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What Drives Size Reductions for Protected Areas?

Evidence about PADDD from across the Brazilian Amazon

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Abstract (173 words)

Protected areas (PAs) have been the most widely used tool to conserve ecosystem services. New PAs are created every year and the effective PAs block some economic development. Yet that opportunity cost of conservation leads PAs to have isolated locations and even to suffer considerable PA degazettements, downsizings and degradation (jointly 'PADDD'). Adding to a sparse literature on PADDD, we assess some drivers of PAs' size reductions, i.e., degazettements and downsizings. We base our empirical efforts upon a simple model of size reductions that result from interactions between agencies with differing objectives, conservation versus development. Gradients across space for the agency benefits and costs yield predictions about where each agency is most against, or for, size reductions for PAs. Analyzing Brazilian Amazon data from a relatively new and growing global data set from PADDDtracker, we find size reductions are influenced by: distance to cities and roads, i.e., transport that affects private profits and public enforcement costs; PA size, which affects enforcement costs; and previous deforestation in a PA, which lowers impacts of PADDD.

Keywords: conservation, PADDD, Land-use change, Brazilian Amazon, public policy

JEL codes: Q56; Q57; Q58; O13; O21

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1. Introduction

Protected areas (PAs) have been employed extensively to conserve ecosystem services by avoiding the degradation of species habitats and consequent biodiversity losses. Since the 1980s, PAs have been the most widely used tool for conservation, in area (Deguignet et al., 2014; Naughton-Treves et al., 2005; Watson et al., 2014). While the Aichi Targets call for more PAs, the current PA area is substantial, e.g., ~15% of global ecosystems were classified as being within PAs during 2016. PAs are most extensive in Latin America and Caribbean, with particular concentration in Brazil (UNEP-WCMC and IUCN, 2016).

The restrictions implied by PAs, however, may often lead to conflict over land use between conservation and development activities (Deguignet et al., 2014; Naughton-Treves et al., 2005; Watson et al., 2014). While some actors are focused on ecosytem services, others care most about the development activities that PAs are trying to prevent (Albers, 2010; Naughton-Treves et al., 2005; Nicolle and Leroy, 2017). That conflict, and the consequent lobbying against PAs by local actors who are development oriented, has implied that PAs are more likely to be established where the economic opportunity costs (OCs) are relatively low (Baldi et al., 2017; Joppa and Pfaff, 2009; Pfaff et al., 2015a; Pfaff and Robalino, 2012).

With such lower profits, and thus pressures, low or no deforestation might occur even without protection. Thus, fully forested PAs are not necessarily impactful (Abman, 2018; Andam et al., 2008; Anderson et al., 2016; Ferraro et al., 2013; Joppa and Pfaff, 2011; Jusys, 2018; Kere et al., 2017; Nolte et al., 2013; Pfaff et al., 2017, 2015b, 2015c, 2014, 2009; Robalino et al., 2017; Sims, 2014). Studies that control for non-randomness in PAs' locations conclude that while PAs do have impacts, on average, often impacts are far less than claimed, if not addressing location bias, and sometimes impacts are zero (Andam et al., 2008; Joppa and Pfaff, 2011; Pfaff et al., 2015b) Without pressures, i.e., with low opportunity costs, even perfectly enforced PAs will not have prevented any development activities (Ferraro et al., 2013; Jusys, 2018; Kere et al., 2017; Pfaff et al., 2017, 2015c, 2014, 2009; Robalino et al., 2017; Sims, 2014).

Once a PA is established, the same types of conflicts with development can trigger PA Degazettement, Downsizing and Downgrading (PADDD) (Watson et al., 2014) – i.e., legal changes in PA size or status (Mascia and Pailler, 2011). For Mascia and Pailler (2011): a downgrading is "a decrease in legal restrictions on the number, magnitude, or extent of human activities within a PA"; a 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 a degazettement is "a loss of legal protection for an entire PA". The most common proximate causes of such PADDD events for PAs, as might be expected, are types of development pressure: hydropower; agricultural expansion; and rural settlement (Bernard et al., 2014; Cook et al., 2017;

Mascia et al., 2014; Mascia and Pailler, 2011; Pack et al., 2016; Symes et al., 2016). Such activities raise risks of PADDD.

PADDD's forest impacts are a function of how a PA has blocked pressure, i.e., the PAs' prior impacts. If a PA was well enforced despite high pressure, and thus had significant impact upon deforestation, then PADDD events could well unleash significant amounts of new forest clearing. Along these lines, Forrest et al. (2015) stress the carbon emissions that could be caused by PADDD in tropical countries (Democratic Republic of Congo, Malaysia and Peru), while Golden Kroner et al. (2016) emphasizes the risks of habitat fragmentation faced in the Yosemite National Park in the US during its downsizing. Yet if there is little pressure to be blocked, so that a PA cannot have much impact (Pfaff et al., 2017), then PADDD may have little impact, at least in the short run. Further, if high pressure caused deforestation inside a PA, so it has little impact, *de jure* PADDD may have no impact since *de facto* PADDD already occurred. Tesfaw et al. (2018) find PADDD more likely if deforestation inside PAs' boundaries is high. They interpret this as resulting from bargaining between an agency focused upon conservation and one focused upon economic development. Consistent with that result, neither they nor Pack et al. (2016) observed short-term impacts from PADDD upon deforestation rates. Emphasizing this result: if higher pressures lead to PADDD in part through past PA invasions or failures, then we might expect the damage from such pressures to (mostly) be done before PADDD officially occurs. If so, a PADDD event may not have much impact, with implications for optimal policy (see Discussion).

Further rigorous research is needed to learn how conservation-versus-development conflict affects PAs via PADDD and, consequently, PA network effectiveness. To the best of our knowledge, only Symes et al. (2016) and Tesfaw et al. (2018) empirically study drivers of PADDD. Symes et al. (2016) find that PA size affects degazettement, controlling for factors in the profitability of development activities across 44 countries and over 110 years. Tesfaw et al. (2018), in contrast, consider a single, large forested state (Rondônia in the Brazilian Amazon) and its 2010 and 2014 PADDD events – in a more spatially focused and controlled analysis. Since state-level results may vary across governance settings, and time periods, clearly more such local studies could add to the empirical PADDD literature. Here, we assess how these conservation-development conflicts have triggered PADDD events across the entire Brazilian Amazon.

Our contributions are theoretical and empirical. Theoretically, we formalize the framework suggested in Tesfaw et al. (2018), then we add the critical issue of illegal PA invasions. PAs are not fully enforced, which is critical for the development gains and the conservation costs of a reduction in the size of a PA. After describing benefits and costs that we think are central within the conflicting objectives of agencies, we consider how interactions between the agencies around PADDD might play out across the landscape. Spatial gradients in those benefits and costs affect where these agencies are most against or for PADDD. We distinguish ‘Lower PA Benefit’ from ‘Higher PA Opportunity Cost’ PADDD stories, noting they are all functions of transport costs, which helps to link the conceptual PADDD settings to our empirics.

This issue is important in Brazil. Like many countries, it has changes over time in agencies' orientations or objectives – even if we consider only the federal policies that vary over time, not more local choices. The desire to placate rural development interests, for instance, can politically internalize the economic pressures that tend to generate lobbying against PA creation and, if a PA exists, then for PADDD events (Bernard et al., 2014; Marques and Peres, 2015; Symes et al., 2016). Time changes in agency objectives, given valid land-use options, are likely to be a function of the economy, the federal budget, and elections.

In terms of the implications for PAs, from 1980 to 2000 there were considerable efforts by the Brazilian government to extend its PA network, with several periods of investments in PAs. However, over time, nearly 20% of the total area that was covered by the Brazilian system of PAs (SNUC - Sistema Nacional de Unidaded de Conservação) has been lost. Since 2000, given the increase in the development pressure, proposals for PADDD events within the Brazilian Amazon have increased greatly, while 13,000 km2 of deforestation have already occurred inside of the conserved areas (Veríssimo et al., 2011) – 3.5% of the total deforestation observed from 1998. This is likely affected by attitudes of the Brazilian government toward agricultural and economic pressures (Bernard et al., 2014; Soares-Filho et al., 2014) that in 2012 resulted in a new forest code that made development projects easier to realize (Soares-Filho et al., 2014).

Empirically, we analyze a new PADDDtracker data set (World Wildlife Fund (WWF), 2017a) and most specifically the data concerning PADDD events for the entire Brazilian Amazon region. We then focus on characteristics of the land, and of PAs, that we believe should enter into the agencies' decision rules, with an emphasis upon the effective opportunity costs of a PA given the variations in baseline pressures. Next, for degazettement and downsizing, both binary, we use a logistic probability model to study the determinants of size reductions. As the weight placed by each state on conservation versus development likely varies, across states (Abman, 2018; Ferraro et al., 2013; Pfaff et al., 2015c, 2015a), we use state dummies to catch any fixed but unobserved heterogeneous elements which influence PADDD decisions.

We find that PA-size reductions are affected by factors in PAs' opportunity costs and enforcement costs, which affect the benefits and costs for development and environment agencies from PA size reductions. First, the distance to cities is important for both private production profits and public enforcement costs. We find that size reductions occur more often closer to cities, where higher pressures mean reductions are more environmentally troubling. This suggests higher bargaining power for development agencies. Second, all else equal, larger PA size also increases PA size reductions. That could follow from costs of enforcement – or, for downsizings, variations in internal outcomes across areas within the larger PAs.

Finally – and related, as a critical internal outcome – more prior deforestation increases size reductions, consistent with influence of environmental concerns. The result makes sense within a bargaining setting, extending Tesfaw et al. 2018 by considering the entire Brazilian Amazon region. Further extensions are provided by showing results hold for subsets of PAs: sub-regions; types of PA; and level of government.

The rest of this article is as follows: Section 2 presents a simple model with the two agencies, focused on economic development and conservation respectively, with spatial gradients in views about PADDD. Section 3 presents the data and our empirical strategy, Section 4 our results, and Section 5 our discussion and conclusion.

2. Agency Perspectives on PA Size Reductions

2.1. Agency Benefits/Costs from Reducing Enforced PAs

Formalizing the intuitive bargaining framework in Tesfaw et al. (2018), to further examine assumptions, we consider all PAs that have already been created. Thus, we need not consider siting, or land purchases, since the PAs are already established. Instead, we consider the net benefit, or cost, of ongoing protection. The choices to be made, then, concern which PAs are left untouched and which PAs are reduced in size. Formalizing, for every PA i the choice is to reduce the size of the PA ($R_i = 1$) or not to reduce ($R_i = 0$). These R_i, i.e., the reductions, refer to either degazetting or downsizing, each of which reduces PA size. We consider environment agency E, focused on environment outcomes, and development agency D, focused on development outcomes. Given their differing interests, agencies' interactions determine R.

From the perspective of social welfare, we highlight the importance of the profitability of a land parcel. Whatever gains in forest an enforced PA provides, it leads some economic gains (OC o_i) to be foregone. What is foregone might be all profits, if the PA is strict and, thereby, allows no production or extraction, else it could be just a fraction of profit (e.g.: a multiple-use PA allows smallholder activities and profit; or, as for indigenous lands, activities are allowed for a particular set of smallholders who use less capital). The OC varies with land characteristics that affect profit (a typical definition of o_i). Land characteristics that raise profits on a parcel increase economic loss (o_i) from an additional unit of PA on that parcel. If we hold fixed a PA's conservation gain, while varying this OC, then for a higher OC the PA looks worse.

2.1.1 Development Agency (D)

The development agency focuses entirely on development objectives, so PAs represent constraints. This constraint rises with the OC o_i. δo_i is D's potential expected economic gain, if the PA is reduced. Thereby, the development agency's benefit from reduction of PA size, and simple preference rule, are:

$$B^D(R_i) = \delta o_i R_i \qquad (1)$$

$$R_i = 1 \; \forall \; o_i \; \geq 0$$

This agency wants all PAs with positive OCs to be reduced, with stronger preference for larger OCs. In considering bargaining over R_i, or social welfare, we can overlay these views with environmental views.

In order to consider landscapes spatially, with both dependable or idiosyncratic determinants for o_i, we consider profits $\pi_i = (P^Q - T_i)*Q_i - (P^K + T_i)*K_i$, with urban market prices (P) for goods (Q) and capital inputs (K), plus transport costs (T_i) to PA_i. We know that high goods prices P^Q (for soy or gold or energy) and yields Q (as affected by rainfall and topography) affect profits. Below, though, we will focus on the transport costs (T) because they are a factor not only in PAs' opportunity costs but also in enforcement.

2.1.2 Environment Agency (E)

PAs' environmental gains are directly related to the economic returns that drive deforestation because the way PAs provide gains is by blocking the deforestation that would have occurred without protection. Thus, gains are limited by threats: high profits imply a high conservation OC and high potential gains; flipping that around, with low threats PAs have lower OC but also lower gains, given less to be blocked. Specifically, protected areas' environmental benefits are the environmental value for any given area (V) times the probability that without protection that area would be developed, such that the value V is lost. Like $B^D(R_i)$, that baseline probability of deforestation d_i^D is a positive function of opportunity costs o_i. Consequently, E's benefit froma PA – $B^E(R_i{=}0)$ – is directly related to the OC, just as was the $B^D(Ri{=}1)$. Thus, E would prefer to not reduce PA size anytime a PA is blocking any pressure, i.e., any positive o_i:

$$B^E(R_i) = V d_i^D(o_i)(1 - R_i) \qquad (2)$$

$$R_i = 0 \; \forall \; o_i \geq 0$$

2.1.3 Tradeoffs

Because OC o_i has two roles – higher OCs raise gains for D and losses for E from $R_i = 1$ – high OC o_i does not make a PA look better or worse, socially speaking, supporting neither PAs nor size reductions. As in Pfaff et al. (2004), then, to publicly assign $Ri = 0$ or $Ri = 1$ one might look for when

D and *E* views are less correlated. One assignment basis could be all factors independent of OC, e.g., values of species (V).

We would also note that an environmental agency might make the socially efficient decisions on R_i if faced with the OC, while analogously a development agency might make the socially efficient R_i decisions if faced with PA gains. The former situation may arise if *E* must pay to conserve on private land – as occurs for payments for ecosystem services (PES) but rarely arises within PAs – or the agency has limited political capital and has to spend more of it to hold of lobbying for higher OCs. If that were the case, *E* might assign scarce $Ri = 0$ where valued species are doing well (high *V*) and, if *V* correlates with isolation, alongside *D*'s views that would push $R_i = 0$ toward more remote areas.

2.2 Allowing for Illegal Deforestation in PAs

2.2.1 Invasion Probabilities

The discussion above presumes that once a PA is established, no clearing occurs inside its boundaries. Put another way, all of the PAs considered above have perfect and costless enforcement: once financial or political capital is spent to establish and maintain a PA, all lands inside are fully protected.

In fact, PAs enforcement can vary significantly, while illegal deforestation also has its benefits and costs. For a given enforcement effort, higher profits raise the benefits from illegal invasions of PAs, assuming that illegal producers or extractors trade profits off against expected punishments, and for instance high transport cost to urban markets (T) lower invasions' profits. Yet transport costs (T) also are a significant factor in costs of enforcement (Sims, 2010). Thus, T does not clearly predict the probability of invasion. Nearer by to a city, e.g., low T raises invasions' profits, yet also facilitates monitoring and enforcement, while far away from cities high T lower both invasion profits and ease of enforcement.

The extreme cases are easy to consider. If enforcement is perfect for all T, we are back to the case above, in which we simply assumed that, once a PA is established, all of the forest inside it is fully protected. However, at the other extreme, if enforcement is a failure for all T, then there is no effective protection. In the latter case, there would effectively be immediate and constant *de facto* degazettement of all PAs. We note that in this latter case, the impacts from any form of official PADDD would be precisely zero: whatever development would occur without any protection is the same as what occurs with official PAs.

Beyond those cases, it is unclear how effects of T play out over a landscape. We do not take a stand but instead consider invasion rising or falling with T, predict agency preferences in each case, then compare to observed PADDD. To represent gradients of invasion rising or falling over a landscape, we consider a probability of illegal deforestation (d_i^I) that is positive. Protection is not perfect, even if a PA is there. Specifically, we will consider two simple cases, both linear in T yet together sufficient to reveal distinct possibilities: illegal deforestation ($d_i^I(T)$) rises with T, i.e., PAs near cities fare better, since monitoring is easier; or illegal deforestation d_i^I falls with T, i.e., PAs near cities fare worse, since pressure is higher.

2.2.2 Invasions' Implications for Agencies' Benefits

Each scenario has implications for each agency. As some extraction always occurs even with protection, the benefits with invasions B^{DI} from $R_i = 1$ are lower ($< B^D$). Recall that, in the extreme, they are zero – because when protection is completely unenforced, there is no difference between the PA and PADDD. Also, with invasion the benefits of keeping the PA ($R_i = 0$) B^{EI} are lower ($< B^E$), as some forest was lost. Thus, both B^D and B^E are lowered by the fraction of forest in PAs that has already been cleared ($1 - d_i^I$).

$$B^{DI}(R_i) = \delta o_i R_i (1 - d_i^I) \qquad (1')$$

$$B^{EI}(R_i) = V d_i^D(o_i)(1 - R_i)(1 - d_i^I) \qquad (2')$$

Naturally it is still the case that if either agency were to dictate R_i, D would always choose $R_i = 1$, and E would always choose $R_i = 0$, whenever profits and thus also the baseline deforestation rates are positive. Yet D had most wanted $R_i = 1$ (and E most wanted $R_i = 0$) near cities, i.e., low T for given P, Q, V. Now, adding invasion possibilities – going beyond Tesfaw et al. (2018) conceptually – with spatial gradients, spatial preferences shift. We can hypothesize different patterns over space in terms of benefits and costs from size reductions. Figures 1A and 1B show relevant possibilities given effects of T on invasions.

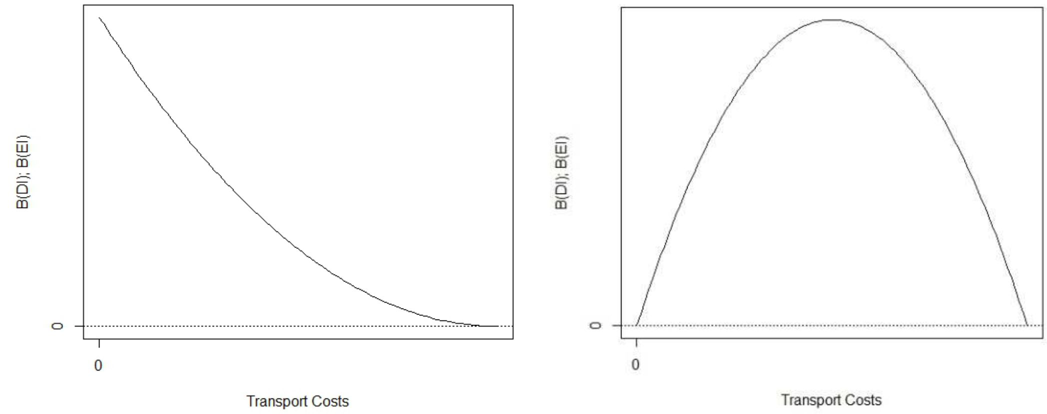

Figure 1 (1A & 1B)[1] *effective benefits (B^{DI}) and costs (B^{EI}) of size reductions given invasions*[2]

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[1] A simple illustration is helpful. Consider $B^D(T)$ = Profit(T) = $B^E(T)$ = Baseline Deforestation $d_i^D(T) = 10$-T, for T = 0-10. Invasion $d_i^I(T)$ is either .1T, rising with T, or (1 - .1T), falling with T, implying $(1 - d_i^I(T))$ also either (1 - .1T) or .1T. The former yields effective $B^{DI}(T) = B^{EI}(T) = 10 - 2T + .1T^2$, in which the gains or losses of $R_i = 1$ always fall with T, while the latter yields effective $B^{DI}(T) = B^{EI}(T) = T - .1T^2$, in which the gains or losses of of $R_i = 1$ rise then fall in T.

[2] We must also note, though, that if profits are very flat, in T, while invasions are more likely near cities because a rise in pressure with lower transport costs overcomes the improved monitoring, then costs of $R_i = 1$ to E, e.g., could rise with T.

Figure 1A combines profits from production (and thus baseline deforestation) falling with T, as typical, with the invasion/enforcement case in which the illegal invasion of PAs is less likely when near to cities[3] because the improvement in effective monitoring nearer by to cities outweighs the higher pressure there. Thus, the probability of illegal invasions is rising with *T*, i.e., as we move to the right within Figure 1A, such that the illegal deforestation that occurs rises as a fraction of the potential deforestation, as *T* rises. This implies that both benefits for *D* and losses for *E* from reduction $R_i = 1$ fall more steeply to the right. Further, they always fall. This means that for this case – as for a case of perfect costless enforcement – the *D* agency will push for $R_i = 1$ nearer to cities, which is also where the *E* agency most wants $R_i = 0$.

Implications for these agencies' views about $R_i = 1$, i.e., size reductions, are different within Figure 1B. Here, invasion is expected to occur more near cities, since higher profits win out over ease of monitoring. Thus, an *E* agency has effectively already lost most PA value, near to cities, and gains less from $R_i = 0$. There is also still low value, though, from keeping PAs on the frontier, where pressure is always lower. Thus, it is in the middle distances T where the post-invasion residual profits and pressures are highest, which means we expect most gain there for an agency *D* and the most loss for an agency *E* from $R_i = 1$. A big difference in Figure 1B is that *E* would focus less on contesting any size reductions near to cities.

2.2.3 Updating Invasion Expectations using Invasion Observations

The above considered expected invasions, given benefits of illegal deforestation and costs of monitoring and enforcement. However, as time passes, agencies also observe actual illegal deforestation rates and, thereby, can update their perspectives on each PA. Thus, actual invasions should affect PADDD as well.

3. Data & Empirical Strategy

3.1 Data

3.1.1 Scope & Observational Units

The Brazilian Amazon is composed of nine states (Roraima, Amazonas, Acre, Rondônia, Amapá, Pará, Mato Grosso, Tocantins and the western part of Maranhão) covering over 5 million km2. In 2010, over one third of this enormous region was under some form of protective zoning, namely Conservation Units (CUs) and varied territories of traditional occupation (Indigeneous Land and Quilombola Territories) (Veríssimo et al., 2011). CUs are managed by the federal, municipal or by the

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Since we do not think profits are very flat in T, plus that might imply pressures no higher near cities, we ignore this case.

[3] We are using the term cities here to reflect the fact that returns from economic development are often based on markets that often are centered around urban populations. However, we must also note that some of the economic development activities that generate PADDD events are establishments of dams for generating hydropower to support development. For that activity, economic returns are highest in particular topographies which allow for the storage of a lot of water, although even then there is a gain to having proximity to urban areas which are the sites of many users of that power.

state governments and can be classified according to degree of permitted intervention (strict conservation or sustainable use).

Our observational units are exactly those protected units, i.e., we do not consider the fates of territories or unprotected or unzoned lands. For the PA boundaries, we use the World Database on Protected Areas (WDPA), a spatially explicit database from the IUCN (IUCN and UNEP-WCMC, 2016). This provides the location of each PA, with characteristics. We use the PADDDtracker database, a spatially explicit database of PADDD events from the World Wildlife Fund (World Wildlife Fund (WWF), 2017a), for information on events. It offers a location and description for each event. Events are classified by type (degazettement, downsizing, downgrading), status (enacted versus just proposed) and listed primary cause (hydropower, other infrastructure, rural settlement, broad policy changes, and other causes (Figure 2)). Other facts include the year of decision. These two database have been overlapped, such that at at each point in time, each PA is indicated as either being the same in terms of boundaries as at the start of our study period or having undergone a size reduction (either a degazettement that eliminated the PA entirely or a downsize that eliminated a portion of the PA). Within the PAs that still have the same boundaries, we note that a few PAs have been downgraded, i.e. their protected status was lowered (e.g., from strict protection to extractive reserve). We drop those PAs.

3.1.2 Dependent Variable (PADDD)

A dummy variable indicates the protected units that suffered either degazettement or downsizing events. Certainly we recognize that degazettements are not the same as downsizings and, further, that within the latter group the share downsized is continuous. Yet the events are too limited to examine that share and, more generally, the total set of PADDD events is limited enough that for now we combined event types.

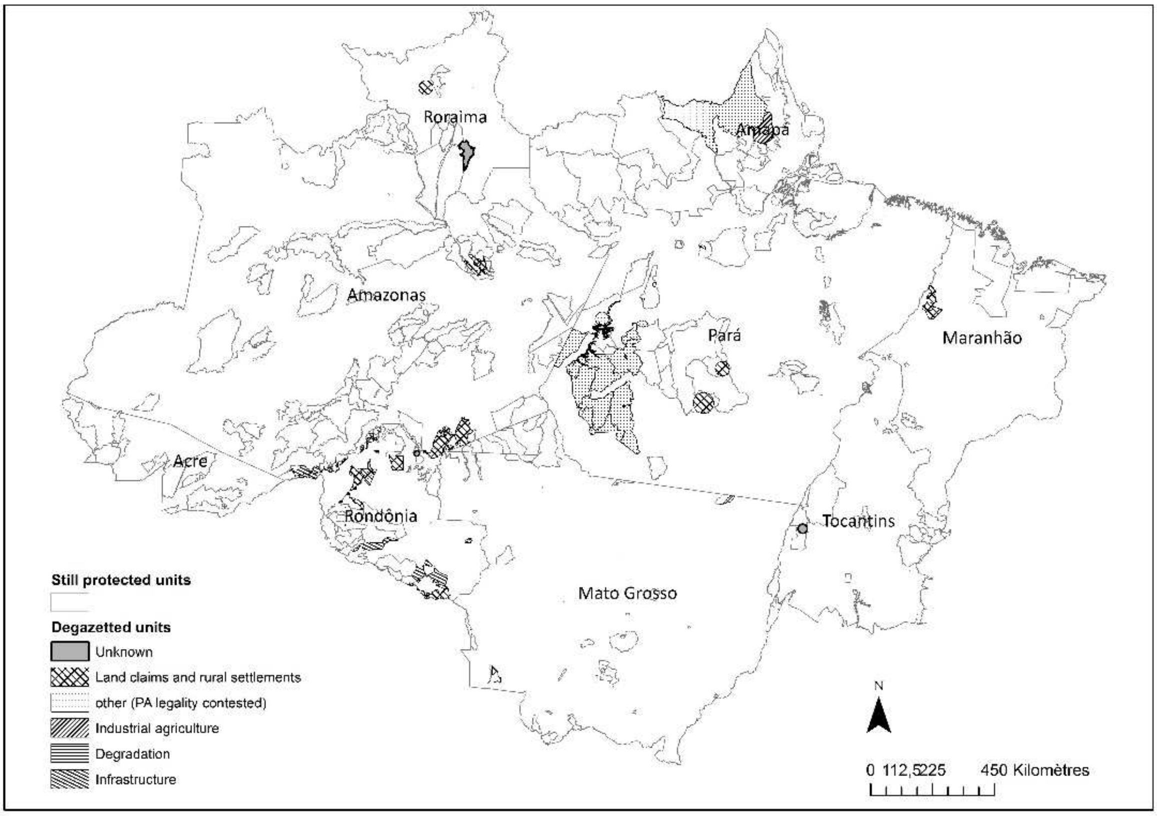

Figure 2 Listed Proximate Causes of Braziliam Amazon PA Degazettements & Downsizings

Up through 2014, 77 PAs experienced PADDD events within the Brazilian Amazon (Pack et al., 2016). Most were degazettement (30) and downsizing (44). Those events in total reduced the PA 'estate' by over 20% (Veríssimo et al., 2011). Most were enacted, i.e., passed into law (48), yet 29 of the proposed events have a more ambiguous status, i.e., are not yet passed into law (Pack et al., 2016). Interestingly, even though PA creation tends to strictly follow a clear process involving civil discussions and technical studies, PADDD is proposed and then enacted by federal or national authorities without any consultation (Bernard et al., 2014; Pack et al., 2016; Veríssimo et al., 2011; World Wildlife Fund (WWF), 2017b).

Our empirical analyses consider both enacted and proposed events, as we are interested in the intention to remove protection from at least part of a PA, again considering both degazettement and downsizing. Most of these reductions in PA sizes were from 2006 onwards (30 degazettements and 21 downsizings).

3.1.3 Independent Variables

We collected data for other independent variables, for the 2000-2005 period, to consider the 2006-2015 probability of size reduction (degazettement/downsizing). These data ranges avoid endogeneity by using depictions of landscapes before PADDD events. We obtain the variables for all 332 observational units that are either still intact PAs (281 observations) or had size reductions in this period (51 observations).

We use average level and growth of Growth Domestic Product (GDP) from 2000 to 2005 (IBGE, 2017) to proxy for municipal economic growth, through varied economic development processes, relevant for PADDD. This reflects pressures from agribusiness (Bernard et al., 2014; Ferraro et al., 2013; Joppa and Pfaff, 2009; Kere et al., 2017; Mascia et al., 2014; Pfaff et al., 2015a; Sims, 2014; Symes et al., 2016).

We proxy for development gains using accessibility to markets, agriculture profitability and population (Tesfaw et al., 2018). We use the distances to the nearest urbanized area in 2005 and to the nearest road in 2006 (DNIT, 2017) per access to markets (Barber et al., 2014; Bax et al., 2016; Bax and Francesconi, 2018; Jusys, 2018; Laurance et al., 2009, 2014) (see, e.g., Figure 3). Average rainfall from 2000 to 2005 (Funk et al., 2015) is a factor in the suitability of land for expansions of agriculture (Bax et al., 2016; Bax and Francesconi, 2018; Kere et al., 2017; Kirby et al., 2006; Sombroek, 2001; Tesfaw et al., 2018). Market sizes are included by using the average population densities during 2000-2005 (CIESIN, 2015).

Other land characteristics that could raise the returns from infrastructure, e.g., for hydropower, include average slope (Jarvis et al., 2008) and proximity to rivers (IBGE, 2017). Being nearer to rivers and on higher slopes (see Figure 3) may make land more suitable for the implementation of hydroelectric dams (Finer and Jenkins, 2012; McClain and Naiman, 2008). We want to be relevant for this infrastructure in particular since hydropower development is currently a leading objective for infrastructure investments in the Brazilian Amazon (Araújo et al., 2012; Fearnside, 2014; World Wildlife Fund (WWF), 2017b).

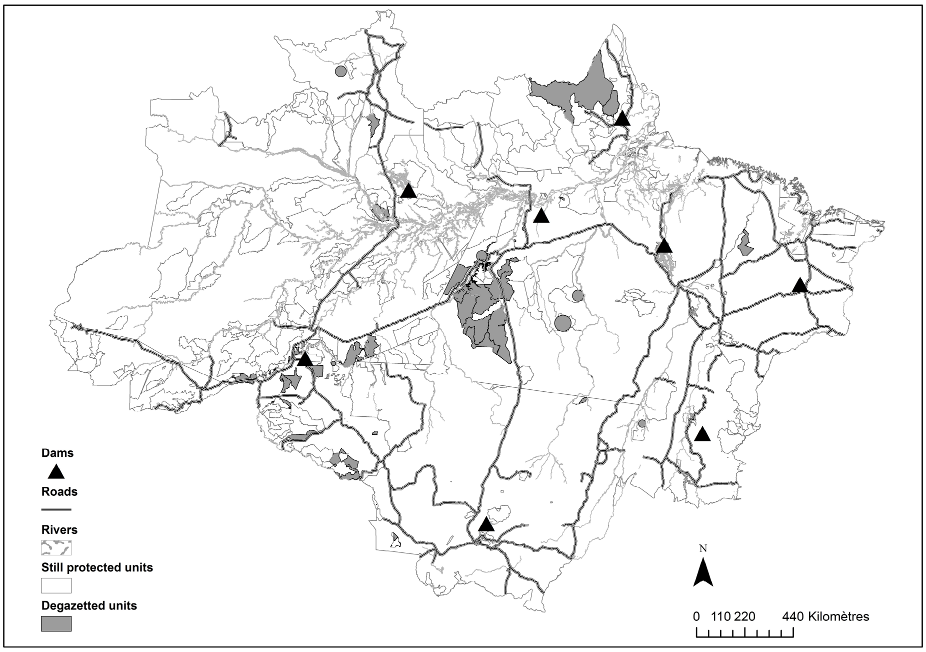

Figure 3 Roads, Rivers and Dams in the Brazilian Amazon

Forest loss 2001-2005 in PAs (INPE, 2017) indicates enforcement – or its lack. Units with more loss of forest during the period are considered relatively poorly enforced. We also use the number of terrestrial endemic species (World Wildlife Fund (WWF), 2006), which could lower size reductions if priorities include species (Tesfaw et al., 2018), plus the proximity to existing dams (Olson et al., 2001). That may proxy for habitat fragmentation (Fearnside, 2014; Finer and Jenkins, 2012; McClain and Naiman, 2008).

PA management costs, per unit area, can rise or fall with size depending upon (dis-) economies of scale (Bruner et al., 2004). We use perimeter-to-area ratio (World Wildlife Fund (WWF), 2017b) as a proxy, as it is lower when the protected unit is larger. It also can measure habitat or PA fragmentation (Albers, 2010; Sims, 2014). We sometimes use size itself (Robinson et al., 2011), which already has been found to affect PADDD's likelihood (Symes et al., 2016). Lastly, the International Union for Conservation of Nature (IUCN) PA category (World Wildlife Fund (WWF), 2017a) indicates management objectives, which link to the costs faced (Bruner et al., 2004; IUCN and UNEP-WCMC, 2016; Symes et al., 2016).

All the covariates were transformed in Geographic Coordinate System "South American Datum 1969" and projected into "UTM Zone 18S (meters)" using ArcGIS 10.4.1. The raster and vector covariates have not been treated similarly, though. A grid of 1.8 x 1.8 km was used to sample the raster dataset (slopes, population density and rainfalls). We extract means, for each cell, allowing us to describe our smallest degazetted or downsized unit. Only averages and weighted averages (by proportion of the unit) have been included in the final estimations. The covariates (GDP, endemic species, deforestation) have been intersected with protected units to compute (weighted) averages for the cells. Geodesic distances to the nearest road, dam and river have been computed in kilometers from the centroid of each CU. A complete description of the source and statistical treatment of the covariates is available in table 1B.

3.2 Empirical Strategy

Our objective is to estimate the probability of a PA being reduced in size. Within any bargaining model considering the two agencies (*D* and *E*), this decision should reflect both B^{DI} and B^{EI} from size reduction. Thus, from (1') and (2') above, we want to consider the factors $V, o_i, \delta, d_i^D, d_i^I$ in impacts of R_i decisions. We will represent as $U^*(R_i)$ the effective 'joint objective' function that arises from agency bargaining.

$$U^*(R_i) = \beta_i X_i + \varepsilon_i \qquad (3)$$

with X_i the covariates that affect agencies' benefits, β their associated parameters, and ε the error term. As our dependent variable $U^*(R_i)$ is latent, we consider a dummy variable R_i taking the value one when a decision to reduce PA size has been taken and the value 0 otherwise, i.e., a binary indicator of an event. Thus, our regression estimates the probability of PAs' size being reduced using a binary variable model.

$$Pr(R_i = 1) = F(\beta_i X) \qquad (4)$$

$$Pr(R_i = 1) = \partial_i(\alpha_1 o_i + \alpha_2 o_i + \alpha_3\, o_i) + \beta d_i - \omega V_i - \sigma Ci + \eta_i + \varepsilon_i$$

Assuming the cumulative distributive function of residuals to be logistic – as a default model to start – we use a logistic probability model estimated by the maximum-likelihood method. In equation (4): the $\alpha_1 o_i$ and $\alpha_2 o_i$ and $\alpha_3\, o_i$ are characteristics of the land that directly affect the return from infrastructure implementation and land claims that yield PADDD (Marques and Peres, 2015; Mascia et al., 2014; Pack et al., 2016; Tesfaw et al., 2018; World Wildlife Fund (WWF), 2017a); βd_i refers to the probability of illegal invasion, proxied by deforestation in PAs; while $\omega V_i - \sigma Ci$ refers to characteristics of lands and PAs that enter net benefits of keeping $R_i = 0$ (Abman, 2018; Joppa and Pfaff, 2011; Nolte et al., 2013).

We believe that agencies' bargaining power is influenced by fixed characteristics of each state (Abman, 2018; Joppa and Pfaff, 2011; Nolte et al., 2013) in terms of environmental and development objectives (Ferraro et al., 2013; Pfaff et al., 2015b, 2015a; Tesfaw et al., 2018). For example, numerous events in the state of Rondônia, versus Amazonas, are consistent with past decisions reflecting local perceptions of benefits and costs of PAs (Sauquet et al., 2014). We account for this by including state dummies η_i.

4. Results

4.1 Descriptive Statistics

Table 1A offers summary statistics for our covariates, broken down as protected units that are still fully protected (1st large meta-column) versus those that have suffered size reduction (2nd large meta-column). Table 1B extends the information above concerning the sources for and descriptions of those variables. We see differences in land characteristics between the groups, with significant t-tests on the inequality of means, as well as Pearson's pairwise correlations. On average, size-reduced PAs were in areas with higher 2000-2005 GDP, closer to 2006 roads and, consistent with those features, also more deforested from 2001 to 2005 (Table 1A). However, there is a negative correlation of size reduction with population density in PAs' areas. Further, size-reduced PAs were larger and endowed with fewer endemic species.

4.2 Illegal Deforestation Inside PAs

Tables 2 (2A, 2B & 2C) consider illegal deforestation inside the boundaries of PAs, the spatial pattern of which was a central issue within our theory about spatial gradients in the agencies' benefits and costs from PADDD. Table 2A considers total area deforested, regardless of PA size, as larger PAs may not have more forests to invade easily: the areas near boundaries that may be more vulnerable do not scale linearly with PA area. Table 2B considers deforestation as a share of total PA area, assuming economic pressures throughout. Table 2C consider the odds of illegal invasions within PAs as a robustness check.

Drawing upon the results in these tables, we conclude that certainly states differ, as expected, with states other than Rondônia having less deforestation within PAs. Also, IUCN categories correlate with higher deforestation rates within PAs (some being legal for multiple-use PAs). The number of endemic species also matters as PA located in lower endemism areas may suffer from poorer enforcement. PA size matters – yet, as expected, the area deforested does not scale linearly with PA size. That could be explain because larger PAs are easier to invaded only until a certain distance from their edge, making the share of area deforested decreasing. Finally, Tables 2A and 2C indicate illegal deforestation occurs more far from cities, perhaps in particular at greater distances when thinking about absolute areas (noting distant PAs also tend to be larger). However, the share of illegal deforestation may fall with urban distance as larger PAs tend to be located farther away. This points to Figure 1A, so a development agency *D* would push more for PA size reductions near cities – yet less far from cities, where an environmental agency would contest them least. Thus, should size reductions occur more near cities, it would look like development bargaining power.

4.3 Drivers of PA Size Reductions

Tables 3 and 4 present the results of a logit model with proxies for varied factors in size reductions. To start, as a broad effect that empirically could absorb some other effects[4], state dummies are significant – again relative to Rondônia, which is the omitted state – a result that is consistent with PADDD facts including numerous PADDD events in Rondônia 2010 and 2014 (considered in (Tesfaw et al., 2018).[5] The bargaining power of environment and development agencies can differ by the state, in the Amazon, where states are large and distinct (Abman, 2018; Ferraro et al., 2013; Nolte et al., 2013; Pfaff et al., 2015a, 2015c; Tesfaw et al., 2018) (Kastens et al., 2017; Veríssimo et al., 2011). Being in Amazonas lowers the likelihoods of a PA size reduction by approximately 10% compared to Rondônia, for instance.

We find a consistently significant negative effect of the distance to the nearest roads on the likelihood of size reduction, in Table 3. When using a non-linear specification to allow this effect to fall off, we also find a significant negative effect on size reductions from higher distance to nearest urbanized area. Linking back to our modeling above, if size reductions are less common with higher transport costs (T), then we might infer more bargaining power in the hands of the development agencies, since

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[4] For instance, without the state dummies in Table 3, the coefficients for the influence of average GDP are highly significant.

[5] Some states (Acre and Tocantins) do not have any degazettement events after 2005. We replaced them by clustered standard errors at the level of the state in the Appendix, allowing residuals to be correlated within states without losing the observations. We have 9 clusters, not enough to guarantee consistent estimates of standard errors (Cameron and Miller, 2015), yet we cannot rely a on non-parametric bootstrap (Esarey and Menger, 2018) because we don't have enough variations within each cluster.

an agency focused on environmental gains would rather see size reductions in remote areas instead of near cities. As the non-linear specification finds this effect out to 400km, after which additional distance from cities raises the likelihood of size reductions, perhaps environmental agencies have influence in remote areas.

We find consistent indications of a significant positive effect of a PA's size on the likelihood of PA size reductions – be that using the area measure itself or the perimeter-to-area ratio (negatively correlated with size, as the perimeter rises linearly with the radius while the area rises with the square of the radius). Small PAs with high perimeter-to-area ratios are less likely to suffer a reduction, consistent with lower management costs for smaller PAs not sprawling across a landscape[6] (Albers, 2010; Bruner et al., 2004). Such a result also could suggest some influence of environmental perspectives upon PA size reductions.

Finally, in terms of robust significant drivers of these PADDD events, a PA's total internal 2001-2005 deforestation has a significant and positive impact on the likelihood of size reduction (extending broadly across the Amazon a result in Tesfaw et al. (2018) for Rondônia). This suggests environmental influence, since the environmental gains from preventing PADDD fall with the level of previous invasion of a PA and, thus, in a bargaining setting an environmental agency would contest less these size reductions (while by contrast development benefits fall with prior invasion, so a development agency would not push for such events).

When controlling for states, number of endemic species has no effect. We do not find consistent impacts either for average slopes, distance to the nearest rivers, average population density or average rainfall. However, average population density in the 10km buffer zone lowers the probability of a size reduction, which is consistent with the results of Symes et al. (2016) who find local population interacted with PA size to correlate positively with PADDD. Insignificance of the differences in average rainfall might be due to averaging of difference impacts, as crops gain but then lose as rain rises (Bax and Francesconi, 2018; Kere et al., 2017; Kirby et al., 2006).

4.4 Robustness Checks (subsets)

We assess the drivers of size reduction for subsets of PAs, based on: whether in the arc of deforestation (Table 4A); type (strict versus mixed use, by IUCN category, Table 4B); and level of governance (Table 4C)[7]. In our sample, most of the PAs that have been degazetted are located in the arc of deforestation and we known PAs in states in the arc are more likely to face high pressures (Pfaff

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[6] It may also be more common for large PAs that internal outcomes vary considerably across distinct sub-regions within a PA and that this is relevant for PADDD events (see results for Rondônia indicating such a possibility within Tesfaw et al. 2018).

[7] Results are presented without state dummies and with clustered standard errors because of the lack of sufficient observations to identify all of these effects, once we have split the data into subsets. However, results for deforestation and development objectives are consistent with the inclusion of state dummies, which remains significant for Amazonas, Mato Grosso and also Maranhao compared to Rôndonia.

et al., 2015a, 2015c, 2014). We note PA type and level of governance are evenly distributed across the PAs without and with size reductions (Pack et al., 2016).

PADDD decisions, though, may be taken quite differently according to PA type and level of governance (Bernard et al., 2014; Ferraro et al., 2013; Jusys, 2018; Kere et al., 2017; Nolte et al., 2013; Pfaff et al., 2017, 2015a, 2014). For example, multiple-use PAs can be more effective than strict PAs, in terms of internal impacts, when located closer to threat – even with higher internal clearing (Ferraro et al., 2013; Jusys, 2018; Nolte et al., 2013), although of course, all else equal, PAs that allow legal internal clearing would avoid less deforestation. Also, federal PAs may have greater impacts than those implemented by states because of the relative higher importance placed upon environmental gains (Herrera et al. 2019). Thus, the PAs implemented by states may be expected to be farther from threats or to lack enforcement. Tables 4 shows that our highlighted results concerning total internal deforestation and distance to roads both are consistent across subsets – as are the results for the perimeter-to-area ratio, reflecting PA size.

In states in the arc of deforestation (Table 4A), the significative and negative impact of distance to the nearest river confirms that more size reductions occurred with lower transport costs and, thus, when profits are higher (reflecting some influence of development agency perspectives, as suggested by prior distance results). Interestingly, though, for the strict and federal PAs (Table 4B and 4C), this relatively higher influence seems to disappear when looking at the effect of the distance to cities – although, as noted, it remains for distances to roads.

5 Discussion & Conclusion

PAs are widely used to limit forest access. Yet their implementation may involve conflicts over land use between conservation and development forces (Deguignet et al., 2014; Naughton-Treves et al., 2005; Watson et al., 2014), leading them to be located in lower-pressure areas (Baldi et al., 2017; Joppa and Pfaff, 2009; Pfaff et al., 2015c) and, thus, to be less impactful than expected (Abman, 2018; Andam et al., 2008; Anderson et al., 2016; Ferraro et al., 2013; Joppa and Pfaff, 2011; Jusys, 2018; Kere et al., 2017; Nolte et al., 2013; Pfaff et al., 2015a, 2015c, 2014, 2009; Robalino et al., 2017; Sims, 2014). We considered an extension of such clashes between development and conservation, reductions in sizes of and even eliminations of PAs. Such PADDD – PA Degazettement, Downsizing, and Downgrading – is more frequent, globally, than seems commonly known (Bernard et al., 2014; Cook et al., 2017; Marques and Peres, 2015; Mascia et al., 2014; Mascia and Pailler, 2011; Pack et al., 2016; Symes et al., 2016).

We studied reductions in PA size across the Brazilian Amazon, one critical location where PAs are being altered due to economic pressures (Bernard et al., 2014; Marques and Peres, 2015; Symes et al., 2016; Veríssimo et al., 2011). We proposed a simple model of size reductions determined by the interactions between environment and development agencies. We accounted for illegal PA invasions and considered spatial gradients within the benefits and costs – for each type of agency – from reductions in PAs' sizes. We used the PADDDtracker data (World Wildlife Fund (WWF), 2017a) and characteristics of protected lands, and of PAs themselves, in order to examine the drivers of recent size reductions for Amazon PAs. We found that transport costs, PA size, and prior internal deforestation have consistent impacts on these PADDD events – controlling for differences across Amazonian states, which are both big and distinct. These results suggested the influences of both development and environment agencies on these events.

Extensions of such research could consider the time before PADDD proposals are enacted, if they are. There may be spatial interactions across events as well, across PAs or actors (Sauquet et al., 2014). Also, one might focus solely on degazettement or downsizing or, for that matter, degradation of a PA's status. A different type of extension could assess the impacts of PADDD events, based upon an understanding of PADDD drivers – such as considered here – which can help to isolate the impacts of PADDD itself.

As PADDD is likely to continue, all of this can inform any decision makers considering conservation-development tradeoffs (Ferreira et al., 2014; Mascia et al., 2014) given ambitions for hydroelectric dams and mining, e.g., in territories with PAs (Araújo et al., 2012; Ferreira et al., 2014; Marques and Peres, 2015; Pack et al., 2016; World Wildlife Fund (WWF), 2017b), which might lose protection (Bernard et al., 2014; Ferreira et al., 2014; Mascia et al., 2014; Mascia and Pailler, 2011; Pack et al., 2016). Actors involved include global institutions, and funders, eager to support not only local economic development but also conservation, for instance in light of the full suite of SDGs. Their optimal interventions surely depend upon the types of conservation-development tradeoffs by local actors that we have considered.

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Table 1A Descriptive Statistics

	PAs Still Fully Protected			PAs Reduced In Size		
	Mean	Minimum	Maximum	Mean	Minimum	Maximum
Average GDP (10000 reals)	86701	328	2000000	158040	1660	2000000
Distance to the nearest road	85	0.1	400	56	2.4	274
Distance to the nearest urbanized area	271	0	846	261	0.1	721
Average slopes	1.68	0.15	8.19	2.05	0.43	6.93
Average rainfalls	2080	954	3218	2086	1273	2990
Distance to the nearest river	46.4	0	306	43.3	0	270
Average population density	165	0	8815	63	0	3033
Total deforestation	19	0	22357	115	0	832
Distance to the nearest dam	344	36	1065	282	6.8	644
PA Size	3669	0.01	48267	7115	0.5	38870
Perimeter-to-Area Ratio	1.78	0.03	74	0.18	0	1.34
High Endemism (<21)	20.85			3.91		
Low Endemism (1-5)	37.81			37.25		
Medium Endemism (6-20)	26.15			39.21		
No Endemism (0)	15.19			19.61		
IUCN Category Ia	11.53			7.84		
IUCN Category II	20.28			27.45		
IUCN Category III	1.75			-		
IUCN Category IV	8.39			-		
IUCN Category V	14.33			7.84		
IUCN Category VI	43.71			56.86		
Observations	286			51		

Note: for Endemism and IUCN Category, we report the frequency.

Table 1B Variables' Sources & Descriptions

Name	Date	Units	Sources	Treatment
GDP	2000 to 2005	1000 reals, current prices	Vector format from the IBGE at the level of the municipality (IBGE, 2017)	Average from 2000 to 2005.
Distance to the nearest road	2006	km	Vector format from the Brazilian Departamento Nacional de Infraestrutura de Transportes (DNIT, 2017).	Geodesic distance of the centroid of each PA to the nearest roads with ArcGIS 10.4.
Distance to the nearest urban area	2005	km	Urbanized spots of more than 100,000 inhabitants in vector format from the IBGE (IBGE, 2017).	Geodesic distance of the centroid of each PA to the nearest urban area with ArcGIS 10.4.
Slopes	-	250m*250m	Gridded elevation data from the Shuttle Radar Topography Mission (SRTM) (Jarvis et al., 2008).	Computed in degree from the horizontal with ArcGIS 10.4.
Rainfalls	2000 to 2005	mm/year 5km*5km	Gridded data from the Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS) (Funk et al., 2015)	Average from 2000 to 2005.
Distance to the nearest river	-	km	Lake, pond and rivers, permanent and navigable in vector format from the IBGE (IBGE, 2017).	Geodesic distance of the centroid of each PA to the nearest river with ArcGIS 10.4.
Population density	2005	1km*1km	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 from 2000 and 2005.
Total deforestation	2001 to 2005	squared km	Vector format from the PRODES System of the Instituto Nacional de Pesquisa Espacial (INPE) (INPE, 2017).	Total from 2001 to 2005.
Distance to the nearest dam	1975 to 2005	km	Dams of more than 0,1km3 in points format from the Global Reservoir and Dam (GRanD) database of the Department of Geography of Mc Gill University in Montreal (Lehner et al., 2011).	Geodesic distance of the centroid of each PA to the nearest dam with ArcGIS 10.4.

Name	Date	Units	Sources	Treatment
PA size	-	squared km	WDPA (IUCN and UNEP-WCMC, 2016)	For PAs reduced in size, we use the size of the PA before the event.
Perimeter-to-area ratio	-	-		The perimeter of each PA is calculated with arcgis 10.4. For PAs reduced in size, we use the perimeter of the PA before the event. The perimeter of the PA has been divided by its size.
Number of endemic species	Before 2006	No endemism: 0 endemic species (baseline); Low endemism: from 1 to 5 endemic species; Medium endemism: from 6 to 20 endemic species; High endemism: from 21 to 47 endemic species	Vector format from the WWF WildFinder database of species distributions (WWF, 2006; Olson et al., 2001).	-
IUCN category	-	Ia: Strict Nature Reserve (baseline); II: National Parks; III: Natural Monument or Feature IV: Habitat/Species Management Area; V: Protected Landscape; VI: PA with sustainable use of natural resources	WDPA (IUCN and UNEP-WCMC, 2016) and PADDDtracker (World Wildlife Fund (WWF), 2017a)	-
Administrative boundaries	-	-	Vector format from the Global Adminsitrative Area (GADM) database (GADM, 2012)	-

<u>Table 2A</u> Illegal Deforestation Within PAs – Absolute surface (sq.km)

Total internal deforestation from 2003 to 2005	(1)	(2)	(3)	(4)	(5)
ln(Average GDP from 2000 to 2002)	10.272 (2.62)***	7.351 (2.18)**	3.690 (1.39)	-1.445 (0.46)	2.339 (0.87)
ln(Distance to the nearest road in 2006)	4.840 (0.62)	5.067 (0.66)	3.495 (0.51)	3.595 (0.52)	5.556 (0.72)
ln(Distance to the nearest urban area in 2005)	9.727 (2.12)**	7.197 (1.82)*			0.173 (0.05)
Distance to the nearest urban area in 2005			0.074 (1.97)*	-0.328 (1.92)*	
Squared distance to the nearest urban area in 2005			0.001 (1.98)**		
ln(Average slopes)	8.103 (0.80)	9.693 (0.93)	0.753 (0.13)	2.417 (0.35)	4.562 (0.59)
ln(Average rainfalls from 2000 to 2002)	2.066 (0.24)	-11.861 (1.24)	-9.543 (0.73)	-38.295 (2.13)**	-12.748 (0.97)
ln(Distance to the nearest river)	7.085 (3.05)***	6.672 (2.98)***	8.912 (2.55)**	7.780 (2.45)**	9.446 (2.49)**
ln(Average population density in 2000)	0.822 (0.28)	6.008 (1.51)	5.767 (2.24)**	3.391 (1.31)	5.233 (1.79)*
ln(Distance to the nearest dam in 2005)	-0.001 (0.00)	-2.837 (0.59)	-0.764 (0.13)	6.070 (0.79)	10.663 (1.16)
ln(PA size)		6.516 (3.52)***	8.445 (3.92)***	8.866 (3.86)***	9.042 (3.89)***
low endemism (1-5) [8]			(1.93)* 6.417	(1.59) 16.039	(1.95)* 6.417
medium endemism (6-20)			(0.78) 12.183	(1.74)* -1.458	(0.78) 12.183
no endemism (0)			(1.03) -0.778	(0.13) 3.043	(1.03) -0.778
IUCN cat. II[9]			-2.610 (0.25)	2.332 (0.19)	-3.221 (0.30)
IUCN cat. III			24.381 (1.21)	13.002 (0.82)	17.909 (0.98)
IUCN cat. IV			30.052 (1.74)*	29.580 (1.66)*	32.083 (1.86)*
IUCN cat. V			43.756 (1.07)	47.788 (1.13)	45.232 (1.04)
IUCN cat. VI			7.702 (0.61)	16.435 (1.17)	8.616 (0.67)
Acre[10]			-2.610 -58.485	2.332 -47.136	-3.221 -68.055
Amapa			(2.53)** -41.063	(1.96)* -31.891	(2.32)** -48.858
Amazonas			(2.53)** -50.223	(1.94)* -38.190	(2.56)** -54.947
Maranhao			(3.44)*** -37.436	(3.07)*** -23.877	(3.23)*** -41.436
Mato Grosso			(1.97)** -39.797	(1.16) -26.573	(1.93)* -40.206
Para			(2.62)*** -12.006	(1.96)* 2.332	(2.50)** -13.950
Roraima			(0.88) -48.599	(0.12) -40.096	(0.95) -70.582
Tocantins			(2.96)*** -45.269	(2.49)** -31.997	(2.97)*** -48.673
cons	-212.385 (1.67)*	-93.004 (0.85)	-50.355 (0.39)	217.536 (1.68)*	-75.138 (0.60)
R^2	0.05	0.07	0.14	0.19	0.14
N	355	355	355	354	354

* p<0.1; ** p<0.05; *** p<0.01

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[8] The number of endemic species are compared to high endemism (>21)

[9] IUCN categories are compared to IUCN category Ia

[10] States are compared to Rondônia

Table 2B Illegal Deforestation Within PAs – Area Fraction

ln(Total area deforested from 2003 to 2005/size of the PA)	(1)	(2)	(3)	(4)	(5)
ln(Average GDP from 2000 to 2002)	0.056	0.006	-0.001	-0.029	-0.007
	(1.98)**	(0.21)	(0.04)	(1.02)	(0.26)
ln(Distance to the nearest road in 2006)	0.001	0.002	0.007	0.005	0.006
	(0.02)	(0.04)	(0.17)	(0.12)	(0.14)
ln(Distance to the nearest urban area in 2005)	0.017	0.031	0.041		
	(0.34)	(0.65)	(0.83)		
Distance to the nearest urban area in 2005				-0.001	0.000
				(2.03)**	(1.39)
Squared distance to the nearest urban area in 2005				0.000	
				(2.77)***	
ln(Average slopes)	0.198	0.224	0.255	0.257	0.254
	(2.31)**	(2.89)***	(3.12)***	(3.17)***	(3.15)***
ln(Average rainfalls from 2000 to 2002)	0.291	0.576	0.524	0.386	0.515
	(2.00)**	(2.97)***	(2.81)***	(2.04)**	(2.75)***
ln(Distance to the nearest river)	0.051	0.026	0.040	0.031	0.038
	(1.77)*	(1.02)	(1.46)	(1.17)	(1.39)
ln(Average population density in 2000)	-0.017	0.014	0.012	-0.009	0.002
	(0.36)	(0.33)	(0.29)	(0.26)	(0.06)
ln(Distance to the nearest dam in 2005)	-0.100	-0.002	-0.018	-0.015	-0.039
	(1.47)	(0.03)	(0.27)	(0.20)	(0.55)
ln(PA size)	-0.075	-0.080	-0.092	-0.092	-0.093
	(3.41)***	(3.26)***	(3.71)***	(3.69)***	(3.74)***
low endemism (1-5) [11]			0.289	0.246	0.277
			(2.18)**	(1.80)*	(2.04)**
medium endemism (6-20)			0.221	0.279	0.227
			(1.41)	(1.75)*	(1.44)
no endemism (0)			0.447	0.416	0.439
			(2.68)***	(2.45)**	(2.60)***
IUCN cat. II[12]		-0.186	-0.192	-0.282	-0.210
		(1.23)	(1.16)	(1.54)	(1.26)
IUCN cat. III		-0.616	-0.677	-0.711	-0.689
		(3.31)***	(3.73)***	(4.05)***	(3.81)***
IUCN cat. IV		-0.219	-0.249	-0.274	-0.256
		(2.11)**	(2.46)**	(2.71)***	(2.51)**
IUCN cat. V		0.206	0.257	0.246	0.251
		(1.79)*	(2.25)**	(2.23)**	(2.21)**
IUCN cat. VI		0.096	0.078	0.092	0.079
		(1.08)	(0.85)	(1.00)	(0.88)
Acre[13]		-0.429	-0.178	-0.098	-0.155
		(1.86)*	(0.61)	(0.33)	(0.52)
Amapa		-1.226	-1.240	-1.160	-1.239
		(7.17)***	(6.65)***	(6.03)***	(6.57)***
Amazonas		-0.903	-0.939	-0.857	-0.935
		(7.00)***	(6.60)***	(5.93)***	(6.53)***
Maranhao		-0.191	-0.152	-0.073	-0.149
		(0.70)	(0.53)	(0.25)	(0.52)
Mato Grosso		-0.703	-0.611	-0.544	-0.615
		(4.80)***	(3.67)***	(3.18)***	(3.69)***
Para		-0.615	-0.625	-0.527	-0.636
		(4.23)***	(3.97)***	(3.29)***	(4.16)***
Roraima		-0.794	-0.836	-0.723	-0.803
		(5.72)***	(5.04)***	(4.17)***	(4.67)***
Tocantins		-0.876	-0.695	-0.621	-0.687
		(5.74)***	(3.56)***	(3.00)***	(3.48)***
cons	-1.789	-3.372	-3.110	-1.444	-2.711
	(1.58)	(2.13)**	(2.08)**	(0.93)	(1.78)*
R^2	0.11	0.38	0.40	0.41	0.40
N	355	355	354	354	354

* $p<0.1$; ** $p<0.05$; *** $p<0.01$

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[11] The number of endemic species are compared to high endemism (>21)

[12] IUCN categories are compared to IUCN category Ia

[13] States are compared to Rondônia

Table 2C Illegal Deforestation Within PAs – Binary independent variable

Logit model 1 : invaded ; 0 : not invaded	(1)	(2)	(3)	(4)	(5)
ln(Average GDP from 2000 to 2002)	0.257 (1.98)**	0.063 (0.42)	0.039 (0.25)	-0.002 (0.01)	-0.054 (0.40)
ln(Distance to the nearest road)	-0.098 (0.47)	-0.189 (0.85)	-0.171 (0.77)	-0.172 (0.78)	-0.162 (0.75)
ln(Distance to the nearest urban area in 2005)	0.379 (2.08)**	0.402 (1.95)*	0.464 (2.07)**		
Distance to the nearest urban area in 2005				0.008 (1.56)	0.002 (1.34)
Squared distance to the nearest urban area in 2005				-0.000 (1.16)	
ln(Average slopes)	0.406 (1.01)	0.398 (0.82)	0.446 (0.88)	0.514 (1.03)	0.497 (1.03)
ln(Average rainfalls from 2000 to 2002)	4.913 (5.57)***	4.216 (3.71)***	3.964 (3.14)***	4.276 (3.32)***	3.813 (2.91)***
ln(Distance to the nearest river+1)	0.054 (0.41)	-0.098 (0.53)	-0.079 (0.40)	-0.068 (0.35)	-0.073 (0.38)
ln(Average population density in 2000)	-0.014 (0.11)	-0.010 (0.05)	0.015 (0.08)	-0.058 (0.35)	-0.076 (0.46)
ln(Distance to the nearest dam)	-0.094 (0.31)	-0.143 (0.38)	-0.253 (0.56)	-0.333 (0.66)	-0.216 (0.46)
ln(PA size)	0.373 (5.37)***	0.270 (2.45)**	0.258 (2.21)**	0.271 (2.35)**	0.264 (2.33)**
Low endemism (1-5) [14]			0.228 (0.40)	0.158 (0.26)	0.083 (0.14)
Medium endemism (6-20)			0.247 (0.31)	0.041 (0.05)	0.179 (0.22)
No endemism (0)			1.012 (1.09)	0.914 (0.98)	0.759 (0.86)
IUCN cat. II[15]		0.773 (1.38)	0.853 (1.48)	0.842 (1.52)	0.838 (1.46)
IUCN cat. III		-0.734 (0.72)	-0.507 (0.48)	-0.637 (0.63)	-0.839 (0.84)
IUCN cat. IV		-2.354 (1.97)**	-2.340 (1.92)*	-2.241 (1.91)*	-2.471 (1.98)**
IUCN cat. V		1.036 (1.47)	1.191 (1.64)	1.157 (1.59)	1.090 (1.54)
IUCN cat. VI		0.878 (1.33)	0.890 (1.32)	0.950 (1.45)	0.959 (1.41)
Acre[16]		2.210 (0.96)	2.530 (1.15)	2.523 (1.06)	2.575 (1.05)
Amapa		-2.537 (2.47)**	-2.462 (1.91)*	-2.648 (2.06)**	-2.409 (1.92)*
Amazonas		-0.674 (0.95)	-0.727 (0.77)	-0.895 (0.95)	-0.723 (0.78)
Maranhao		-0.829 (0.93)	-0.878 (0.84)	-1.149 (1.14)	-1.004 (0.98)
Mato Grosso		-1.095 (1.79)*	-0.976 (1.19)	-1.161 (1.44)	-0.980 (1.17)
Para		0.208 (0.27)	0.353 (0.33)	0.122 (0.12)	0.316 (0.30)
Roraima		0.192 (0.13)	0.155 (0.10)	0.121 (0.08)	0.217 (0.14)
Tocantins		-2.816 (3.61)***	-2.654 (2.60)***	-2.824 (2.86)***	-2.650 (2.61)***
cons	-42.768 (5.87)***	-33.539 (3.61)***	-31.549 (3.13)***	-31.704 (3.06)***	-27.709 (2.67)***
Pseudo R2	0.31	0.44	0.44	0.44	0.44
MacFadden's ajusted R2	0.26	0.33	0.31	0.31	0.31
AIC	295.46	268.04	272.35	274.30	274.05
N	355	355	354	354	354

* $p<0.1$; ** $p<0.05$; *** $p<0.01$

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[14] The number of endemic species are compared to high endemism (>21)

[15] IUCN categories are compared to IUCN category Ia

[16] States are compared to Rondônia

Table 3 Risks of PA Size Reductions[17]

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
ln(Average GDP from 2000 to 2005+1)	1.206	1.178	1.005	1.006	1.209	1.069	1.071
	(1.05)	(1.10)	(0.03)	(0.03)	(1.13)	(0.38)	(0.39)
Distance to the nearest road in 2006	0.991	0.990	0.989	0.981	0.991	0.989	0.980
	(-2.21)**	(-2.19)**	(-2.58)**	(-2.23)**	(-1.96)**	(-2.18)**	(-2.26)**
Squared distance to the nearest road in 2006				1.000			1.000
				(1.09)			(1.45)
Distance to the nearest urban area in 2005	0.999	0.999	0.991	0.992	0.998	0.992	0.993
	(-0.50)	(-0.88)	(-2.32)**	(-2.16)**	(-1.23)	(-1.97)**	(-1.75)*
Squared distance to the nearest urban area in 2005			1.000	1.000		1.000	1.000
			(1.98)**	(1.82)*		(1.46)	(1.20)
Average slopes	1.187	1.171	1.213	1.205	1.156	1.186	1.176
	(1.09)	(1.06)	(1.24)	(1.19)	(0.86)	(0.98)	(0.92)
Average rainfalls from 2000 to 2005	1.000	1.000	0.999	0.999	1.000	1.000	1.000
	(-0.12)	(-0.57)	(-0.88)	(-0.81)	(-0.23)	(-0.42)	(-0.38)
Distance to the nearest river	0.999	1.001	1.000	1.001	1.002	1.002	1.003
	(-0.13)	(0.09)	(-0.02)	(0.14)	(-0.02)	(0.23)	(0.45)
Average population density from 2000 to 2005	1.000	1.000	1.000	1.000			
	(0.23)	(0.34)	(0.31)	(0.28)			
Average population density from 2000 to 2005 in the buffer zone					1.000	0.999	0.999
					(-0.52)	(-0.63)	(-0.65)
ln(Total deforestation from 2000 to 2005+1)	1.380	1.337	1.265	1.256	1.419	1.378	1.366
	(2.45)**	(2.47)**	(1.96)*	(1.89)*	(3.02)***	(2.71)***	(2.59)***
Distance to the nearest dam in 2005	1.000	1.001	1.001	1.001	1.002	1.002	1.002
	(0.26)	(0.44)	(0.50)	(0.50)	(0.33)	(0.23)	(1.04)
ln(Size of the PA)	1.437	1.427	1.514	1.527			
	(2.80)***	(2.98)***	(3.42)***	(3.47)***			
Perimeter-to-area ratio					0.206	0.190	0.186
					(-2.42)**	(-2.55)**	(-2.59)***
Low endemism (1-5)[18]	0.326						
	(-0.82)						
Medium endemism (6-20)	0.301						
	(-1.00)						
No endemism (0)	0.628						
	(-0.37)						
IUCN cat II[19]	4.796						
	(1.61)						
IUCN cat V	1.790						
	(0.50)						
IUCN cat VI	2.537						
	(1.18)						
Amapa[20]	1.131	1.303	1.109	1.030	1.242	1.395	1.200
	(0.09)	(0.25)	(0.10)	(0.03)	(0.18)	(0.27)	(0.14)
Amazonas	0.080	0.130	0.127	0.120	0.130	0.137	0.128
	(-2.39)**	(-2.89)***	(-2.82)***	(-2.79)***	(-2.64)***	(-2.53)***	(-2.51)**
Maranhao	0.252	0.466	0.451	0.397	0.988	1.120	0.947
	(-1.11)	(-0.98)	(-1.01)	(-1.17)	(-0.01)	(0.09)	(-0.04)
Mato Grosso	0.025	0.055	0.050	0.046	0.065	0.063	0.056
	(-2.76)***	(-2.65)***	(-2.65)***	(-2.69)***	(-2.49)**	(-2.50)**	(-2.58)***
Para	0.493	0.580	0.630	0.605	0.992	1.173	1.146
	(-0.68)	(-0.78)	(-0.67)	(-0.72)	(-0.01)	(0.22)	(0.19)
Roraima	0.207	0.226	0.212	0.213	0.254	0.236	0.244
	(-1.14)	(-1.37)	(-1.45)	(-1.44)	(-1.14)	(-1.16)	(-1.13)
Pseudo R2	0.31	0.28	0.30	0.30	0.31	0.32	0.32
MacFadden's ajusted R2	0.14	0.16	0.16	0.16	0.18	0.18	0.18
AIC	233.34	228.49	226.29	227.59	211.91	211.41	212.29
Number of observations	292	292	292	292	284	284	284

* p<0.1; ** p<0.05; *** p<0.01

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[17] Results are robust to a change from the logit model to a probit model and to ordinary least square. In regressions (2) to (7), removing the number of endemic species and the IUCN categories has no impact and allows us to gain degrees of freedom.

[18] The number of endemic species are compared to high endemism (>21)

[19] IUCN categories are compared to IUCN category Ia.

[20] States are compared to Rondônia

Table 4A Risks of PA Size Reductions -- Robustness

	In the Arc of deforestation	
ln(Average GDP from 2000 to 2005+1)	1.097 (0.73)	1.027 (0.17)
Distance to the nearest road in 2006	0.986 (-2.37)**	0.986 (-2.86)***
Distance to the nearest urbanized area in 2005	0.990 (-1.87)*	0.989 (-3.46)***
Squared Distance to the nearest urbanized area in 2005	1.000 (1.65)*	1.000 (2.76)***
Average slopes	1.144 (0.97)	1.126 (1.28)
Average rainfalls from 2000 to 2005	1.000 (-1.00)	0.999 (-1.12)
Distance to the nearest river	0.988 (-2.80)***	0.988 (-8.77)***
Average population density from 2000 to 2005		1.000 (-0.05)
Average population density from 2000 to 2005 in the buffer zone	1.000 (-0.29)	
ln(Total deforestation from 2000 to 2005+1)	1.573 (3.22)***	1.538 (1.81)*
Distance to the nearest dam in 2005	1.003 (1.65)*	1.003 (1.94)*
Ln(PA size)		1.342 (1.16)
Perimeter to area ratio	0.198 (-1.84)*	
Pseudo R2	0.28	0.25
MacFadden's ajusted R2	0.16	0.13
AIC	161.06	170.16
Number of observations	180	183

* $p<0.1$; ** $p<0.05$; *** $p<0.01$

Table 4B Risks of PA Size Reductions – Robustness

	Mixed Use PAs		Strict PAs	
ln(Average GDP from 2000 to 2005+1)	1.051	1.033	1.359	1.277
	(0.29)	(0.15)	(2.44)**	(4.20)***
Distance to the nearest road in 2006	0.981	0.981	0.996	0.996
	(-4.41)***	(-5.19)***	(-2.74)***	(-3.93)***
Distance to the nearest urbanized area in 2005	0.992	0.991	1.001	1.000
	(-2.32)**	(-2.30)**	(0.24)	(0.08)
Squared Distance to the nearest urbanized area in 2005	1.000	1.000	1.000	1.000
	(2.18)**	(2.50)**	(0.23)	(0.45)
Average slopes	1.494	1.463	1.036	1.008
	(2.87)***	(3.49)***	(0.16)	(0.07)
Average rainfalls from 2000 to 2005	1.000	1.000	1.001	1.001
	(-0.07)	(-0.01)	(0.71)	(1.00)
Distance to the nearest river	0.991	0.992	1.007	1.006
	(-1.40)	(-1.61)	(0.92)	(0.99)
Average population density from 2000 to 2005		0.991		1.000
		(-2.22)**		(0.24)
Average population density from 2000 to 2005 in the buffer zone	0.994		1.000	
	(-2.18)**		(2.30)**	
ln(Total deforestation from 2000 to 2005+1)	1.557	1.417	1.785	1.852
	(4.38)***	(2.15)**	(6.28)***	(5.13)***
Distance to the nearest dam in 2005	1.001	1.001	0.993	0.993
	(0.59)	(0.68)	(-2.39)**	(-2.40)**
Ln(PA size)		1.295		1.235
		(1.76)*		(0.93)
Perimeter to area ratio	0.302		0.173	
	(-2.21)**		(-1.38)	
Pseudo R2	0.30	0.28	0.30	0.27
MacFadden's ajusted R2	0.16	0.15	0.05	0.03
AIC	144.09	158.41	93.61	96.02
Number of observations	211	219	112	113

* *p*<0.1; ** *p*<0.05; *** *p*<0.01

Table 4C Risks of PA Size Reductions – Robustness

	State Agencies		Federal Agencies	
ln(Average GDP from 2000 to 2005+1)	1.336 (1.41)	1.405 (1.26)	0.868 (-0.60)	0.902 (-0.48)
Distance to the nearest road in 2006	0.986 (-3.72)***	0.990 (-2.05)**	0.990 (-3.13)***	0.988 (-4.73)***
Distance to the nearest urbanized area in 2005	0.992 (-2.76)***	0.994 (-1.85)*	1.002 (0.32)	0.999 (-0.11)
Squared Distance to the nearest urbanized area in 2005	1.000 (5.58)***	1.000 (3.26)***	1.000 (-0.28)	1.000 (0.14)
Average slopes	0.567 (-4.45)***	0.599 (-6.33)***	1.845 (3.27)***	1.940 (4.56)***
Average rainfalls from 2000 to 2005	0.999 (-0.71)	0.999 (-0.66)	1.000 (0.19)	1.000 (-0.37)
Distance to the nearest river	1.008 (1.04)	1.005 (0.65)	0.994 (-0.49)	0.995 (-0.65)
Average population density from 2000 to 2005		0.999 (-0.63)		0.537 (-2.76)***
Average population density from 2000 to 2005 in the buffer zone	0.999 (-0.96)		0.827 (-2.97)***	
ln(Total deforestation from 2000 to 2005+1)	1.613 (4.20)***	1.681 (2.64)***	1.657 (4.42)***	1.501 (2.73)***
Distance to the nearest dam in 2005	0.997 (-1.02)	0.998 (-0.90)	0.998 (-1.06)	0.997 (-1.28)
Ln(PA size)		1.020 (0.08)		2.761 (2.95)***
Perimeter to area ratio	0.564 (-2.22)**		0.023 (-2.96)***	
Pseudo R2	0.36	0.30	0.31	0.37
MacFadden's ajusted R2	0.16	0.11	0.14	0.21
AIC	101.86	111.76	124.61	118.42
Number of observations	178	181	145	150

* $p<0.1$; ** $p<0.05$; *** $p<0.01$