Spatial analysis of enforcement for reducing deforestation in the Brazilian Amazon: an exploratory study in Pará state

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Abstract. Deforestation rates in Brazilian Amazon declined dramatically since 2004. The expansion of protected areas (PA), law enforcement and a set of policy interventions have contributed to this decrease. This paper aims to develop an exploratory analysis of the space-time patterns of seizures related to illegal logging in the period between 2004 and 2015 for the state of Pará. We used the IBAMA's seizures and DETER database to produce kernel density maps for four periods between 2004 and 2015. The results showed that the location of seizures operations was more influenced by proximity to cities and mobility axes than by the location of deforestation itself. In addition, places with high rates of deforestation without law enforcement showed declines in rates as well as those that had more enforcement. We also analyzed spatial patterns of law enforcement with the presence of PAs considering different institutional arrangements by comparing the ratio between the number of IBAMA's seizure operations and the deforested area and the distance to the nearest border of active PAs. We found that enforcement was higher inside strictly protected (SP) areas than sustainable use (SU), but SU areas have higher influence on the enforcement in the outside, close to its borders, probably due to the proximity to the cities and consequent greater accessibility, leading to lower costs for their execution.

Keywords. Law enforcement; Deforestation; Protected Area; Spatial point pattern analysis.

1. Introduction

Deforestation in the world's tropics is an urgent international issue, particularly with regard to their role as a major carbon sink and stock (CHAMBERS et al., 2001). Deforestation and biomass decay have accounted for approximately 11% of global greenhouse gas emissions (IPCC, 2014). The Amazon represents more than half of the remaining tropical rainforests on the planet, which accounts for about 10% of the world's carbon reserves in its ecosystem. This fact raises concerns about the extent of forest clearings, especially in the Brazilian Amazon.

The intense occupation of the Amazon began in the early 1970s. Although extensive areas remain intact, the rate of forest loss is one of the highest of the world, especially in the "*arc of deforestation*" along the southern and eastern edges. The vastness of the remaining forests means that the potential impacts of continuously deforestation are much more important than the already severe impacts that have occurred to date (FEARNSIDE, 2005). Therefore, combating illegal deforestation in Brazilian Amazon have been a major policy for the Brazilian government and for international organizations for more than a decade. Selective logging is one of the many land uses on the developing frontiers in the Brazilian Amazon, and it was often a precursor to deforestation (ASNER et al., 2006). Income from logging may be invested in other economic activities such as cattle ranching or intensive agriculture, facilitating complete deforestation, and selective logging rapidly increases access to forests through unofficial logging roads (SOUZA; ROBERTS; COCHRANE, 2005).

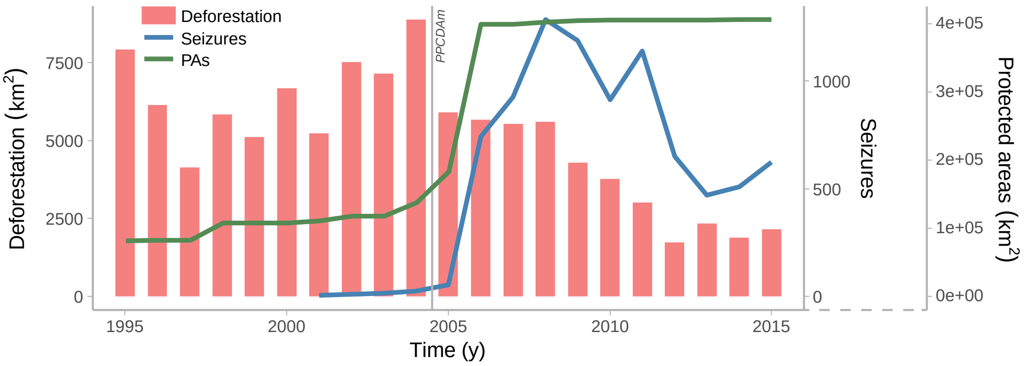

Figure 1. Deforestation rates and IBAMA's seizures related to illegal logging and protected areas in Pará state. The red bars correspond to the rate of deforestation in the year, the blue line the amount of seizures made by IBAMA in the year, and the green line to the accumulated area of conservation units. Source: Prodes (2015); IBAMA (2016).

Deforestation in the Brazilian Amazon slowed down substantially since 2004. In Pará state (Figure 1), for example, the annual deforestation rate was 8,870 km² in 2004 and decreased to 2,153 km² in 2015.

According to Nepstad et al., (2014) three stages of deforestation decline in the Amazon can be distinguished. First, from the 1990s through 2004, the stage of agro-industrial expansion when the commodity market conditions and technological advances favored the first large scale expansion of soy and other mechanized crops into the region. . In the second stage, from 2004 through 2006, called the by the authors as frontier governance, was created the "Plan for the Protection and Control of Deforestation in the Amazon" (PPCDAm). The plan was articulated around three thematic phases: (1) land and territorial planning (2004-2008); (2) environmental monitoring and control (2009-2011); and the last phase (3) promotion of sustainable production activities (2012-2015). In this period, federal and state governments focused efforts on creating protected areas (PA), totaling 25 million hectares of Conservation Units in Amazon (MMA, 2013). The law enforcement capacity increased (Figure 1) with the launch, in 2004, of the Detection of Deforestation in Real Time (DETER) system for rapid assessment of forest cover changes in the Brazilian Amazon made by the National Institute for Space Research - INPE (ANDERSON et al., 2005). DETER was developed as an alarm system to support law enforcement of illegal deforestation by IBAMA. In 2006, major soybean traders signed the Soy Moratorium, agreeing not to purchase soy grown on lands deforested after July 2006 in the Brazilian Amazon (GIBBS et al., 2014). In third stage, since 2007, a set of regulatory policies were created, such as the Critical Municipalities program that suspended access to agricultural credit for those farms and ranches located in the 36 municipalities with the highest deforestation rates.

The creation and maintenance of PAs is one of the most effective strategies for the conservation of the natural resources in the Amazon (NEPSTAD et al., 2006; SOARES-FILHO et al., 2010; VERÍSSIMO et al., 2011). In Brazil, "Conservation Units"[1] are areas instituted and managed by the federal, state, or municipal governments. According to the Conservation Units National System (from portuguese, SNUC. BRASIL, 2000, Art. 15), they are defined as being *"territorial spaces and their environmental resources including waters, with relevant natural characteristics, legally instituted by the Government, with objectives of conservation and defined boundaries, under a special administrative regime, to which are applied adequate guarantees of protection"*. The Conservation Units can be classified in two management groups: Strictly Protected (SP) and Sustainable Use (SU). Each group can be further sub-classified into diverse categories, according to the degree of conservation and use allowed in its area.

[1] Although protected areas is a broader term, in this work, it refers to Brazilian Conservation Units defined by Conservation Units National System (from portuguese, SNUC. BRASIL, 2000).

Despite the great importance of PAs and its influence in reducing deforestation, Anderson et al., (2016) findings point out that factors beyond the zoning policies are needed to explain the large decline in deforestation rates seen in Brazil since 2004. In addition to the expansion of PAs, Fearnside (2016) and Nepstad et al., (2014), believe that remote sensing based monitoring, enforcement of laws, interventions in soy and beef supply chains and restrictions on access to credit have contributed to this decline. It is not clear how, if any, the major 2007-2008 world economic crises impacted the deforestation rates in the Brazilian Amazon.

In this sense, this paper seeks to investigate two main issues: (1) Do the long-term dynamics of enforcement spatially match the deforestation hot spots? (2) Law enforcement actions by IBAMA is driven by the presence of PAs? Therefore, this study aims to develop an exploratory analysis of the spatial and temporal patterns of IBAMA's seizures related to illegal logging in the period between 2004 and 2015 for the state of Pará, in Brazilian Amazon.

2. Methodology

2.1. Study area

The State of Pará (Figure 2) extends 1,247,955 km², and has 7,581,051 inhabitants, which represents a population density of 6.07 people per km² (IBGE, 2010). It is the second largest state in Brazil and covers a quarter of the Legal Amazon. The region known as the Amazon *arc of deforestation* covers the southeastern area of Pará. This region has the highest rates of deforestation in Legal Amazonia, mainly driven not only by the expansion of agricultural, cattle raising and logging activities, but also investments in large infrastructure projects such as roads and dams, growth of small and medium-sized cities, among other factors (CARVALHO, 2012).

Despite the decrease observed in the deforestation of the Legal Amazon since 2004, the state of Pará did not follow the rate of other states and showed an increasing tendency of its contribution of the deforested area in the Legal Amazon (LIMA, 2013). Therefore, Pará should have the attention of environmental inspection institutions and other bodies dedicated to reducing Amazon deforestation.

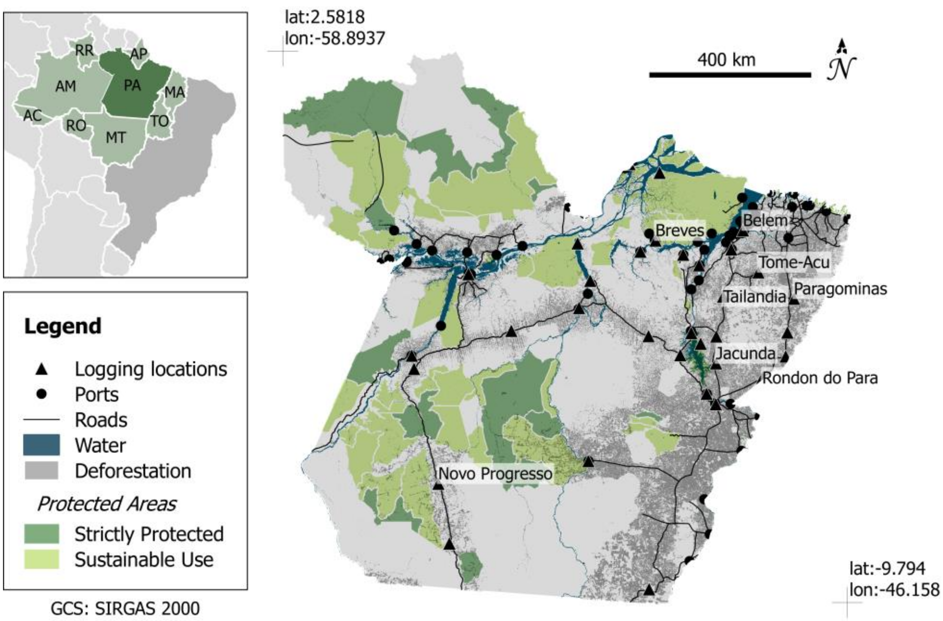

Figure 2. Study area: Pará state. Tagged logging locations (towns) have a production of over 500,000 m³. Source: Logging locations (Brazilian Forest Service/Imazon, 2010); Ports and roads (BRASIL/MT, 2016); Land cover (TerraClass – INPE/EMBRAPA, 2014); Boundaries of Brazilian protected areas (MMA, 2016).

2.2. Data

The database of seizures of the Brazilian Institute of Environment and Natural Resources (IBAMA) consists of the records of infractions carried out between 2001 and 2016 in Brazilian Legal Amazon. In total, the dataset presents 26,679 seizures. We selected seizures related to illegal timber, during the years of 2004-2015, in Pará state, which represented 8,523 seizures. Seizures related to illegal logging refer to wood, tools and transportation. Among this subset, only 1,520 events had consistent coordinates and could be geocoded. When more than one sort of product had been seized, the database repeated the event. We have selected only the unique events for the same date and location (n=898), what we denominated as *operations.*

In order to analyze the space-time patterns of deforestation and forest degradation, we used DETER data. DETER's remote sensing source is MODIS sensor, which has spatial resolution of 250 m. The changes in forest cover that DETER can detect are related to forest clear-cutting, forest degradation – preparatory to deforestation – and fire scars. DETER may also include areas with logging activities.

2.3. Methods

In order to analyze how the seizures operations and deforestation varied and related in space and time, we calculated *kernel density maps* for the point patterns of seizure operations and deforestation grouped in four three-year periods (2004 to 2006, 2007 to 2009, 2010 to 2012, 2013 to 2015), and also for the whole period (2004 to 2015).

The kernel density map is used to analyze the spatial behavior of point patterns. This method provides, through interpolation, the process intensity throughout the study region. It works by applying a *kernel function* in a radius of influence, or *bandwidth*, where 1 (one) corresponds to the event position and 0 (zero) to the border of influence. Thus, kernel density estimation calculates a magnitude-per-unit area from a point pattern using a kernel function to fit a smoothly tapered surface to each point. The cell value is given by the ratio between the sum of the overlapping kernel values and the area of the radius of influence (GATRELL et al., 1996). We used the *adaptive bandwidth* and the *quartic kernel function*. With adaptive bandwidth, sub-areas in which events are more densely packed than others – where more detailed information on the intensity variation is available – are estimated using a smaller bandwidth than elsewhere, avoiding smoothing out too much detail (BRUNSDON, 1995).

Kernel density estimation is of most value in estimating the intensity of one type of event relative to another (GATRELL et al., 1996). We performed separate kernel estimates relating to seizures operations and to deforestation occurrences respectively, and then calculated the ratio of the two, with a view to evaluating spatial variations in the enforcement. This could help identify peaks in the resulting surface corresponding to possible locations of clusters, or at least sub-regions with varying degrees of enforcement worth further examination. As suggested by Gatrell et al. (1996), we "over-smoothed" the kernel density estimate of the denominator of the ratio – the deforestation – by selecting a large bandwidth (*300 km*).

Finally, in order to relate spatial patterns of law enforcement with the presence of PAs considering different institutional arrangements, we calculated the distance from each point, either from the operations or from deforestation, to the nearest PA by management group – SP or SU – and government level – federal or state. We considered only existing PAs in the event year. Subsequently, we again compute the ratio between the number of seizures operations and deforested/degraded area. The values obtained by the ratios were compared with the distance and analyzed graphically.

Results

2.4. Exploratory spatial analysis of IBAMA's seizures

Figure 3 shows the kernel density maps, seizures operations, (*center*) DETER deforestation weighted by area and (*right*) the ratio between both estimations, for the periods 2003 to 2006, 2007 to 2009, 2010 to 2012 and 2013 to 2015 (rows 1, 2, 3 and 4 respectively).

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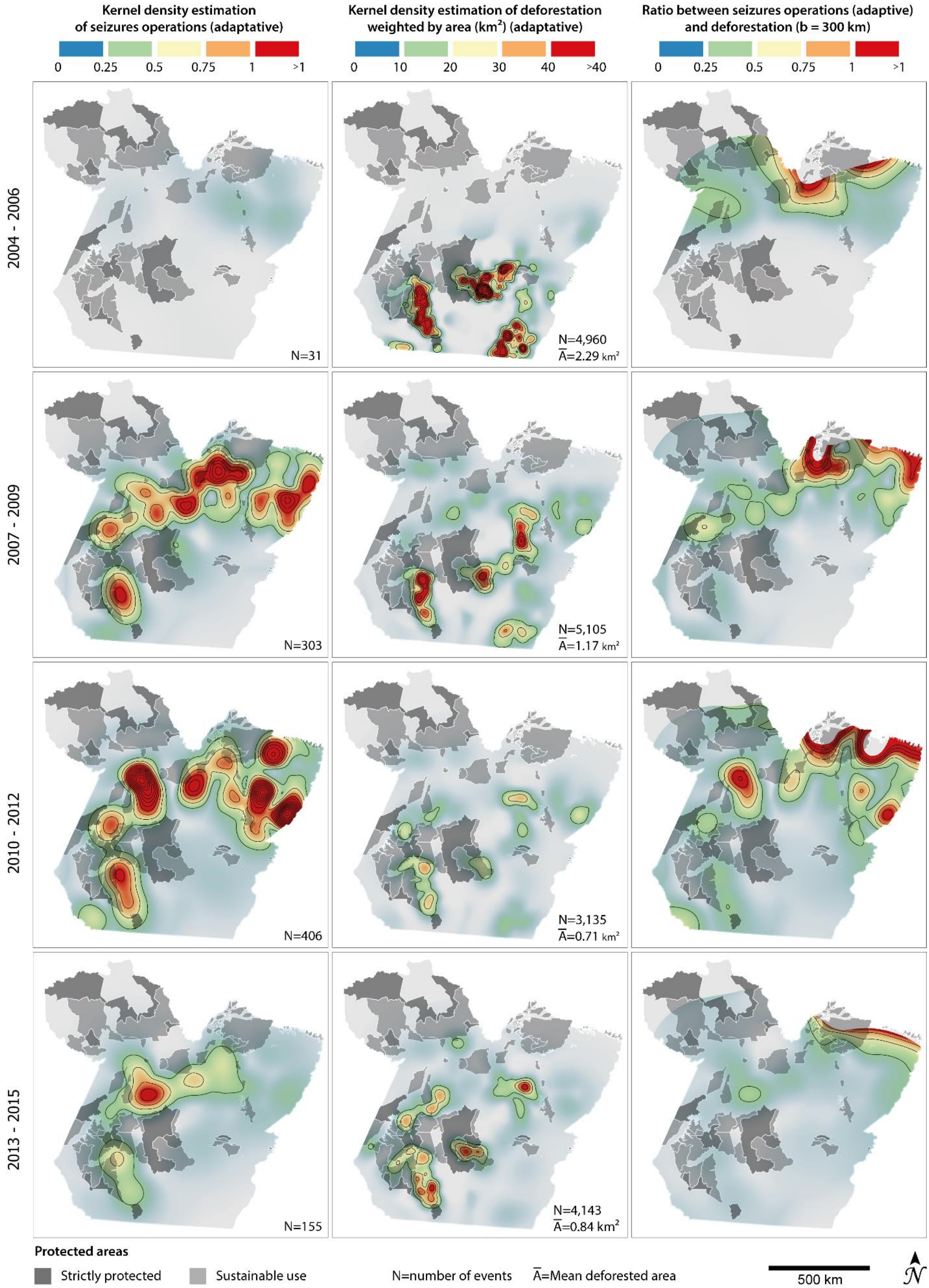

Figure 3. Kernel density estimation maps of (*column 1*) seizures operations, (*column 2*) DETER deforestation weighted by area and (*column 3*) the ratio between both estimations; for the periods 2003 to 2006, 2007 to 2009, 2010 to 2012 and 2013 to 2015 (*rows 1*, *2*, *3* and *4* respectively).

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The first period presents a few seizure events (31) and a pattern of intense and concentrated deforestation in the regions around the municipalities of Novo Progresso, São Félix do Xingu and Santana do Araguaia. In the region of Novo Progresso, a high influence of the BR-163 highway is observed in the deforestation spatial pattern.

In the following periods, densities of deforestation, previously high and concentrated, spread to other regions of Pará and lost intensity until the period 2010-2012 and increased again in the last (2013-2015). Seizure densities increased between 2007 and 2012, and decreased again between 2013 and 2014. It is possible to observe a strong influence of the roads – BR-163 and Transamazônica highway –, rivers and proximity to the northeast of Pará – where the capital, Belém, and big cities such as Ananindeua and Santarém are situated – in the location of the seizure operations.

For all the periods, the relative density of deforestation operations presented higher values in the northeast region, as well as in the Transamazônica highway and Amazonas river axis. Although IBAMA uses the DETER system to monitor and direct its actions, the location of the seizures occurred mainly where there is no high density of deforestation. In the northeast region of Pará, for example, there were high densities of seizures, however few deforestation occurrences alarmed by DETER. The high densities of seizures in this region are due to the proximity to the cities, since the distance traveled and other logistical issues influence the costs associated with law enforcement, favoring accessible areas (ANDERSON et al., 2016; TEURES; CASTILHO, 2011).

Although high concentrations of seizures were not observed in Terra do Meio – municipalities of São Félix do Xingu and Altamira –, and in the region of the municipalities of Santana do Araguaia and Cumaru do Norte, a decrease in deforestation density was observed as well as the region along the BR-163 highway. This finding may indicate that other factors, besides the seizures carried out by IBAMA, have influenced the reduction of deforestation in these regions. One can also point out that it may be likely that the improvement in law enforcement in the state as a whole in a given period, has led the landholders to associate deforestation with higher risks of reduced access to markets and finance or fines, embargos on their products, and even prison sentences (FEARNSIDE, 2016; GIBBS et al., 2014; NEPSTAD et al., 2014).

2.5. Relating law enforcement with the presence of protected areas (PAs)

Assuming that PAs are priority areas for the conservation of biodiversity and natural resources and, therefore, are under special management regime, we expect higher law enforcement in order to reduce deforestation in their interior and borders. We also expect enforcement to differ in distinct institutional arrangements. PA’s management groups – *strictly protected (SP)* and *sustainable use (SU)* – have different objectives, leading to distinct regulations. The PA’s government levels – *federal* and *state* – differ in access to human and financial resources, and criteria for its creation, location and management.

Despite the general improvement in law enforcement and the decline in deforestation, it was not possible to visually identify in the density maps a higher effort in enforcing the reduction of deforestation in PAs. Figure 4, on the other hand, depicts the relationships: (1) the ratio between the number of IBAMA’s seizure operations and the deforested area as an enforcement proxy, and (2) the distance to the nearest border of *active* PAs.

In Figure 4 is depicted the enforcement inside, represented by negative values, to the left of the PA’s border, and enforcement outside, represented by positive values, to the right of the PA’s border. Inside the PAs, as expected, enforcement was higher in SP group than SU, and followed the same growth feature as they approach the edge. This is because in SP areas, land use is more restrictive than in SU areas. In SP areas, only the indirect use of natural resources is allowed. Generally, these areas present greater visibility and resources than SP due to their ecological importance and, therefore, there is greater enforcement in their regulation in their interior than in SU areas. Despite legally protected, the enforcement inside SU areas is lower than outside, suggesting that no extra efforts is conducted when comparing to non-protected areas.

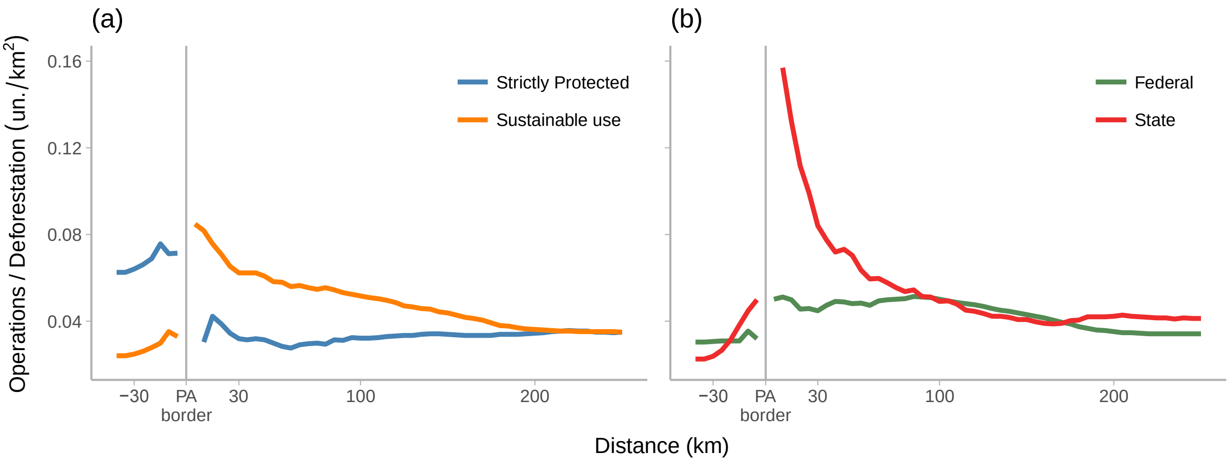

Figure 4. Comparing the ratio of seizure operations by deforested area, as a proxy to enforcement, and the distance to PAs (5 km increments) by (a) management groups and (b) government level. Source: Seizure operations by IBAMA (IBAMA, 2016); Boundaries of Brazilian protected areas (MMA, 2016); Computed by authors.

Outside SP areas is observed low enforcement values with little variation depending on the distance to the edge, and the SU areas exhibited the highest rates that decreased as the distance from the borders increases. SP areas are dedicated to the conservation of biodiversity and natural resources and therefore tend to be located in remote regions, away from areas of high deforestation rates, and the logistic costs for law enforcement at its borders are higher (ANDERSON et al., 2016). The scarcity of human resources and financial resources are the great for the consolidation of the PAs of the Amazon (VERÍSSIMO et al., 2011). In contrast, SU areas were often created in response to frontier expansion, and tend to be located close to more structured and accessible regions, thus reducing enforcement costs, causing high rates near their boundaries, where there is more regulation.

Within the PAs, both levels of government presented close enforcement features. Abroad, the border regions of the state-level PAs had high enforcement, higher than the federal level, which decreases as distance from the PA, while at the federal level, enforcement varied little according to the distance to the border. State PAs predominantly belong to the SU group (73% in area) and therefore enforcement has a lower cost, because they are generally more accessible.

3. Concluding remarks

This study is a preliminary analysis that seeks to investigate spatial patterns over time of IBAMA seizures, taking into account the deforestation occurrences indicated by DETER, as well as to investigate the relationship between law enforcement and the presence of PAs.

Our findings suggest that:

(1) The location of seizures operations was more influenced by proximity to cities and mobility axes than by the location of deforestation itself.

(2) Places with high rates of deforestation without law enforcement showed declines in rates as well as those that had more enforcement.

(3) Within the PAs the degree of restriction, indicated by the management group, influences the enforcement efforts – SP areas have a higher enforcement inside than sustainable use areas;

(4) The enforcement inside SU areas is lower than outside, suggesting that despite legally protected, this areas have no more efforts for enforcement than not PAs;

(5) Outside of PAs, the accessibility of the places to be inspected by IBAMA, and consequently the costs of enforcement, influence more than the level of restriction of the PA; and

(6) State PAs present higher values of enforcement than federal ones as the distance to the PA's border decreases.

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