Law but not order: Effectiveness of Brazil's Native Vegetation Protection Law in preventing forest loss in human occupied areas of the Amazon

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Research Article

Keywords: Amazon, deforestation, environmental legislation, land use, protected areas, indigenous lands.

Posted Date: March 17th, 2022

DOI: https://doi.org/10.21203/rs.3.rs-1458805/v1

Abstract

With continued forest loss in tropical regions, it is important to understand whether and how public policies influence deforestation rates. One potentially important policy is Brazil's "Native Vegetation Protection Law" (NVPL), passed in 2012 and popularly known as the New Forest Code. The goal of the law is to prevent forest loss; however, its success at maintaining forest is unclear. We analyze the effectiveness of the law in the state of Amazonas, Brazil by measuring forest loss in 2009 and 2012, pre implementation of the new vegetation protection law (NVPL) and comparing this to loss that occurred in 2015 and 2018, post-NVPL, in Settlement Projects (SP) affected by NVPL and Indigenous Lands (IL) and State/National Forests which were not under the mandate of the NVPL. We used these last two categories as Control Areas. Forest loss was greatest in SP during both time periods relative to two other categories considered. Implementation of the NVPL did not reduce overall deforestation in SPs. However, it did keep deforestation within the 20% limit set by NVPL in 31 of 35 SPs surveyed. In addition, forest cover decreased in only a few SPs. The variable with the strongest influence on deforestation within SP and IL was intensity of human land use in surrounding areas. We also found that IL and CU categories play an important role in maintaining overall forest cover.

Introduction

Worldwide approximately 230 million ha of tropical forests worldwide have been converted to agricultural lands over the past 40 years (Gibbs et al., 2010; Hansen et al., 2013). In the Brazilian Amazon in the 1970s, forest clearcutting was closely associated with road construction and colonization projects (Fearnside, 2005; Peres et al., 2010). This type of development was promoted by the Brazilian government to ensure land sovereignty and to promote economic activities (Carvalho et al., 2002). Through both federally sanctioned initiatives and private projects, forested land was subdivided into small family farms and farming cooperatives, referred to as "land reform settlements" (Brazil, 1964). Over time, several different categories of land reform settlements were designed and established (Alencar et al., 2016). These differed by ownership type (private or collective), land use permitted, and whether land could be sold. Since 2004, new settlements must also follow sustainability mandates; for example, settlements designated as Sustainable Development Projects and Agro-extractive Settlement Projects were required to use forest products sustainably and agricultural products must also be sustainably produced (Alencar et al., 2016; Ezzine-de-Blas et al., 2011).

About 8% of the Brazilian Legal Amazon (41.8 million ha) is occupied by 3,589 land reform settlements (Alencar et al., 2016). Other categories in the Amazon that allow human occupation include Indigenous Lands (IL) and sustainable use Conservation Units (CU). Among the different categories of land reform settlements, Settlement Projects (SP) have been identified as responsible for most forest clearcutting (13.7% of deforested area), with IL and CU experiencing lower amounts of deforestation (2 and 3.5% respectively; MapBiomas, 2021). In the Brazilian Legal Amazon, the state of Amazonas still maintains 90% of its area under natural vegetation, with about 50% of this designated in different protected area categories, including ILs, as well as different sub-categories of CUs such as Extractive and Sustainable Development Reserves, National and State Forests and National and State Parks (Campos & Higuchi, 2009). Most deforestation in the region has occurred in the southeastern Amazon, an area known as the Arc of Deforestation (Azevedo et al., 2016; Barber et al., 2014; Laurance et al., 2002; Tritsch & Le Tourneau, 2016).

To control and reduce forest loss in Brazil, the federal government in 2012 passed the Native Vegetation Protection Law – NVPL (Brazil, 2012). This law replaced an older law known as the Brazilian Forest Code (Brazil, 1964). The main change was those rural properties in the Amazon biome were now required to maintain 80% of their area as undisturbed natural vegetation (Legal Reserve (LR)) to preserve forests and biodiversity (Covre et al., 2015). The older Brazilian Forest Code only required protection of up to 50% of an area as a LR. An important innovation in the new law was the creation of an Environmental Rural Registry (Cadastro Ambiental Rural, CAR), a mandatory national, electronic public data base of all rural properties (Brazil, 2012). A further goal of the registry was to link properties to environmental information. This development allowed us to measure the effectiveness of the NVPL as a means of preventing or reducing forest loss in areas of legal human occupation in the Amazon.

In the past, higher deforestation levels were noted in SP compared to IL and CU (Alencar et al., 2016; MapBiomas, 2021). However, deforestation in lands occupied under different categories of human occupation can be differently influenced by anthropogenic and landscape factors (MapBiomas, 2021). Important factors to consider are amount of resources available, transportation and transport costs, resources provided by the government, crops grown and human population density (Laurance et al., 2002; Pfaff, 1999; Tritsch & Le Tourneau, 2016). We compare forest loss before and after implementation of NVPL to assess the effectiveness of the new law in the state of Amazonas, Brazil. We sought to determine: 1) If NVPL helped maintain forest cover in SP, which are affected by NVPL, and 2) If forest loss was similar across SP, and IL and CU. The latter two are not governed by the NVPL and served as controls in our study. We also asked what anthropogenic and landscape factors influence forest loss across the three areas, and 4) whether the effects of anthropogenic and landscape factors changed with the implementation of NVPL. We predicted that: 1) forest loss would decrease after implementation of the NVPL in SP; 2) forest loss in IL and CU would not change; 3) anthropogenic and landscape factors, such as human population density, forest loss in adjacent buffer areas and distance to nearest population centers would influence forest loss in the SP, but not in IL and CU; and 4) that the effects of the anthropogenic and landscape factors would remain constant even after implementation of NVPL.

Materials And Methods

Study Area

The Brazilian state of Amazonas is located in the central region of the Amazon basin (Fig. 1). With an area of 155,916,788.9 ha it is the largest state in Brazil and represents 31% of the Brazilian Legal Amazon (IBGE, 2020). We examined three legal categories of human occupied areas: SP, IL and CU. SP are naturally vegetated areas set aside for human colonization by people from outside the local region and often from outside the state (INCRA, 2004). These colonists are meant to seek sustainable livelihoods as small-scale farmers (INCRA, 2004). IL are areas occupied by indigenous peoples and recognized by the federal government (Brazil, 1988). They are permanently inhabited, used for productive activities, and essential for the preservation of natural resources necessary for the physical and cultural well-being of indigenous people. Indigenous people have exclusive use rights of their areas, except for the subsoil (Brazil, 1988). We assessed National and State Forests, categories of Sustainable Use CU, where authorized activities —primarily sustainable use of forest resources and scientific research— are considered less damaging to forests than those allowed in SP (Alencar et al., 2016; MapBiomas, 2021). The forest use in this case is usually the sustainable logging of native forests (Brazil, 2000). IL and CU (National and State Government Forests) were analyzed as Control Areas due to show little forest loss (MapBiomas, 2021) and are dispensed by NVPL (Brazil, 2012). In Amazonas there are 35 SP with a total area of 1,415,057.2 ha; 148 IL, with an area of 56,342,236.02 ha; 12 National Forests, with 9,983,819.96 ha; and eight State Forests that cover 2,584,929.62 ha (see appendix for more details). For convenience, we include areas that have at least some portion of their territory within the state of Amazonas.

Forest loss

We analyzed cover and land use maps from the MapBiomas collection 4.1 (MapBiomas, 2020) to quantify the amount forest loss in SP, IL and CU. The MapBiomas maps and datasets are freely available. The project classifies and geo-references information using LANDSAT data for all Brazilian biomes at a 30-m resolution. These data are generated annually with 95.9% accuracy level using an automatic classification routine applied to satellite images for the whole Amazon biome (https://mapbiomas.org/analise-de-acuracia). The analytical routine separates a number of cover and land use classes. However, our preliminary analysis identified that the routine overestimated the pasture class due to the miss-classification of agriculture or urban infrastructure classes to pasture. Thus, we limited our analysis to the native forest class and grouped all land under active human use into one category, an “Anthropogenic cover class.” Changes in the amount of this latter class amounted to forest loss or increase. Areas covered by water were omitted from analyses. Landsat data were analyzed for the years 2009, 2012, 2015 and 2018. Cover data for the years 2009 and 2012 were grouped and categorized as pre-implementation of NVPL (Pre-NVPL, while 2015 and 2018 data are affected by NVPL (Post-NVPL). For more details on the differences between the older Brazilian Forest Code and NVPL see Covre et al., 2015, Magano et al., 2021 and Pertille et al., 2017. The year 2018 was the most recent date with available land cover data in MapBiomas. We exclude from analysis any locations in settlements, indigenous lands, and conservation units that were created after the NVPL. SP shapefiles were provided by the National Institute for Colonization and Agrarian Reform (Instituto Nacional de Colonização e Reforma Agrária—INCRA) (http://certificacao.incra.gov.br/csv_shp/export_shp.py). We calculated land cover for each SP using its total area (perimeter). Eighty percent of the area of each SP must be preserved as a native forest Legal Reserves in the Amazon biome (Brazil, 2012). Legal Reserves for some SP are collective, rather than assigned to each individual family lot, while in others they may be assigned to each family lot. For many adjacent family lots, legal Reserves overlapped in area, potentially leading to an overestimation of these areas. Such overlap made it difficult to accurately assess cover of the Legal Reserves for each family lot. For simplicity, we therefore assumed that the total area of each SP equaled a single rural property. In addition to the requirement of forested Legal Reserves, additional natural areas, such as riparian corridors, steep slopes and other sensitive ecosystems, must also be maintained under forest cover as Permanent Protection Areas (Brazil, 2012).Shapefiles of IL were obtained from the National Indian Foundation (Fundação Nacional do Índio – FUNAI) (http://www.funai.gov.br/index.php/shape) and those for CU from the Ministry of Environment (Ministério do Meio Ambiente – MMA) (http://mapas.mma.gov.br/i3geo/datadownload.htm). All federally designated areas with at least part of their surface area within the state of Amazonas were included in the analysis.

We used QGIS v3.10 software (QGIS Development Team, 2020) to extract and analyze land cover and land use classes from the Google Earth Engine platform of MapBiomas (GEE; Gorelick et al., 2017). When shapefiles were not available on GEE (for example, all the SP and some IL and CU), we obtained data on the areas of human occupation from INCRA, FUNAI or MMA as a mask onto the Amazon raster of MapBiomas. We used the attribute table for each area under human use in each year to obtain cover and land use classes. The values obtained were extracted first as the total number of pixels and then converted into ha (each pixel ≈ 0.09 ha). We use the percentage of cover and land use classes for each area under human occupation pre- and post-NVPL, to avoid overestimation for large areas. All images were systematized in UTM projection Sirgas 2000 datum.

Anthropogenic and landscape factors

We evaluated the impact of area accessibility and landscape-scale land use as factors that potentially contribute to forest loss (Table 1). All variables and their potential impact are listed in Table 1. To assess accessibility, we measured the distances to nearest cities, roads and waterways. Distance to the variable of interest was measured as the minimum distance from the centroid of the SP polygon to the nearest city, road or waterway. Shapefiles of cities were obtained from the Brazilian Institute of Geography and Statistics (Instituto Brasileiro de Geografia e Estatística – IBGE) https://www.ibge.gov.br/geociencias/downloads-geociencias.html); of roads from the Instituto do Homem e Meio Ambiente da Amazônia (Imazon; https://imazongeo.org.br/#/); and of waterways from IBGE (http://www.metadados.geo.ibge.gov.br/) and the National Water Agency (Agência Nacional de Águas – ANA; https://metadados.ana.gov.br/geonetwork/srv/pt/main.home). For landscape-scale land use characteristics areas we used: 1) the population size of the county where the study area is embedded, 2) area size, 3) date established (creation time), 3) geographical location (latitude and longitude), and 4) external deforestation pressure calculated as the amount of forest loss in a 5 km buffer surrounding the borders of the areas under study. These variables have been previously identified as driving forest conversion to agricultural land use (see Table 1). County seats provide the most accurate population estimates for a geopolitical unit for the state of Amazonas. Population size was collected from IBGE (https://www.ibge.gov.br/estatisticas/sociais/populacao/9103-estimativas-de-populacao.html). Area size, creation time and geographical location data were collected from INCRA, FUNAI and MMA. Data for calculating external deforestation pressure were collected from the GEE platform in MapBiomas, as it provides a raster of polygons in the 5 km buffer area around study areas with land use categories identified. If the data were unavailable in the GEE platform, we generated these buffers using QGIS software and shapefiles for the state of Amazonas, as a base layer. All data on the anthropogenic factors were measured pre- and post-NVPL period.

Table 1
The anthropogenic and landscape factors examined, their impact and source of information

Factors	Impact	Sources
Anthropogenic (accessibility)		
Distances: to cities	Proximity to cities tends to increase forest loss. For example: markets for agricultural and other products increase deforestation; roads permit access for tractors and heavy machinery, ease gasoline transportation and, movement by people.	Berenguer et al., 2021 Pfaff, 1999 Pfaff et al., 2015
to roads	Road proximity increases forest loss. Roads connect forests to cities and increase the flow of goods and people. Roads also increase the opening of illegal roads.	Barber et al., 2014 Brandão Jr & Souza Jr, 2006 Laurance et al., 2002 Jusys, 2018
to waterways	Function is similar to roads but without cars, because of these waterways are somewhat less harmful. Historically, this is one of the main means of travel in the Amazon	Barber et al., 2014 Laurance et al., 2002
Landscape-scale land use characteristics		
Human population size of nearest county	Areas with bigger population should show more forest loss. This because more people mean more demand for natural resource, greater flow of forest products, and more people to invade forests.	Laurance, 1999 Tritsch & Le Tourneau, 2016
Area size	Smaller areas should show greater forest loss. This because these areas are more exposed to surrounding property owned by non-indigenous people.	Cabral et al., 2018 de Almeida-Rocha & Peres, 2021
Establishment time	Amount of area deforested is linked to the age of areas.	Alencar et al., 2016
Geographical location (Latitude and Longitude)	Proxy for locating where deforestation happens most. For example, areas located to the south and west of the Brazilian Amazon have a greater record of forest loss.	Fearnside & De Alencastro Graça, 2006 A. M. dos Santos et al., 2021
External pressure (buffer 5km around)	Amount of area deforested outside the border of area.	Cabral et al., 2018 de Almeida-Rocha & Peres, 2021 Ferreira et al., 2005

Data analyses

We compare forest loss pre- and post-NVPL for SP, IL and CU using total area (ha) and percentage of area deforested. To assess the effectiveness of the NVPL for forest preservation, we compared the mean percentage of forest loss between pre- and post-NVPL periods by sampling unit. We test the significance of differences using a paired t-test. Percent of forest cover was transformed into log + 1 to achieve normality in data distribution. We analyzed forest loss (response variable) by anthropogenic factors (predictor variables) using the Negative Binomial GLM (Zuur et al., 2009), using the 'MASS' statistical package (Venables & Ripley, 2002). We tested for multicollinearity between predictor variables for each time frame and area class of human occupation, using the Spearman correlation test. None of the predictor variables were correlated ($r < 0.75$). GLM models were used to analyze the relationship between the response and predictor variables. We estimated the independent contributions of each predictor variable of the GLM models using hierarchical partitioning of the 'hier.part' package (Mac Nally & Walsh, 2004). All statistical analyses were performed with R version 3.5.1 (R Core Team, 2018).

Results

We obtained data for 35 SP, 116 IL and 16 CU (10 National Forests and 6 State Forests), for a total of 167 areas (see Appendix). These areas represent 37.8% of the land area of the state of Amazonas; SP covered 0.9%, IL 30.4% and CU 6.5% of the state. After the implementation of NVPL, SP experienced the highest deforestation rates in all years except for 2015 (Fig. and Table 2,). IL and CU (also designated as Control areas in this study) showed the same increasing deforestation tendency as SP across all years but at lower levels. For SP and CU overall, the amount of forest cover did not change significantly ($p > 0.05$) after implementation of the NVPL (Fig. and Table 3). However, for 30 of 35 SP forest loss was less than 20% permitted by law (Fig. 3a and Table 2). In contrast, forest loss increased on IL post NVPL (Fig. 3b and Table 3).

Table 2
Percentage of forest loss in Settlement Projects (SP) pre and post NVPL implementation. Bold numbers indicate SP where deforestation exceeded the (20%) legal limit imposed by the NVPL. Negative forest loss change indicates increase of forest cover.

Settlement Project name	2009 forest loss	2012 forest loss	2015 forest loss	2018 forest loss	Pre-NVPL forest loss (2009 and 2012)	Post-NVPL forest loss (2015 and 2018)	Forest loss change between Pre-NVPL and Post-NVPL
Acari	6.13	7.64	8.79	12.30	6.88	10.54	3.66
Água Branca	5.40	9.32	4.72	6.87	7.36	5.80	-1.57
Aliança	5.60	5.67	3.39	3.50	5.63	3.44	-2.19
Aquidaban	17.50	22.23	22.91	24.05	19.86	23.48	3.62
Beruri	0.52	0.92	0.85	1.08	0.72	0.96	0.24
Boia	4.61	2.60	2.75	2.37	3.61	2.56	-1.05
Canoas	5.54	6.00	5.79	5.80	5.77	5.80	0.02
Caviana	11.09	14.21	13.45	14.98	12.65	14.22	1.57
Crajari	2.40	1.18	0.90	0.48	1.79	0.69	-1.10
Engenho	8.85	17.55	17.39	17.18	13.20	17.29	4.09
Espigão do Arara	9.74	11.52	12.28	13.95	10.63	13.11	2.48
Iporá	9.27	11.63	9.70	10.59	10.45	10.15	-0.30
Manaquiri I Gleba 06	0.81	3.30	4.22	4.42	2.06	4.32	2.27
Manaquiri II Gleba 07	1.63	2.83	4.10	6.85	2.23	5.47	3.25
Matupi	32.88	41.10	49.87	60.68	36.99	55.27	18.28
Monte	29.76	37.19	44.98	53.35	33.48	49.16	15.69
Nazaré	11.71	14.57	12.23	14.15	13.14	13.19	0.06
Nova Residência	5.09	8.71	6.55	6.90	6.90	6.73	-0.18
Pacia	2.98	4.20	3.53	3.72	3.59	3.62	0.03
Panelão	18.24	11.85	11.85	13.79	15.04	12.82	-2.23
Paquequer	6.11	7.19	7.63	9.24	6.65	8.44	1.79
Piaba	8.05	11.53	10.76	11.78	9.79	11.27	1.48
Puraquequara	19.36	22.10	15.57	16.38	20.73	15.98	-4.75
Puxurizal	7.85	9.91	7.83	9.57	8.88	8.70	-0.18
Rio Juma	13.50	15.90	18.03	24.33	14.70	21.18	6.48
Rio Pardo	2.72	2.85	2.65	2.50	2.78	2.57	-0.21
Riozinho	23.83	24.56	17.94	20.24	24.20	19.09	-5.11
Sampaio	15.49	15.47	13.62	14.33	15.48	13.98	-1.51
Santo Antônio	10.20	10.12	7.49	8.22	10.16	7.85	-2.30
São Francisco	12.34	13.41	15.19	18.19	12.87	16.69	3.82
Tarumá Mirim	5.59	6.10	4.98	5.72	5.84	5.35	-0.49
Uatumã	5.47	4.69	4.47	5.13	5.08	4.80	-0.28
Umari	8.26	12.15	11.16	13.35	10.20	12.25	2.05
Urumutum	21.93	17.29	15.74	16.43	19.61	16.09	-3.52
Vila Amazônia	23.77	24.98	26.38	23.43	24.37	24.90	0.53

Table 3
Descriptive statistics of forest loss for human occupation categories pre and post NVPL.

Category	Period	Area (ha)	Percentage (%)
Settlement Project	Pre-NVPL	5868.1 ± 17846.6	11.52 ± 8.67
	Post-NVPL	8071.03 ± 25749.86	12.79 ± 11.73
Indigenous Land	Pre-NVPL	499.05 ± 960.1	3.07 ± 7.64
	Post-NVPL	732.78 ± 1473.15	3.76 ± 8.4
Conservation Units	Pre-NVPL	1490.38 ± 2004.28	0.19 ± 0.22
	Post-NVPL	1536.88 ± 1910.83	0.2 ± 0.19

Table 4. Summary of Negative Binomial Generalized Linear Models for Settlement Projects and Indigenous Lands, in relation to anthropogenic factors influencing forest loss pre and post NVPL. Total explained variance of each model and independent explanatory power (HP) based on hierarchical partitioning of each significant variable are shown. Only independent power of explanatory variables with significant effect are given.

Category	Period	Variance explained	Roads			Population size			Area size			Creation time			Latitude			External press	
			z		HP (%)	z		HP (%)	z		HP (%)	z		HP (%)	z		HP (%)	z	
Settlement Project	Pre-NVPL	0.63	-4.42	***	21.4							2.18	*	8.9	-4.17	***	27.9	4.52	***
	Post-NVPL	0.64	-3.00	**	6.5										-4.82	***	42.4	4.87	***
Indigenous Land	Pre-NVPL	0.68				2.09	*	3.0	-5.95	***	39.2							4.58	***
	Post-NVPL	0.62				2.35	*	5.2	-6.21	***	42.7							3.43	***

*P < 0.01; **P < 0.001; ***P < 0.0001

Anthropogenic and landscape factors influenced forest loss in SP and IL, but not in the Control areas (CU; Fig. and Table 4). For SP, the strongest factor affecting forest loss was deforestation levels in the 5 km zones surrounding the study area. The next factors, in order of importance, were latitude, distance to road and establishment date (Fig. and Table 4). Forest loss in 5 km around SP was positively correlated with forest loss inside settlement areas, both pre- and post-NVPL (Fig. 4a and 4b). Forest loss negatively correlated with latitude and distance to roads pre- and post-NVPL, with greater deforestation in the south of the state and settlements near roads (Fig. 4c, 4d, 4e and 4f). Forest loss positively correlated with the date of establishment of settlements, but only for the pre-NVPL period (Fig. 4g).

For IL, forest loss in the 5 km surrounding area was the factor that most increased loss within areas, followed by area size, and human population size of the nearest county seat (Fig. and Table 4). For IL, human population size of the nearest county was positively correlated with forest loss inside the areas, pre- and post-NVPL (Fig. 4h, 4i, 4l and 4m). The size of IL was negatively correlated with forest loss in both periods, with larger areas experiencing less deforestation (Fig. 4j and 4k).

For SP and IL, all factors influenced forest loss pre and post NVPL, except for the establishment date for the category SP, which only had an influence pre-NVPL (Fig. and Table 4).

Discussion

The state of Amazonas has the most extensive forest cover of all states in the Brazilian Legal Amazon, but deforestation here has been increasing (de Vasconcelos et al., 2013). Although SP represent a small proportion of the state, relative IL and CU, these areas experienced the highest levels of forest loss in our and other studies (e.g., Alencar et al., 2016; Massoca, 2010; Yanai et al., 2017, 2020).

Contrary to our prediction 1 for SP, the implementation of NVPL did not reduce forest loss across years (2008, 2012, 2015, 2018) or periods (pre and post NVPL). These areas are used by small-scale farmers for agriculture and livestock production (INCRA, 2004); therefore, we expected higher levels of deforestation relative to IL and CU (control areas). However, deforestation within most SP remained within the 20% limit permitted by law until 2018, indicating that the law functioned as planned. However, deforestation levels exceeded the 20%, in 5 SP, indicating that more study is needed to determine driving factors. Roriz et al., (2017) assessed the potential impact of the NVPL on deforestation levels for one county in the Amazon region under three modeling scenarios: 1) a baseline scenario, 2) full compliance with the old Forest Code and 3) using the NVPL. Their model indicated that the best scenario for avoiding forest loss occurred under the old Forest Code. Our field based effort, using a larger sample size of all counties of the state of Amazonas, indicate that implementation of NVPL succeeded, in that 1) it kept forest loss below the 20% established by law and 2) deforestation levels remained unchanged between sampling periods.

We also showed that Control Areas – IL and CU (National and State Forests) contributed little to deforestation overall, corroborating our prediction 2. This result has also been observed for other areas of the Brazilian Amazon (Moutinho et al., 2016). IL and CU were overall, the best categories of human inhabited lands for maintaining intact forests, as also observed by Iwamura et al. (2014, 2016), despite constant pressure from illegal invasions by loggers and others (Nepstad et al., 2006; Paiva et al., 2020). However, in our study IL was the only human occupation area that experienced increasing deforestation post-NVPL. This may be due to increased illegal invasions by loggers, miners and land-grabbers (Conceição et al., 2021; Fragoso & Reo, 2013; Overman et al., 2018, 2019).

As expected for prediction 3, anthropogenic and landscape factors impacted deforestation levels in the same direction and intensity pre- and post-NVPL. However, for SP and IL, increasing deforestation in 5 km areas outside their borders strongly impacted forest loss levels inside. This was also observed by Iwamura et al. (2016) for indigenous areas in Guyana. SP and IL were the most vulnerable to land development in bordering areas. Land development outside these areas facilitates invasion by illegal gold miners and land grabbers (Nepstad et al., 2006; Overman et al., 2018, 2019).

Settlements (SP) close to roads, with older establishment dates and in southern Amazonas, had the highest rates of deforestation of any areas in our study. The southern region lies adjacent to the “Arc of Deforestation,” an area that has experienced very high rates of forest clearing for a very long time (de Vasconcelos et al., 2013). A recent weakening of environmental laws dramatically increased deforestation throughout the Amazon (Santos, 2020). We noted that more forest loss occurred near roads, a pattern similar to that described by Barber et al., (2014). Road building was also observed as contributing to forest loss in the state of Pará, Brazil (Brandão Jr & Souza Jr, 2006). Roads increase the flow of people into forests. They also facilitate the movement of heavy machinery used in logging, leading to higher rates and larger areas being deforested (Laurance et al., 2009). Roads also increase the flow of goods and materials for use by colonists in SP (Cambraia & Amaro, 2008) and this also contributes to higher deforestation levels.

For IL, area size and distance from cities were key factors influencing forest loss. Smaller IL closer to larger cities experienced the highest deforestation levels. A higher perimeter to inner area ration means that more of this area is open to land grabbers (Nepstad et al. 2006).

Contrary to prediction 4, the year of SP establishment had no impact on post-NVPL deforestation levels. For SP the pre-NVPL period corresponded with when deforestation levels were highest in the Brazilian Amazon (Alencar et al., 2016). Older SP were governed entirely by the old Forest Code (Law 4771/1965), which was less restrictive than the new NVPL.

Conclusion

Contrary to our prediction that the NVPL would have no impact on deforestation levels, we found that the NVPL contributed to maintaining forest cover in SP, as forest loss remain unchanged and below the legally-permitted 20% deforestation limit. Between control areas, CU forest loss was low, but somewhat higher in IL. IL (and CU) are not under the jurisdiction of the NVPL, and some areas of IL experienced forest loss above 20%. Our study corroborates what has been shown as a trend for deforestation, by other studies in the Brazilian Amazon (Amin et al., 2019; Cabral et al., 2018; Kere et al., 2017), for other Amazonian countries (Armenteras et al., 2009; Oliveira et al., 2007), and Pantropically (Deininger & Minten, 1999; Porter-Bolland et al., 2012).

For SP, the greatest amount of deforestation occurred in older areas, near roads, located further south in the border of the Arc of Deforestation and surrounded by lands with high levels of deforestation. For SP, all these factors provide easy access to these areas likely helped the advance of the agricultural frontier into the region (Alencar et al., 2016). For IL, smaller areas in counties with high population density and surrounded by lands with high levels of deforestation experienced the highest deforestation levels. For IL, this is may be due to influences of other not traditional communities affecting the behavior of IL populations (Schneider et al., 2021) or for direct interventions of not traditional communities (Conceição et al., 2021). While we examined anthropogenic and landscape factors affecting forest loss individually, these likely also interact and perhaps produce more significant impacts than what we observed under the NVPL. We suggest that field studies – in situ – should also examine how drivers of forest loss interact for all land use categories (see also Yanai et al., 2020), and especially to identify the real actors of deforestation (Fearnside, 2008).

Current policies of the Brazilian federal government have weakened environmental laws, and this has negated the positive effect of the NVPL (Artaxo, 2019). The recent weakening of environmental laws by President Bolsonaro starting in 2019, resulted in increased deforestation across the Amazon (Abessa et al., 2019; Brasil-Debate, 2020; (Abessa et al., 2019; Brasil-Debate, 2020; Fonseca et al., 2021; MapBiomas, 2021; Menezes & Barbosa, 2021). For example, for SP, an amnesty was declared for people who violated the 20 percent clearing limit (Laudares et al., 2019). Further, although rural properties in the Amazon biome must maintain 80% of their area as LR, this requirement can be reduced to 50% if more than 65% of a state’s territory is protected public land. These alterations in law could lead to loses of 6.5–15.4 million hectares of private land to legal deforestation (Freitas et al., 2018). Government agencies that regulate deforestation need continued support to enforce forest protection laws in Brazil.

Declarations

Acknowledgements

We thank Kirsten Silvius for two critical reviews of the manuscript, and two anonymous reviewers for comments and suggestion on a first submission. ARAS is grateful to Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES; process # 1755707) and Brazilian Council for Scientific and Technological Development (CNPq; process # 140161/2019-8) for granting a PhD program scholarship. PEDB was supported by a postdoctoral scholarship from PNPD/CAPES (process # 88887.370067/2019-00). This is publication number 56 from the Amazonian Mammals Research Group.

Disclosure of Potential Conflicts of Interest

The authors declare that they have no conflict of interest

Data availability statement

The datasets generated and analyzed during the current study are available in the appendix. Data were obtained from the MapBiomas website (https://mapbiomas.org/).

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Figures

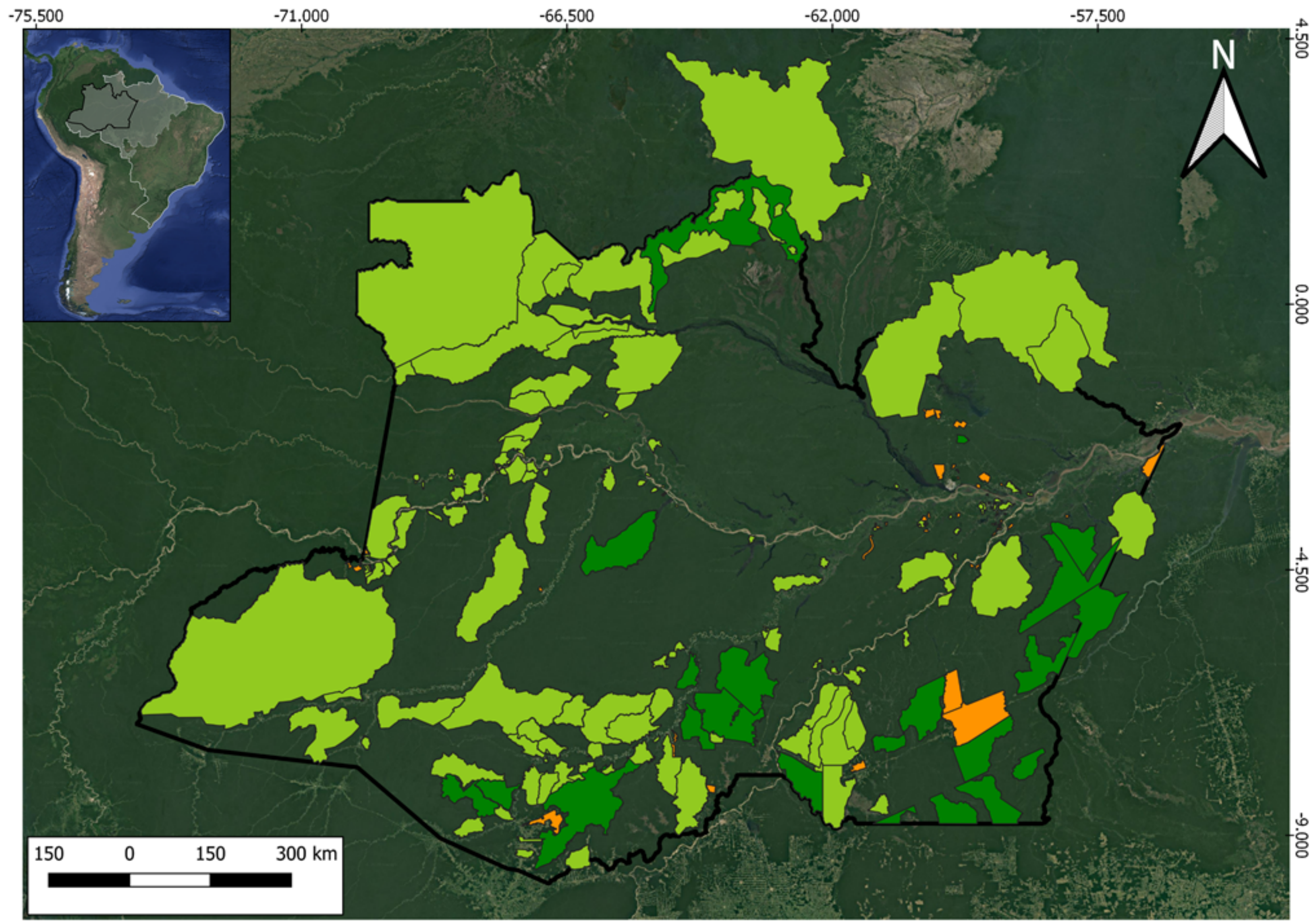

Figure 1

Map of the state of Amazonas with the location of Settlement Projects (SP: orange), and control areas: Indigenous Lands (IL; light green) and Conservation Units (CU; dark green). The top left corner shows the location of the Brazilian Legal Amazon (shaded white polygon) and the state of Amazonas (black line polygon) within South America.

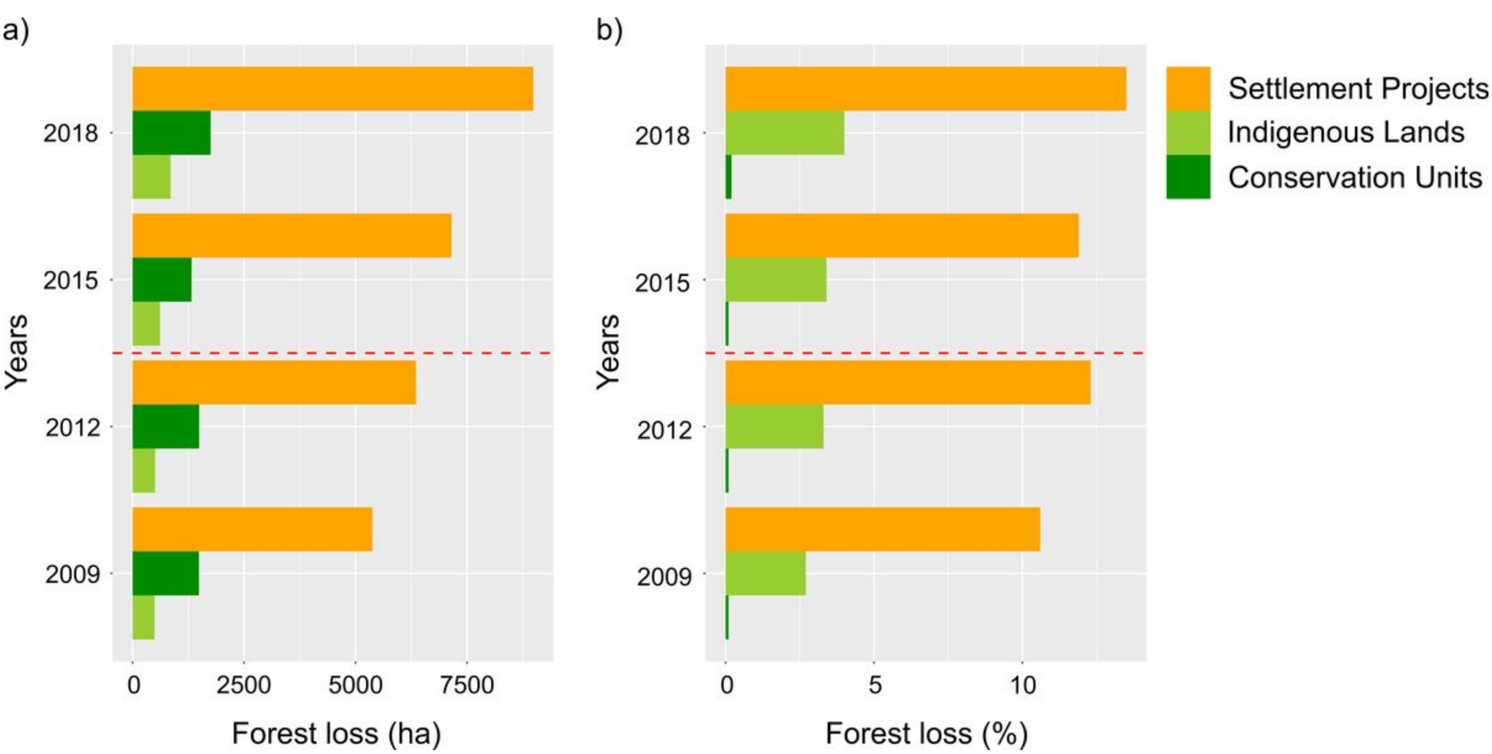

Figure 2

Mean forest loss for Settlement Projects, Indigenous Lands and Conservation Units over time; (a) amount of area deforested (b) the percentage of area deforested. Settlement Projects (orange bars); Indigenous Lands (yellow green bars); and Conservation Units (green bars). Dashed red line represent the implementation of the NVPL in 2012.

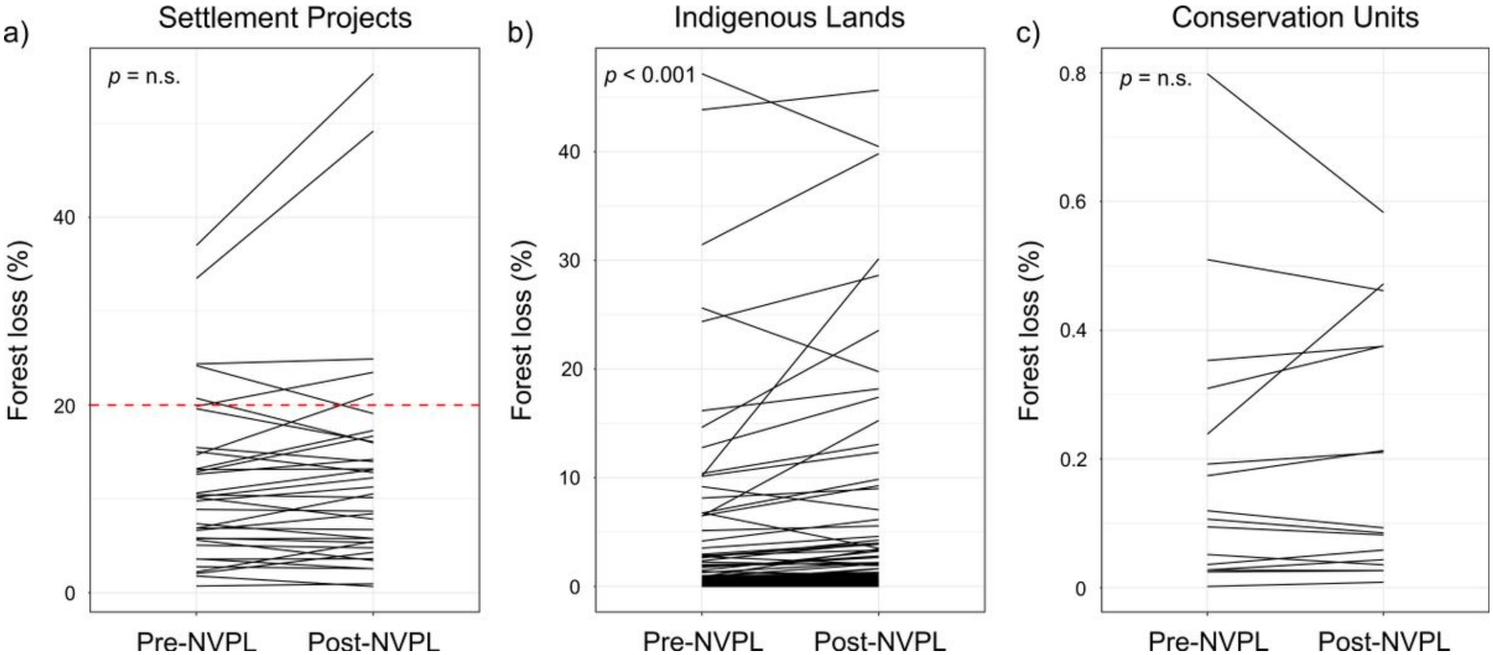

Figure 3

Comparison of the forest loss pre and post NVPL for Settlement Projects (a), Indigenous Land (b), and Conservation Units (c). Dashed red line in (a) represents the threshold percentage of native forest that must be protected according to the NVPL. This amounts to 20% of the area of SP for land use and 80% for native forest.

n.s.: not significant.

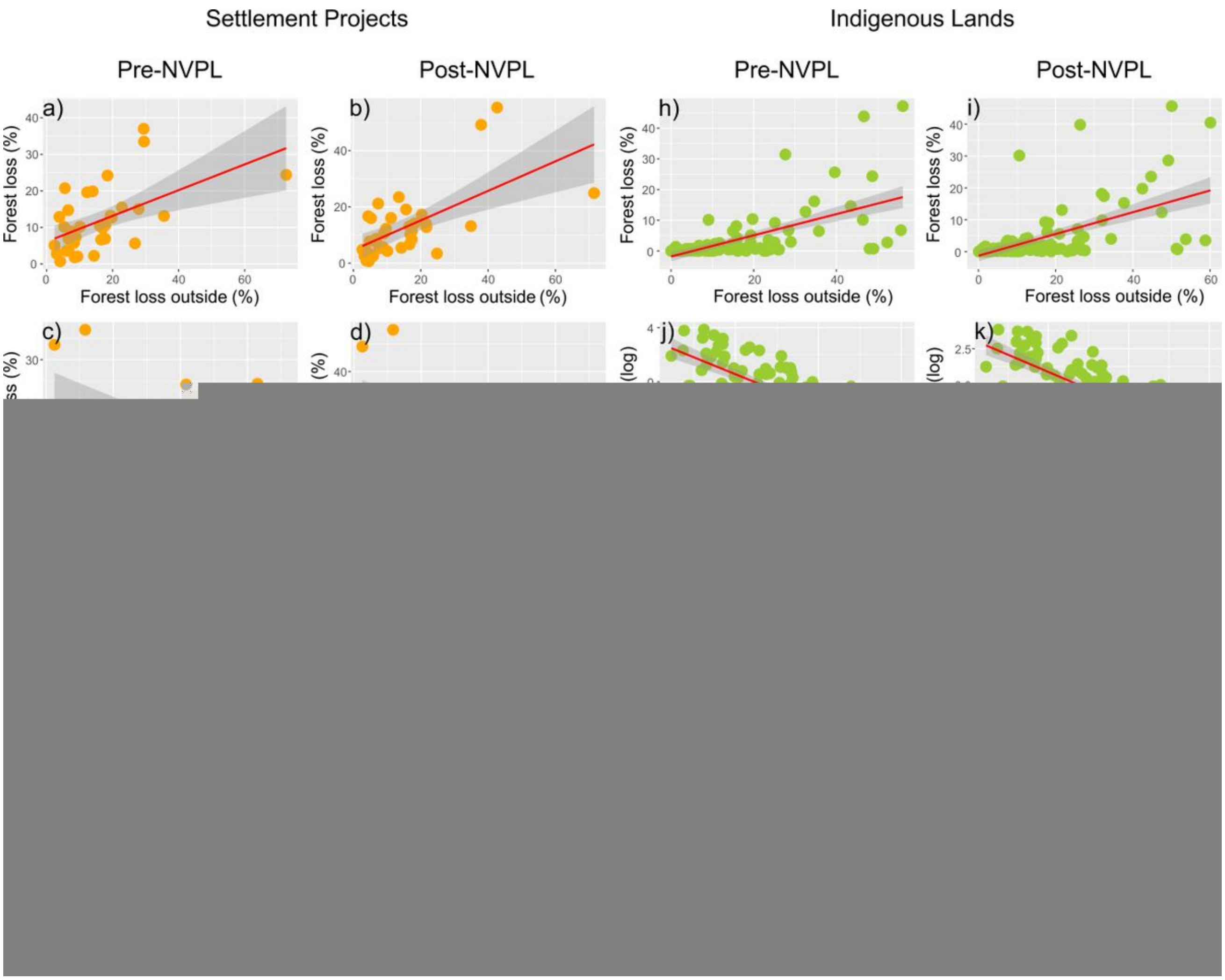

Figure 4

Scatter plot of anthropogenic factors that significantly influenced forest loss Figures a to g represent Settlement Projects and h to m Indigenous Lands. For the y-axis, figures a to i indicate the percentage of deforestation in the area and from j to k the log-normal transformation of the percentage of area deforested. The x-axis presents: a) and b) Percentage of the SP surrounding 5 km zone deforested pre and post NVPL respectively, c) and d) latitude in degrees (°) of the SP pre- and post-NVPL, e) and f) distances (km in log-normal) from the nearest roads to the SP pre- and post-NVPL, g) establishment years of the SP pre-NVPL, h) and i) Percentage of 5 km area surrounding Indigenous Lands deforested before and after NVPL implementation respectively, j) and k) area size (ha in log-normal) of the Indigenous Lands pre and post-NVPL, and, l) and m) population size in log-normal of counties around the Indigenous Lands pre- and post-NVPL.

Supplementary Files

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- SupMatTab1.xlsx