The role of Protected Areas on active fires occurrence: an exploratory study in Acre state, Brazilian Amazon

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Abstract. Conservation scientists consider the designation of Protected Areas an important strategy to mitigate socio-environmental damages, biodiversity loss and climate change. Significant environmental impacts are caused every year by fires in Amazonia. In this study, we explore the hypothesis that Protected Areas have an inhibitory role on fire occurrence in Acre state. Then we evaluate the patterns of fires occurrence in different management categories and jurisdiction. For this, it was considered buffers of different sizes inside and around the protected areas perimeter. Fire density was calculated for each buffer, and comparisons between inside versus outside were carried out. It is observed that outside Protected Areas fire density is always higher than inside, indicating the presence of inhibitory process by the protected area borders. The results also showed that such inhibitory process does not occur equally among management categories and jurisdiction. Moreover, this study highlights the importance of establishment of buffer zones based on technical studies and considering the importance on protect not only the protected area itself, but also its surroundings.

Keywords: Protected Area; MODIS; active fire, fire density.

1. Introduction

The increase of greenhouse gases in the atmosphere caused by human activities is considered the mainly factor to climate change since mid-century XX (IPCC, 2014). The human activities that cause environmental damages, and consequently contribute to the increase in the temperatures due to the emissions of CO_2 to the atmosphere are directly involved with changes on land cover and use. There is an agreement among conservation scientists that protected areas, including those with resident human populations, are needed for an effective global strategy to minimize climate change, and preserve tropical forests, its goods and its ecosystems services (NEPSTAD et al., 2006). Pimm et al. (2001) concludes that protection of a substantial proportion of the world's remaining biodiversity is feasible in part because approximately 2 million km^2 of tropical forests are already protected by indigenous people. Officially recognized indigenous lands of the Brazilian Amazon alone comprise half of this total (NEPSTAD et al., 2006).

Forests fires can bring great harm to the ecosystem and human population. Burned forests become more susceptible to reoccurrence of fire (NEPSTAD, 1999; MORTON et al., 2013), they present biomass loss (ANDERSON et al., 2015), and change on species composition and structure (BARLOW et al., 2012). In response to growing fire and deforestation threat, Brazilian Federal government started in 2004 the Action Plan to Deforestation Prevention and Control in Legal Amazon (from Portuguese, PPCDAm). Land tenure and territorial planning were the objectives of its first phase (2004-2008), what created several conservation zones and homologated indigenous lands (MMA, 2013).

Brazil has its own Conservation Zones National System (from Portuguese, SNUC). SNUC defines Conservation Zones as territorial spaces and their environmental resources with relevant natural characteristics, legally established by the Government, with conservation objectives and defined boundaries, under a special administration regime, to which adequate protection guarantees apply (BRASIL, 2000). Furthermore, SNUC provides that all zones are managed by a public power sphere that could be municipal, state or federal, and divided in two big groups: 'Strictly Protected' and 'Sustainable Use'. 'Strictly Protected' zones aim the maintenance of ecosystems free of changes caused by human interference, admitting only the indirect use of their natural attributes (BRASIL, 2000). This group includes the most restrictive categories, not allowing human habitation within their boundaries. On the other side, 'Sustainable Use' zones are stablished to ensure the sustainability of renewable environmental resources and ecological processes, maintaining biodiversity and other ecological attributes, in a socially fair and economically viable way (BRASIL, 2000). Indigenous Land is not defined as a Conservation Zone. However, it is considered a Protected Area. These lands are not managed by a public power, but instead by the indigenous people living there.

A concern considered by conservationists is regarding the edge effect. Forest fragmentation enhances the exposure of forests to processes that threaten the stability of functioning and biodiversity (VEDOVATO et al., 2016), by increasing the forests edges. Considering this issue, SNUC also regulates that a few categories of 'Sustainable Use' Conservation Zones, must have a buffer zone, and when convenient, ecological corridors. The agency responsible to manage the zone may establish specific rules that regulates the occupation and use of natural resources within the buffer zones and corridors (BRASIL, 2000). The delimitation of their limits must be defined on the zone's Management Plan, and it is specific to each zone. Not having a general rule to establish a limit for buffer zones turns the analysis of its effectiveness more complicated. Furthermore, a great number of Conservation Zones do not have a Management Plan yet, what makes them more susceptible to edge effects and isolation, since they do not have an established buffer zone.

In the absence of a clear and definitive buffer limit, for this study we considered two possible legal resolutions for our analysis: (1) CONAMA Resolution nº 428/2010 defines a buffer of 3 km around the zone to Conservation Zones that do not have buffer zones established yet. This rule was effective until December 2015 though (CONAMA, 2010). (2) Decree nº 99.274/1990 establishes that any activity that could affect biota done within a buffer of 10 km around Conservation Zones perimeters is subordinate to specific rules established by CONAMA (BRASIL, 1990).

Acre state has almost half of its territory protected someway (Conservation Zones or Indigenous Lands) (ANDERSON et al., 2016, in press). It has been impacted by extreme droughts and floods events, and has developed its own warning system that daily monitors the risk of forest fires on its situation room, at the Climate Change Institute (IMC-AC). Acre state was also the epicenter of the 2005 drought (ARAGAO et al., 2007), and highly impacted by the 2015/16 drought (JIMENEZ-MUÑOZ et al., 2016) Therefore, Acre is an interesting case study to be considered.

Although the literature of fire impact on Amazonian ecosystems has increased in the recent years (ANDERSON et al., 2015; SATO et al., 2016; VASCONCELOS et al., 2015), studies addressing the role of different categories of Protected Areas on inhibition of fire are still lacking. Besides that, active fire products obtained by satellites have improved in the last years (ANDERSON et al., 2016, in press), therefore it is interesting to evaluate long-term patterns and changes through time. In this study, we explore the hypothesis that Protected Areas have an inhibitory role on fire occurrence in Acre state. Then we evaluate the patterns of fires occurrence in different management categories and jurisdiction. In addition, it is analyzed the occurrence of fire in different buffer sizes to evaluate the dynamic of fire inhibitory process as areas more distant from the protected area perimeter are considered.

2. Methodology

2.1. Study area

The study area covers the extent of Acre state, located southwestern Amazonia (Figure 1).

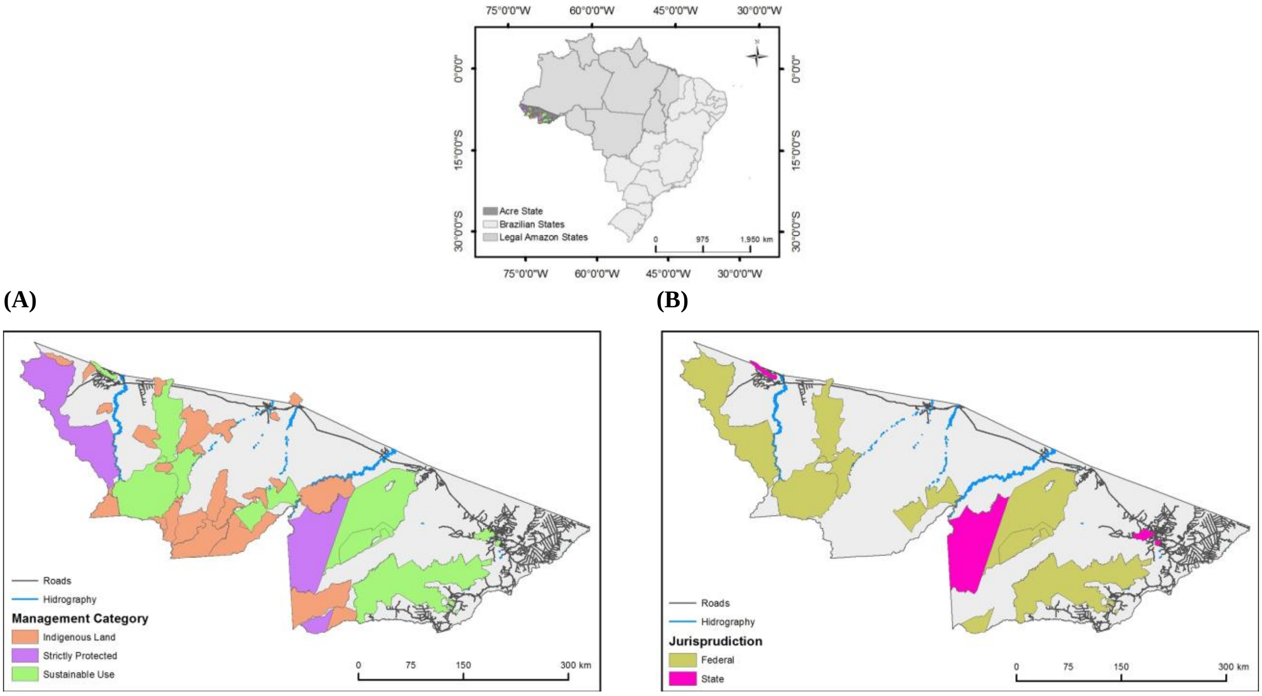

Figure 1. Study area localization. (A) Protected areas per management category. (B) Protected areas per jurisdiction.

Acre state accounted for 44 protected areas, considering three management categories: ‘Indigenous Land’, ‘Sustainable Use’, ‘Strictly Protected’ (Table 1).

Table 1. Acre Protected Areas divided by management category and by jurisdiction.

	Count	Area (ha)	% Total (ha)
Management Category			
Indigenous Land	29	2,519,424	34.4
Sustainable Use	12	3,193,080	43.6
Strictly Protected	3	1,610,191	22
Total	**44**	**7,322,695**	
Jurisdiction			
Federal	11	4,048,868	84.3
State	4	754,403	15.7
Total	**15**	**4,803,271**	

2.2. Data

The occurrence of fires can be related to (1) expansion of economic activities, (2) effects of investments in roads and other infrastructures that cause direct environmental damages, and (3) agricultural settlements – either planned or spontaneous – motived by agrarian reform pressures (NEPSTAD et al., 2006). This way, Protected Areas that are far from mainly agricultural settlements have a negligible short-term effect on inhibiting fire, but may have a very important effect as the frontier grows nearer (NEPSTAD et al., 2006). Adapting Nepstad et al. (2006) methodology, we evaluated the inhibitory role of Protected Areas on fire occurrence using hot pixel density along the Protected Areas perimeter. Therefore, the ratio of burning in buffer zones outside versus inside these areas boundary provides a measure of performance.

We used hot pixels, which consists of satellite acquired data of radiance emitted by burning matters – in other words, active fires. These matters emit energy mainly at median thermal wavelength (3,7 µm a 4,1 µm). We used MODIS ACQUA MCD14ML collection 5.1 product, from 2003 to 2015. The MODIS active fire product detects fires in 1 km pixels that are burning at the time of overpass. 'Hot pixel' expression is used here to refer to active fires detected by the sensor. It was only considered hot pixels with detection confidence higher than 30%.

The protected Areas boundaries were extracted from the World Database on Protected Areas. Such database has information about both conservation zones and indigenous lands, and it is constantly updated (UNEP-WCMC, 2016). We grouped here the different area designations according to SNUC: 'Strictly Protected' and 'Sustainable Use'. Later on this paper, we refer to three management categories, which are defined by 'Strictly Protected', 'Sustainable Use' zones, and 'Indigenous Land' areas. The jurisdiction analysis considered only areas managed by the State or Federal agencies, thus the 'Indigenous Land' category was not considered.

2.3. Methods

The influence of reserves on the spatial occurrence of fires was measured by comparing fire density (number of hot pixel per square kilometer) on different management categories and jurisdiction. Two analysis were carried out. The first one used the average from 2003 to 2015. Secondly, we performed the analysis yearly. The fire density (also called hot pixel density) was measured within 3-km-wide, 10-km-wide, and 20-km-wide buffers along the inside and outside of the areas perimeter. The 20-km-wide buffer was used to encompass in the analysis areas that are not under some regulation. We used different buffer sizes to evaluate the effectiveness of buffer zones around Protected Areas. For areas < 200,000 ha in size, inside the zone fire density on 20-km-wide buffer considered the entire area.

Nonparametric statistics were used to make comparisons among management categories due to the highly skewed distribution of the fire density data. Based on an adaptation from Nepstad et al. (2006) methodology, the comparison of the inhibition of fire (outside buffer vs. inside buffer values) within each management category and jurisdiction was made by Wilcoxon signed-rank test for dependent samples. The comparison of fire occurrence inhibition across categories and jurisdiction was made by Kruskal-Wallis one-way analysis of variance for independent samples. For this, the dependent variable was the ratio between inside and outside buffer values. All tests considered a significance level of 0.05, and they were carried out in R software.

3. Results and discussion

3.1. General comparison inside versus outside Protected Areas

The comparison of the hot pixel density inside and outside the Protected Areas demonstrates that outside fire rates are higher than inside in all management category, and buffer sizes (Figure 2A). This result is supported by Wilcoxon signed-rank test. All comparisons were statistically significant according to this test ($p<0.05$).

As expected, the hot pixel density increased outside, and decrease on inside buffer (closer to the protected areas central parts) as the buffer size increases. This does not occur for 'Strictly Protected' areas though.

The difference between fire occurrence inside and outside of 'Strictly Protected' areas is subtler. For this category, both inside and outside densities decreases as buffer size increases. A visual analysis points that the decrease of outside density could be explained by a high concentration of hot pixels along the border of *Parque Nacional da Serra do Divisor*. Although it is only one area, it is responsible for 52% of the total area designated as 'Strictly Protected' in Acre. The high concentration of hot pixel along the border was detected by the narrowest buffer, but it was diluted with the buffer area increment.

When comparing Federal and State zones, the Federal zones present higher density of hot pixels most of the times (Figure 2B). In general, outside fire pixels density is higher than inside.

We observe the same pattern as the other protected areas: hot pixel density increases in outside, and decrease in inside buffer as the buffer size increases. The exception here is for outside buffers of Federal zones that decrease with the increment of the buffer area. As it was observed for ‘Strictly Protected’ zones, this could be due to high concentration of hot pixels along the zone border.

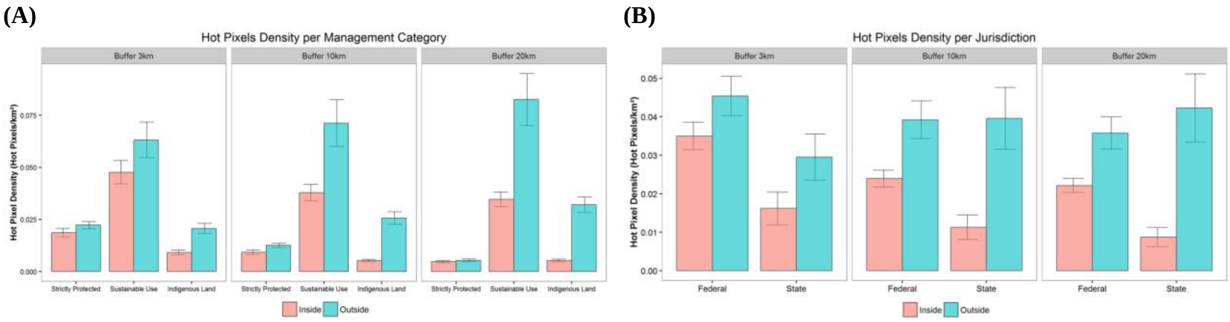

Figure 2. Hot pixel density per (A) management category, and (B) per jurisdiction inside and outside different buffer sizes.

The difference between inside and outside is higher for State zones in all buffers sizes, and it gets more discrepant as the buffer size increases. All comparisons outside versus inside fire pixels in Protected Areas were statistically significant using Wilcoxon signed-rank test ($p<0.05$).

3.2. General comparison among management categories and jurisdiction

After comparing outside versus inside hot pixel density along management categories and jurisdiction, the comparison between these classes were made. For this, the fire density was substituted by the ratio inside by outside. For management categories, no significant difference ($p<0.05$, Kruskal-Wallis test) at the 3 km buffer was found for the comparison between ‘Strictly Protected’ and ‘Sustainable Use’ (Figure 5A). All the other comparisons were significantly. The differences observed were an indicative that occurrence of fire does not happen in the same proportion on different management categories.

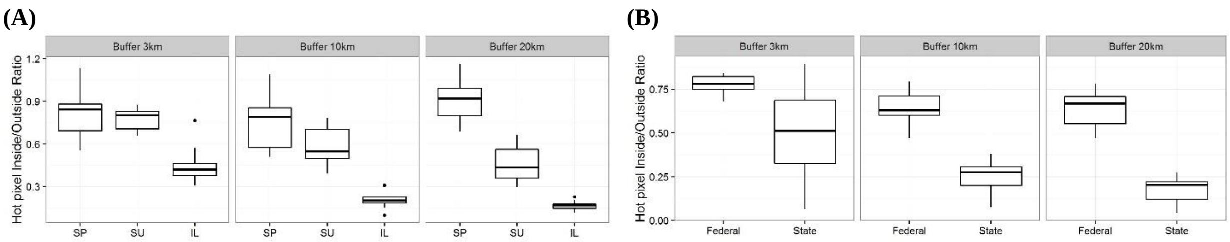

Figure 5. Comparison of hot pixel inside/outside ratio in different (A) management category; (B) jurisdiction, considering different buffer sizes. IL (Indigenous Land); SU (Sustainable Use); SP (Strictly Protected).

All comparisons among Federal and State areas were significantly different ($p<0.05$, Kruskal-Wallis test) (Figure 5B). The more distributed (bigger box on boxplot), the more variable is the ratio inside versus outside throughout the years. This occurs when outside fire density exhibits a different pattern from inside. This difference can be used as an indicative of management. We can think that if outside and inside densities are varying together, what is causing this variation does not changes over border, and therefore could be a climate variable for example. On the other hand, if outside and inside densities fluctuate dissimilarly, inside management could be causing the fluctuation. Following this rationale, the variation of fire occurrence around ‘Indigenous Land’ areas are more related to climate variance than to management. The opposite can be applied for state zones considering the buffer of 3 km. As the buffer size increases, State zones ratio seems to be less related to management.

3.3. Comparisons inside versus outside fire occurrence in protected areas yearly

When distinguishing the previous results by year, the peaks observed in 2005 and 2010 are related to extreme droughts events occurred in Amazonia (ARAGÃO et al., 2007; MARENGO et al., 2011) (Figure 6A). 'Strictly Protected' zones presented low hot pixel density along the years, and although the outside density had always been lower than inside, both densities were not significantly different and stable through time. This category seems to be less vulnerable to fires during extreme droughts. The 'Indigenous Land' areas presented the inside hot pixel density approximately to the 'Strictly Protected' areas, and the outside increased with the increment of buffer area. This statement suggests that 'Strictly Protected' areas have more effective buffer zones, and as the buffer size increases, the 'Indigenous Land' areas turns more vulnerable to environmental variables, like droughts, what could explain the growth in fire density. 'Sustainable Use' zones presented the biggest outside fire density throughout the whole period. It is also evident the high discrepancy among inside and outside hot pixel densities for this category.

(A) **(B)**

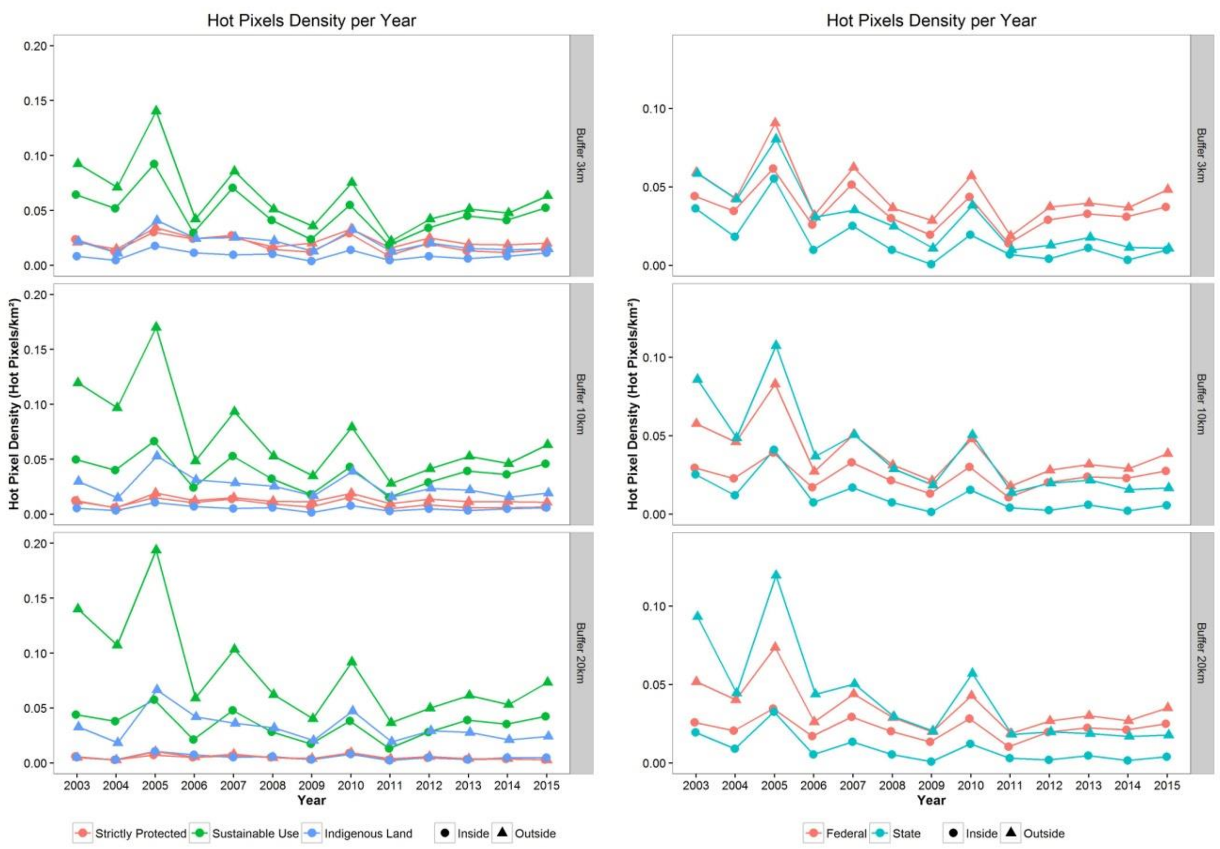

Figure 6. Hot pixel density inside and outside different buffer sizes per year, and (A) management category; (B) jurisdiction.

Analyzing the two jurisdictions, State protected areas has a better performance inhibiting fire inside, considering the narrowest buffer (Figure 6B). As the buffer size increases, we observe a shift on outside hot pixel density for State areas, which become higher than in Federal areas. This pattern does not occur from 2011 to 2014 though. In February 2011, the State Commission of Environmental Risk Management started its activities getting together institutions representatives to elaborate a strategic plan to reduce forest fires within the state. On that moment, it was created the Integrated Plan for the Prevention, Control and Combat of Forest Fires in the State. Cardozo et al. (2013) attributes this reduction to the implementation of public policies by the State government, to a more effective enforcement and offer of other management techniques for the farmers in substitution to the use of fire.

4. Considerations

Based on the main questions that boosted this work, we argue that there is an inhibitory role played by Protected Areas regarding to fires. It is clear that fire density outside the perimeter of these areas is higher than inside, significantly.

Although ‘Strictly Protected’ zones presented the lowest fire densities, both inside and outside, the border of ‘Sustainable Use’ zones and ‘Indigenous Land’ areas seemed to play a major role on the inhibitory process. Nepstad et al. (2006) concluded that it is not only the management category, more restrictive, that matters for inhibition of deforestation and fire. The spatial configuration and surroundings of the Protected are the most important factors. Even more restrictive, generally ‘Strictly Protected’ zones are located at remote places, where the land use is not intensive dynamic. Still, ‘Sustainable Use’ zones and ‘Indigenous Land’ are commonly created nearer agricultural settlements and urban centers. For Acre state, particularly, Anderson et al. (2016, in press) observed that ‘Indigenous Land’ areas were the land tenure class that presented the lowest hot pixel accumulated from 2000 to 2014. The ‘Sustainable Use’ classes presented a higher score in fire density due to its the proximity to settlements projects and private lands, both classes that registered the highest number of active fires in the period.

In addition, the State zones play an important role on fire inhibition, and their management are notable mainly nearby the protected areas perimeter.

Analyzing different buffer sizes allowed us to quantify the dynamic of the fire inhibitory process as it encompasses areas more distant from the protected area border. The fire inhibitory process does not occur only inside the protected area, but also on their surroundings. This result highlights the importance of establishment of buffer zones based on technical studies and considering the importance of it to an effective protection.

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