# What drives the withdrawal of protected areas? Evidence from the Brazilian Amazon

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**Abstract**

Since the late 1970s protected areas have been one of the most widely used regulatory tools for the conservation of ecosystem services. In this paper, we assess the possible drivers to the choice of withdrawing protected areas in the Brazilian Amazon. Protected areas are subject to inefficiencies because of the existence of conflicts over land between conservation and development activities. Further addititionality is an issue, as protected areas tend to be located in areas with low opportunity cost of conservation, where forests are not likely to be cleared. This issue is particularly important in the Brazilian Amazon where growing development must be combined with the need to avoid deforestation. We first present a simple model of degazettement choice which leads us to assess how the presence of two agencies having different development and conservation objectives can lead to implementing this decision. We suggest that the probability to decide the removal of protected areas is larger in places with low and high development pressures. Then, we investigate the empirical determinants of protected area withdrawal by taking advantages of the new PADDDtracker dataset (WWF, 2017b). We confirm that the likelihood of degazettement is strongly influenced by development pressures, through characteristics of the land that enable agricultural and infrastructure development, and by variables related to protected area quality of enforcement. As protected areas located in highest pressure areas are likely to be more additional, there is a risk that only the most effective protected areas may loose their protection.

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# 1 Introduction

Protected Areas (PAs) are implemented to avoid the degradation of species habitats and biodiversity losses, by regulating resource use and access to land through property rights. Since the beginning of the 1980s, they have been one of the most widely used regulatory tools, firstly for the conservation of biodiversity and then for the conservation of ecosystem services as well as for the maintenance of human well-being (Naughton-Treves et al., 2005; Deguignet et al., 2014; Watson et al., 2014). Following the Aichi Biodiversity Target of the Strategic Plan for Biodiversity 2011-2020 adopted at the 10th meeting of the Conference of the Parties in 2010 (Convention on Biological Diversity, 2011), 14,7% of the worlds ecosystems were classified as PAs in 2016. The most extensive coverage takes place in latin America and Caribbean countries with half of it located in Brazil (UNEP-WCMC and IUCN, 2016). This extention, which is expected to rise until reaching 17% of the earth surface, lead to the emergence of conflicts over land between conservation and development activities (Naughton-Treves et al., 2005; Deguignet et al., 2014; Watson et al., 2014). Indeed, several actors rely on the provision and maintenance of ecosytem services while the establishment of a conservation area may prevents development activities over the territory (Albers, 2010; Nicolle and Leroy, 2017; Naughton-Treves et al., 2005).

The difficulties of managing PAs effectively in the context of the conservation-development trade-off have been widely underlined. First, in order to avoid economic losses due to conflicts over land, PAs are more likely to be established where conservation opportunity costs (OCs), i.e. economic pressures, are low (Joppa and Pfaff, 2009; Pfaff et al., 2015a; Baldi et al., 2017). As a result, observing low levels of deforestation where PAs are located does not necessarily mean that they have contributed to avoiding deforestation (Pfaff et al., 2015a,b; Kere et al., 2016; Joppa and Pfaff, 2011; Pfaff and Robalino, 2012; Ferraro et al., 2013; Nolte et al., 2013; Sims, 2014; Pfaff et al., 2016; Anderson et al., 2016; Andam et al., 2008). Indeed, what would have occurred without protection is not observable and varies with the amount of pressure occurring in the landscape. Many studies that control for the non-random location of PAs conclude that they are effective in average but not as much as when their non-random location have not been accounted for (Andam et al., 2008; Joppa and Pfaff, 2011; Pfaff et al., 2015b). This result depends on the extent of economic pressures occuring on the landscape (Pfaff et al., 2015a; Kere et al., 2016; Joppa and Pfaff, 2011; Ferraro et al., 2013; Pfaff et al., 2016) as well as on the ability of the PA to prevent development activities. The former is link to the characteristics and political context of the land (Ferraro et al., 2013; Sims, 2014; Pfaff et al., 2015a; Kere et al., 2016) whereas the later depend on the characteristics of the PA (Nolte et al., 2013; Sims, 2014; Pfaff et al., 2015a; Anderson et al., 2016).

The conflicting land uses between PA sitting and development activities may have reinforced PAs location bias and influenced their effectiveness as it has triggered Protected Area Downgradement, Degazettement and Downsizement (PADDD) (Watson et al., 2014). These phenomenona, which are in acceleration since the 2000s, are known as legal changes in the status or size of PAs (Mascia and Pailler, 2011). For (Mascia and Pailler, 2011, p. 11), downgrading is "a decrease in legal restrictions on the number, magnitude, or extent of human activities within a PA", downsizing is "a decrease in size of a PA as a result of excision of land or sea area through a legal boundary change" and degazettement is "a loss of legal protection for an entire PA". Their most common proximate cause have been widely documented in the recent litterature and are all related to growing development pressures such as: hydropower development, agricultural extension and rural settlement (Mascia and Pailler, 2011; Mascia et al., 2014; Pack et al., 2016; Bernard et al., 2014; Cook et al., 2017; de Marques and Peres, 2015; Symes et al., 2016). Although PADDD might have impacts on biodiversity and on the attainment of the 2020 Aichi biodiversity targets, those impacts in term of conservation outcomes are not well-known and differ according to the inclusion of the past additionality of the PA. When it is taken into account, neither Tesfaw et al. (2018) nor Pack et al. (2016) find a short term impact of PADDD on deforestation rates in the state of Rondônia as well as in the Brazilian Amazon between 2000 and 2012. However, Forrest et al. (2015) focus on the large forest carbon emissions that could be caused by PADDD in three tropical countries (Democratic Republic of Congo, Malaysia and Peru) and Golden Kroner et al. (2016) underlines the risk of habitat fragmentation in the Yosemite National Park in Australia during its downsizement process.

As PAs tend to be located in low pressure areas and given the fact that PADDD seems to happen where the OC of conservation is high (Symes et al., 2016; Tesfaw et al., 2018), there is a risk that only effective PAs may be downgraded, downsized or degazetted. However, an effective management of PAs could be to make use of PADDD for the least effective one in order to be able to affect ressources toward those that are achieving the best (Fuller et al., 2010). As underlined, PADDD decisions are made at the intersection of development and environment objectives. Yet, more research is needed to fully understand how the conflicts between conservation and development activities over land may affect the management and coverage of PAs through PADDD as well as the resulting effectiveness of the PA network. To the best of our knowledge, only Symes et al. (2016) and Tesfaw et al. (2018) empirically study the drivers of PADDD. Symes et al. (2016) find out that the size of the PA influence its probability to be removed while Tesfaw et al. (2018) find out that it is the conservation outcome of the PA that matter the most. Symes et al. (2016) use variables related to the profitability of development activities in 44 countries over 110 years while Tesfaw et al. (2018) propose an analytical framework where conservation and development agencies bargain about PA removal. Each agency look at the potential costs and benefits of PADDD, which vary over the territory. PADDD is expected when the conservation costs of the decision are low for the environmental agency and when the development benefits that can be generated are high for the development agency. They use a linear probability model on the state of Rondônia and suggest that the conservation cost of the decision strongly matter. Even though Tesfaw et al. (2018) provide a first analytical framework, their analysis remains preliminary and their results are only based on the state of Rondônia which has experienced numerous PADDD events in 2010 and 2014.

The objective of this article is to provide an empirical assessment on how the conservation-development trade-off may trigger entire losses of protection in the Brazilian Amazon. Following the analytical framework of Tesfaw et al. (2018), we go further into detail on each agency decision rule and we make them interacting with the conservation OCs varying over the territory. These conservation OCs enter in each agency decision rule and are empirically assessed through caracteristics of the land and of PAs. This issue is particularly important in Brazil, which is likely to have a political and economic landscape that facilitate the significant rise of PADDD (Bernard et al., 2014; de Marques and Peres, 2015; Symes et al., 2016). Despite the considerable efforts of the Brazilian government to extend and to harmonize its PA network since 1980, more than 50,000 km$^2$ of Conservation Units (CUs) have been lost from 1990 to 2012 (Bernard et al., 2014). Since 2000, as a result of economic development pressures, proposed PADDD has increased in the Brazilian Amazon (Veríssimo et al., 2011) and 13,000 km$^2$ of deforestation has been observed inside CUs in 2009 (Veríssimo et al., 2011). This have been helped by the shifting attitude of the brazilian government toward agricultural and economic pressures, which has become more sensible to increasing political lobbying (Soares-Filho et al., 2014; Bernard et al., 2014). In 2012, this have resulted in the implementation of a new forest code which might make development project easier to realize (Soares-Filho et al., 2014).

We first present a simple model of degazettement choices to assess how the interaction between two agencies with different development and conservation objectives can lead to the implementation of this decision. Our approach distinguishes itself from previous research: after describing the objectives of the two players, we consider several cases of interactions between them to analyse how degazettement decisions are undertaken when the conservation OCs varies over the territory. We propose to distinguish two main channels to describe how these variations can bring about PADDD: i) A Low Benefit (LB) channel for PAs that are greatly biased in location (i.e. situated over lower OCs area). They are difficult to maintain, even though they are less subject to conflicts over land and better enforced, since their additionality is likely to be very low. ii) A High Cost (HC) channel for PAs that are not biased in location (i.e. situated over higher OCs area). They are difficult to maintain, even though they are highly additional, since they are more subjects to conflicts over land and less likely to be well-enforced. Afterwards, we take advantages of the PADDDtracker dataset (WWF, 2017b) to provide empirical complements to the model. First, we empirically assess conservation OCs through characteristics of the land and of PAs which enter in each agency decision rule. Second, as the decision of degazettement is a latent binary variable, we use a logistic probability model estimated by the maximum likelihood method to investigate on the empirical determinants of PA degazettement. We confirm that the likelihood of degazettement is higher in areas with high OCs of conservation, mostly driven by a favorable economic landscape enabling pressure coming from the agribusiness and infrastructure sectors. We emphasize the positive role of being situated on higher slopes and near roads on the likelihood of PADDD since it increases the expected benefits of hydropower development and agricultural extention. Environmental objectives seem to matter as well since PAs situated in areas of high biodiversity value are less likely to be PADDD compared to those which are already degraded and badly enforced. The expected environmental benefits and the quality of PAs enforcement are thus key variables in the PADDD decision process. However, we believe that they mostly matter at the end of this decision process, when the likelihood of PADDD is already significant due to high OCs of conservation. We account for fixed effects of PA location to check the robustness of the model, which make use believe that state preferences toward environment and development objectives strongly matter in the degazettement decision process.

This article is organized as follows: Section 1 present the objectives of the two agencies in the economic model of degazettement choices. In section 2, we analyse different types of interactions between the environmental and the development agencies to explain how the combination of their objectives may lead to PA degazettement. In section 4, we present our empirical strategy, the construction of our database and the results of the estimations. Section 5 discusses and concludes.

## 2 A simple economic model of degazettement choice

We consider a set of PAs that have been implemented in the past. For various reasons (institutional or political change, impact evaluation), those PAs have to be evaluated ; the choice has to be made of which PAs will remain implemented, and which will be degazetted.

We consider two institutional players: an environmental agency ($EA$) and a development agency ($DA$). For every PA $i$, the choice to degazette the PA ($D_i = 1$) or not ($D_i = 0$) has to be made. The main variable that will influence the choice to degazette is the OC of conservation in the area $o_i$. Indeed, we assume the OC to be a composite measure of the characteristics of the land and of PAs that have an influence on (i) development pressures in the area and (ii) the additionality potential (or location bias) of the PA: low OCs areas are likely to be unthreatened, and PAs implemented in those areas are then likely to have low additionality.

### 2.1 Development agency

The $DA$ entirely focuses on development objectives, which means that PAs necessarily represents a constraint to those objectives. This constraint is increasing in the OC $o_i$. $wo_i$ represent the DA's potential expected payoff if the PA is degazetted.

The $DA$'s utility from degazettement and his degazettement decision rule are thus:

$$\begin{aligned} U_{DA}(D_i) &= wo_i D_i \qquad (1) \\ D_i &= 1 \; \forall \, o_i > 0 \\ D_i &= 0 \; \forall \, o_i = 0 \end{aligned}$$

Thus, the $DA$ would prefer that all PAs with positive OCs be degazetted, but his preference is stronger for PAs where OCs are larger.

### 2.2 Environmental agency

The environmental agency evaluates the PA effectiveness when deciding to degazette or not. The cost of PA $i$ implementation is $C_i(o_i)$, while its environmental benefit is $b_i(o_i)$. Thus the $EA$

utility, her net benefit from degazettement ($B_i(o_i)$) and the decision rule of the $AE$ are:

$$\begin{aligned} B_i &= C_i(o_i) - b_i(o_i) \\ U_{EA}(D_i) &= B_i D_i \\ D_i &= 1 \;\forall\, C_i(o_i) > b_i(o_i) \\ D_i &= 0 \;\forall\, C_i(o_i) \leq b_i(o_i) \end{aligned} \tag{2}$$

The management cost $C_i(o_i)$ in (3) is composed of two elements: a fixed cost $h_i$ and a variable cost $c_i(o_i)$. Variable costs are increasing and convex in OCs.

$$C(o_i) = h_i + c(o_i) \tag{3}$$

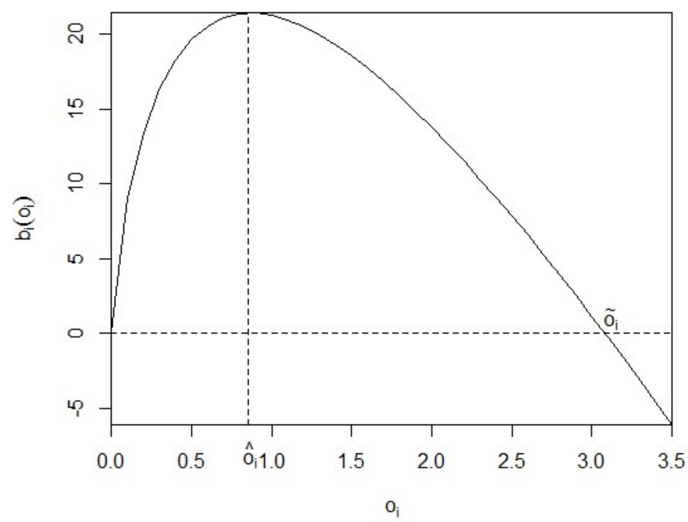
The environmental benefits $b_i(o_i)$ in equation (4) depends on (i) the PA potential additionality in terms of avoided deforestation $e_i(o_i)$ and (ii) the probability of the park unit to be well-enforced $p_i(o_i)$. Potential additionality is increasing and concave in OCs $o_i$ and the enforcement probability is decreasing and convex. PAs are expected to be more additional in terms of avoided deforestation on areas where development pressures are high but are more lilely to be ineffective due to lack of enforcement.

$$b_i(o_i) = p_i(o_i)e_i(o_i) \tag{4}$$

Thus, one can expect a inverted-U shaped form of environmental benefits from the PA (figure 1)[1]. When OCs are low, the probability of enforcement is high, but the potential additionality is low. When $o_i$ increases, enforcement probability first decreases slowly while potential additionality rapidly increases. Thus, environmental benefits increases. When OCs reach a certain point $\hat{o}_i$, the negative effect on enforcement probability becomes larger than the positive effect on potential additionality, and environmental benefits start decreasing, until they reach 0 again for a certain level $\tilde{o}_i$ of OCs.

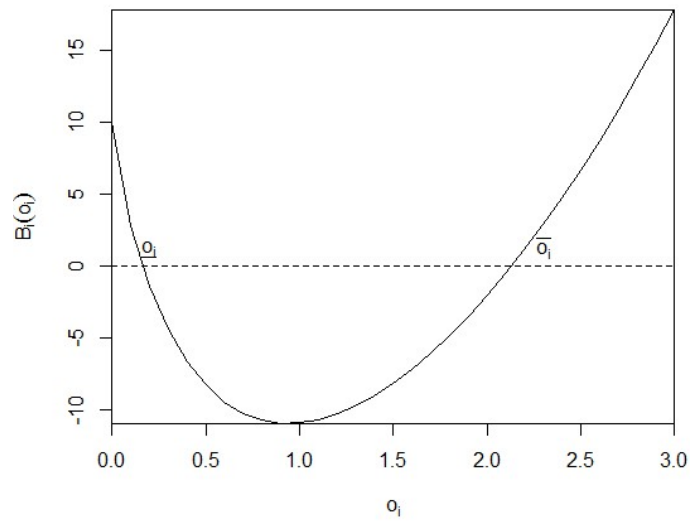
[1]Calibration for our illustrative simulations is provided in appendix.

Figure 1: Expected environmental benefits




When combining the management cost and the environmental benefit, the net benefit from degazettement ($B_i(o_i)$) takes the form of a U-shaped function (figure 2). When OCs are null, the net benefit from degazettement equals fixed costs from PA maintenance. As $o_i$ increases, the net benefit from degazettement are first decreasing: the increase in management costs is lower than the increase in environmental benefit. It will decrease until the point where its marginal cost from PA management equal her marginal expected benefits from it : $\frac{\partial c_i(\tilde{o}_i)}{\partial \tilde{o}_i} = \frac{\partial e_i(\tilde{o}_i)}{\partial \tilde{o}_i} p_i(\tilde{o}_i) + \frac{\partial p_i(\tilde{o}_i)}{\partial \tilde{o}_i} e_i(\tilde{o}_i)$. After that point, for higher level of OC, her net losses increase again because she is still facing increasing management cost minus diminishing expected environmental benefits.

Figure 2: Net benefits from degazettement



# 3 Degazettement choice

First, we focus on the simple case where the $EA$ is the only decision maker. Second, the case of joint-maximization is considered.

## 3.1 Environmental agency as the only decision maker

In this case, we consider that the degazettement choice is made only considering the $EA$'s payoff. In order to determine when the environmental agency decides to degazette or not the area to maximize her utility $U_{EA}(D_i)$, we have to find the level of OCs for which the net benefit from PA degazettement are positive or negative, and the variable influencing this result. As mentioned before, the payoff from degazettement has a U-shaped form. Thus, an interval $[\underline{o}_i, \bar{o}_i]$ inside (outside) which the payoff from degazettement is negative (positive) is likely.[2]

When the EA has a net benefit from PA degazettement ($o_i < \underline{o}_i$ and $o_i > \bar{o}_i$), she decides to degazette the area ($D = 1$) to maximise her utility. For low OCs, she prefers to degazette the area because her fixed cost $h_i$ are too high compared to her expected benefits given the low additionality of the parc : we call that the LB channel. For high value of OCs, her overall management costs $C_i(o_i)$ are too high compared to her expected environmental benefits $B_i(o_i)$ due to high economic pressures : the HC channel. For intermediate value of development pressure, expected benefits from degazettement are negative as her costs from PA maintenance are smaller than expected environmental benefits. She thus choose to maintain the area ($D = 0$) to maximize her utility.

**What drives the decision rule for the environmental agency?**

Values of OCs of conservation for which the EA decides to shift her decision of degazettement, either due to high pressure in the HC channel or due to low additionality in the LB chanel, can vary depending on her overall management costs, on the enforcement probability and on the PA expected additionality.

We can obtain situations were the EA decides to take more (less) degazettement decisions in both chanels (higher -lower- $\underline{o}_i$ and lower -higher- $\bar{o}_i$) if higher (smaller) fixed costs make the net benefits from PA degazettement displacing upward (downward) (figure 3). If the PA expected additionality is increasing faster (slower) with OCs, the EA will take more (less) degazettement decisions in the LB chanel and less (more) degazettement decisions in the HC chanel ($\underline{o}_i$ and $\bar{o}_i$ are

[2]There can also be extreme cases where the payoff is always positive (in this case, degazettement always takes place) or partially negative (degazettement is implemented only for highest values of development pressures).

both higher -lower-) (figure 6). Indeed, the EA's payoff decrease slower (faster) with OCs when development pressure are low and increase slower (faster) when they are high. If the EA's variables costs are increasing faster (slower) with OCs, the EA will take more degazettement decision in the HC chanel (lower -higher- $\bar{o}_i$). Indeed, the EA's payoff from PA degazettement is increasing faster (slower) with OCs in the HC chanel (figure 4) while it has a weak effect and stay the same in the LB chanel. The same phenomenon is hapenning when the PA enforcement probability is decreasing faster (slower) with OCs (figure 5).

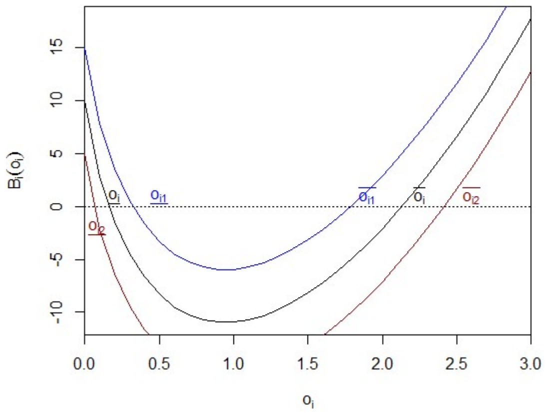



Figure 3: Impact of fixed costs on PA degazettement

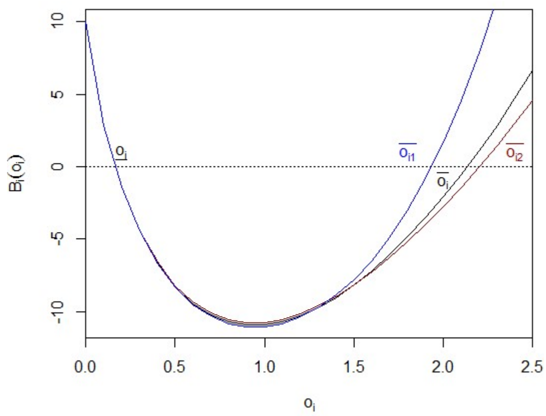



Figure 4: Impact of cost convexity on PA degazettement

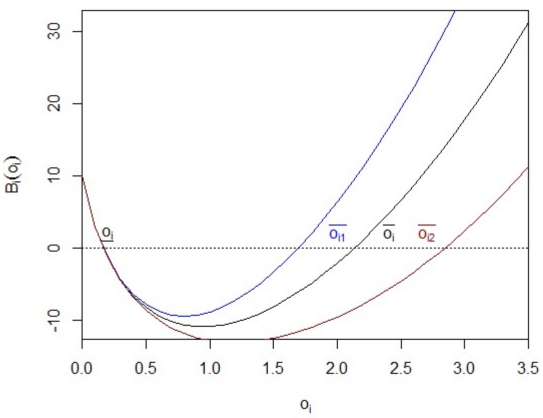



Figure 5: Impact of enforcement probability on PA degazettement

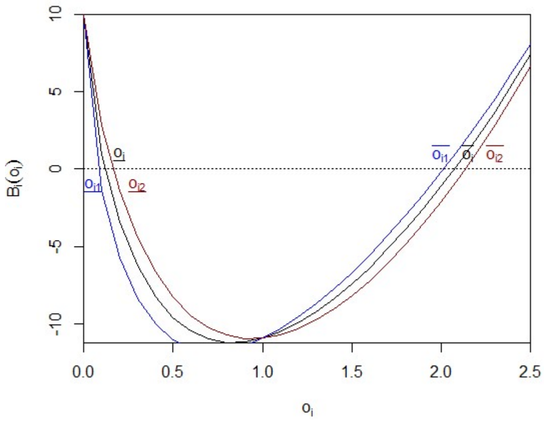



Figure 6: Impact of expected additionality on PA degazettement

The empirical analysis will allow us to verify whether the EA behaves as in our economic model. If a lot of (few) degazettement are observed in the HC chanel, it may be the effect of high (low) fixed costs, fastly (slowly) increasing variable costs with OCs, fastly (slowly) diminishing PA enforcement probability or slowly (fastly) increasing PA expected additionality. If a lot of (few) degazettement are observed in the LB chanel, it may be driven by high (low) fixed costs or fastly (slowly) increasing PA expected additionality with OCs. When taken together, the effet of these variables are likely to reinforce or to mitigate each other effect.

### 3.2 Joint maximization with asymmetric weights

We assume that the degazettement choice is made balancing the $EA$ and $DA$'s payoffs. It may be the case if a government aims to balance the environmental and development interests. In order to investigate the behavior of a central decision maker, both environmental and development agency utility functions are taken into account in a social benefits function from PA degazettement $\Omega_i$ (equation 5). The decision maker can assign different weightings $z$ to environmental and development objectives according to social preferences:

$$\Omega_i = zB_i + (1-z)\,wo_i \quad \text{with} \quad z \in [0;1] \tag{5}$$

The central regulator follows a decision rule $JM$ with the objective of maximizing social benefits from PA degazettement:

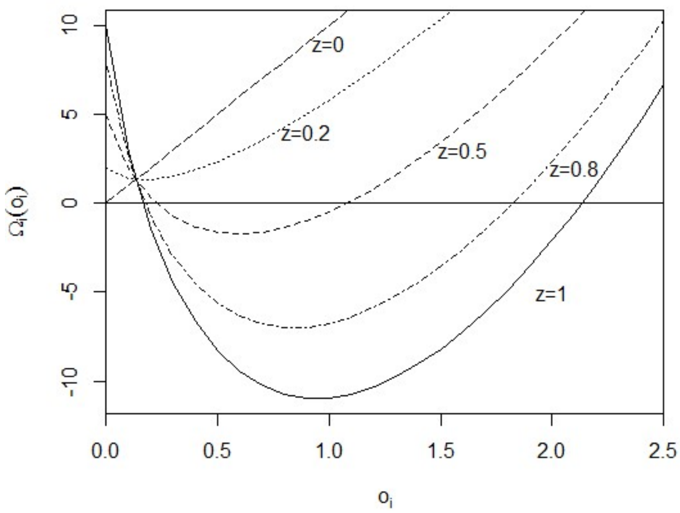
$$\begin{aligned} JM(D_i) &= \Omega_i D_i \\ D_i &= 1 \ \forall \ (1-z)\,wo_i > zb_i(o_i) - zC_i(o_i) \\ D_i &= 0 \ \forall \ (1-z)\,wo_i \leq zb_i(o_i) - zC_i(o_i) \end{aligned} \tag{6}$$

When $z = 0$, the regulator behaves as if the DA were the only decision maker and social benefits from PA degazettement are equivalent to DA's expected development profits from PA degazettement $wo_i$. When $z = 1$, only environmental goals matter and the regulator behaves as if the EA were the only decision maker. Social benefits from PA degazettement are equivalent to EA's net benefit from PA degazettement $B_i(o_i)$.

When $z \in ]0,1[$, both environmental and development goals matter though their weight are not the same. Therefore, PAs are degazetted if their potential expected development profits $wo_i$ from being degazetted are higher than the net environmental benefits from being maintained. In other words, to maintain a PA, the overall management costs have to be lower than the difference between its environmental benefits and the expected profits that could be done if the area were degazetted (equation 7). Results in terms of PA degazettement will depend on particular weights $z$ given to environmental and development objectives in the society (exemple with diverse weight are provided in figure 7).

As economic development starts to matter in social preferences ($z < 1$), social benefits from PA degazettement will change compared to the case where only the EA's payoff were considered $B_i(o_i)$. Firstly, the smaller weight given to the EA's payoff makes $\Omega(o_i)$ less convexe with a lower intercept. Then, the inclusion of the DA's payoff make $\Omega(o_i)$ rotating upward compared to $B_i(o_i)$, which have an impact on the values of OCs for which degazettement is implemented. If $z > 0.5$, nothing change in the LB channel as the effect of the EA decision rule is strong enough in social benefits from PA degazettement. If $z < 0.5$, the effect of the EA decision rules is no longer sufficiently strong: more degazettement is expected in both LB and HC channels. Therefore, when development preferences are strong enough, all PAs are degazetted[3].

Figure 7: Social benefits from PA degazettement with diverse weight




# 4 What are the determinants of PADD in the Brazilian Amazon?

## 4.1 Theoretical predictions to be empirically tested

Our theoretical model suggests that the probability to decide the degazettement of PAs is larger in places with low OCs, or high OCs. This probability is lower when OCs are intermediate. When OCs are low, expected development benefits are positive and there is low additionality of the PA, meaning it can be degazetted at low environmental costs. When OCs are high, expected

[3] A game where both the EA and the DA are cooperating in order to know the value for which one area will be degazetted has also been developed and is available in the appendix. Results are equivalent to those of a joint maximisation with equal weights.

develppment benefits are much higher and the PA may be ineffective because high development pressures make enforcement too costly. For the EA, degazettement decisions should depend on: i) the cost of maintaining the PA unit protected which is composed of a fixed part and a variable part ; ii) the expected environmental benefits of maintaining it. For the DA, the degazettement decision is made as soon as the expected development profits that can be made in the area are positive. All these elements of decision depend on the OC of conservation which vary over the landscape.

In this section, the determinants of a strict loss of protection of PAs in the Brazilian Amazon are empirically investigated. The OC of conservation is assessed through a composite measure of characteristics of the land and of PAs which are expected to enter in the expected development profits, expected additionality and enforcement probability of each still protected and degazetted PA units. We use standard characteristics which are known to be good predictor of PA location toward area of low profitability. This allow us to investigate on whether PAs lose protection due to high pressure or due to low benefits. Furthermore, the kind of conservation-development interactions at stakes in the management of PAs can be assessed.

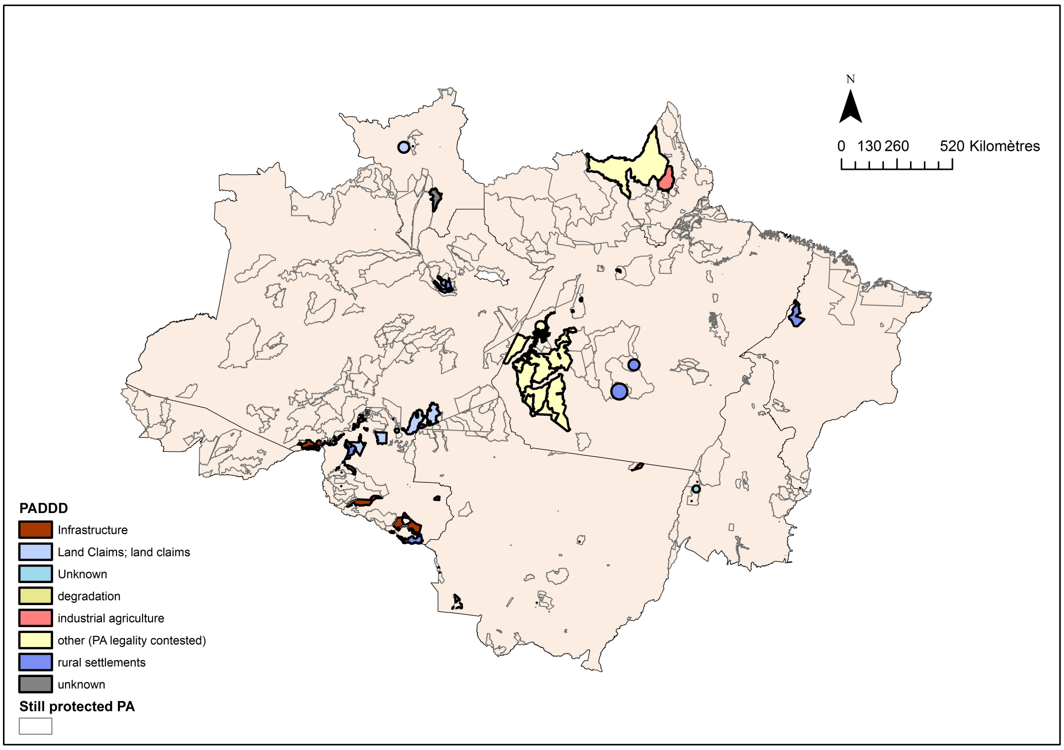
The evolution of the conservation-development trade-off toward more protection in the Brazilian Amazon during the two last decades makes the assumption of the DA being the only decision maker very unlikely. Moreover, since the causes of degazettement appear essentially linked to development processes, the EA being the only decision maker appears also to be a very unlikely. Thereby, the possible results from the empirical model should either indicates the existence of a decision process that is made balancing environmental and development objectives with asymmetric weights or a cooperation between the two agencies in order to maximize a joint payoff.

## 4.2 Data and empirical strategy

### 4.2.1 Observation Unit

We use PADDDtracker and the World Database on Protected Areas (WDPA), which are spatially explicit database of PADDD and PAs from the World Wildlife Fund (WWF, 2017b) and from the IUCN (IUCN and UNEP-WCMC, 2017). These two database allow us to have the precise identification, location and description of each PADDD and PAs with detailed information on their caracteristics from 1970 to 2015. PADDD events are classified according to their type (degazettement, downsizement or downgradement) and status (enacted or proposed) and according to the cause of the decision. Other available and useful information include the year of the decision as well as its description before and after the PADDD decision has been made. The WDPA allows us to have supplementary elements on other PAs existing in the territory and on their type of management.

Figure 8: Causes of PA degazettement and downsizement




In addition to degazettements, the analysis has been extended to downsizements because these decisions also represent a complete loss of protection for a PA unit. However, downgradements have been excluded from the sample as they are not considered as strict losses of protection and because many of them come from reclassifications due to the establishment of the new System of National Units of Conservation (SNUC) (Bernard et al., 2014). We use proposed events, which has not been yet enacted into law, as well as enacted ones as we are interested in explaining the intention to remove protection. Data for our explanative variables have been found within a 2000-2005 period of time, as a result, we explain the probability of PA degazettement and downsizement from 2006 to 2015. This choice allows us to avoid endogeneity issues by using variables describing the history of the landscape before any decision has been made. This range of year is considered to be enough as degazettements and downsizements have mostly been taken from 2006 onwards.

Our observation unit is the intersection between the two database in the Brazilian Amazon. Indigenous land have been excluded from the intersection to avoid misleading overlaps as they are not involved in PADDD decisions (Veríssimo et al., 2011). We thus obtain 332 observation units, which are either intact (281 observations) or which have been degazetted during the period (51 observations). A dummy variable taking the value of 1 (and 0 otherwise) has been attributed to each unit if a decision of degazettement or downsizement has been observed.

### 4.2.2 Empirical strategy

Our objective is to estimate the probability for a unit of PA to loose its protection status. This decision is based on the net utility the decision maker expect to get when he decides to remove a PA unit $U(D_i)$.

We thus want to estimate the following model:

$$U^*(D_i) = \beta_i X_i + \epsilon_i \tag{7}$$

With $U^*(D_i)$ being the non-observed utility that is expected from degazetting one unit of PA $i$, $X_i$ the vector of covariates entering in the utility of the decision maker, $\beta$ their associated parameters and $\epsilon$ the error term. As our dependent variable $U^*(D_i)$ is latent, we consider a dummy variable $d_i$ which takes the value of one when a decision of degazettement is taken, and 0 otherwise:

$$\begin{cases} d_i = 0 \;\; if \;\; U(D_i) \leqslant 0 \\ d_i = 1 \;\; if \;\; U(D_i) > 0 \end{cases} \tag{8}$$

As a result, the probability for a PA unit $i$ to be degazetted is estimated by a binary variable model which takes the form of equation 9. The vector of covariates $X_i$ represents the linear combination of the caracteristics of the land and PAs entering in the DA's expected development profits $w(o_i)$ and in the EA's net benefits $B_i(o_i)$ from the degazettement of each unit $i$ of PAs (equation 11).

$$Pr(d_i = 1) = F(\beta_i X_i) \tag{9}$$

We assume the cumulative distributive function of our residuals to be logistic, hence, we use a logistic probability model estimated by the maximum likelihood method. The reduced form of the model is as follows:

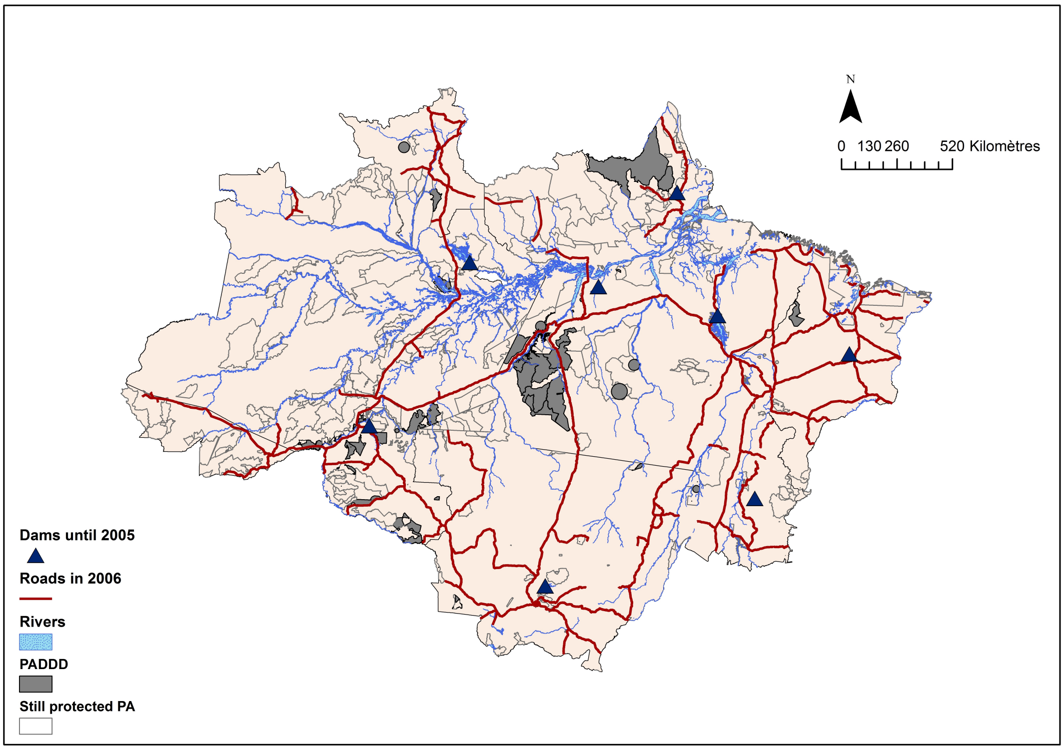
$$\begin{aligned} Pr(d_i = 1) &= w_i(\alpha o_i) + p_i(-\sigma_1 o_i + \sigma_1^2 o_i) - e_i(\sigma_2 o_i) + c_i(\sigma_3 o_i) + C_i + \epsilon_i \qquad (10) \\ &= w_i(\alpha_1 o_i + \alpha_2 o_i) + p_i(-\sigma_1 o_i + \sigma_1^2 o_i) - e_i(\sigma_2 o_i) + c_i(\sigma_3 o_i) + C_i + \epsilon_i \end{aligned}$$

The DA's expected development profits $w_i$ are first approached by the level of development of the area where the PA is located (equation 11). Afterwards, the OC of conservation entering in the DA's expected development profits are broken down in two parts: $\alpha_1 o_i$ and $\alpha_2 o_i$, which respectively stand for the caracteristics of the land that directly affect the return from infrastructure implementation and the return from land claims, two main proximate causes of degazettement decisions (figure 8 below) (Mascia et al., 2014; Pack et al., 2016; de Marques and Peres, 2015; Tesfaw et al., 2018; WWF, 2017a). The OC of conservation entering in the EA's expected benefits from degazettement is composed of characteristics of the land and of PAs $\sigma_1 o_i$ $\sigma_2 o_i$ $\sigma_3 o_i$ that respectively enter in the probability of the PA unit to be well-enforced $p_i$, the expected environmental benefits $e_i$ and the fixed and variables management costs ($c_i$ and $C_i$).

#### 4.2.3 Description and treatment of covariates

First, we use the average Growth Domestic Product (GDP) *mean_gdp* from 2000 to 2005 (IBGE, 2017) as a proxy for the economic development through the industrialization process of the municipalities which overlap with PAs. We believe it to be a strong predictor of pressures coming from the agribusiness sector and thus to rise the OC of conservation (Bernard et al., 2014; Kere et al., 2016; Joppa and Pfaff, 2009; Ferraro et al., 2013; Sims, 2014; Pfaff et al., 2015a; Mascia et al., 2014; Symes et al., 2016). Afterwards, we assess the characteristics of the land that affect the benefits from economic development from land claims and infrastructure implementation (Tesfaw et al., 2018). Those rising the returns from rural settlement are approximated by the accessibility of the PA to markets, the profitability of agricultural activities and the population pressures in the PA. We use the distance to the nearest road in 2006 (DNIT, 2017) because we expect them to positively influence the accessibility of the PA to markets (Symes et al., 2016; Laurance et al., 2014, 2009; Bax and Francesconi, 2018; Bax et al., 2016) (figure 9). The average rainfalls from 2000 to 2005 (Funk et al., 2015) are included to proxy the suitability of lands for the extention of agricultural activities (Sombroek, 2001; Kirby et al., 2006; Kere et al., 2016; Tesfaw et al., 2018; Bax and Francesconi, 2018; Bax et al., 2016). The population pressures are approximated by the average population density occuring in the area between 2000 and 2005 (CIESIN, 2015). The characteristics of the land rising the returns from infrastructure implementation are approximated by the average slopes (Jarvis et al., 2008) and by the proximity of the PA to rivers (IBGE, 2017). Indeed, being situated nearest to rivers and on higher slopes (figure 9) may make the lands more suitable for the implementation of hydroelectric dams (Finer and Jenkins, 2012; McClain and Naiman, 2008). We focus on this type of infrastructure because hydropower development is the first objective of infrastructure implementation in the brazilian Amazon (Fearnside, 2014; WWF, 2017a; Araújo et al., 2012).

Figure 9: Roads, rivers and dams




We use the total forest losses from 2001 to 2005 (INPE, 2017) as the characteristic of the land entering in the probability of the CU to be well-enforced. CUs which have endured higher deforestation rates during the period are expected to be badly enforced compared to those who have not. We assume that the probability of being well enforced is low as soon as deforestation occur within the CU. We make the non-linear effect of enforcement lying on the strength of forest clearings which indicate differences in the level of pressure. Hence, this variable has been included in its square shape to distinguish between areas of high pressure, which have a low probability of being correctly enforced and areas of low pressure which have a higher probability. We use a factor variable standing for the number of terrestrial endemic species (WWF, 2006) and the proximity to existing dams as characteristics of the land entering in the expected environmental benefits of maintaining PAs. Indeed, the number of endemic species represent a motivation to reach the target of the CBD and has been used as a planning tool to assess biodiversity priorities in areas which deserve greater attention due to environmental threats (Olson et al., 2001). This variable is expected to have a negative influence on the likelihood of degazettement if environmental priorities matter (Tesfaw et al., 2018). Being close to existing dams may have a negative influence on the expected environmental benefits of PA maintenance due to the impacts it may have on the fragmentation of habitats and the emissions of greenhouse gas(Fearnside, 2014; Finer and Jenkins, 2012; McClain and Naiman, 2008). We use the size of the CU (WWF, 2017b) as the characteristic of PAs entering in their management costs due the impacts it has on the human and technical ressources they need (Veríssimo et al., 2011; IUCN and UNEP-WCMC, 2017; Symes et al., 2016). Management costs can decrease or increase with the size of the CU depending on the existence of economies of scale (Bruner et al., 2004). It has also been found to have an effect on the likelihood of PADDD (Symes et al., 2016) since it is directly related to the OC of its existence compared to other type of land uses. Lastly, we use the International Union for Conservation of Nature (IUCN) category (WWF, 2017b) to obtain supplementary information on the management objectives of each CU. This can inform us on the type of issues and thus fixed costs which are faced by the EA (Bruner et al., 2004; IUCN and UNEP-WCMC, 2017; Symes et al., 2016).

All the covariates were transformed in Geographic Coordinate System "South American Datum 1969" and projected into "UTM Zone 18S (meters)" for the analysis using ArcGIS 10.4.1. The raster and vector covariates have not been treated similarily. A precise grid of 1,8km by 1,8km have been drawn to sample the raster dataset (slopes, population density and rainfalls) at the same scale. This choice has been made because it make us able to describe our smallest degazetted or downsized area. Then, we have extracted their mean over each square using zonal statistics, which allows us to have their complete distribution over each observation unit. The vector covariates (GDP, number of endemic species and deforestation) have directly been intersected with CUs in order to have the exact proportion of their values over each one of them. Only the average of their distribution and the weighted average of their proportion have been included in the estimations. The geodesic distance to the nearest road, dam and river has been computed from the centroid of each CU. A complete description of the source and statiscal treatment of each covariate is available in table 6 in the appendix.

### 4.3 Results

A description of the main summary statistics of our covariates, broken down by still protected (1) and degazetted CUs (2), is available in the appendix (tables 5, 6 and 7). We observe some differences between land characteristics on still protected and degazetted CUs which are confirmed by significant Student's t-statistic on the equality of mean and Pearson's pairwise correlations (table 8). On average, degazetted CUs seem to be situated on areas with higher GDP from 2000 to 2005, with their centroid being closer to roads in 2006. However, we observe a negative correlation between the average population density and the decision of degazetting a CU. In addition, degazetted CUs were situated on areas that were larger, more deforested from 2001 to 2005 and that were endowed with a lower number of terrestrial endemic species.

### Basic specification

Our basic specification is presented in table 1 below. As mentioned, we first estimate a simple model (1) in which the conservation OCs entering in the DA's preferences are represented via the average GDP at the municipality level. In the second model (2), they are broken down to integrate the characteristics of the land rising the expected profits from development activities at the level of the CU. In the third model (3), we go further to look at the characteristics of the land (forest cover losses, average population density and average rainfalls) in the 10km buffer zone of the CU. These external pressures might indeed have an enter in the quality of enforcement of the CU and on the profitability of development activities. The average GDP at the municipal level is not included in these two last estimations to avoid colinearity between the explanatory variables. In each model, the conservation OCs entering in the preferences of the EA are entirely assessed.

Our results in model (1) indicates a significant and positive effect of the average GDP at the municipality level on the likelihood of degazettement. The economic landscape in which the CU is located does matter as a higher GDP may enable pressures coming from the agribusiness and infrastructure sectors. This is consistent with the development objectives having a considerable weight in the decision process of degazettement (Bernard et al., 2014; Mascia and Pailler, 2011; Mascia et al., 2014). When we look further into the characteristics of the land at the scale of the CU in model (2), we first find a significance and positive effect of being situated on higher slopes on the likelihood of degazettement. This may rise the expected profits from the construction of hydroelectric dams and this is in line hydropower development being an important proximate cause of degazettement (Bernard et al., 2014; Pack et al., 2016; Mascia and Pailler, 2011; Mascia et al., 2014; WWF, 2017a). The lack of significance of the proximity to rivers does not seem surprising as the effect of hydropower development is mostly driven by the land's topography. Then, we find a negative and significant effect of the distance to the nearest road which indicates that the proximity of the PA to markets increases the likelihood of degazettement. This is consistent with land claims for agricultural extention being also an important proximate cause of degazettement (Symes et al., 2016; Laurance et al., 2014, 2009). The lack of significance of average rainfalls may be related to its unclear impact on agricultural activities as their profitability can be reduced when they turn to be excessive (Kere et al., 2016; Bax and Francesconi, 2018; Kirby et al., 2006). It also may indicates that degazettements for agricultural extention are mostly driven by the proximity of the CU to

Table 1: Basic specification

| Variables | (1) | (2) | (3) |
|---|---|---|---|
| **The Development Agency** | | | |
| Average GDP from 2000 to 2005 | 0.409 | | |
| | (3.32)*** | | |
| Average slopes | | 1.465 | 1.692 |
| | | (3.07)*** | (3.23)*** |
| Distance to the nearest river | | -0.362 | -0.319 |
| | | (1.79)* | (1.56) |
| Average rainfall | | -0.531 | 1.766 |
| | | (0.43) | (0.52) |
| Average rainfall in the buffer zone | | | -2.924 |
| | | | (0.89) |
| Average population density | | -0.224 | 0.274 |
| | | (0.63) | (0.76) |
| Average population density in the buffer zone | | | -0.556 |
| | | | (2.32)** |
| Distance to the nearest road | | -0.668 | -0.745 |
| | | (3.17)*** | (3.39)*** |
| **The Environmental Agency** | | | |
| Total deforestation | -0.610 | -0.561 | -0.480 |
| | (2.29)** | (2.44)** | (2.19)** |
| Squared total deforestation | 0.101 | 0.107 | 0.104 |
| | (3.07)*** | (3.60)*** | (3.91)*** |
| total deforestation in the buffer zone | | | 0.038 |
| | | | (0.52) |
| High endemism (>21) | -1.464 | -1.969 | -2.315 |
| | (1.69)* | (2.20)** | (2.40)** |
| Low endemism (1-5) | -0.409 | -1.969 | -2.315 |
| | (0.89) | (2.02)** | (2.22)** |
| Medium endemism (6-20) | 0.214 | -0.208 | -0.250 |
| | (0.47) | (0.39) | (0.43) |
| Distance to the nearest dam until 2005 | | -0.742 | -0.915 |
| | | (2.47)** | (2.91)*** |
| PA size | 0.227 | 0.302 | 0.285 |
| | (1.80)* | (2.01)** | (1.72)* |
| IUCN category II | 1.206 | 1.086 | 1.278 |
| | (1.73)* | (1.34) | (1.52) |
| IUCN category V | -0.212 | -0.717 | -0.869 |
| | (0.20) | (0.56) | (0.70) |
| IUCN category VI | 1.155 | 0.836 | 0.966 |
| | (1.75)* | (1.24) | (1.38) |
| Pseudo R2 | 0.23 | 0.33 | 0.35 |
| MacFadden's ajusted R2 | 0.15 | 0.21 | 0.22 |
| AIC | 240.99 | 224.83 | 216.05 |
| Number of observations | 332 | 335 | 326 |

* $p < 0.1$; ** $p < 0.05$; *** $p < 0$

Covariates which are not normally distributed are included in logarithme.

We have added 1 to the variable that displays 0 in order to keep them when linearized.

markets. The lack of significance of the average population density may be related by its unclear impact on the development of large scale infrastructure or agricultural project.

Even though we have found a strong influence of development objectives in the degazettement decision process, environmental objectives seem to matter as well. Indeed, our results indicate that degazettements are less likely to happen in CUs which are endowed with a high and with a low number of endemic species compared to those which are not where degazettements are more likely. The EA is not willing to take a degazettement decision in areas which represent management priorities to reach the biodiversity targets (Baldi et al., 2017), whatever the quality of enforcement and the level of pressure occuring in the CU[4]. The importance of high expected environmental benefits on PA maintenance may be reinforced by the negative effect of the distance to the nearest dam on the likelihood of degazettement (Fearnside, 2014; Finer and Jenkins, 2012; McClain and Naiman, 2008). The cumulated deforestation over 2001-2005 displays a strong non linear effect on the likelihood of degazettement. Results indicate a negative effect of deforestation occurring in the area on the likelihood of degazettement, but only until a threshold where this effect reverse and become positive. This result is consistent with our expectation on the behavior of the EA. At the beginning, lower forest clearings in the CUs make the probability of enforcement high enough, the likelihood of degazettement is thus decreasing. When the pressures rises, the probability of enforcement diminishes, which make the probability of being degazetted increasing. These results are close to those of Tesfaw et al. (2018) who find the bad environmental effectiveness of CUs to be positively associated with degazettement in the state of Rondônia. The size of CUs seems to have a marginal but positive influence on the likelihood of degazettement, which may rather indicates that larger PAs are more costly to manage (Veríssimo et al., 2011; Bruner et al., 2004). However, one other possible explanation refers to the results of Symes et al. (2016) who find PA size to be the strongest predictor of PADDD due to their larger OC of conservation.

Even though the preferences of the EA matter in the degazettement decision process, we don't think that they come first when the characteristics of the land increases the OC of conservation. We think that the DA is willing to take a degazettement decision as soon as the characteristics of the land make the profits from agricultural or infrastructure development positive. This decision is likely to be reinforced when PAs are not expected to provide sufficient environmental benefits and

[4]The interaction beetween the number of endemic species and forest cover losses over the area is never significant, which may indicates that the expected environmental benefits are valued without considering pressure occuring in the area.

moderated in areas which might represent management priorities to reach the biodiversity targets (Baldi et al., 2017).

In model (3), only the average population density in the 10km buffer zone of the CU has a negative impact on its probability of being removed. This result is surprising and differ from that of Symes et al. (2016) who find the local population interacted with the size of the PA to be positively associated with PADDD due to land claims reasons. Here, we believe that population density outside CUs may rather prevent the development of agricultural and infrastructure projects or lower the pressures due to better enforcement (Naughton-Treves et al., 2005; Robinson et al., 2014). Unlike us, Tesfaw et al. (2018) find a significant and positive effect of deforestation inside the buffer zone of the CU in the state of Rondônia, which is not surprising as it is used as a proxy for the quality of enforcement[5].

## Robustness checks

First, we want to account for the effect of the localisation of the PA in the states of the Brazilian Amazon. We thus choose to add state fixed effects in our estimations. This choice is made because, whatever the level of PA management, PADDD attempts are mainly undertaken on state decree, either in agreement with the federal governement or in order to overturn their decision (WWF, 2017b). We thus believe that the bargaining power of both the DA and the EA may be influenced by the fixed characteristics of each state (Nolte et al., 2013) and by their different behavior toward environmental and development objectives (Pfaff et al., 2011, 2015a; Tesfaw et al., 2018). For exemple, the high number of PADDD events in Rôndonia compared to those of Amazonas make us think that there could be spatial patterns across the decision processes (Sauquet et al., 2014). The results obtained on Fisher test (table 9 in the appendix) conducted for the inclusion of state dummies allow us to reject the null that they are jointly significant.

To go further, we allow the residuals to be correlared within each state by using Clustered Robust Standard Errors (CRSE). We have 9 cluster, which is not enough to guarantee consistent estimates of standard errors. We thus use a non parametric bootsrap procedure with 500 replications to reinforce the robustness of the residual estimates (Esarey and Menger, 2018; Cameron and Miller, 2015). Results are presented in table 2 below for each model. This choice is made because ignoring the possible correlations among observations when the data are clustered may bias the estimation of

[5]The inclusion of the rate of change between deforestation outside and inside CUs do not show any effect. This may indicate that the quality of enforcement is already captured by our non linear specification on cumulated internal deforestation.

the variance-covariance matrix, especially when the independant variables show correlation within each state (Esarey and Menger, 2018).

In model (1), the average GDP is no longer significant, which may indicates that the construction of this variable was already capturing a strong difference of the development stage of each state. In model (2) et (3), the conclusions on the impacts of the characteristics of the land entering in the DA's decision rule do not change. However, the conclusions on those entering in the EA's decision rule are less clear. Only the quality of enforcement seems to have a non linear impact on the likelihood of degazettement. Variables related to the CU's expected environmental benefits and management costs should thus be strongly correlated within states. That make use believe that the net expected benefits of maintaining CUs do not enter in the EA's decision rule as much as expected. We rather think that degazettement decisions are based on state preferences toward development or environmental objectives, either through land characteristics which rise the expected profits from economic development, or through land characteristics which lower the CUs' quality of enforcement.

## Table 2: Robustness check

| Variables | (1) CRSE | (1) Bootstrap CRSE | (2) CRSE | (2) Bootstrap CRSE | (3) CRSE | (3) Bootstrap CRSE |
|---|---|---|---|---|---|---|
| The Development Agency | | | | | | |
| Average GDP from 2000 to 2005 | 0.409 | 0.409 | | | | |
| | (2.58)*** | (1.21) | | | | |
| Average slopes | | | 1.465 | 1.465 | 1.692 | 1.692 |
| | | | (4.00)*** | (2.62)*** | (4.03)*** | (3.43)*** |
| Distance to the nearest river | | | -0.362 | -0.362 | -0.319 | -0.319 |
| | | | (2.82)*** | (1.71)* | (1.77)* | (1.23) |
| Average rainfall | | | -0.531 | -0.531 | 1.766 | 1.766 |
| | | | (0.53) | (0.26) | (0.50) | (0.16) |
| Average rainfall in the buffer zone | | | | | -2.924 | -2.924 |
| | | | | | (0.85) | (0.26) |
| Average population density | | | -0.224 | -0.224 | 0.274 | 0.274 |
| | | | (0.56) | (0.25) | (0.80) | (0.35) |
| Average population density in the buffer zone | | | | | -0.556 | -0.556 |
| | | | | | (3.63)*** | (2.63)*** |
| Distance to the nearest road | | | -0.668 | -0.668 | -0.745 | -0.745 |
| | | | (3.78)*** | (2.31)** | (5.41)*** | (3)*** |
| The Environmental Agency | | | | | | |
| Total deforestation | -0.610 | -0.610 | -0.561 | -0.561 | -0.480 | -0.480 |
| | (4.37)*** | (2.05)*** | (3.75)*** | (1.90)* | (3.50)*** | (1.64)* |
| Squared total deforestation | 0.101 | 0.101 | 0.107 | 0.107 | 0.104 | 0.104 |
| | (3.82)*** | (2)** | (3.95)*** | (1.91)** | (4.38)*** | (2.18)** |
| Total of deforestation in the buffer zone | | | | | 0.038 | 0.038 |
| | | | | | (0.55) | (0.40) |
| High endemism (>21) | -1.464 | -1.464 | -1.969 | -1.969 | -2.315 | -2.315 |
| | (1.11) | (0.76) | (2.11)** | (1.22) | (2.44)** | (1.33) |
| Low endemism (1-5) | -0.409 | -0.409 | -1.170 | -1.170 | -1.372 | -1.372 |
| | (0.54) | (-0.29) | (1.41) | (0.72) | (1.75)* | (0.83) |
| Medium endemism (6-20) | 0.214 | 0.214 | -0.208 | -0.208 | -0.250 | -0.250 |
| | (0.22) | (0.14) | (0.26) | (0.14) | (0.29) | (0.16) |
| Distance to the nearest dam | | | -0.742 | -0.742 | -0.915 | -0.915 |
| | | | (1.56) | (1.06) | (2.04)** | (1.37) |
| PA size | 0.227 | 0.227 | 0.302 | 0.302 | 0.285 | 0.285 |
| | (1.50) | (0.75) | (1.76)* | (0.82) | (1.43) | (1.25) |
| IUCN category II | 1.206 | 1.206 | 1.086 | 1.086 | 1.278 | 1.278 |
| | (1.47) | (1.35) | (1.34) | (1) | (1.63) | (1.65) |
| IUCN category V | -0.212 | -0.212 | -0.717 | -0.717 | -0.869 | -0.869 |
| | (0.25) | (0.23) | (0.68) | (0.53) | (0.64) | (0.70) |
| IUCN category VI | 1.155 | 1.155 | 0.836 | 0.836 | 0.966 | 0.966 |
| | (1.76)* | (1.32) | (1.28) | (0.88) | (1.54) | (1.57) |
| Pseudo R2 | 0.23 | 0.23 | 0.33 | 0.33 | 0.35 | 0.35 |
| MacFadden's ajusted R2 | 0.15 | 0.15 | 0.21 | 0.21 | 0.22 | 0.22 |
| AIC | 240.99 | 240.99 | 224.83 | 224.83 | 216.05 | 216.05 |
| Number of observations | 332 | 332 | 335 | 335 | 326 | 326 |

* $p < 0.1$; ** $p < 0.05$; *** $p < 0$

Covariates which are not normally distributed are included in logarithme.

We have added 1 to the variable that displays 0 in order to keep them when linearized.

## 5 Discussion and conclusion

Our research question was to understand the determinant of PA withdrawal in territories where interaction between development and environmental objectives are at stakes. PAs are strong and widely used regulatory tools to limit resource use and access to land (Naughton-Treves et al., 2005; Deguignet et al., 2014; Watson et al., 2014). Their implementation may create conflicts over land between conservation and development activities (Naughton-Treves et al., 2005; Deguignet et al., 2014; Watson et al., 2014). Some evidence on the existence of such conflicts have been found: first, PAs tend to be located in low pressure areas (Joppa and Pfaff, 2009; Pfaff et al., 2015a; Baldi et al., 2017), which make them not as additional as expected in the fight against deforestation (Pfaff et al., 2015a,b; Kere et al., 2016; Joppa and Pfaff, 2011; Pfaff and Robalino, 2012; Ferraro et al., 2013; Nolte et al., 2013; Sims, 2014; Pfaff et al., 2016; Anderson et al., 2016; Andam et al., 2008). Second, a worldwide phenomenon of PADDD has been observed since the last two decades, which seems to be driven by the development pressures (i.e. the OC of conservation) occuring in the landscape (Mascia and Pailler, 2011; Mascia et al., 2014; Pack et al., 2016; Bernard et al., 2014; Cook et al., 2017; de Marques and Peres, 2015; Symes et al., 2016).

In this article, we assess the possible drivers to the choice of withdrawing PAs in the Brazilian Amazon, where the conservation-development trade-off is an important issue. Indeed, deforestation is rising and PAs are being removed due to development pressures (Veríssimo et al., 2011; Bernard et al., 2014; de Marques and Peres, 2015; Symes et al., 2016) even though strong efforts have been made to fight against deforestation and to extend the PA coverage. We have first propose a simple economic model of degazettement choice where we assume that PADDD decisions are made through interactions between the decision rules of environmental and development agencies. We suggest that the probability of being degazetted is large, either in places of low OCs, or in places of high OCs. When the OC of conservation is low, degazettements happen because of low environnemental additionality, whereas it happens due to lack of enforcement and despite high potential additionality when it is low. Then, we have taken advantage of the PADDDtrack database (WWF, 2017b) to assess the OC of conservation and to investigate on the empirical determinants of CU withdrawal. We have used a logistic probability model in which the likelihood of degazettement is explained by a linear combination of characteristics of the land and of PAs entering in each agencies' decision rules.

Firstly, we confirm that the likelihood of degazettement is strongly influenced by development objectives, through a favorable economic landscape enabling pressure coming from the agribusiness and infrastructure sectors (Kere et al., 2016; Bernard et al., 2014; Pack et al., 2016; Mascia and Pailler, 2011; Mascia et al., 2014). We emphasize the positive role of being situated on higher slopes and near roads as it respectively increases the expected benefits of hydropower development and agricultural extention (Symes et al., 2016; Tesfaw et al., 2018; Laurance et al., 2009, 2014; Finer and Jenkins, 2012; McClain and Naiman, 2008). However, we find a negative relationship between population density in the 10km buffer zone of the CU and its probability of degazettement. That is not consistent with population pressure being a predictor of PADDD (Symes et al., 2016). On the contrary, it may indicates that the presence of human population does not necessarily rise the OC of conservation, either because it prevents large scale development project, or because it enhances protection (Blackman et al., 2015; Robinson et al., 2014). Environmental objectives also have an impact on the likelihood of degazettement. Our significative result on the proximity to dams indicates that the EA is less willing to take a degazettement decision when the CU is less likely to be degraded due to its remoteness from dams. Likewise, as soon as the CU is endowed with a high or a low number of endemic species, its higher expected environmental value make the likelihood of degazettement lower, whatever the level of development pressure in the area. In addition, assuming that CUs which have undergone forest clearings within their boundaries are badly enforced, we find a non linear effect of deforestation on the likelihood of degazettement. PAs which have undergone lower forest clearings have a lower probability of being badly enforced and thus, a lower probability of being degazetted. However, PAs which have undergone higher deforestation rates have a lower probability of being well enforced, which make them more likely to be degazetted. Lastly, we confirm the influence of the size of the CU as a predictor of degazettement due to the effect it has on management costs (Veríssimo et al., 2011; Bruner et al., 2004) and the OC of its existence (Symes et al., 2016).

The DA behaves as in our economic model but the EA doesn't seem to. Indeed, she is likely to take a degazettement decision only when the PA is badly enforced or when it has a low expected environmental value. She is not able to evaluate the PA real additionality and does not take a degazettement decision if the PA is correctly enforced or is expected to have a high environmental value. We believe that the decision power of the EA matter when the OC of conservation is already high due to favorable land characteristics rising the expected benefits of development activities. PADDD decisions in the HC chanel may thus either be reinforced or moderated by the expected environmental quality of the PA. This is not consistent with PADDD decisions being entirely unilateral, implemented by considering only development objectives with no civil or technical consultation (Bernard et al., 2014; Mascia and Pailler, 2011; Mascia et al., 2014; Araújo et al., 2012). We believe the bargaining power of each agency to be influenced by the fixed caracteristics of their location (Nolte et al., 2013; Pfaff et al., 2011, 2015a). Indeed, PADDD decisions are mainly undertaken under state decrees (WWF, 2017b) and can be shaped by their different behavior toward environment and development objectives. After testing for state fixed effects, which are not significant, we use CRSE with a non parametric bootstrap procedure to test the robustness of our results. We validate the behaviour of the DA but that of the EA seems to have less importance than expected in the decision process due to a possible correlation of the expected environmental benefits and management costs of CUs within states. We thus believe that the preferences of the state have a strong impact on the bargaining power of each agencies in degazettement decisions.

The environmental effects of PADDD are not well-known (Forrest et al., 2015; Golden Kroner et al., 2016; Tesfaw et al., 2018; Pack et al., 2016) but this phenomenon is not likely to decrease, especially due to the ambitions to foster hydropower development in the territory (WWF, 2017c; Pack et al., 2016; Araújo et al., 2012). In our empirical model, the EA evaluates the PA effectiveness by only considering the expected benefits of the PA instead of evaluating its real additionality. Having more information on the OCs of conservation and on the additionality of the PA could inform decision makers on the long-term impact of their decision. Indeed, PAs located in highest pressure areas seem to be those suffering the most from PADDD, even though they may turn to be highly additional (Cook et al., 2017). If implemented on PAs with low probability of being additional, PADDD is not necessarily bad (Bernard et al., 2014; Fuller et al., 2010) and can be usefull to consolidate protection in highest pressure areas.

In order to broaden the scope of our study, it would be interesting to analyse downgrading events and to make the difference between proposed PADDD and enacted ones. Downgrading events have not been included because we don't think that our transmission chanel apply well in those case. In addition, making the difference between enacted and proposed PADDD to understand how the sequence of the decision is made necessitate to known the year of proposal of enacted PADDD. Further work should consist in studying the real impacts of degazattement and downsizement in the Brazilian Amazon over the period under study when the OCs of conservation vary. This might provide usefull information on the real additionality of PADDD hapening in high and lower pressure areas to really inform decision maker on how to deal spatialy with the conservation-development trade-off (Mascia et al., 2014).

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# 6 Appendix

### Functional forms and parameters used for the simulations

$$
\begin{aligned}
C_i(o_i) &= h_i + \frac{1}{a}o_i^a \\
p_i(o_i) &= 1 - (\frac{o_i}{1+o_i})^b \\
e_i(o_i) &= so_i^d \\
U_{DA}(D_i) &= wo_iD_i \\
B_i(o_i) &= h_i + \frac{1}{a}o_i^a - (1 - (\frac{o_i}{1+o_i})^b)so_i^d \\
U_{EA}(D_i) &= B_i(o_i)D_i
\end{aligned}
\tag{11}
$$

Table 3: Parameters values

| Variable | Value |
|---|---|
| $o_i$ | $\in [0, 10]$ |
| $h_i$ | 10 |
| $a$ | 3 |
| $b$ | 0.8 |
| $d$ | 0.8 |
| $s$ | 50 |
| $w$ | 10 |

### Specific cases

Specific cases in which no degazettement is implemented in the LB channel (figure 10) can be driven by negligible fixed costs in EA's net benefits from PA degazettement. Yet, PA degazettement will always happen in the HC chanels because of increasing variables costs and decreasing environmental benefits with OCs. In addition, sufficiently high fixed costs will result in PA degazettement for all value of OCs (figure 11).

Figure 10: Negative and positive net losses from PA management

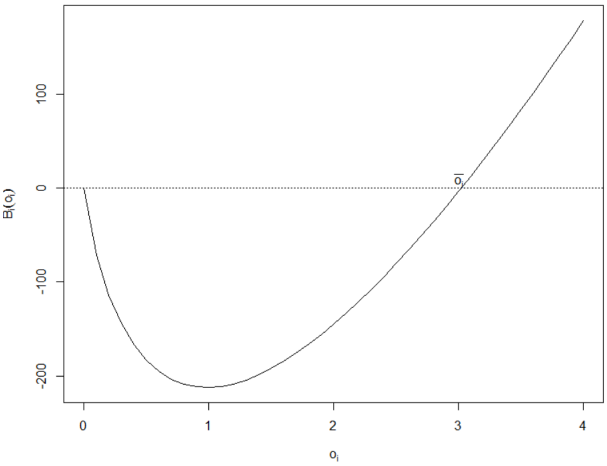
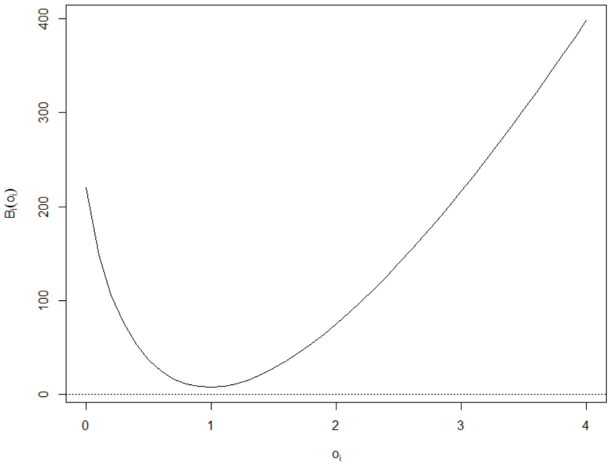



Figure 11: Positive net losses from PA management




**Cooperative game**

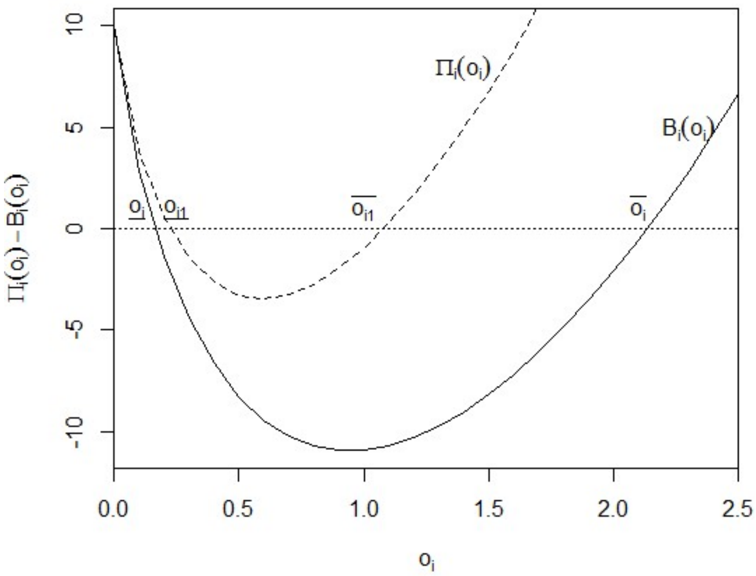
Here, we assume that both the EA and the DA are cooperating in order to know the value of development pressures for which one area will be degazetted. They take their decision by maximizing their joint payoff $\pi_i(o_i)$.

$$\pi_i(o_i) = B_i(o_i) + w(o_i) \tag{12}$$

They take their cooperative decision by following a decision rule $CG$ with the objective of maximizing their joint payoff from PA degazettement (equation 14). As in the precedent case, PAs are degazetted as soon as the overall management cost from their maintenance is higher than the difference between their expected environmental benefits and the potentiel expected profits from their degazettement.

$$\begin{aligned} CG(D_i) &= \pi_i D_i \\ D_i &= 1 \ \forall \ wo_i > b_i(o_i) - C_i(o_i) \\ D_i &= 0 \ \forall \ wo_i \leq b_i(o_i) - C_i(o_i) \end{aligned} \tag{13}$$

Figure 12: Joint payoff from PA degazettement




The joint payoff from PA degazettement is greater in the case of cooperation. Here, compared to the case where the EA where considered as the only decision makers, the inclusion of the DA's payoff makes $\pi_i$ higher for each value of OCs (figure 12). However the dividend of cooperation will not be the same for each agency. Indeed, for each value of OCs, the decision rule that predominate is that of the agency who value the area the most either for conservation or for development objectives.

For PAs whose OCs are lower than $\underline{o}_i$ or higher than $\bar{o}_i$, both agency agree on degazettement as their individual benefits are positive. However, the values of $\underline{o}_{i1}$ and $\bar{o}_{i1}$ for which they cooperate are respectively higher and lesser (figure 12). Their cooperation result in more PA degazettement both in the LB and in the HC channels. The effect is greater in the HC channel because the DA expected payoff is increasing in $o_i$ and the EA expected environmental benefits are decreasing fastly compared to her overall management costs.

In order for the cooperation to be stable, compensation through transfer payments can be done i) by the DA to the EA for the loss of PAs that were supposed to be maintained in the absence of cooperation and ii) by the EA to compensate the DA for the foregone expected development profits of non degazetted PAs. One solution to share the benefits of cooperation in a fair and Pareto-improving way is to use the Nash bargaining procedure. Each agency can thus recover her non cooperative outcome and half of the dividend of their cooperative outcome.

**Description of covariates**

Table 4: Source and description of variables

| Variable name | Date | Source | Treatment |
|---|---|---|---|
| The Development Agency | | | |
| GDP | 2000 to 2005 | Vector format from the IBGE at the municipality level in current prices (1000 real) (IBGE, 2017) | Average from 2000 to 2005. |
| Slopes | - | Gridded elevation data from the Shuttle Radar Topography Mission (SRTM) (Jarvis et al., 2008). 90m resolution, resample in 250 by 250 meters. | Computed in degree from horizontal over each observation unit with ArcGIS. |
| Distance to the nearest river | - | Lake, pond and rivers, permanent and navigable. Vector format from the IBGE (IBGE, 2017) | Distance of the centroid of each CU to the nearest river. |
| Rainfalls | 2000 to 2005 | Gridded annual data from the version 2.0 of Climate Hazard Group InfraRed Precipitation with Station Data (CHIRPS) (Funk et al., 2015). 0,05 degree of resolution. | Average from 2000 to 2005. |
| Population density | 2000 and 2005 | Gridded data from The Gridded Population of the World (GPW) version 4 from the 2006 Global Rural-Urban Mapping Project (GRUMP) of the Center for International Earth Science Information Network (CIESIN, 2015) . | Average between 2000 and 2005. |
| Distance to the nearest road | 2006 | Vector format from the Brazilian Departamento Nacional de Infraestrutura de Transportes (DNIT, 2017) | Distance of the centroid of each CU to the nearest roads with ArcGIS |
| The Environmental Agency | | | |
| Enforcement | | | |
| Total deforestation | 2001 to 2005 | Vector format from the PRODES System of the Instituto Nacional de Pesquisa Espacial (INPE) (INPE, 2017) | Total from 2001 to 2005. |
| Expected environmental benefits | | | |

| | | | |
|---|---|---|---|
| Number of endemic species | - | Vector format from from the WWF WildFinder database of species distributions (WWF, 2006; Olson et al., 2001).<br>High endemism: from 21 to 47 endemic species ; medium endemism: from 6 to 20 endemic species ; low endemism: from 1 to 5 endemic species ; no endemism (0 endemic species) is the baseline. | - |
| Distance to the nearest dam | from 1975 to 2005 | More than 0,1km$^3$.<br>Point format from the Global Reservoir and Dam (GRanD) database of the Department of Geography of Mc Gill University in Montreal (Lehner et al., 2011). | Distance of the centroid of each CU to the nearest dam. |
| Management costs | | | |
| Pa size | - | WDPA (IUCN and UNEP-WCMC, 2017) | - |
| IUCN category | - | PADDDtracker (WWF, 2017b)<br>II: National Parks ; V: Protected Landscape ; IV: Habitat/Species Management Area ; Ia (Strict Nature Reserve) is the baseline. | - |

**Descriptive statistics**

Table 5: Dependants variables

| | (1) | | | | (2) | | | |
|---|---|---|---|---|---|---|---|---|
| | Mean | Sd | Min | Max | Mean | Sd | Min | Max |
| mean_gdp | 864014.9 | 2982346 | 3281 | 2.01e+07 | 1580397 | 3953781 | 16602.65 | 2.01e+07 |
| dist_roads | 84.87841 | 76.98803 | .1455309 | 400.3318 | 56.34097 | 55.71756 | 2.445773 | 274.2852 |
| mean_slope | 1.683869 | 1.387819 | .1502362 | 8.187457 | 2.053847 | 1.107261 | .4287834 | 6.929451 |
| rainfalls | 2092.526 | 460.8493 | 935.0685 | 3293.312 | 2086.953 | 342.6698 | 1266.997 | 2966.936 |
| dist_rivers | 46.53005 | 54.7527 | 0 | 306.1169 | 43.26907 | 46.93101 | 0 | 270.2112 |
| mean_pop | 164.0121 | 829.5456 | .0003693 | 8815.419 | 62.5102 | 424.6055 | .0014448 | 3032.622 |
| tot_def | 189.5319 | 1428.223 | 0 | 23571.35 | 1145.235 | 2090.466 | 0 | 8318.601 |
| dist_dams | 342751.7 | 205711.9 | 36337.19 | 1065188 | 282362.5 | 181903.9 | 6775.725 | 643929 |
| size_PA | 3656.121 | 6712.911 | .0154457 | 48266.96 | 7113.078 | 8869.612 | .08985 | 38870 |
| Observations | 287 | | | | 51 | | | |

Note: Sd, Min and Max respectively stand for Standard deviation, Minimum and Maximum.

Table 6: Number of terrestrial endemic species

| | (1) | | (2) | |
|---|---|---|---|---|
| | Obs | Freq | Obs | Freq |
| high endemism (>21) | 59 | 20.77465 | 2 | 3.921569 |
| low endemism (1-5) | 108 | 38.02817 | 19 | 37.2549 |
| medium endemism (6-20) | 74 | 26.05634 | 20 | 39.21569 |
| no endemism (0) | 43 | 15.14085 | 10 | 19.60784 |
| Total | 284 | 100 | 51 | 100 |
| Observations | 284 | | 51 | |

Note: Obs and Freq respectively stand for Number of observations and Frequency.

Table 7: IUCN categories

| | (1) | | (2) | |
|---|---|---|---|---|
| | Obs | Freq | Obs | Freq |
| II | 58 | 20.20906 | 14 | 27.45098 |
| III | 5 | 1.74216 | | |
| IV | 24 | 8.362369 | | |
| Ia | 33 | 11.49826 | 4 | 7.843137 |
| V | 41 | 14.28571 | 4 | 7.843137 |
| VI | 126 | 43.90244 | 29 | 56.86275 |
| Total | 287 | 100 | 51 | 100 |
| Observations | 287 | | 51 | |

Note: Obs and Freq respectively stand for Number of observations and Frequency.

Table 8: Pearson's correlations

| | (1) | |
|---|---|---|
| | Parameter | P-value |
| mean_gdp | .1356033 | .0818284 |
| dist_roads | .0118433 | -.1367576 |
| mean_slope | .0721601 | .0979317 |
| rainfalls | .934403 | -.0044935 |
| dist_rivers | .6894804 | -.0218114 |
| mean_pop | .3940732 | -.0465731 |
| tot_def | .0000584 | .2168094 |
| dist_dams | .0503595 | -.1065328 |
| size_PA | .0014305 | .1727621 |
| n_spc | .0076005 | .1456068 |
| iucn_cat | .8814688 | .0081404 |
| Observations | 338 | |

**Robustness checks**

Table 9: State fixed effects

| Variables | (1) | (2) | (3) |
|---|---|---|---|
| **The Development Agency** | | | |
| Average GDP | 0.306 | | |
| | (1.81)* | | |
| Average slopes | | 1.387 | 1.411 |
| | | (2.33)** | (2.06)** |
| Distance to the nearest river | | -0.363 | -0.316 |
| | | (1.50) | (1.17) |
| Average rainfalls | | 1.186 | 0.645 |
| | | (0.59) | (0.16) |
| Average rainfalls in the buffer zone | | | 0.720 |
| | | | (0.19) |
| Average population density | | -0.203 | 0.356 |
| | | (0.49) | (0.80) |
| Average population density in the buffer zone | | | -0.591 |
| | | | (1.93)* |
| Distance to the nearest road | | -0.722 | -0.755 |
| | | (3.04)*** | (2.90)*** |
| **The Environmental Agency** | | | |
| Total deforestation | -0.580 | -0.642 | -0.519 |
| | (2.03)** | (2.38)** | (2.07)** |
| Squared total deforestation | 0.087 | 0.107 | 0.100 |
| | (2.48)** | (3.01)*** | (3.33)*** |
| Total deforestation in the buffer zone | | | 0.042 |
| | | | (0.56) |
| High endemism (>21) | -0.095 | -0.050 | -0.214 |
| | (0.07) | (0.03) | (0.14) |
| Low endemism (1-5) | -0.942 | -1.103 | -1.540 |
| | (1.07) | (1.21) | (1.52) |
| Medium endemism (6-20) | -0.715 | -0.709 | -0.767 |
| | (1.02) | (1.02) | (1.09) |
| Distance to the nearest dam | | -0.501 | -0.616 |
| | | (1.46) | (1.77)* |
| PA size | 0.311 | 0.399 | 0.356 |
| | (2.39)** | (2.78)*** | (2.09)** |
| IUCN category II | 1.822 | 1.702 | 1.843 |
| | (1.98)** | (1.59) | (1.65)* |
| IUCN category V | 0.681 | 0.187 | -0.092 |
| | (0.51) | (0.13) | (0.07) |
| IUCN category VI | 1.293 | 0.975 | 1.031 |
| | (1.68)* | (1.20) | (1.20) |
| Pseudo R2 | 0.30 | 0.37 | 0.40 |
| MacFadden's ajusted R2 | 0.17 | 0.21 | 0.21 |
| AIC | 223.86 | 214.95 | 207.51 |
| Number of observations | 293 | 296 | 288 |
| State fixed effects | No (F=15.94) | No (F=11.60) | No (F=14.34) |

* $p < 0.1$; ** $p < 0.05$; *** $p < 0$

Covariates which are not normally distributed are included in logarithme.

We have added 1 to the variable that displays 0 in order to keep them when linearized.