

Economic Relations and Land Degradation in the Amazon:

The ecological realities of the Amazon have led to a convoluted history of social and economic relations. Indigenous Peoples have resided in the Amazon for thousands of years. They have developed an intimate knowledge of and relationship with the unique ecosystems they inhabit that will be reviewed later in this paper. The onset of Western colonization, however, posited the Amazon in a different light, as an object of conquest from which both national destiny and untold riches could be drawn. In the hundreds of years since Europeans first set foot on the continent, the Amazon has been the site of various economic visions. While difficulties comprehending the ecology of the region staved off significant profit for colonists for several hundred years, the Rubber Boom of the 1800s proved to be the economic spark that the basin was presumably waiting for. For about a hundred years, starting in the 1820s, the economies of the Amazon were arranged mainly to support the production and international sale of rubber. The rubber economy of the region experienced additional booms with the invention of vulcanized rubber in 1839 and rubber tires –and the subsequent automobile industry– in 1870 (Dürr, 2020). Although the rubber boom brought the global market to the forests of the Amazon, it brought with it an economic system that didn't represent the onset of industrial capitalism that was presenting itself elsewhere across the world. Instead, the rubber economy relied on a semi-feudal extractivist system. Peasant rubber tappers or *seringueiros*, would live and tap in small local communities (*seringals)*. Extracted rubber balls were then sold to *barracao* trading posts belonging to increasingly wealthy rubber barons for measly and grossly inflated basic goods. This system prevented any economic mobility and was usually backed by threats of violence (Hecht & Cockburn, 2011). Although the rubber boom began to recede in the 1910s, the increased presence of non-Indigenous and mixed-race extractivists in the inner Amazon, as well as the precedent of debt peonage to larger landowners, remained.

The rubber boom had also opened the gates of the Amazon to the global economy at large. The next century was dotted with large-scale development projects that proved to be of high cost, both monetarily and in terms of human lives, despite being largely unsuccessful. Construction of the Madeira-Mamore railroad, completed in 1912, cost up to 10,000 workers their lives before the end of the rubber boom a few years later rendered it essentially useless (Neeleman et al, 2013). From 1928-1945, Henry Ford's *Fordlandia* rubber plantation, built with no mind paid to natural conditions, lost over 9 million dollars before being sold back to the Brazilian government (Hecht & Cockburn, 2011). Early projects like these spoke to the enigmatic nature of the Amazon's ecology as it applied to modern capitalistic enterprises, and also to the international desire for increased economic development in the region. In the years after World War II, large-scale economic expansion projects were amplified as Brazil went through severe political unrest, revealing itself in the form of coups in 1945 and '54 and a prolonged military autocracy from 1964-85 (Skidmore, 1988). Under the rule of the military generals, Amazon development was seen as part of the Brazilian national destiny more than ever before. The government gave large-scale development plans in the inner Amazon every economic break in the book. Among other projects, it funded the construction of a Trans-Amazonian Highway, finished in 1972, and encouraged increased settlement in the Amazon by allocating parcels of land in the inner reaches of the forest to poor settlers from the North. These and similar policies displaced thousands of Indigenous Peoples and other Forest People like *seringueiros* and led to widespread social unrest (Hecht & Cockburn, 2011).

Even after the return of a democratic regime in Brazil in 1988, the push for privatization and development continued, with further consequences for rural communities and the forest. Although gold mining had always been present on the banks of Amazonian rivers, the second gold rush of the 1980s brought more miners to the basin than ever before. Most mining in the Amazon is done in *garimpos*, generally primitive and labor-intensive mining claims where *garimpeiros* scour the mud by hand looking for the rare opportunity for upward mobility. *Garimpeiros*, usually poor landless men from local peasantry or nearby urban populations, can hardly be blamed for the socioeconomic situation they find themselves in that forces them to rely on the *garimpo.* However, mining in this method is still highly unsustainable. Approximately 2 tons of mercury and other harmful chemicals are released into the waterways for every 1 ton of gold extracted at placer mines (Hecht & Cockburn, 2011). Multiple studies have found that in areas with high mining concentrations, such as the Tapajós watershed, fish, river dolphins, and other riparian vertebrates display dangerous levels of mercury contamination (Da Silva-Junior et al, 2018; Mosquera-Guerra et al, 2019). In many cases, this contamination is also found at unusually high concentrations in local rural populations, who rely on river fish as a dietary staple. Mercury poisoning can have significant negative effects on the nervous system, including motor skill depreciation, blindness, deafness, and even death (Mosquera-Guerra et al, 2019). On top of affecting ecosystem health, Amazonian mining causes significant land degradation. Between 2005 and 2015, mining operations were estimated to account for 9% of all Amazonian deforestation, significantly increasing deforestation statistics up to 70 km away from active mining sites (Sonter et al, 2017). Mining operations also regularly intrude on Indigenous lands and national parks, furthering social unrest in the basin (Hecht & Cockburn, 2011).

Although mining operations have had significant negative effects on regional ecology, the most unsustainable economic practice of the last 40 years has been large scale deforestation due to the presence of industrialized ranching projects. 90% of forest cleared in the Amazon is to make room for ranching operations, which replace productive native ecosystems with exotic grass pastures that are not adapted to the shallow Amazonian soils. This results in 'feeble monocultures' that have microclimates that can be up to 20^ F warmer than surrounding areas, affecting local water economies and regional climate. These pastures are easily outcompeted by nonproductive brush, resulting in the need to clear more land for pasture and an unsustainable positive reinforcement cycle (Hecht & Cockburn, 2011). Largely thanks to private ranching operations, the Amazon has displayed the highest absolute rate of deforestation ever measured in the last 40 years (Zimbres et al, 2017). Expansion of agribusiness also displaces small-scale agriculturists, many of whom have been cultivating their lands generationally for up to 200 years, in addition to increasing the removal of Indigenous Peoples from their traditional lands (Gutberlet, 1999). Although there have been past efforts by the government to curb this unsustainable development, many have been reversed in the last several decades, punctuated most recently by the large-scale deregulation of agribusiness under the current Bolsonaro regime. Expansion of livestock and pasture lands increased from 37 million to 57.8 million acres between 1995 and 2017 (Domingues & Sauer, 2022).

Although the basin has a long and convoluted history of socio-economic relations, several common themes have presented themselves. As time has passed, larger and larger economic interests have prevailed, more often than not at increasing ecological costs to the natural environment of the basin. Furthermore, the various large and small-scale economic projects of the area have almost always led to antagonism between corporate and governmental interests, landless peasantry, and Indigenous Peoples of the basin.

Protected Areas and Indigenous Lands:

Natural Protected Areas (PAs) have long been viewed as one of the most essential tools in conservation. Like many countries, the Brazilian government has a system of PAs established to ensure threatened land is protected from unsustainable development. The Brazilian system of PAs is divided into National PAs (NPAs) and State PAs (SPAs). The land protected by each category is similar in area, with 52% of the PA system falling under federal authority and 48% under state authority (Ryland & Brandon, 2005). The areas within these PAs are designated as one of two protection statuses. Strictly protected areas include National Parks, Biological Reserves, Ecological Stations, Natural Monuments, and Wildlife Refuges, and are regulated with protection of biodiversity as the first and foremost goal. Strictly protected areas have staunch zero-extraction policies. Protected Areas of Sustainable Use have joint goals of sustainable extraction and biodiversity protection, supporting a range of economic activities that are sustainably regulated. These include National Forests, Environmental Protection Areas, Areas of Ecological Interest, Extractive Reserves, Fauna Reserves, and Sustainable Development Reserves. Federally protected areas are about 48% strictly protected areas and 52% protected areas of sustainable use, whereas areas under state control have only 16.5% of lands under the status of strict protection, and 84.5% of lands designated as protected areas of sustainable use (Ryland & Brandon, 2005).

Brazil also contains a network of lands officially tenured to their original Indigenous inhabitants. Indigenous Lands (ILs) in Brazil are often communally managed by tribes in accordance with traditional practices. They are often officially recognized as public lands over which individual tribes have legislative autonomy, allowing them to control economic practices that take place on their lands. To say ILs were codified by any legislation would be a short-sighted approach, as all of the Amazon was at one point stewarded by Indigenou People, but official recognition of ILs as legal entities came in the 1988 Constitution. This recognized Indigenous Residents of these areas as the original and rightful inhabitants of their lands, prioritizing these land rights over any other claims (Begotti & Peres, 2020). While not technically PAs, ILs often show positive conservation statistics due to the lack of degradative practices like mining and logging within their borders (Begotti & Peres, 2020).

All three aforementioned land designations represent significant areas of the Amazon Basin. Indigenous Lands take up around 22.85% of land in the Brazilian Amazon, with NPAs representing around 12.97% and State PAs representing about 11.45%.

3: GIS Analysis: PAs and Conservation:

Objectives:

Geographic Information Systems, or GIS, can be a very useful tool in both visualization and analysis of spatially dependent data. With the emphasis on land use, rights, and relations across space, conservation in the Brazilian Amazon presents a perfect candidate for an effective GIS exploration. In this analysis, I seek to determine the comparative effectiveness of NPAs, SPAs, and ILs in curbing land degradation in the Brazilian Amazon region.

Data in Use:

Vector layers for land designations were taken from 2020 data published by the Amazon Network of Georeferenced Socio-Environmental Information (*Rede Amazônica de Informação Socioambiental Georreferenciada* or RAISG), an Amazonian-based program that gathers and disseminates on-the-ground data into public GIS layers. I downloaded layers showing NPAs, SPAs, and Indigenou Lands in the Amazon (RAISG, 2020a; 2020b; 2020c). Conservation success is a vague and hard-to-measure statistic that incorporates a multitude of factors, so effectively describing it in an analysis such as this one would prove to be challenging. I used two datasets to serve as proxy-statistics for conservation. Firstly, I used forest loss statistics from the Global Forest Loss data gathered by Hansen et al and updated every year. The data in use is updated to 2020 and was taken from the Global Forest Watch Website (Hansen et al, 2013). While forest degradation is a multifaceted process, deforestation represents degradation at its most extreme and difficult to reverse. Additionally, I used 2020 data from RAISG that reported locations and extents of mining operations across Amazonia, containing one layer that showed all areas where mining was present and another that presented only illegal or illegitimate mining to determine the total of these operations are occurring on the various types of PA (RAISG, 2020d; 2020e). While most mining practices are degradative in nature, illegal mining operations are important to measure separately, as they lack regulation, likely leading to more destructive processes and higher levels of contamination. As these two statistics are related but very different in process and measurement, I ran separate analyses for each rather than creating a composite statistic. Although tempted to run a third set of analyses using regional biodiversity, I decided against this, as biodiversity may vary for reasons other than degradation, such as difference in ecotone, proximity to rivers, or terrain profile. Additionally, biodiversity statistics would likely be skewed due to the fact that many governmental PAs are sited in areas of high biodiversity, not vice versa. Lastly, several layers were pulled from the ArcGIS online database: a referenced basemap and map of Brazilian state boundaries to contextualize data spatially and a layer designating the border of the Brazilian Amazon, which data were clipped to to perform analysis on the correct scale (ESRI, 2009; IBGE, 2014; GFW, 2015).

Methodology:

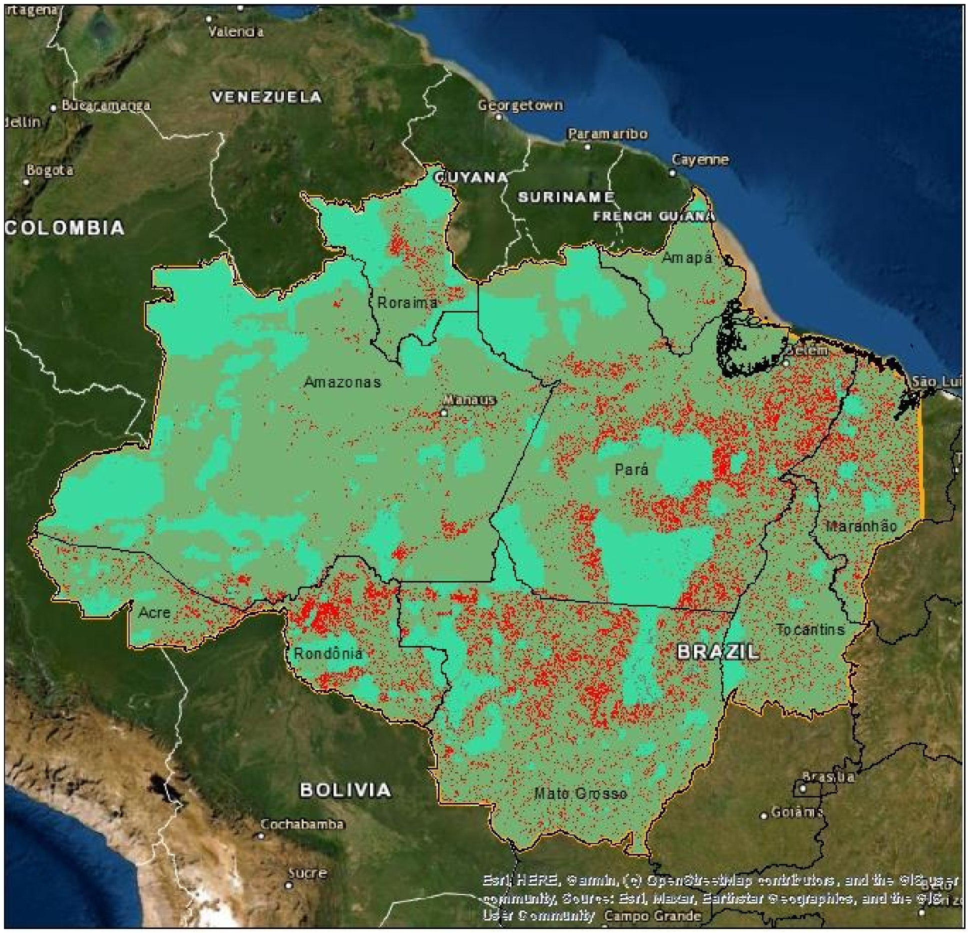
The entire extent of spatial analyses were performed in ArcMap 10.0. After all necessary data layers were downloaded, they needed to be pre-processed to be effectively analyzed. Pre-processing involved several steps. First, a file geodatabase (.mdb file) and toolbox (.tbx file) were created to ensure effective data storage. The geodatabase stored all downloaded and created layers, even ones not used in the final analysis. The toolbox contained several models that saved individual processes (reprojecting, clipping, etc.) so that work could be backtracked and reapplied easily if layers were lost or processed incorrectly. After creation of this geodatabase and toolbox, all layers were reprojected using the Project Tool into a common projection, the widely used WGS 1984. Next, individual layer files had to be further preprocessed to be able to effectively analyze them. Data layers from RAISG (PAs, Mining) were in vector format, representing an object view where polygons of data existed in empty space. To use the map algebra necessary for analysis, layers were required to be in raster format, or field view, where each individual cell was assigned a value that represented their designation. These layers were transformed into raster data using the Polygon to Raster tool. The forest loss layers were already in raster format, but had to be downloaded as individual 'tiles' representing 10^ Latitude by 10^ Longitude areas. Given the size of the study area, it was necessary to combine all individual tiles that contained an area of the Brazilian Amazon (10 Total tiles) into a single raster layer. This was done using the Mosaic to new Raster tool. Next, I reclassified the data in all layers to classes that could be more easily analyzed and compared. The forest loss data contained a temporal element in which cells were assigned a number between 0 and 20. 0 designated the area as still containing forest cover and integers from 1 to 20 represented the year of deforestation (1=2001, 2=2002, et cetera). While this element is certainly useful for other data collection, it did not pertain to my project, so I used the Reclass Tool to reclassify the data into a binary layer, with 1 representing deforestation and 0 representing intact forest cover. Further reclassifying operations were done on the PA raster layers, using the Reclass Tool again to redesignate all cells that fell within the represented land structure to 1 and all NoData cells (land outside of the PAs) to 0. This created more binary layers for Indigenous Land, NPAs, and State PAs. Finally, I used the Clip tool in the data management toolset to limit the study areas of each layer to the boundary of the Brazilian Amazon. This process created layers for ILs, NPAs, SPAs, Total Mining Operations, Illegal Mining Operations, and Deforestation that were all in the WGS 1984 projection, in raster format, classified in ready-to-use ways, and only represented land within the boundaries of the Brazilian Amazon. After preprocessing was completed, I moved on to analysis of the statistics in relation to one another. I used two tools to determine conservation within different land designations. For deforestation, I used the Zonal Statistics as Table tool. I input each of the finalized PA layers against the finalized deforestation layer, and produced tables that summarized the statistics for deforestation between the two ‘zones’ in each layer. These zones were land areas that were inside of (1) or outside of (0) the designated PA. Because the deforestation layer was also given a binary classification and because each individual cell had a set value of 0 (forested) or 1 (deforested), the mean statistic for each zone could be used to determine the amount of deforestation that occurred within that zone as a decimal, which were then converted to percentages. I extrapolated the Mean and Standard Deviation of each zone within each layer and also found the difference between the means of zones 1 and 0 to determine how much deforestation was sequestered by each PA designation. For mining data, I used the Boolean And tool. The Boolean And tool takes two inputs (mining or illegal mining layers and PA layers) and creates a new layer that contains only the areas in which the two layers overlap. In this case, two new layers were created for each PA type, one that showed all mining operations that occurred within land designated to that PA system and one that showed all illegal mining operations within the same areas. The total values for the area within these layers could then be found in the attribute table for each layer under the Count statistic. However, each layer was analyzed and presented in the unit of decimal degrees. To translate each layer into kilometers, a more widely applicable unit of measurement, I performed a series of operations. First, the cell size, or resolution, of each layer was recorded. For the illegal mining layers, the cell size was .12 degrees by .12 degrees. As there are 111 kilometers in a degree, these cells were 13.32 by 13.32 kilometers, or 177.42 square kilometers. For total mining layers, cell size was .14 by .14, which can be converted into 241.49 square kilometer cells. These final cell sizes were then multiplied by the individual Count values (total number of cells) to determine how many square kilometers fell into each category. These operations resulted in zonal statistics of percentage of deforestation in various PAs as well as total kilometers of mining and illegal mining that has taken place in these PAs.

4: Results:

In the following section I will present both the final GIS maps of the different spatial relationships of study as well as the corresponding statistics for each map.

Deforestation Results:

Generally, the statistics for forest cover between different PAs showed only minor differences. However, there were still some definite conclusions from the maps and statistics.



Indigenous Lands and Deforestation

Forest Condition

Brazilian Amazon Border

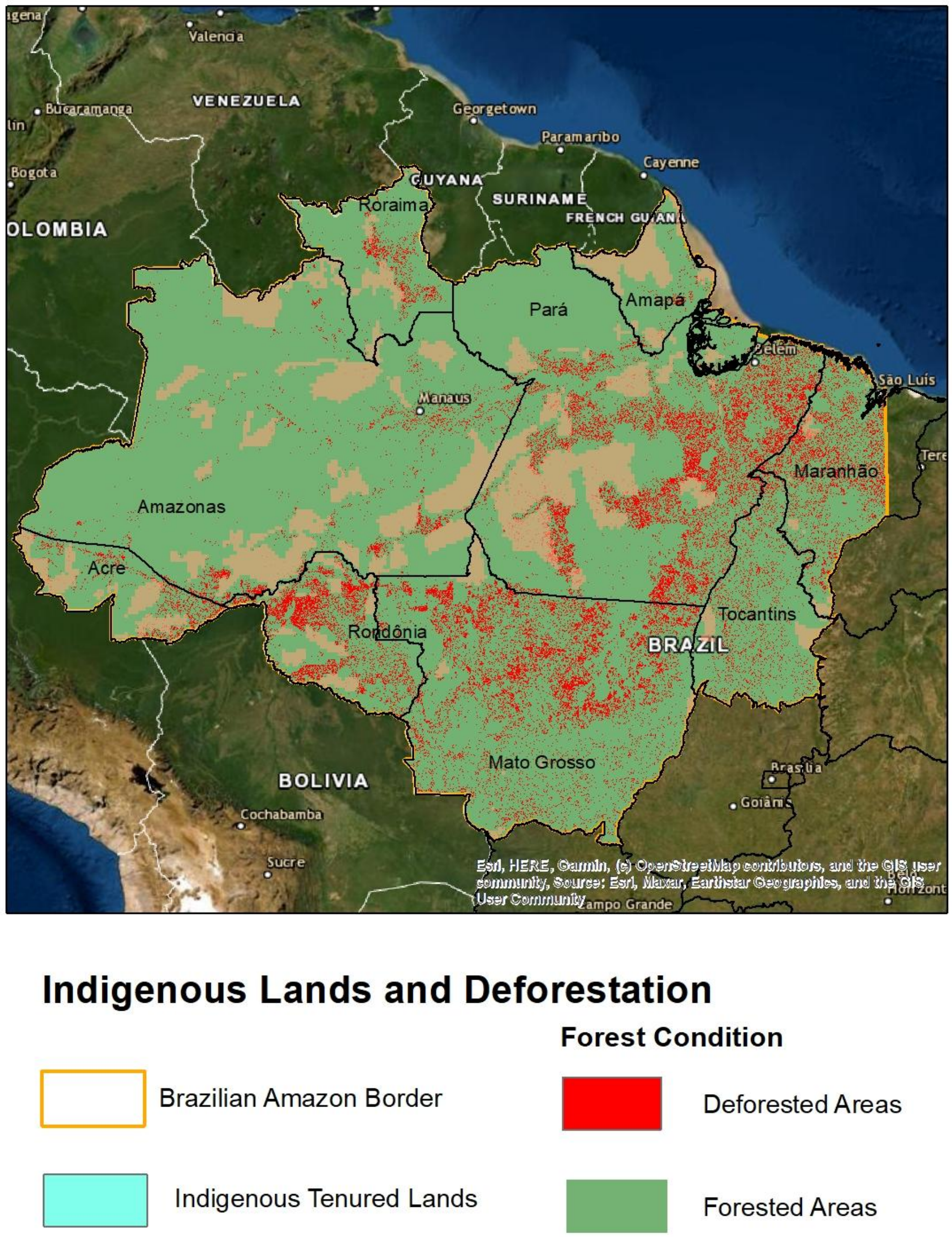
Forested Area

Indigenous Lands

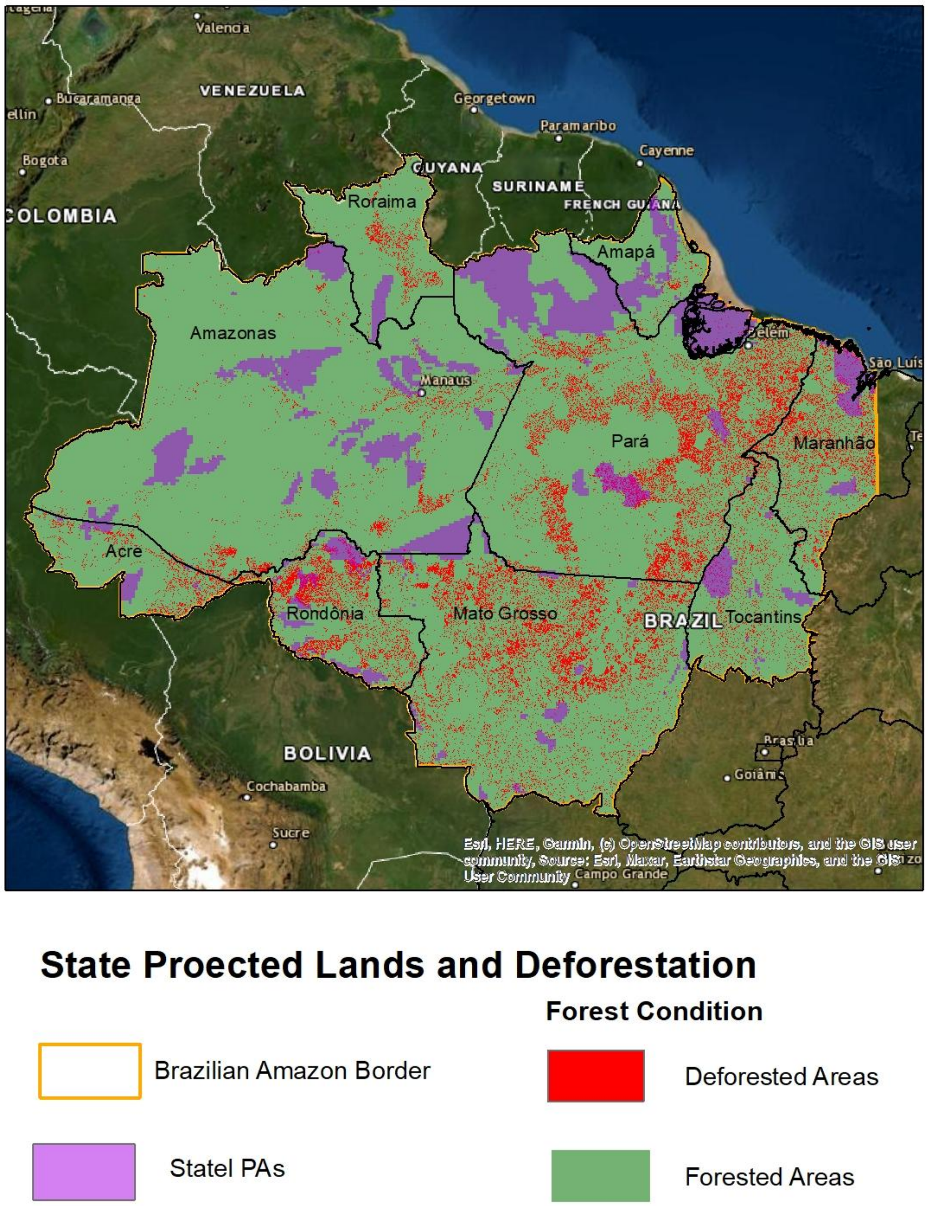
Deforested Area

Land titled under Indigenous Tenure in 2020 (Fig. 3) had the least amount of deforestation of the three types with a deforestation rate of 2.5%, and lands outside of Indigenous areas had higher levels of deforestation (11.2%) than those outside of National or SPAs. This led to a larger difference in means (8.7%) between land inside and outside designated Indigenous Areas than National or State PAs. ILs also covered the most ground area in the study, covering

22.85% of the Brazilian Amazon Basin, which corresponds to 1,188,109 square kilometers of land.



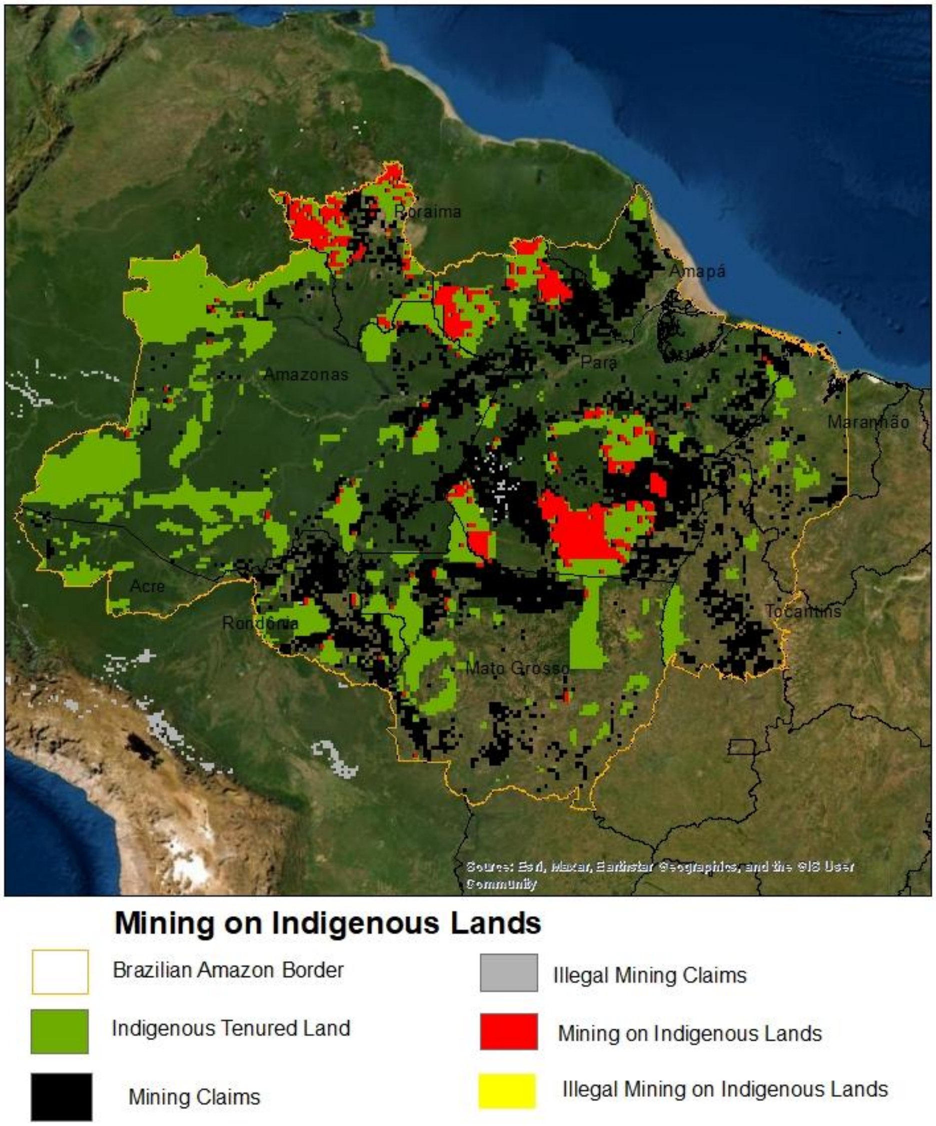
National PAs, taking up 12.97% of the study area (674,388 square kilometers), showed the next-best statistics on forest loss (Fig. 4). Deforestation rates within the PAs, at 2.8%, were slightly higher than those of ILs, and rates of non-PA lands, at 10.2%, were slightly lower, leading to difference in means of 7.3%. The difference in means statistic showed more significant differentiation from Indigenous statistics than individual means did.



SPAs appeared to be the least effective tactic of the three in staving off deforestation (Fig. 5). SPAs cover 11.45% of land in the Brazilian Amazon, taking up 595,354 square kilometers. They show the highest rate of deforestation within their boundaries (4.1%), the lowest among outlying land (9.9%), and the lowest difference in means (5.7%) of all PA systems. However, it is worth noting that SPAs had the highest Standard Deviation (SD) values for lands within the designation. The SD for SPAs, at .198, is higher than ILs at .157 and NPAs at .177. Interestingly, SPAs also had the lowest SD for lands outside of their boundaries, at .298, lower than the corresponding values for ILs at .316 and NPAs at .303.

Mining Results:

The results of the mining operation analysis led to slightly different conclusions than those of the deforestation operations.



ILs contain by far the largest area of mining operations within their boundaries, at around 192,226 square kilometers (Fig. 6). However, basing conclusions solely off of area mined would be short-sighted, as Indigenous land also takes up almost as much space as that of National and State PAs in the basin combined. The percentage of ILs that contained mining operations were much more comparable to governmental PAs, standing at 16.18%. ILs also had a very low amount of mining operations demarcated as illegal, at only 177.42 square kilometers (.014%), correlating to only one pixel of the map (Fig. 7).

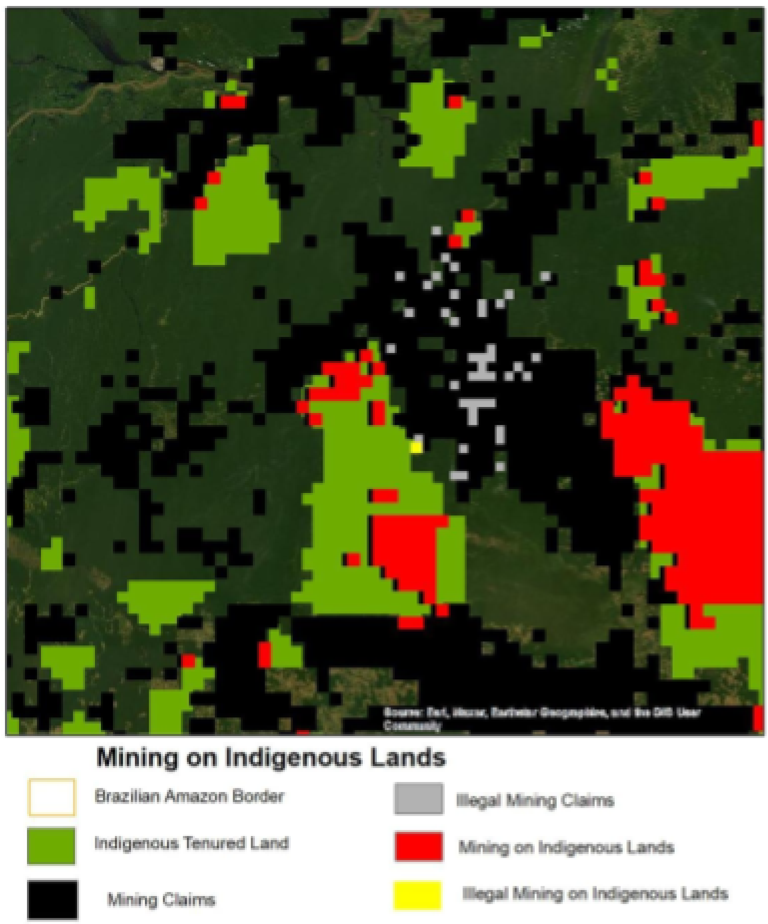
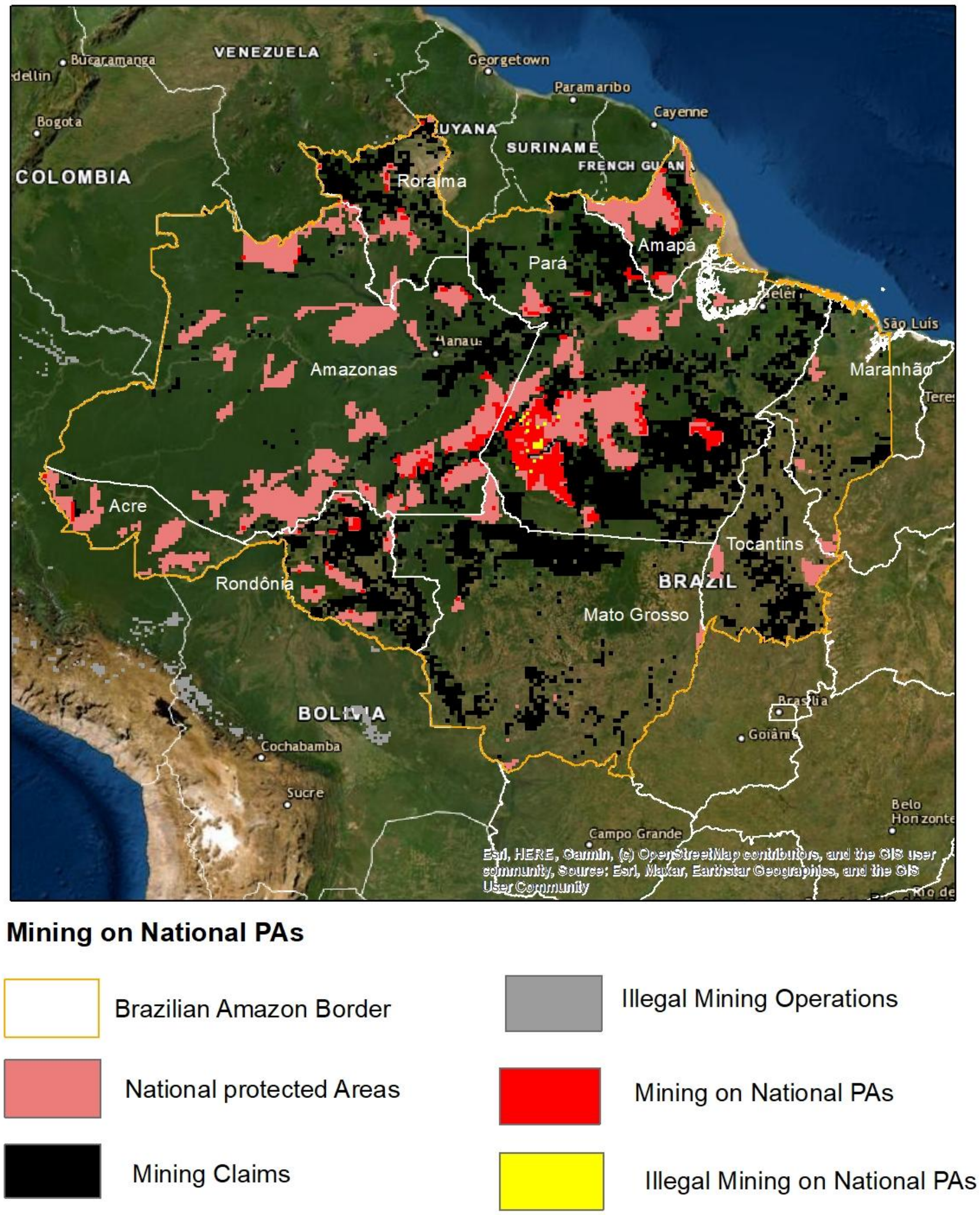


Fig 7: The single pixel of illegal mining operations on Indigenous Land displayed in Figure 6.



National PAs displayed both the smallest land area (106,014 square kilometers) and the lowest percentage (15.27%) of total mining operations within their boundaries. However, they also displayed by far the highest levels of illegal mining operations (3,726 km2 or .055%) of the three PA types (Fig. 9).

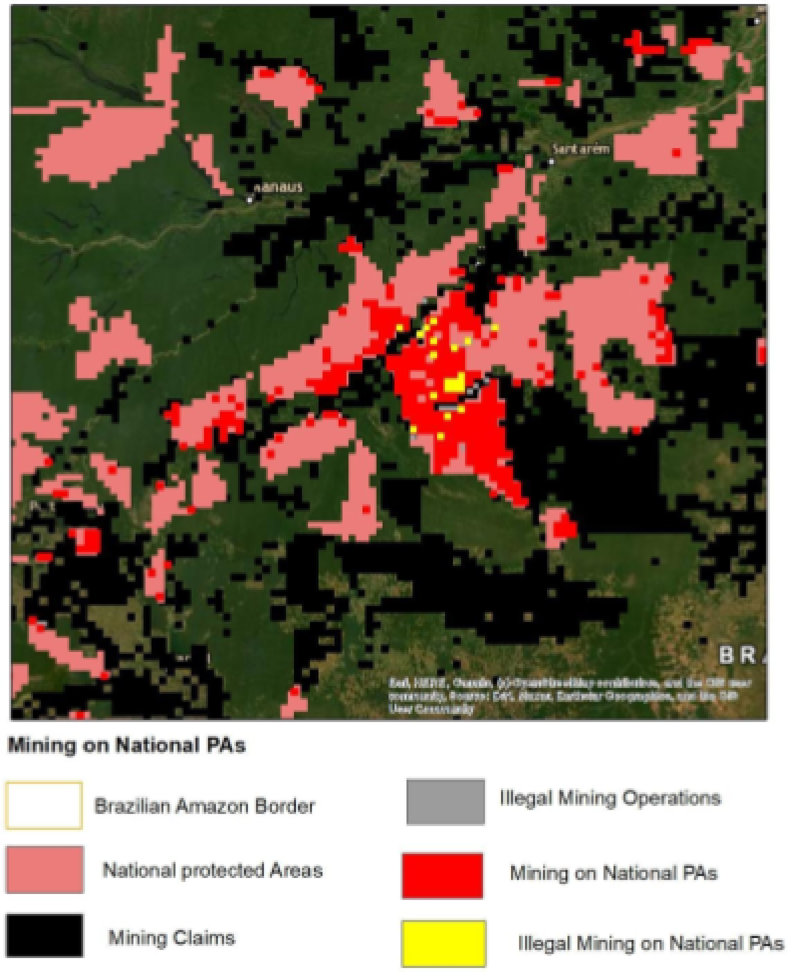
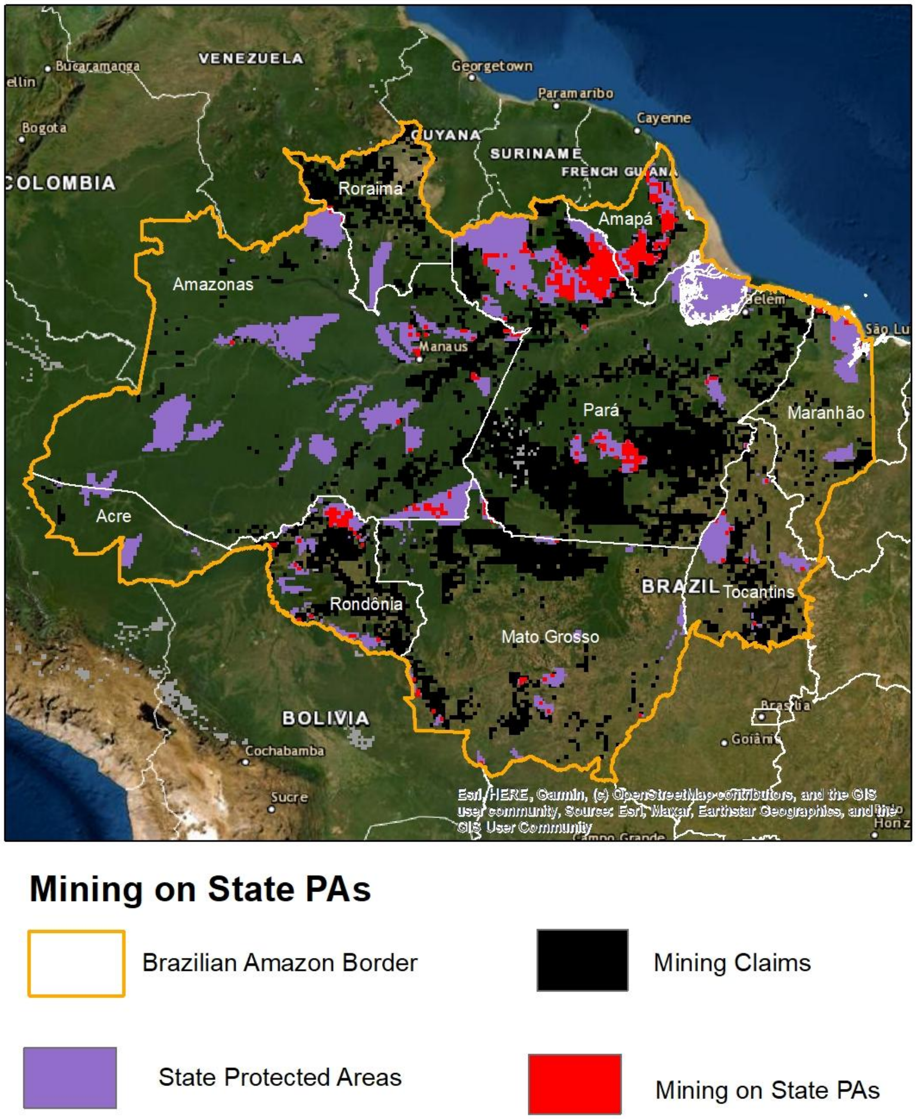


Fig. 9: Focus on Illegal Mining operations on National PAs in the Brazilian Amazon.



Mining statistics on State PAs presented an interesting combination of figures. While SPAs showed the highest percentage of mined land on them at 16.27% (96,837 km2), they also appeared to have no illegal mining operations, at least not at the resolution of the maps, for potential reasons that will be discussed later.

5: Discussion:

The following section will attempt to use information gathered from the GIS analysis portion of this project contextualized with socioeconomic and ecological realities of the Brazilian Amazon to draw connections between spatial statistics and on-the-ground realities. While this analysis will attempt to draw conclusions based on the present data, it is important to remember that the resolution and broad categorization of the data in use prevents certain conclusions from being made.

Broader Conclusions from Analysis:

Although the statistical results from the GIS analysis can certainly be used to draw conclusions, there are other contextual situations that should be analyzed to properly determine the effectiveness of PAs in conservation.

First, it appears that PAs on a generalized scale are much more effective in protecting against deforestation than mining within titled lands, as all three land types showed relatively high percentages of mined area and relatively low percentages of deforestation. For NPAs and SPAs, this is likely because of the presence of sustainable use areas within the border designations, where a certain amount of mining may be legal. For ILs, these statistics could represent mines that are owned or operated by Indigenous Peoples, or mines in which local tribes are given a percentage of profits as has been agreed upon in multiple situations (Hecht & Cockburn, 2011).

The use of only broad designations of State- or National-Level PAs can obscure some amount of information. Both of these PA types cover large numbers of specific PAs, with a variety of different priorities, regulations, and levels of success. For example, NPAs include both National Park lands, strictly protected areas with strict anti-exploitation regulations, and National Forests, sustainable use areas where under Brazilian Law up to 20% of forest cover can be cleared (Azevado et al, 2017). This likely explains the slightly larger Standard Deviations in forest loss statistics of Governmental PAs over ILs, as specific demarcation are likely to have much higher or lower numbers than the average.

Although mining presence and deforestation both appear as suitable proxies for conservation success, deforestation likely presents a more objective set of data. Minerals like gold are not evenly distributed, making mining a spatially dependent industry. This is reflected in the amount of mining that takes place on certain land demarcations based on where these regimes are located in space. The maps describing mining above clearly show that a large percentage of mining operations take place in the southeastern portion of the Brazilian Amazon, centered in the watersheds of the Tapajós, Xingu, and Tocantins rivers. The Tapajós has been cited as the most productive waterway in terms of gold mining, producing a total of 60 tons of gold as of 2011 (Hecht & Cockburn, 2011). The area between the Tapajós and the Xingu also appears to be the focal point of illegal mining operations. While the fact that SPAs showed no level of illegal mining within their boundaries is significant, it is also worth noting that there are very few of these areas, all small in size, in the section of the study area where illegal mining takes place. On the other hand, there are several large NPAs and areas of Indigenous Land within this zone.

In the deforestation section of the analysis, Indigneous Lands appeared to be a conservation unit of equal or perhaps slightly better effectiveness than National or State PAs. When considering broader spatial and social contexts, however, they are likely much more effective, and sited in areas of higher conservation necessity. Often, both National and State PAs are sited in areas that already display ecological richness or attractiveness. This characteristic is displayed in PAs across the spectrum. Ecological Reserves, one of the most staunch environmental protection areas, require a technical study ensuring they are ecologically sound enough to justify protection. Even much more lenient areas like National Forests are sited on areas with predominantly native tree cover (((o))eco, 2013). Indigenous Areas have different criteria, focusing on land that has cultural significance to groups of Native People (De Almeida, 2011). These lands do not always coincide with areas of particular ecological richness, and thus Indigenous conservation efforts often have their work cut out for them. This is reflected on the maps, where ILs are often located in areas surrounded by large amounts of deforestation, with National and State PAs less so (Fig. 9).

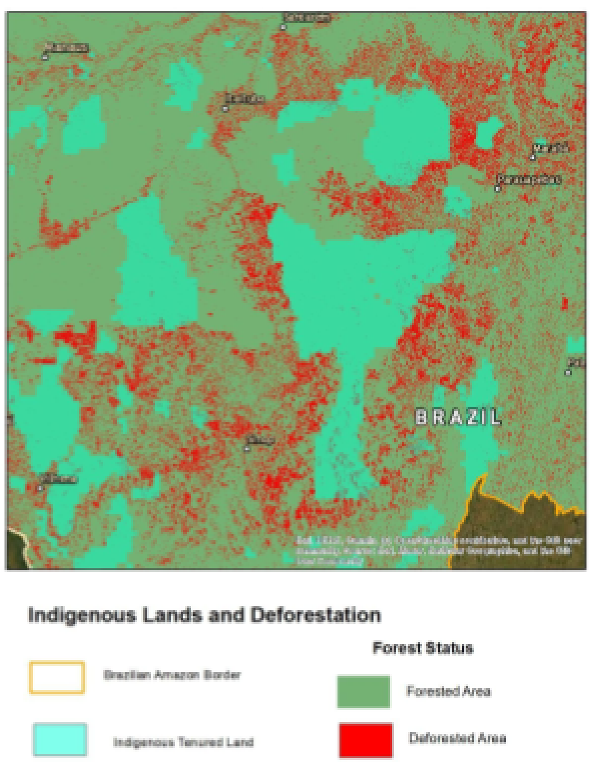


Fig. 9: Focus on Indigenous Lands in areas with otherwise high deforestation rates.

The fact that Indigenous Lands are often threatened at their borders by high deforestation rates, and are able to quell this deforestation and in fact have better forest cover statistics than those of State and National PAs should be viewed as a massive conservation success, and further evidence the merit of Indigenous Lands as sustainable areas in Brazil and elsewhere.

Political Ecology and Conservation

This section will introduce the framework of political ecology and its applications in studies like this one. Political Ecology studies the overlap of policy, sociological phenomenon, and environmental processes as it applies to creation of sustainable futures (Porto-Goncalves & Leff, 2015). Put simply, this framework goes beyond which lands have been preserved and which haven't, and explores the social contexts behind these differences. When applied in a postcolonial society ike Brazil, it can be used to deconstruct classical approaches to ecology, politics, and economics, and instead build a framework that focuses on the lived realities of those people who are most directly connected with the environment in which they live (Porto-Goncalves & Leff, 2015). Since the birth of the environmental movement, many novel ideas and reworkings of political ecology have come from Latin American thinkers, particularly rural workers and Indigenous Peoples who have been faced with degradation of and removal from their lands. These new imaginings of the human-environment nexus reject capitalistic dichotomies that set workers and natural settings on opposite sides of processes of commodity production and instead refocus on the intimate connections that smallholders have with their lands (Porto-Goncalves & Leff, 2015).

Traditional Ecological Knowledge

Indigenous Peoples have lived in the Amazon for many millennia, with the first human settlements estimated to have arrived in the area 10,000 to 30,000 years ago. Pre-colonization, Indigenous populations may have measured up to 10 million (Clement et al, 2015). Through generations of lived experience, their descendants have developed a deep and intimate connection with the land known as Traditional Ecological Knowledge (TEK). The specifics of TEK can incorporate varying levels of spirituality or empirical observation, but the basis of the idea is that over hundreds or thousands of years residing in an area, traditional peoples develop a thorough scientific understanding of the cycles, relationships, and limits of the land they reside in. This deep knowledge usually comes with a second foundational belief that human and nonhuman members of an ecosystem are all part of the same subjective community, which emphasizes sustainable use and reciprocity with the land (Pierotti & Wildcat, 2000). In the words of Alfredo Wagner B. De Almeida, "Practices of mutual assistance, focusing on renewable natural resources, reveal a profound knowledge specific to the ecosystems in question" (De Almeida, 2011). This stands in stark contrast to the general Western worldview that posits nature as an object of dominion from which humanity as a subjective force can extract everything it needs to grow and realize national and cultural destinies.

These opposing worldviews have often come to a head in the Amazon Basin. As reviewed before, large enterprises often show a lack of ecological understanding as they look to improve the bottom line, and these short-sighted priorities often reduce the productivity of their operations in addition to harming the environment around them. Indigenous Peoples, on the other hand, often look to preserve the land for future seasons and generations. An excellent example of this distinction is the use of fire in the forest. The Kayapó people who inhabit the states of Para and Mato Grosso have an agricultural fire practice that follows successional paths in a manner in-tune with the natural cycles of the area, including nutrient-poor soils that are sensitive to large disturbance events (Hecht & Cockburn, 2011). In late spring to early summer, following biological indicators like flowering trees, the Kayapó will start to thin the forests to ensure fires will be localized and plant quick-sprouting plants like yams and sweet potatoes. In August to September, small-scale fires are set, mindful of temporal weather conditions and closely monitored by shamans with deep knowledge of local fire ecology. After the fires are put out, the prior planted root crops will sprout almost immediately, setting off successional processes and ensuring that soil will stay in place. After this, short-cycle crops that can fill up large areas like corn, beans, and squash are planted, with longer-cycle plants like fruit trees dispersed within these crops. When crops are harvested for use, the cooking is done within the fields and cooking stations are moved regularly so that nutrient-filled ash can enrich the soil. When the fruit trees grow, they provide an environment for native shade-tolerant plant species and a food source for local animals as well as people (Hecht & Posey, 1989). This process follows carefully researched natural cycles, leaving behind areas that can easily be integrated back into the natural landscape and are sometimes more nutrient-rich than beforehand. Practices such as this one have been applied for centuries, contributing to many landscapes where the lines between 'natural' and 'manmade' environments are blurred, speaking to the longevity of indigenous tenure and intimacy of TEK in practice (Hecht & Cockburn, 2011).

The industrial agricultural operations of the past 150 or so years use fire in a vastly different way, as a tool for forest clearing and economic preparation with little regard to ecological processes like succession. Generally, fires are set in July to October to dispose of woody debris from recently-cleared forest, old pastureland, and roadside vegetation. These fires are set on scales much larger than those of the Kayapó, and easily become out-of-control, especially when climatic conditions like unusually dry El Niño years are not taken into account by those who set the fires. These unsustainable fire practices contribute to the majority of Amazonian deforestation, which peaked in 2004 at 27,772 square kilometers of forest loss (Sheikh et al, 2021). As mentioned before, these burned areas are usually replaced with highly unproductive pastureland that quickly becomes degraded shrubland, providing little to no productivity in either an ecological nor an economic sense.

The above example of TEK and other iterations of these forms of knowledge and practice are very likely a partial explanation of how ILs tend to be relatively successful areas of conservation. However, to assume that all Indigenous Peoples across the basin have the same visions and practices of land stewardship would be greatly reductionist. Indeed, in many cases Indigenous Peoples are involved in mining and logging practices on their lands for monetary reasons (a phenomenon that does not make their claims to these lands any less valid) (Hecht & Cockburn, 2011). A case-by-case study of TEK would require much more focused and finer-resolution studies, but for the purposes of this study, it can be viewed as one of several likely reasons that ILs are often viewed as conservation successes.

Political Ecology of ILs in the Amazon Basin

Indigenous groups have mostly been viewed as a roadblock to the economic success of those who would hope to exploit and profit off of the Amazon. This has led to a long history of conflicts between the original residents of the basin and its settlers, with Indigenous Peoples usually finding themselves pushed out of their native land or worse. As in countless other colonized countries, the history of violence against Indigenous Peoples is gruesome. European settlement of the region has decimated populations through disease or intentional violence. According to anthropologist Darcy Ribeiro, as many as 80 entire tribes were wiped out altogether between 1900 and 1957, and total numbers of Indigenous Peoples went from over a million to 200,000 within that time (Hecht & Cockburn, 2011).

Similarly to many histories of colonizer-Indigenous relations, isolated mortality statistics tell only a portion of the story of Indigenous decimation. From the inception of European settlement, Indigenous Peoples were enslaved en masse. Enslaved Indigenous Peoples were considered to be of 'higher value' than those of foreign descent due to their intrinsic knowledge of the forest, which could be capitalized upon by their enslavers. At one point in the 17th century, Indigenous Slaves were more common than African ones in Northern Brazil (Sommer, 2005).

Furthermore, through such processes as enslavement, debt peonage, and displacement from traditional lands, many Indigenous identities were repressed by detribalization. Detribalization, or assimilation, separates Native peoples from cultural complexes like land, languages, traditions, and religious beliefs, weakening cultural identities and bonds and furthering systems of colonization. In many cases, almost all cultural connections are lost. The Aguano people of Peru, despite still residing in a homogenous cultural society, now speak Spanish, worship as Roman Catholics, and even refer to themselves by a different name, Santacrucinos (Olson, 1991). Many communities of *caboclos,* or peasants, across the Basin are made up of detribalized Indigenous Peoples, forced over the generations into petty extraction as a means to survive (Hecht & Cockburn, 2011).

Faced with disease, acculturation, enslavement, and genocide, many Indigenous groups rebelled against settlers, but very few had success on a large scale. One such case is that of the Munducucu, a warring tribe who successfully raided Portuguese settlements several times in the 1780s. Fearing further attacks by the tribe and recognizing the usefulness of the 20,000-man army at their disposal, the Portuguese decided to entice the tribe into a truce, and for much of the rubber boom, the Munducucu aided rubber barons as extractors and transporters of rubber and as slavers. By the late 19th century, however, the agreement had turned into little more than debt peonage. Unfair economic agreements and large-scale degradation of their home on the Tapajós has reduced the once feared Munducucu to a population of around 1500 people spread across 6 or so settlements (Hecht & Cockburn, 2011). Many stories similar to that of the Munducucu exist throughout history, with tribes acting in individual resistance being easily subdued by the colonial apparatus through force or economic coercion.

In the 1970s, Indigenous resistance and advocacy began to show forms of cohesion and the political power that comes with it. In 1974, Catholic missionaries in Mato Grosso organized the first 'Assembly of Indian Chiefs', in which 16 representatives from 9 different tribes assembled to discuss tribal realities. While this meeting was by all accounts small and unproductive, it represented a significant shift in Indigenous action in Brazil as the first officially recorded instance of Indigenous leaders that did not share ethnic boundaries meeting to discuss land issues. Many more of these 'Assemblies of Indian Chiefs' followed, gaining momentum as Indigenous Peoples who had always been excluded from governmental processes became more and more well-versed in the political realm (Philippe-Belleau, 2014).

Although early official collaboration may have been helped by Indigenist missionaries, it didn't take long for Indigenous Peoples to recognize their ability to effectively organize on their own terms. In 1980, the Indigenous People's Union, or *União da Nações Indígenas* (UNI) was formed. The UNI quickly became an important player in Amazonian geopolitics, lobbying for recognition and legitimation of Indigenous land rights and incorporation of TEK into the budding environmental movement of Brazil. The UNI and other organizations were able to effectively lobby for Indigenous rights in the 1986-87 constitutional convention. The 1988 Constitution affirmed millenia-old land rights and granted Indigenous Peoples new rights to self-organize and to participate in congressional review of new mining or damming proposals in areas that would affect them (Hecht & Cockburn, 2011). The 1980s also saw the Indigenous movement gain somewhat unprecedented support in the international environmental community, recognizing the merits of TEK as a viable conservation approach. In 1988, two Kayapó chiefs, Paiakan and Kuben-i, were unfairly jailed for accusations of sedition after denouncing a damming project in Brazil at a conference on Tropical Deforestation in Florida, which they had been formally invited to. These arrests were met with mass protests, in which rural populations, scientists, and trade unionists of over 54 different groups demonstrated outside of the courtroom in Belem, eventually helping to get the charges dropped (Hecht & Cockburn, 2011). Since then, Indigenous action has only increased, springing up wherever large-scale degradation threatens the forest, often supported by multinational NGOs and scientific foundations. In the 1990s, Indigenous groups successfully halted several development projects in the Amazon (Philippe-Belleau, 2014). These groups helped gain ILs new legitimacy with the creation of the Sustainable Development of Traditional Communities Commission in 2004, further validating Indigenous land rights and concepts of TEK on a national scale (De Almeida, 2011). Today, more than 200 Indigenous Organizations exist, protecting the rights of both the people and the environments that are native to the Amazon Basin (Philippe-Belleau, 2014).

However, despite these successes, there are still significant hurdles to the progress of traditional land tenure. Lands rights in the Amazon have always been convoluted, especially with the large-scale settlement efforts of the mid-to-late 20th century, and today as much as 12 million acres of land in Eastern Amazonia alone are unclear in terms of ownership (Hecht & Cockburn, 2011). Further, while official recognition of lands can help stave off threats of degradation and exploitation, oftentimes communities must go through a long and often arduous process to actually gain recognition. As of 2020, 20 Indigenous Land allotments in Brazil had been fully regularized and codified, while 27 still awaited finalization (CIMI-N1, 2020). These areas awaiting ratification are often still vulnerable to economic exploitation (De Almeida, 2011). Furthermore, ILs in Brazil are facing increased threats of destruction at the hands of agribusiness lobbies and increasingly right-wing national politics. The last decade has seen many Indigenous areas downsized to make way for developmental projects, consistent with increased deregulation of corporate activity in the region (Begotti & Peres, 2020).

New Social Movements in the Amazon

The unified Indigenous movement of the 1970s came within the context of a larger social phenomenon within the Amazon Basin: that of New Social Movements (NSMs). NSMs brought together rural forest peoples across a multitude of identity forms and occupations in resistance to the increased privatization and destruction of their lands at the hands of Brazil's military government and the global economy as a whole. The NSMs of the 1970s had several key distinctions that separated them from prior social movements and distinguished them as novel and meaningful agents of change (De Almeida, 2011). NSMs centered around the unique identities of rural forest peoples, politicizing the connections between occupational, sociopolitical, and ethnic identities. Where previous social movements usually fought solely on economic grounds, these new movements demanded the recognition of their lands, practices, and political histories. Amazonian NSMs were also among the first political movements to focus on the essential connection between traditional peoples and economies and ecological health, presenting TEK and other forms of Local Ecological Knowledge (LEK) as legitimate and underutilized tools of conservation (de Almeida, 2011). As mentioned before, Indigenous lands today owe their existence to deliberate and grassroots Indigenous land organizations including UNI, and without these movements, it is unclear how much officially codified Indigenous land would exist in the basin today.

Although Indigenous organization can be viewed as the most regionally significant and successful NSM (at least in terms of actualized land designation), the movement certainly owes other movements some level of credit for its success. Of course, to discuss social movements of the Amazon without mention of Chico Mendes and the *seringueiro* movement would be to leave out one of the most important environmental movements of the 20th century. A rubber tapper from Acre who had been raised on revolutionary rhetoric, Francisco "Chico" Mendes began to work in state trade unions after the military junta of the 60s. He quickly realized that any demands for economic relief would be fruitless without land recognition (Revkin, 2004). In 1976, Mendes and his supporters organized the first *empate,* or standoff. When crews protected by armed guards arrived in a *seringal* to clear the forest, the entire community, including women and children, physically stood between the forest and its intended destroyers. Mendes recognized the importance of bystander interpretation, and knew that police and militia members would not fire on women and children for fear of public perception. After the success of the first *empate*, the strategy spread, slowing deforestation in Acre and inspiring similar direct action in Rondônia and Amazonas. By Mendes' own estimation, the *empates* preserved nearly 3 million acres of forest (Hecht & Cockburn, 2011).

When it became clear that direct action in isolated cells would not suffice, Mendes and his union, backed by unprecedented international support, organized a national conference of *seringueiros* in Brasilia. Here, 130 representatives from various states came together to discuss the future, hatching a radical new idea for land use: Extractive Reserves (Cardoso, 2017). These reserves would be officially designated areas where *seringueiros* would share collective ownership of the land and the commodities extracted from it, rejecting the idea of private land ownership and saving forested areas from unsustainable ranching practices while supporting the extractivist agriculture on which *seringueiros* and other rural workers depended (Hecht & Cockburn, 2011). In 1990, the state legally recognized the idea and began designating areas as extractive reserves. Since then, 37 of these reserves have been created, housing 50,000 people and showing the conservation world that when local populations are given control of their resources, both the people and the environment benefit (Cardoso, 2017).

Furthering the idea of collaborative resistance, Mendes helped to create the Brazilian Amazon Alliance of People of the Forest (APF) in 1987, bridging the gap between rubber tappers and other extractivists and Indigenous Peoples, a relationship that had historically been tense at best, largely thanks to government colonization projects that placed extractivist operations further and further into Indigenous territories (APF, n.d.). Jaime Araújo, a governing member of the Rubber Tappers' Council, stated 'we have the same way of life, and the same enemies: the rancher and the logger. The isolation we live in as tappers and Indians intensifies the solidarity among men and reinforces the bonds of family, friendship, and cordiality between people.' Since its inception, the APF has used solidarity of rural communities to further land and livelihood rights for its constituents. Unfortunately, Mendes did not live to see the full fruits of his labor, being murdered by ranchers' hired guns on December 22, 1988 (Hecht & Cockburn, 2011).

A combined analysis of New Social Movements and conservation units in the Brazilian Amazon provides a vital link between independent rural resistance to exploitation and protected areas that succeed in halting degradative practices like mining or logging.

Political Ecology of PAs

It is also important to evaluate the history and reality of Governmental PAs against which I've compared Indigenous Lands. The first official PAs in Brazil were codified with the passage of the 1934 Forest Code, which made way for the first official National Parks, the Itatia and Órgãos to be founded in the Rio de Janeiro region in 1937. The demands for these new areas reflected the early environmental movement of the time, inspired heavily by the foundation of Yellowstone National Park in 1872. The first National Forest was designated in Ceará in 1946, and the 1965 Forest Code Amendment included the category of National Forest as well (Rylands & Brandon, 2005). With the combination of the strengthened global environmental movements and the emphasis of human-environmental interactions of the 1970s, many new iterations of PAs were developed in the latter part of the 20th century and early 2000s, including Fauna Reserves (1967) and Ecological Stations (1981). In 2000, the National System of Nature Conservation Units (SNUC) was founded, creating a new department to oversee present PAs and introducing several PA systems to the National Government of Brazil, including Extractive Reserves (L. 9.98/2000).

The rationale behind early Brazilian PAs reflects those of many of the first National Parks and other such areas: that of a distinct separation of humanity and 'wilderness', consistent with the prevailing views of the time that saw nature and culture as separate and opposing entities. As such, early environmentalists and other advocates for PA systems often saw removal of Indigenous populations as at worst a necessary evil (Zaitchek, 2018). Even more modern iterations of PAs in Brazil have a well-documented history of displacement of traditional populations, replacing entire communities of forest people with a few underpaid forest guards (Hecht & Cockburn, 2011). Essentially, this practice replaces populations with vested interests in protecting the land and livelihoods on which they depend with guards who have too little presence to ward off degradation, and are often susceptible to bribery for higher wages than they make (Hecht & Cockburn, 2011).

Global Contexts of Indigenous Land Tenure

The research presented here has definite reflections and applications on the global scale. By some measures, Indigenous Lands cover around 25% of all terrestrial land area, coinciding with 40% of land cover classified as not impacted by industrial activity (O'Bryan et al, 2021). These lands aren't just successful in conservation in the Amazon, either. Indigenous lands have been found to have slightly greater vertebrate species richness and equal vertebrate biodiversity to Governmental PAs in Australia and Canada in addition to Brazil (Schuster et al, 2019). Another study found that out of 4460 mammal species that had been studied at length by the IUCN, 60% had at least 10% of their habitat on Indigenous Managed Areas, with 23% having over 50% of their habitat located in Indigenous Land. For endangered or threatened species, 26% had over 50% of their habitat in such areas (O'Bryan et al, 2021). Indigenous Lands have been found to stave off deforestation in other studies as well. Sze et al (2022) found that across the global tropics, Indigenous Land showed significant decreases in deforestation levels compared to non-protected land, and performed comparatively to governmental PAs in deforestation statistics, even showing better statistics in Africa.

However, it is important to note that advocating for traditional communities' rights to their lands on solely environmental and empirical levels runs the risk of reducing land rights to an argument of numbers, and adding the potential for criticism of these rights if the statistics do not remain positive. Indigenous Peoples have a right to their land first and foremost, regardless of what they do with that land and how they protect it. The fact that TEK, sustainability, and land tenure cooperate on a high level is certainly a benefit to global conservation strategies, but in no way the end-all be-all in the argument for Indigenous or other communally tenured lands. Global decolonial studies recognize returning of land rights to Indigenous Communities as an essential process of decolonization. These rights stand for much more than ownership of land, being recognized as deeply intertwined with bodily and cultural sovereignty (McDonnell & Regenvanu, 2022).

The Single Yellow Pixel: Limitations of Research.

While this study and its results demonstrate the potential of a synthesis of GIS methods and political-ecological analysis in examining Amazonian land use and degradation, it would be remiss not to mention the downfalls of this particular evaluation. Chief among these is the resolution and currency of the GIS data in use. The Hansen et al. dataset is an incredibly useful metric in that it offers worldwide statistics on deforestation rates updated regularly. However, using this dataset to measure smaller areas can present limitations as the data is at a relatively coarse resolution of 30 by 30 meter pixels (Hansen et al, 2013). This resolution runs the risk of completely excluding small-scale deforestation practices, such as selective logging, which has become more and more of a concern in the Amazon in the last 20 years and is difficult to measure using satellite data (Asner et al, 2005).

Additionally, it is important to draw attention to the mining and illegal mining designations in the analysis. While the results show that ILs have an incredibly low level of degradation due to illegal mining, this is likely a significant underestimation of the true relationship between these two variables. For example, one of the most prevalent environmental problems in the Brazilian Amazon at the moment comes from illegal encroachment of mines on the Yanomami preserve in the Roraima Province in the Northwest of the Brazilian Legal Amazon. In 2021 alone, illegal mining in the Yanomami Reserve increased by as much as 46%. With this rise in mining came multiple reports of physical and sexual violence against Yanomami Peoples and a rise in levels of mercury poisoning to up to 92% of samples taken within th community (Porier & Vargas, 2022). Despite pressure from multiple advocacy groups, the Bolsonaro Administration has denied the presence of any evidence of violence or illegal mining in the area. Interestingly enough, all of the mining in the Yanomami reserve and the surrounding areas was not demarcated as illegal in the layers in use (Fig. 10)

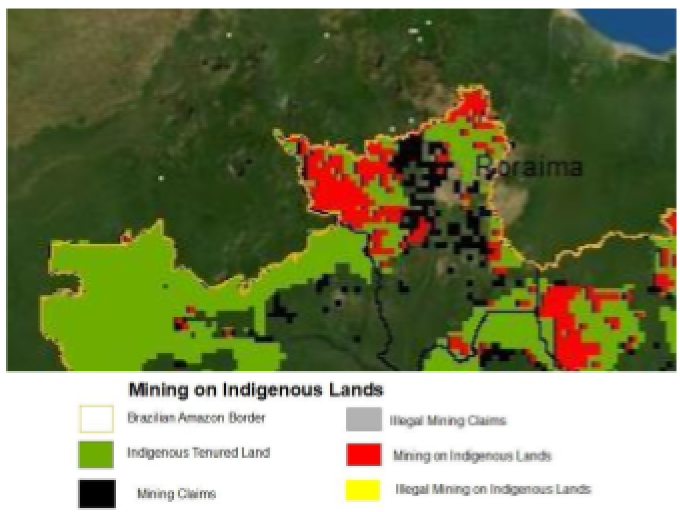


Fig. 10: The Yanomami and surrounding ILs in NW Brazilian Amazon, codified as having legitimate mining operations despite multiple other reports.

This discrepancy draws attention to the designations of legal vs. illegal mining in the region and how these legal descriptions may not reflect on-the-ground practices and the effects of these operations on local communities. Similarly, the Bolsonaro regime put forth several pieces of legislation that threatened ILs' status as protected from degradative operations. The bill (PL 191/2020), in particular, represents a threat to Indigenous conservation, attempting to open up ILs for exploitation of water and mineral and organic resources (dos Santos et al, 2022). Clearly, the designations of illegal versus overall mining operations may come into further question with legislative changes such as these, and demarcation of mining areas on ILs as legal does not automatically correlate with sustainable or reciprocal practices. Although Jair Bolsonaro's notably degradative regime came to an end on October 30th, to be replaced by Luiz Inacio Lula da Silva, who has a relatively good track record in reducing forest degradation in his previous two terms, it remains to be seen how the new administration will respond to crises in the Yanomami and other regions, especially facing an antagonistic right-wing congress (Urzedo & Chatterjee, 2020).

Clearly, the single yellow pixel of illegally mined Indigenous Land is a drastic misinterpretation, and this lack of nuance can be reflected in other areas of this analysis. However, I don't intend for these results to be used in and of themselves as evidence for conservation or policy strategies, but rather as a framework connecting GIS operations with regional socio-environmental contexts, through which more fine-resolution analyses can be made in areas of focus.

6: Conclusions:

GIS analysis comparing official Indigenous Lands to National- and State-managed PAs found relatively similar metrics across the board for deforestation. Indigenous Lands, representing by far the most area, displayed the lowest average deforestation and the highest difference in means with land outside of their boundaries. In evaluating mining operations on each PA designation, Indigenous land had a similar percentage of mined area to Governmental PAs, with slightly more than National PAs and slightly less than State PAs. While Indigenous Lands also showed very few areas of illegal mining in this analysis, real-life developments in the basin as well as mining practices that are nationally legal but nonetheless degradative and hostile toward Indigenous Peoples leave this part of the analysis in doubt.

Delving into the political ecology of Indigenous Lands evidences the methods of Traditional Ecological Knowledge which allow them to perform so highly in sustainability measures such as these. TEK often proves to be perhaps even more intuitive of natural ecosystems than modern empirical science, and encourages methods of sustainable extraction and land stewardship which nurture the ecosystems in which Indigenous Peoples live and contribute toward a sustainable future in the Amazon. However, recognition of the land rights that allow for these methods to be successful has been no easy feat. Modern Indigenous land titles are thanks to centuries of struggle, owing their existence particularly to the Indigenous Movement of the last 50 years and other rural social movements of forest peoples.

While the GIS analysis in this project is in too coarse a resolution to solely be relied upon for conclusions about conservation metrics in the area, this paper demonstrates how GIS analytics and political-ecological research can be used in tandem to draw conclusions not only about conservation metrics in the Amazon and similar areas, but also the reasoning behind these conservation successes and failures. Even at its relatively rudimentary level, this analysis also adds to the growing body of literature that cites ILs as a particularly potent conservation strategy moving forward, in addition to an essential aspect in decolonization strategies in South America and worldwide.

Acknowledgements:

First, I would like to thank my faculty advisor Elizabeth Pike for suggesting that my previous work on the Amazon could be synthesized into a thesis, even though my original thoughts were that I didn't have enough time. I would also like to recognize the support I have received from my entire committee. I am thankful for the excellent work of my primary advisor Cassandra Brooks, first for instructing Environmental Governance, which opened my eyes to the potentials of communal land management in the environmental field, validating many personal beliefs of mine for the first time in the academic realm, and also for helping me to pull so many pieces together and focus on a scope that would provide a robust paper without drifting too far out of focus. Additionally, I would like to thank my secondary reader, Joe Bryan, who essentially acted as a second primary advisor for me throughout this process, providing me with new frameworks and approaches and a plethora of excellent literature to explore. Finally, I would like to acknowledge Colleen Scanlan Lyons, my honors rep, whose expertise of the Amazon region opened my eyes to the potential and limitations of my particular project. The GIS analysis portion of this research could not have happened without the help of Geography Librarian Phil White, who helped me decipher the complicated field of finding and downloading available spatial layers. Among literature researched, the Fate of the Forest by Susanna Hecht and Alexander Cockburn was immensely helpful. This book provides such an excellent outline of the unique eco-social relations that make the Amazon so fascinating and difficult to study. I cannot recommend this book enough. Finally, I would like to acknowledge the excellent work of RAISG in providing access to ground-truthed and culturally collaborative GIS data to me and so many others, for free.

Bibliography:

Aliança dos Povos da Floresta (APF). Chico Mendes, the Forest Peoples Alliance and Reducing Emissions from Deforestation and Forest Degradation (REDD). (n.d.). United Nations Framework Convention on Climate Change. Retrieved October 8, 2022 from https://seors.unfccc.int/applications/seors/attachments/get_attachment?code=OLGQQS4EA85NIU7962K0JV6LJ2O6HKZB

Alves, B. Amazon land area distribution by country 2020. (2022, June 21). Statista. Retrieved September 26, 2022, from https://www.statista.com/statistics/1251193/amazon-land-area-distribution-country/

Araújo, J. D. A., Ghelfi, A., & Val, A. L. (2017). Triportheus albus Cope, 1872 in the Blackwater, Clearwater, and Whitewater of the Amazon: A Case of Phenotypic Plasticity? Frontiers in Genetics, 8. https://www.frontiersin.org/articles/10.3389/fgene.2017.00114

ArcGIS [GIS software]. Version 10.0. Redlands, CA: Environmental Systems Research Institute, Inc., 2010

Asner, G. P., Knapp, D. E., Broadbent, E. N., Oliveira, P. J. C., Keller, M., & Silva, J. N. (2005). Selective Logging in the Brazilian Amazon. Science, 310(5747), 480–482. https://doi.org/10.1126/science.1118051

Azevedo, A. A., Rajão, R., Costa, M. A., Stabile, M. C. C., Macedo, M. N., dos Reis, T. N. P., Alencar, A., Soares-Filho, B. S., & Pacheco, R. (2017). Limits of Brazil's Forest Code as a means to end illegal deforestation. Proceedings of the National Academy of Sciences, 114(29), 7653–7658. https://doi.org/10.1073/pnas.1604768114

Basis Legislation of the Presidency of the Republic—Law No. 9,985 of July 18, 2000. (In Portuguese). Retrieved November 7, 2022, from https://legislacao.presidencia.gov.br/atos/?tipo=LEI&numero=9985&ano=2000&ato=77ck3aq1kMNpWTfc9

Begotti, R. A., & Peres, C. A. (2020). Rapidly escalating threats to the biodiversity and ethnocultural capital of Brazilian Indigenous Lands. Land Use Policy, 96, 104694. https://doi.org/10.1016/j.landusepol.2020.104694

Cardoso, C. A. S. (2017). The Rubber Tappers and the Development of Extractive Reserves. In Extractive Reserves in Brazilian Amazonia. Routledge.

Clement, C. R., Denevan, W. M., Heckenberger, M. J., Junqueira, A. B., Neves, E. G., Teixeira, W. G., & Woods, W. I. (2015). The domestication of Amazonia before European conquest. Proceedings of the Royal Society B: Biological Sciences, 282(1812), 20150813. https://doi.org/10.1098/rspb.2015.0813

Conselho Indigenista Missionário Regional Norte 1. CIMI Brasil (2020). Indigenous Lands, legal vulnerability, and current territorial issues in the Brazilian Amazon amidst COVID-19. Retrieved from https://www.ohchr.org/sites/default/files/Documents/Issues/IPeoples/SR/COVID-19/IndigenousCSOs/BRAZIL_CIMI_Informe.pdf

Da Silva-Junior, F. M. R., Oleinski, R. M., Azevedo, A. E. S., Monroe, K. C. M. C., Dos Santos, M., Da Silveira, T. B., De Oliveira, A. M. N., Soares, M. C. F., & Pereira, T. D. S. (2018). Vulnerability associated with "symptoms similar to those of mercury poisoning" in communities from Xingu River, Amazon basin. Environmental Geochemistry and Health, 40(3), 1145–1154. https://doi.org/10.1007/s10653-017-9993-7

De Almeida, A. W. B. (2011). Traditional Lands in Brazil. Projeto Nova Cartografia Social da Amazônia.

Dinerstein, E., Olson, D., Joshi, A., Vynne, C., Burgess, N. D., Wikramanayake, E., Hahn, N., Palminteri, S., Hedao, P., Noss, R., Hansen, M., Locke, H., Ellis, E. C., Jones, B., Barber, C. V., Hayes, R., Kormos, C., Martin, V., Crist, E., … Saleem, M. (2017). An Ecoregion-Based Approach to Protecting Half the Terrestrial Realm. BioScience, 67(6), 534–545. https://doi.org/10.1093/biosci/bix014

Domingues, G., & Sauer, S. (2022). Amazonian socio-environmental frontier: Struggles, resistance and contradictions in confronting the agrarian extractive frontier. Third World Quarterly, 0(0), 1–19. https://doi.org/10.1080/01436597.2022.2124965

dos Santos, A. M., da Silva, C. F. A., de Melo, S. N., de Almeida Junior, P. M., & Bueno, L. F. (2022). Influence of deforestation inside and outside indigenous lands in the Brazilian Amazon Biome. Regional Environmental Change, 22(2), 77. https://doi.org/10.1007/s10113-022-01937-9

Dürr, J. (2020). A brief economic history of the Amazon (1720–1970). The Journal of Peasant Studies, 47(3), 609–612. https://doi.org/10.1080/03066150.2020.1726580

ESRI (2009) World Imagery. [digital map]. https://www.arcgis.com/home/item.html?id=10df2279f9684e4a9f6a7f08febac2a9. Retrieved October 9, 2022.

Foley, J. A., Asner, G. P., Costa, M. H., Coe, M. T., DeFries, R., Gibbs, H. K., Howard, E. A., Olson, S., Patz, J., Ramankutty, N., & Snyder, P. (2007). Amazonia revealed: Forest degradation and loss of ecosystem goods and services in the Amazon Basin. Frontiers in Ecology and the Environment, 5(1), 25–32. https://doi.org/10.1890/1540-9295(2007)5[25:ARFDAL]2.0.CO;2

Global Forest Watch (GFW). (2015). Brazil Biomes. [digital map]. https://www.arcgis.com/home/item.html?id=54ec099791644be4b273d9d8a853d452. Retrieved October 9, 2022.

Gomes, C., Gomes, A., Alencar, A., Vadjunec, J., & Marques, L. (2018). Extractive Reserves in the Brazilian Amazon thirty years after Chico Mendes: Social movement achievements, territorial expansion and continuing struggles Reservas Extrativistas na Amazônia Brasileira trinta anos depois de Chico Mendes: conquistas do movimento social, expansão territorial e lutas contínuas. Desenvolvimento e Meio Ambiente, 48. https://doi.org/10.5380/dma.v48i0.58830

Grandin, G. (2009). Fordlandia: The Rise and Fall of Henry Ford's Forgotten Jungle City. Macmillan.

Gutberlet, J. (1999). Rural Development and Social Exclusion: A case study of sustainability and distributive issues in Brazil. Australian Geographer, 30(2), 221–237. https://doi.org/10.1080/00049189993710

Hansen, M. C., Potapov, P., Moore, R., Hancher, M., Turubanova, S., Tyukavina, A., Thau, D., Stehman, S., Goetz, S., Loveland, T., Kommareddy, A., Egorov, A., Chini, L., Justice, C. O., & Townshend, J. (2013). High-Resolution Global Maps of 21st-Century Forest Cover Change. Science (New York, N.Y.), 342, 850–853. https://doi.org/10.1126/science.1244693

Hecht, S. B., & Cockburn, A. (2011). The Fate of the Forest: Developers, Destroyers, and Defenders of the Amazon, Updated Edition. University of Chicago Press. http://ebookcentral.proquest.com/lib/ucb/detail.action?docID=719231

Hecht, S. B., and D. A. Posey. 1989. Preliminary Results on Soil Management Techniques of the Kayapó Indians. Advances in Economic Botany 7: 174–188.

IBGE (2014). Brazilian States IBGE 2014. [digital map]. Instituto Brasileiro de Geografia e Estatística. https://services1.arcgis.com/RTK5Unh1Z71JKIiR/arcgis/rest/services/brazilian_states_ibge_2014/FeatureServer

Junk, W. J., Wittmann, F., Schöngart, J., & Piedade, M. T. F. (2015). A classification of the major habitats of Amazonian black-water river floodplains and a comparison with their white-water counterparts. Wetlands Ecology and Management, 23(4), 677–693. https://doi.org/10.1007/s11273-015-9412-8

Leduc, A. O. H. C., De Carvalho, F. H. D., Hussey, N. E., Reis-Filho, J. A., Longo, G. O., & Lopes, P. F. M. (2021). Local ecological knowledge to assist conservation status assessments in data poor contexts: a case study with the threatened sharks of the Brazilian Northeast. Biodiversity and Conservation, 30(3), 819–845. https://doi.org/10.1007/s10531-021-02119-5

McDonnell, S., & Regenvanu, R. (2022). Decolonization as practice: Returning land to Indigenous control. AlterNative: An International Journal of Indigenous Peoples, 18(2), 235–244. https://doi.org/10.1177/11771801221100963

Mosquera-Guerra, F., Trujillo, F., Parks, D., Oliveira-da-Costa, M., Van Damme, P. A., Echeverría, A., Franco, N., Carvajal-Castro, J. D., Mantilla-Meluk, H., Marmontel, M., & Armenteras-Pascual, D. (2019). Mercury in Populations of River Dolphins of the Amazon and Orinoco Basins. EcoHealth, 16(4), 743–758. https://doi.org/10.1007/s10393-019-01451-1

Neeleman, G., Neeleman, R., & Davis, W. (2013). Tracks in the Amazon: The Day-To-Day Life of the Workers on the Madeira-Mamoré Railroad. University of Utah Press. http://ebookcentral.proquest.com/lib/ucb/detail.action?docID=3443896

O'Bryan, C. J., Garnett, S. T., Fa, J. E., Leiper, I., Rehbein, J. A., Fernández-Llamazares, Á., Jackson, M. V., Jonas, H. D., Brondizio, E. S., Burgess, N. D., Robinson, C. J., Zander, K. K., Molnár, Z., Venter, O., & Watson, J. E. M. (2021). The importance of Indigenous Peoples' lands for the conservation of terrestrial mammals. Conservation Biology, 35(3), 1002–1008. https://doi.org/10.1111/cobi.13620

((o))eco. (2013, April 19). O que são Unidades de Conservação. ((O))Eco. https://oeco.org.br/dicionario-ambiental/27099-o-que-sao-unidades-de-conservacao/

Olson, J. S. (1991). The Indians of Central and South America: An Ethnohistorical Dictionary. Greenwood Publishing Group.

Philippe-Belleau, J. (2014). History, Memory, and Utopia in the Missionaries' Creation of the Indigenous Movement in Brazil (1967–1988). The Americas 70(4), 707-730. doi:10.1353/tam.2014.0057.

Porier, C. & Vargas, A.P. *Illegal Miners Terrorize Brazil's Yanomami Communities | Amazon Watch*. (2022, May 19). https://amazonwatch.org/news/2022/0519-illegal-miners-terrorize-brazils-yanomami-communities

Porto-Gonçalves, C. W., & Leff, E. (2015). Political Ecology in Latin America: The Social Re-Appropriation of Nature, the Reinvention of Territories and the Construction of an Environmental Rationality. Desenvolvimento e Meio Ambiente, 35, 65–88. https://doi.org/10.5380/dma.v35i0.43543

Pierotti, R., & Wildcat, D. (2000). Traditional Ecological Knowledge: The Third Alternative (commentary). Ecological Applications, 10(5), 1333–1340. https://doi.org/10.1890/1051-0761(2000)010[1333:TEKTTA]2.0.CO;2

RAISG (2020a). 2020 - Áreas Naturales Protegidas Nacionales. [digital map]. RAISG - Red Amazónica de Información Socioambiental Georreferenciada. https://dev.amazoniasocioambiental.org/en/maps/

RAISG (2020b). 2020 - Área Naturales Protegidas Departamentales. [digital map]. RAISG - Red Amazónica de Información Socioambiental Georreferenciada. https://dev.amazoniasocioambiental.org/en/maps/

RAISG (2020c). 2020 - Territórios Indígenas. [digital map]. RAISG - Red Amazónica de Información Socioambiental Georreferenciada. https://dev.amazoniasocioambiental.org/en/maps/

RAISG (2020d). 2020 - Zonas Minerías. [digital map]. RAISG - Red Amazónica de Información Socioambiental Georreferenciada. https://dev.amazoniasocioambiental.org/en/maps/

RAISG (2020e). Mineria Ilegal 2020. [digital map]. RAISG - Red Amazónica de Información Socioambiental Georreferenciada. https://dev.amazoniasocioambiental.org/en/maps/

Revkin, A. (2004). The Burning Season: The Murder of Chico Mendes and the Fight for the Amazon Rain Forest. Island Press. http://ebookcentral.proquest.com/lib/ucb/detail.action?docID=3317660

Rylands, A. B., & Brandon, K. (2005). Brazilian Protected Areas. Conservation Biology, 19(3), 612–618.

Schipper, J. Amazonian Subrealm. (n.d.). One Earth. Retrieved October 9, 2022, from https://www.oneearth.org/ecoregions/rio-negro-campinarana/

Schuster, R., Germain, R. R., Bennett, J. R., Reo, N. J., & Arcese, P. (2019). Vertebrate biodiversity on indigenous-managed lands in Australia, Brazil, and Canada equals that in protected areas. Environmental Science & Policy, 101, 1–6. https://doi.org/10.1016/j.envsci.2019.07.002

Sheikh, P. A., Meyer, P. J., Procita, K., & Hoover, K. (2021). Fire and Deforestation in the Brazilian Amazon. Congressional Research Service. https://crsreports.congress.gov/product/pdf/IF/IF11306/3

Skidmore, T. E. (1988). The politics of military rule in Brazil, 1964-85. New York : Oxford University Press. http://archive.org/details/politicsofmilita00skid

Sommer, B. A. (2005). Colony of the Sertao: Amazonian Expeditions and the Indian Slave Trade. The Americas, 61(3), 401–428. https://doi.org/10.1353/tam.2005.0053

Sonter, L. J., Herrera, D., Barrett, D. J., Galford, G. L., Moran, C. J., & Soares-Filho, B. S. (2017). Mining drives extensive deforestation in the Brazilian Amazon. Nature Communications, 8(1), 1013. https://doi.org/10.1038/s41467-017-00557-w

Sze, J. S., Carrasco, L. R., Childs, D., & Edwards, D. P. (2022). Reduced deforestation and degradation in Indigenous Lands pan-tropically. Nature Sustainability, 5(2), 123–130. https://doi.org/10.1038/s41893-021-00815-2

Tigre, M. A. (2019). Building a regional adaptation strategy for Amazon countries. International Environmental Agreements: Politics, Law and Economics, 19(4), 411–427. https://doi.org/10.1007/s10784-019-09443-w

Urzedo, D. & Chatterjee, P. (2020). The Colonial Reproduction of Deforestation in the Brazilian Amazon: Violence Against Indigenous Peoples for Land Development. Journal of Genocide Research, 23(2), 302-324. https://discovery-ebsco-com.colorado.idm.oclc.org/c/3czfwv/viewer/pdf/6ncpxq4tfr

Vallejos, P. Q., Veit, P., Tipula, P., & Reytar, K. (2020). Undermining Rights: Indigenous Lands and Mining in the Amazon. https://www.wri.org/research/undermining-rights-indigenous-lands-and-mining-amazon

Venticinque, E., Forsberg, B., Barthem, R., Petry, P., Hass, L., Mercado, A., Canas, C., Montoya, M., Durigan, C., & Goulding, M. (2021). Amazon Rivers Order 7 to 11. [digital map]. Science for Nature and People Partnership (SNAPP) https://knb.ecoinformatics.org/view/doi%3A10.5063%2FF1BG2KX8#snapp_computing.6.1

ZAITCHIK, A. (2018). HOW CONSERVATION BECAME COLONIALISM. Foreign Policy, 229, 56–63. https://www.jstor.org/stable/26535794

Zimbres, B., Peres, C. A., & Machado, R. B. (2017). Terrestrial mammal responses to habitat structure and quality of remnant riparian forests in an Amazonian cattle-ranching landscape. Biological Conservation, 206, 283–292. https://doi.org/10.1016/j.biocon.2016.11.033