

The impact of Protected Areas on Deforestation? An Exploration of the Economic and Political Channels for Madagascar's Rainforests (2001-12)*

Sébastien Desbureaux^{1,2}, Sigrid Aubert^{3,4}, Laura Brimont^{2,5}, Alain Karsenty², Alexio Clovis Lohanivo^{3,4}, Manohisoa Rakotondrabe⁴, Andrianjakarivo Henintsoa Razafindraibe⁴ and Jules Razafiarjoana⁴

¹ Université d'Auvergne-CERDI, Clermont-Ferrand (France)

² CIRAD-BSEF, Montpellier (France)

³ CIRAD-GREEN, Antananarivo (Madagascar)

⁴ ESSA-Agro Management, Antananarivo (Madagascar)

⁵ IDDRI, Paris (France)

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Abstract

Protected Areas (PAs) remain the central instrument to protect Madagascar's threatened biodiversity. We combine matching and regressions in a quasi-natural experiment setting to analyze PAs' additionality annually between 2001 and 2012 and study the channels that moderate the impact. PAs' have allowed to stabilize deforestation around a positive without having halting it. They have recreating some law effectiveness in areas where initial law enforcement was the lowest, limiting what we call opportunistic deforestation. However, additionality decreases when poverty rates increase. Effectively stopping deforestation will require ambitious policies to trigger the necessary agricultural transition for the country.

JEL Codes: Q2, Q28, Q58, 013

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1 Introduction

The evaluation of the impact of conservation policies is a growing topic in the literature that is recognized to still lag behind many other fields such as education, health or development policies [10]. The analysis of Protected Areas (PA)'s effectiveness, the dominant instrument in conservation policies, has attracted the attention of the majority of these studies [24]¹ that in overall find only a limited environmental additionality across several tropical countries [37]. However, little attention has yet been devoted to studying the mechanisms explaining their impact [20]. This paper embraces this approach by presenting an analysis of the impact of PAs on deforestation in Madagascar annually between 2001 and 2012 and consider two mediators to explain their partial effectiveness: an economic one through initial level of poverty rates and a political one exploiting the original heterogeneity in law enforcement among localities.

Madagascar is known for its exceptional while threatened biodiversity. The most recent IUCN Red List of Threatened Species warns of the possible disappearance of 927 of Madagascar's animal and plant species, the second highest figure in Africa after Tanzania (958 species). What makes Madagascar unique is that the great majority of its species are endemic, such as lemurs of which 94% of the 101 species are threatened with extinction. This information sadly backs up Madagascar's status as a global biodiversity *Hot Spot* [30, 40].

This threat can be explained by the reduction and the fragmentation of natural habitats, most notably generated by a continuous process of deforestation over the past decades [1, 51]. Whilst it would be difficult to estimate precisely the original surface area of the island's forests [35], it is possible that half of the forests have disappeared, particularly since the middle of the 1950s [29]. The eastern rainforest corridor -the focus of our study, clearly illustrates this process. Whereas only a few decades ago, there was an uninterrupted band of forest running the length of the island from north to south, now only a mere narrow scattered and interrupted strip remains (Figure 1). This can be attributed to anthropic pressures, the most damaging of which include the itinerant farming practice of slash-and-burn, or *tavy* in Malagasy, logging, coal mining and other mining activities [49].

From 1927, PAs have started to be established as a mean of conserving a "few specimens of the fauna and flora"². With the emergence of a willingness in the political agenda to stem the accelerating deforestation of the end of the XXth century, PAs have remained the dominant instrument on which public action hinges: PAs covered in Madagascar 1.7 million hectares in the early 2000s and an ambitious plan to triple the protected surface was launched in 2003 with the creation of New Protected Areas (NPA). Many inhabitants living adjacent to these lands saw restrictions placed on their access rights. Compensation schemes have been established for them, mainly in the form of Integrated Conservation and Development Programs (ICDP). In the same way, more than 1,248 transfers of local community management have been carried out

¹See for example of the ones that are said to meet "best practices guidelines" [19] : [2, 14, 23, 41, 43, 48].

²Madagascar. Bulletin économique (Tananarive). 1927: p 105. Digital French colonial archives can be found in Bibliothèque Nationale Française's web portal GALICA.

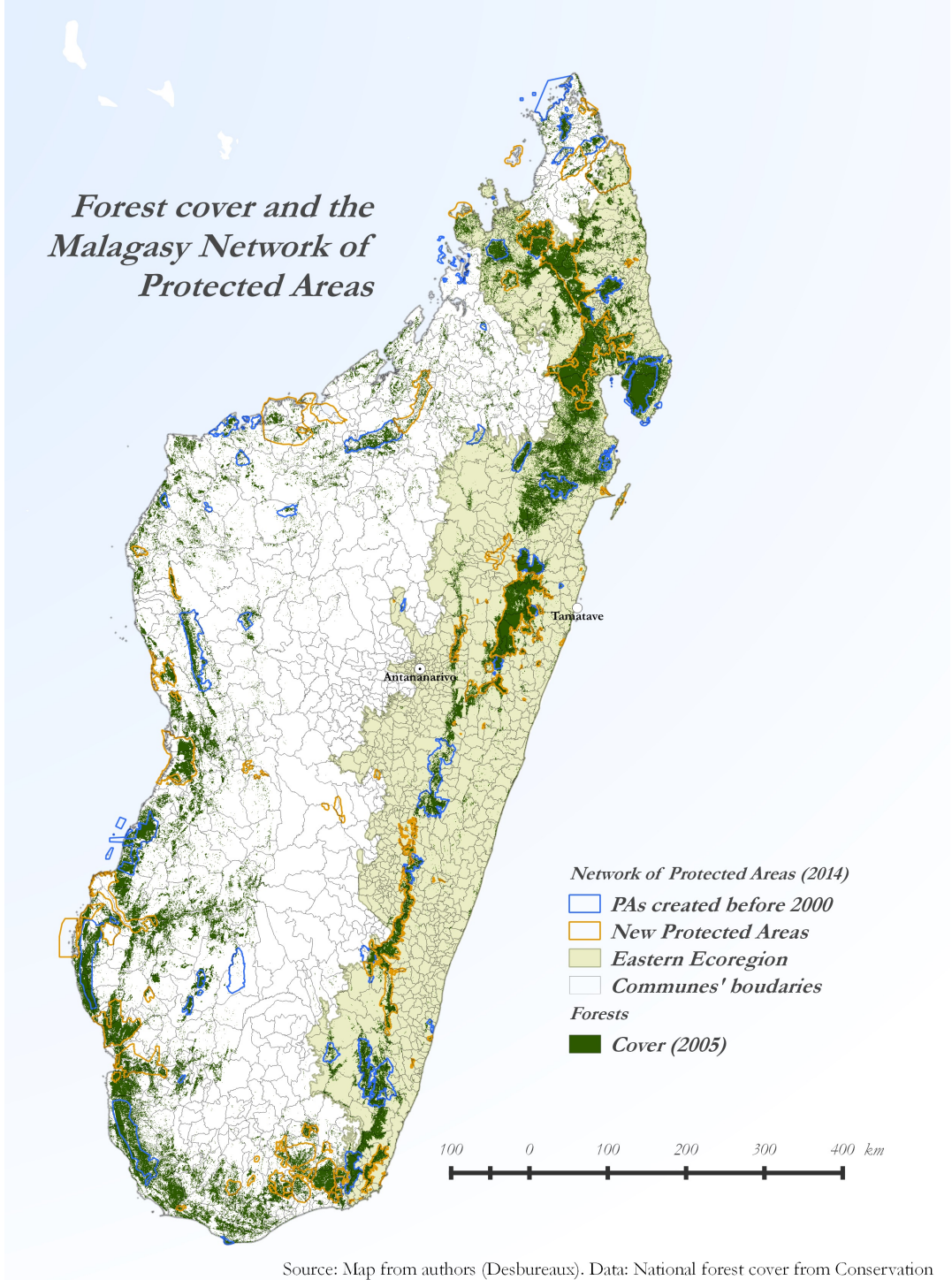


Figure 1: PAs and Forest cover

from 1996 to 2014³ and have been largely used to accompany the creation of NPAs in order to enable the local residents to invest in the sustainable use of resources. In total, PAs and NPAs currently cover 40% of the remaining forests⁴ and number of the interested parties involved in conservation is continuing to press for the extension of this network [47]⁵. Yet, we know very little of the environmental effectiveness of these PAs in Madagascar.

To our knowledge, two published studies [27, 50] and one unpublished manuscript [25] reveal the environmental impact of PAs in Madagascar. All suggest that PAs contributed very little towards limiting deforestation between the years 1990 and 2000: Gorenflo et al. (2011) found that the probability of a plot becoming deforested over ten years is only 5% less when it is located inside a PA [27]. Put another way, there would be a 95% chance that an area inside a PA which “should” be deforested were to be so, regardless of the establishment of the PA. A fourth study [52] confirms this existent yet low impact of PAs for 2 over 4 study cases in the humid forest and spiny-dry forest between 2000-05 and 2005-10. Nevertheless, it has to be pointed out that the evaluation of effectiveness of PAs is not the central issue of these three published studies and that the authors offer little explanation of the nature of a causal mechanism that would explain this limited effect.

We clarify here the causes of deforestation in Madagascar and draw up an analytic framework for studying the year on year environmental additionality of PAs between 2001 and 2012, defined here as the decrease in deforestation rate brought by the presence of PAs compared to similar yet unprotected areas. We propose to distinguish two processes that are driving deforestation in Madagascar: a deforestation by necessity rooted in the “poverty-environment trap” issue [5, 8], and an opportunistic deforestation following the difficulties of the fragile authorities to enforce law. We combine matching and regressions to show that the principal environmental contribution of PAs has consisted in stabilizing deforestation in a trend, while deforestation in comparable but unprotected areas has been erratic over the period. As an illustration, while the country experienced an upsurge in deforestation rates from 2007 with the dismantlement of power and subsequent political crisis, the level of deforestation inside PAs has remained comparable to the pre-crisis level. However, the overall effect has been limited with a one fifth reduction in deforestation rates inside historic PAs established up to the 1990s and currently no clear evidence of an impact inside NPAs. The later as well exhibit no sign of an increasing impact when considering the number of years for which the NPA has been established. We explain this limited impact by two mechanisms echoing the distinction we have drawn between deforestation by necessity and opportunistic deforestation. First, the additionality of PA is decreasing with poverty rates for both historic PAs and NPAs suggesting that when deforestation by necessity is the issue, tackling deforestation dominantly through PAs might be not effective. Second, PAs has allowed to significantly reduce deforestation only

³Data collected in 2012-13 by Alexio Lohanivo, joint project between CIRAD Madagascar and Ministère des Eaux et des Forêts.

⁴Authors’ computation. We calculated the area of forest that lies into a PA using Conservation International’s 2005 forest cover map and the 2014 SAPM shapefile.

⁵Going in this direction, President Hery Rajonamimpianina announced at the 2014’s World Park Congress an extension by three of Marine PAs by 2020 as the core of his so-called “Sydney’s Vision”.

when the initial law enforcement was at the lowest: PAs have allowed to bring back some enforcement in quasi law-less areas only but have failed to increase it when existing (while minimal) capacities were present. The limited available means might appear as an explanation for that.

We believe the contribution of this paper to the literature to be threefold. First, our analysis contributes to extend the scope of the “*Conservation Evaluation 2.0*” research program [37] geographically to a fewly studied continent – Africa, politically to the context of an unstable country governed by a fragile state, and socio-economically to the context of one the least developed country of the planet. In the economic and political context of Madagascar, the management of PAs is underfunded making people wondered if PAs are not simply “Paper Parks”, i.e. PAs existing *de jure* but not *de facto*. One can strongly doubt about effectiveness of paper parks, as highlighted in Mexico (Blackman et al. 2015). Second, the new time series of deforestation data compiled by Hansen et al. (2013) [28] enable us to draw additional insights compared to most existing studies by tracking the evolution of the impact of PAs across 12 consecutive years. Third, our set of covariates mainly come from a detailed socio-economic database collected by the ILO-Cornell project. Relying on this dataset distinguish our study from most similar studies that primarily use bio-geographic data (slope, euclidean distances etc). This database will allow us to discuss different mechanisms of the impact of PAs, namely poverty and remoteness.

The remaining of the paper is organized as follows: firstly, we revisit the pressures that are leading to deforestation in eastern Madagascar to better characterize the process (Section 2). Section 3 presents the data and the empirical strategy; and Section 4 the results. We finally draw in Section 5 the policy implications of our findings.

2 Background: Deforestation and Protected Areas in Madagascar

2.1 The Anthropic Factors of Deforestation

Deforestation has for principal driver in Madagascar small scale agriculture through the practice of slash-and burn rice cultivation. In the eastern eco-region, the ILO-Cornell database informs that 88% of the population had agriculture as a primary activity in 2001. 71% primarily cropped rice, the staple food in Madagascar. Rice farming by itinerant slash and burn, known as *tavy*, remains the dominant technique to crop rice, despite being officially prohibited since the 1860s. Irrigated rice cultivation, the alternative to slash-and-burn, was used by only 12% of households in average in 2001. *Tavy* has been recognized as the main source of pressure on the forests in this region since the beginning of the colonial era [31]. The practice of *tavy* involves cultivating rainfed rice on hill slopes and using the burnt plant matter to naturally fertilize the soil after several years of fallow. In the context of important demographic growth (2.9% annual national average according to World Bank data, even greater in rural settings), these fallow lengths have diminished resulting in a more rapid exhaustion of the soil rendering it unsuitable for farming after 4 or 5 rotations [12]. Yields, in the order of one tonne per hectare, don’t always cover families’

needs and are less than those obtained by lowland farming or that requiring more sophisticated agronomic techniques.

The continued illegal practice of *tavy* coincides in part with the difficulty of transition towards these other technologies, associated with a lack of infrastructures which would enable lowlands to be farmed, a lack of access to agricultural inputs, and a lack of knowledge of alternative practices. Risk aversion might as well represent an important barrier for farmers to shift technologies [9]. Likewise, farming the slopes allows farmers to reduce their exposure to the high risk of cyclone damage in this part of the island⁶. Finally, over and above a simple economic activity, *tavy* is a socially-rooted practice which replicates a certain type of social organization [7] (Desbureaux and Brimont 2015).

Moreover, households devote part of their time to revenues generating activities so as to acquiring basic necessary goods. These include cash crops (vanilla, cloves, sugar cane, etc), logging, coal mining and other mining activities. Logging, coal mining and mineral extraction, notably gold, all illegal in the natural forest, is currently reported by conservation actors to constitute, in the extent of their practice, the second greatest cause of deforestation. In many communes, these activities may represent the only source of monetary income for households⁷.

2.2 The “Poverty-Environment Trap” Situation: Deforestation By Necessity

These various pressures show that households are almost entirely dependent on the access to forests to ensure the conditions of their survival. Continuous clearing of new plots is their main response to the situation of socio-economic fragility in which they find themselves. This fragility can be put down to a number of factors. These are firstly of a social order. Households live in a state of land and property insecurity and the members are of a low educational standard [46]. There are also economic factors: households are directly exposed to the strong volatility of markets for agricultural commodities, whether it is rice, vanilla or cloves. They are physically isolated by their remoteness from major markets: 42% of rural communes are at more than 24h driving from the nearest urban commune during the 6 months of the rainy season ; 17% of rural communes even are at more than 48h and 7 at more than 72h. This high isolation limit them in the development and diversification of income generating activities. Such households present all the characteristics of capability deprivation, as articulated by Sen, which explains their difficulty in visualizing themselves in an alternative future.

Households respond to this context by clearing the forest, which leads to a situation that we call here a *deforestation by necessity*, one which enables households to fulfill their subsistence requirements in response to their state of socio-economic fragility. This situation fully corresponds to the well-known “poverty-environment trap” [4, 8].

⁶See the report *Perceptions et stratégies d'adaptation paysannes face aux changements climatiques à Madagascar, Agronomes et vétérinaires sans frontières* by Delille (AVSF), 2011.

⁷e.g. our field observations (2012) in the commune of Didy regarding gold mining.

2.3 Opportunistic Deforestation

The fragility of households at a local level is reinforced by the shortcomings of the country's legal and institutional framework. One typical shortcoming is a preponderance for a certain blurring of the legal contours, in particular where forestry is concerned. In the absence of a legal code and considering the production conditions of laws [32], the legal and regulatory framework is often misunderstood or disregarded by citizens [26], whilst government officials often come up against numerous flaws and inconsistencies [6].

This legal blurring is furthermore amplified by an unstable political context. In recent years, the country has experienced two coups d'états, in 2002 and 2009, the most recent giving way to a so called 4 years period of transition. During these crises, the state's capacity to apply its laws has been impeded due to the drop in available means of government and the rise in corruption. Even before the crisis, ILO-Cornell data indicate that police officers (i.e. *police* and *gendarmes*) are present in only half of the communes. The political and economic crisis of 2009 contributed thus to reinforcing the powers of those economic officials organizing informal sidelines in forestry products, as well as those of the PAs' delegated managers, all to the detriment of the forestry commission with diminished means at their disposal. These factors lead to a major upturn in deforestation and degradation. It translated into a massive increase in illegal logging of precious species and softwood in a context of relative impunity [44]. As an illustration, in the rural commune of Didy during 2009/2010, we estimate that 99.7% of the timber removed illegally from the forest took place without any sanctions, regardless of the fact that the lorries transporting it must have crossed several barriers and checkpoints⁸.

Added to deforestation by necessity, Madagascar experiences what we refer to an issue of *opportunistic deforestation*, that is to say additional deforestation enabled by the authorities' incapacity to enforce the law within the bounds of its territory, to such an extent that locals have taken advantage by extending their forest clearing above and beyond their strict subsistence requirements.

In clarifying these two phenomena, we are not aiming at differentiating one group of people clearing the forest by strict necessity from another merely taking advantage of opportunities, nor is it our intention to weigh up and apportion quantitatively the precise difference between two types of deforestation. The boundary separating the two phenomena is too porous for that, making it quite difficult in many circumstances to differentiate strictly between them. We hope rather by this distinction to clarify that at the level of a farming household, these two phenomena play a joint role in the decisions taken about forest clearance: households strip the forest to fulfill their subsistence needs, but may also simultaneously take advantage of the failings of

⁸Estimates of the amount of timber removed are those recorded by Andriantahina, Diagnostic du fonctionnement de la filière illicite de bois d'oeuvre dans la Commune Rurale de Didy District d'Ambatondrazaka Région Alaotra –Mangoro, s.l.: Projet Cogesfor (2010). We compared these estimates with the number of penalty notices issued by the forestry commission in the locality that year, as recorded by the DREF (regional environment and forestry agency) at Ambatondrazaka in May 2012. Additionally, these sanctions concerned the stripping of 87ha of forest between 2003 and 2011 (DREF), when our calculations from Hansen's data testify to a clearing of around 3000ha of forest, for the dense forests alone.

government to pursue, or even extend their forest clearance activities. It would be wrong to assume that deforestation by necessity and opportunistic deforestation act independently of each other and that the level of deforestation is nothing but the sum of the two. We think on the contrary that these two dimensions interact. Applying the logic of Boserup (1965) [11], it makes little sense to view Malagasy farmers as mere passive players incapable of adapting to the legal context of intervention: faced with a ban on forest clearing, we could rightly assume that a farmer would adapt his practices in favor of more land-economical farming methods. Otherwise, how would we explain the persistence of *tavy*? Failure to enforce laws (i.e. opportunities) is hardly an incentive to local households to innovate towards new practices: it is very probable then that the frailty of the institutional framework, a source of opportunistic deforestation, maintains the pursuit of a stable trend in deforestation by necessity, and that it is partially responsible for the absence of a “natural” decrease in the latter.

2.4 Curbing Deforestation With Protected Areas?

From herein, the issue of curbing deforestation in Madagascar becomes a dual one. It seems necessary to be able to deal with both, the dependency of local residents on resources, the source of this deforestation by necessity, and at the same time, the fragility of the institutional framework which enables opportunistic deforestation to persist. The establishment of PAs aims largely to address the second issue. In a quasi lawless state as Madagascar, creating PAs might be an effective way to increase law enforcement on the ground. The establishment of PAs aims primarily to curtail the shortcomings of the national legal framework by reinstating the areas “by law” in poorly controlled zones. The appointment of a management officer, who acts as an intermediary for the forestry administration, theoretically makes it easier to apply closer controls on anthropic activities and influence local populations by enhancing awareness

Furthermore, in the context of sustainable development promotion, and taking account of the need to consider the inescapable restriction of local populations’ access rights to forestry resources [18], various local development compensatory programs have been initiated jointly with PAs. The purpose of these has been to reduce the causes of deforestation by necessity. These have been implemented in the established PAs notably by *de jure* allocating 50% of the income generated from park entrance fees towards financing projects in favor of populations suffering negative impacts of deforestation. Furthermore, in at least four NPAs, REDD+ projects (CAZ, CoFaV, Makira and PHCF) have enabled the prospect of compensation from profits from the trading of carbon credits to be envisaged⁹. These development programs are often launched on a community-wide level, based on management transfers that NGOs generally create to accompany NPAs.

PAs and NPAs are all included in the Madagascar’s network of protected areas (SAPM - Système des Aires Protégées de Madagascar). Currently, they are 138 PAs in Madagascar. 50 of them are the “historic” PAs created between 1927 and the 1990s. They are managed by the public agency Madagascar National Parks. The others 88

⁹See, for example, the World Bank Report “Assessment of the design elements of a sharing mechanism of benefits from carbon revenues ‘Madagascar CAZ’ REDD Project” (2013)

are new PAs (NPA) that have started to be established from 2004 with the help of national and international conservation NGOs.

3 Data

Our study deals with the environmental effectiveness of PAs and NPAs with respect to the additional deforestation their presence has or has not enabled to avoid in natural forests. We focus our study to the eastern ecoregion (as defined by WWF, see Figure 1) in which is located the rainforest corridor. The eastern ecoregion is where the authors have the most field experience.

3.1 Protected Areas

We take into consideration every PAs and NPAs from the eastern ecoregion that were included in the SAPM in 2012 whether they have a temporary (NPAs) or a permanent protection statut (PAs). We have 24 historic PAs and 31 NPAs impacting respectively 109 and 126 localities ¹⁰. Figure 2 displays the evolution of the number of PAs and NPAs within the period of this study for the area of interest.

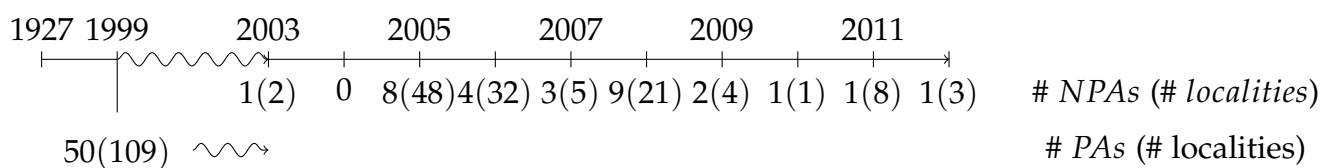


Figure 2: Timeline of the creation of New Protected Areas

3.2 Socio-Economic Variables

We use the ILO-Cornell commune census from 2001 jointly conducted by Cornell University, FOFIFA and INSTAT to include information on economic, social and political characteristics at the locality level. Information was gathered for 1385 of the 1392 communes of the country ¹¹. We complete the census with annual population data at a district level from INSTAT. We spacialized the database using official communes boundaries from GADM (Global Administrative Areas) in order to merge socio-economic and forest cover data.

3.3 Environmental Outcome: Forest Cover

We use data of vegetation cover from Hansen et al. (2013) version 1 [28]. Hansen et al. (2013) compiled more than 740,000 Landsat TM images to produce annual global

¹⁰Madagascar is administratively divided in 22 *Régions*, 112 *Districts*, 1395 *Communes* i.e. localities and 17 544 *Fonkontany*. *Communes* can be either Urban ones or Rural ones. *Communes* would correspond to U.S. municipalities.

¹¹The database can be downloaded at the project website <http://www.ilo.cornell.edu/index.html>

deforestation maps between 2000 and 2012 [28] at a 30m resolution. We base our analysis on two spatial layers: original tree cover from 2000 and annual vegetations losses from 2001 to 2012. For our area of interest, we define natural tropical rainforest as areas presenting a forest canopy greater than or equal to 78% per pixel in 2000¹². We then focus on annual vegetation losses on pixels that we have initially defined as forests in 2000. Because we are interested in natural habitats, we do not take into account vegetation regrowth as we are unable to characterize if pixels where regrowth happened correspond to dense forests or to another type of vegetation (namely *savoka*, the vegetation regrowth in pastures between two cropping cycles when practicing *tavy*). We retained only the communes where the surface area of forest is at least 50ha as PAs are aiming at protecting sufficiently large and continuous patches of forest.

Our outcome variable is the deforestation rate in commune i for year t , that is the percentage of forest cover loss between the end of year $t - 1$ and the end of year t :

$$Def_{i,t} = \left| \frac{Forest_{i,t} - Forest_{i,t-1}}{Forest_{i,t-1}} \right| \quad (1)$$

where $Forest_{i,t}$ represents the surface of forest cover in locality i at the end of year t . We take the absolute value of the percentage so that higher deforestation rate means higher $Def_{i,t}$.

Likewise, we incorporated a selection of biophysical data (slope, elevation). The list of covariates, the origins of data and summary statistics are presented in Table 1. In total after spatial matches of dataset, the information was gathered for 561 localities.

¹²The definition of what represents a forest is a multi-controversial issue. There are two basic approaches: one is based on the type of soil usage, the second on the density of trees present in a contiguous area. On the basis of our data, we adopted the second definition. The FAO defines a closed forest as a contiguous zone of 1ha with a tree density of at least 40%. In the case of Madagascar, a threshold of this order would have lead us to consider non natural forests such as eucalyptus plantations. A 78% threshold allowed us to closely reproduce the reference map of non- degraded forests in Madagascar drawn up by Conservation International. See for example, [29].

Table 1: Data and summary statistics

Source	Data & Variables	Mean All (Standard Deviation)	Mean PA (Standard Deviation)	Mean NPA (Standard Deviation)	Mean Unprotected (Standard Deviation)
SAPM-CIRAD	Network of protected areas	\			
	Annual mean deforestation rate (commune, 2000-12, in %)	2 (5)	0.8 (1)	1.4 (2)	2.7 (6)
Hansen/UMD/Google/USGS/NASA (2013)	Forest cover in <i>ha</i> within communes	8 445 (17 134)	18 469 (25 915)	13 676 (20 070)	3 067 (7 217)
	Travelling time to nearest town – rainy season (hours)	22 (24)	25 (24)	23 (28)	21 (22)
	Population in agricultural sector (%)	88 (16)	87 (16)	89 (15)	88 (18)
	Irrigated rice paddy per inhabitant (%)	13 (24)	14 (26)	13 (24)	13 (24)
ILO-CORNELL	Poor people (%) ^a	51 (25)	50 (27)	48 (25)	54 (25)
	Destitute people (%) ^b	9 (13)	7 (11)	9 (13)	10 (14)
	Police (1 if yes) ^c	0.59 (0.49)	0.55 (0.49)	0.6 (0.48)	0.6 (0.49)
	Population commune 2001	13 451 (8 202)	12 118 (8 361)	13 189 (7 634)	13 995 (8 294)
	Population district (Average 2001-12)	193 615 (70 897)	164 939 (73 584)	185 672 (61 406)	206 274 (70 176)
INSTAT	Average slope (%)	8.4 (3.5)	10.7 (3.4)	9.2 (2.9)	7.4 (3.4)
DEM data	Average elevation (meters)	580 (515)	725 (399)	609 (454)	522 (559)

a: "Those who face food security problems seasonally, whether it is a bad year or not" (ILO-Cornell)
b: "Those who do not have enough to eat throughout the year" (ILO-Cornell)
c: Defined as the presence of *Policiers* and/or *Gendarmes*

4 The impact of Protected Areas On Forest Cover Losses And Its Mediators: Methodology And Results

In this section, we first quantitatively validate our dual story of deforestation by necessity and opportunistic deforestation with our data. Then, we expose why simple regression techniques fails to capture a causal impact of PAs on deforestation and present a sequential identification strategy of the impact with two methodologies: repeated cross section matching to obtain first causal insights, then post-matching regressions to refine our definition of the counterfactual and of the treatment, and analyze mechanisms. For each step, we present the methodology then the estimates.

4.1 Starting Point: A Quantitative Validation

We first confirm our story of deforestation drivers with a panel regression on the whole sample of localities. Results are presented in Table 2. As we expect, we find a lower deforestation rate in localities in which policemen are present, i.e. in which initial opportunities of deforestation are *ceteris paribus* lower. As well, deforestation increases with the share of poorest people confirming the idea of a deforestation by necessity. The relationship is attenuating as the share of destitute people increase: the marginal increase of deforestation with poverty rate is positive yet diminishing. Interestingly as in Thomas et al. (2007) and Gorenflo et al. (2011), we do not find evidence at a locality scale of a link between population and deforestation [50]¹³.

Summary statistics from Table 1 and results from Table 2 also indicate that deforestation rates are lower inside localities impacted by PAs than outside them. A simple mean comparison - the most naive estimate of an impact of a PA, indicates that deforestation within historic PAs is more than four times lower than in unprotected localities (Table 1). However, important differences regarding the characteristics of localities for which forests are protected and the ones for which forests are not protected prevent us to conclude directly for an impact. Simply controlling for observable covariates through a simple regression already reduces the impact by almost two (Table 2).

Doing that is still not fully satisfactory to obtain a quantification of the causal impact. Indeed, PAs are for example located structurally in more forested, more isolated and less populated localities than outside PAs (Figure 2). In other words, PAs are located in areas that are less prone to forest clearing in essence. Taking every unprotected localities for the analysis would constitute a poor counterfactual of what would have happened with PAs even when controlling for observable differences. We use matching methods to correct for these differences.

¹³Lets however recall that we only capture a dynamic of population growth at a district level which does not allow us to study finely the relation at the locality scale

Table 2: Validation of deforestation drivers

	(1)	(2)
VARIABLES	Poor + Destitutes	Destitutes
Poors	0.000303* (0.000173)	
Poors ²	-2.78e-06* (1.60e-06)	
Destitutes		0.000260 (0.000229)
Destitute ²		-3.65e-06 (3.31e-06)
Policemen	-0.00333* (0.00189)	-0.00353* (0.00182)
Travel time (rainy season)	-6.99e-05 (4.92e-05)	-5.93e-05 (5.21e-05)
Irrigated rice	-0.000167*** (4.54e-05)	-0.000172*** (4.55e-05)
Population (district)	0 (0)	0 (0)
Population 2001 (locality)	1.36e-07 (1.44e-07)	1.59e-07 (1.41e-07)
Tree cover	-1.47e-08*** (4.78e-09)	-1.33e-08*** (4.52e-09)
Slope	-0.00132*** (0.000335)	-0.00129*** (0.000337)
Elevation	2.56e-05*** (4.27e-06)	2.56e-05*** (4.40e-06)
PA	-0.00863*** (0.00204)	-0.00851*** (0.00206)
NPA	-0.00728*** (0.00189)	-0.00727*** (0.00189)
Constant	0.00499 (0.00557)	0.00890** (0.00443)
Observations	6,571	6,571
Number of id	558	558
Year FE	Yes	Yes

Clustered standard errors (locality) in parenthesis
*** p<0.01, ** p<0.05, * p<0.1

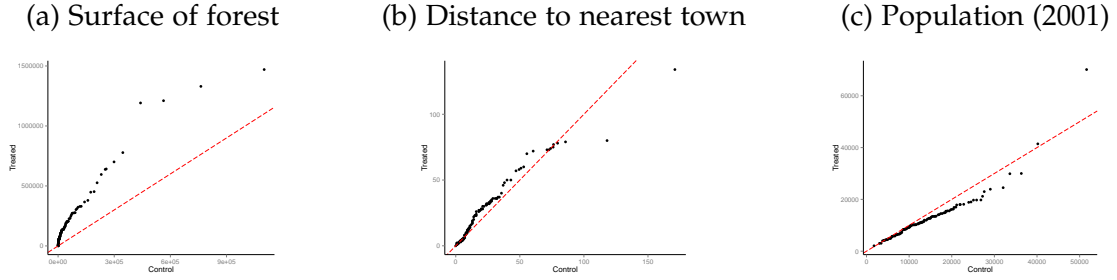


Figure 3: A poor counterfactual before matching: An illustration

4.2 Matching

4.2.1 Methodology

Matching methods aim at obtaining better counterfactuals by creating pairs of observations that are comparable in every observable aspects X_i that are likely to influence the level of the outcome (apples to apples comparisons), but one: being impacted by the policy reform (treated group, T) or not (control group, C). We select X_i in light of the findings from the literature studying the determinants of tropical deforestation [3, 34] presented in Table 1. The underlying assumption to obtain an unbiased causal estimator of PAs on deforestation is that X_i is taking into account all the variables that are affecting deforestation. This is the so-called unconfoundedness hypothesis [45]:

$$Def_i^T, Def_i^C \perp PA | X_i \quad (2)$$

However, the more covariates we control for, the more difficult it is to find pairs of similar observations in a finite sample. To overcome this curse of dimensions, one solution would consist in enlarging the sample size by conducting an analysis at a pixel level. Because we have a rich socio-economic data set defined at a locality scale, it makes more sense to stick to our aggregated scale. Instead, we use the Genetic Matching approach developed by Diamond and Sekhon (2012) [17]. Genetic Matching finds the optimal weight to give to each covariates in order to maximize the quality of the balance between control and treated groups and so reduce both the bias and the mean square error of the estimated causal effect. We choose a one to one nearest neighbor matching. To limit further potential bias, we use caliper to improve covariates balance. Calipers define the limit of tolerated quality of our matches. If a match do not lie below the caliper limit, then it is excluded. We fix this limit to half of the standard deviation of matching covariates. As robustness checks, we also conduct analyzes at pixel level and test our results with different matching estimators (Mahalanobis, Propensity Score, equal weights, 2 nearest Neighbor). Each method provide consistent estimates of the Average Treatment of the Treated (ATT) over the years 2001-12 (Figure 6).

Even if we take pains to draw up an exhaustive list of covariates to control for, we cannot exclude the possibility of the presence of unobserved heterogeneity biasing the results and their causal interpretation. For NPAs, we have pre-treatment observations of the outcomes at least for 3 years. We use them to correct for pre-treatment

differences using a Difference-in-Difference (DID) matching approach. Consistency of DID rely on the conditional parallel trend assumption in which we assume that unobserved heterogeneity can be present among observations but is time invariant. In other words, we assume that before treatment, unprotected treated and controls follow the same trend.

For both PAs and NPAs, we use as rolling control groups all the localities that are not impacted by PAs during the studied year, that is localities that have never been impacted by any PA over the period and localities that will be impacted by a PA but that yet don't have one the year we make the estimation. We present two different graphs for the results: one for historic PAs and the second one for NPAs.

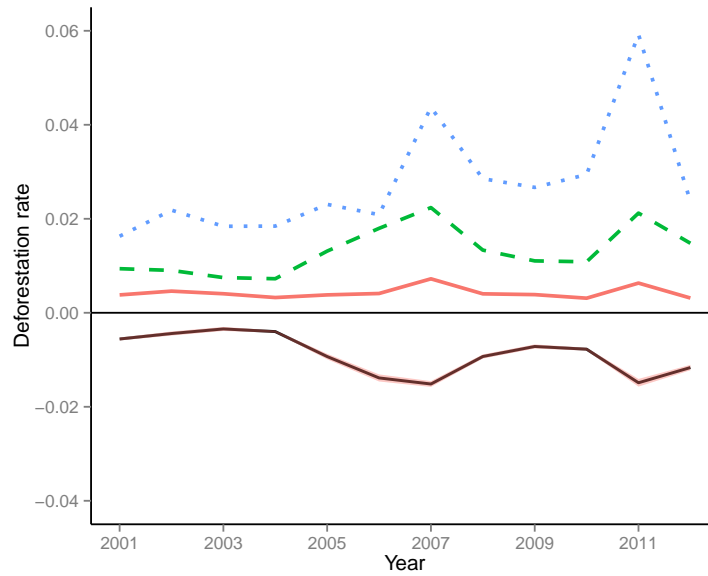
4.2.2 Matching Results

The results of the environmental effectiveness of PAs and NPAs are synthesized in Figure 4. The balance is presented in Appendix 7.1. The average deforestation rate in treated areas is in red (plain) and the average deforestation rate in control areas is in green (long dash). In blue (small dash), we draw the deforestation rate for every unprotected areas (matched ones and unmatched ones). The ATT is in black. For the period 2001-2012, Figure 4 - a strongly suggests that historic PAs have helped curbing annual deforestation without halting it. As for NPAs (Figure 4 - b and c), the early impact appears much more limited particularly because of the higher heterogeneity in the impact among localities as reflected by larger confidence intervals.

Deforestation in unprotected areas has been erratic, with a major upsurge in overall deforestation from 2007, closely coinciding with the beginning of the disintegration of the state power, leaving even greater windows of opportunities for deforestation. On the contrary, deforestation within PAs and to a lesser extent within NPAs has been stable, only wavering marginally from one year to another in a consistently positive direction (around 0.5% per year), and has been systematically inferior to deforestation within unprotected localities. This trend however seems not to show signs of having receded over the 12 previous years, revealing, for the time being, a level of deforestation which is incompressible.

These first matching results strengthens us in identifying two mediators explaining the impact: (1) PAs might have reduced opportunities of deforestation (no upsurge during the political crisis), and (2) the persistence of a stable positive trend of deforestation suggest that deforestation by necessity continues.

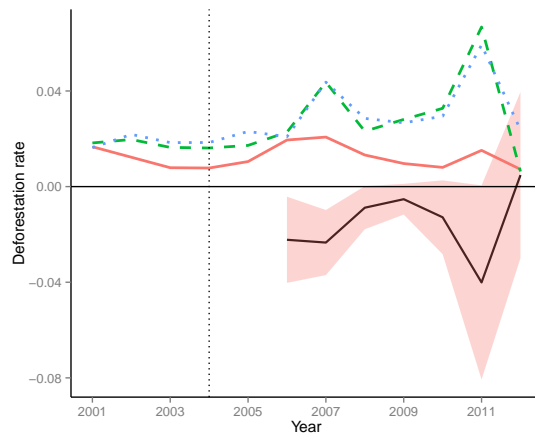
(a) PAs vs unprotected areas that year vs all unprotected areas, 01-12



(b) NPAs vs matched unprotected areas vs all unprotected areas, DID estimate, 06-12



(c) NPAs created before 2007 vs matched unprotected areas vs all unprotected areas, DID estimate, 06-12



Note: For the treated group in (b) the left graph: we take before 2004 every localities as none was impacted by PAs at the time. From 2005, we take as treated localities that have the current year been concerned by the creation of a NPA.

Figure 4: The impact of PAs and NPAs on deforestation in the Eastern forest corridor, 2001-12

Differences in outcomes before treatment when dealing with NPAs suggest that unobserved heterogeneity might remain in our estimates between protected and unprotected areas. When controlling it with DID for NPAs, we do not find a systematic additionality anymore. Focusing on early created NPAs, we do not find a a better impact neither. However, the common trend hypothesis necessary for DID is hardly satisfied particularly when focusing on those early created ones which makes our DID-estimate probably biased.

To control for this unobserved heterogeneity, we propose to use the classification of new PAs to construct a tighter control group by only taking localities targeted for the creation of NPAs. The rationale is that if some forests have been classified instead of others, it might reveal a stronger similarities between them and existing PAs in terms of anthropic pressures compared to the ones that remain unclassified at the end of the period.

We expect in this framework that before treatment, a significant difference in deforestation rate should exist between them and already protected forests, and that this difference should decrease when treatment occurs. Doing so in a static cross-section framework would be poorly convincing. We have to refine the construction of our treatment to analyze this switch in protection status to particularly capture potential anticipation effects and lags between the official creation and actual implementation when getting closer from the year of the classification of the forest.

4.3 Regression

4.3.1 Methodology

Following the insights from matching, we now combine pre-matching of data and regressions techniques. Matching helps us to stick with a more convincing counterfactual while regressions allow us to construct a finer definition of our treatment variable and to test for moderators that might explain this partial efficiency of PAs.

For that, we construct the variable $Ttreat$: the time in years between the date of observation and the official creation of the PA:

$$Ttreat_{i,t} = Year - Year\ creation_{i,t} \quad (3)$$

We hence have $Ttreat_{i,t} < 0$ before the creation of the PA in locality i at date t and $Ttreat > 0_{i,t}$ after its creation. Even before their creation, we can expect impacts of PA of an undefined sign. On the one hand, the official creation of a PA is generally marking the end of a policy process of several years so that before creation creation, early interventions might have initial impacts. On the other hand, a purely economics rationale can lead to a negative impact before creation through anticipations effects from locals: it is better to clear land now before the creation rather than when it will be protected as sanctions and control will increase through time. As well, $Ttreat$ might matter after treatment. For NPA, we might observe initial lags before observing first impact on the ground so that the impact of PAs might be a function of the length of time the treatment has been implemented. $Ttreat$ will hence allow us to explicit this dynamic in the measurement of the effect.

We rely on the rolling base enrollment of new localities within the period to construct our treatment Tr as a 3-levels variable with $Tr = 0$ for localities with historic PAs created before 1990, $Tr = 1$ for localities not yet under protection and $Tr = 2$ for localities when the new PA has been created. We use $Tr = 0$ as a baseline to observe potential shift in values when new localities become protected.

We enrich the dynamic of our model by exploring differences in the intensity of the effect between years by conditioning the impact on years dummies on top of standard years fixed effects. We finally test for hypothesis regarding a decrease of

opportunistic deforestation and *statu quo* of deforestation by necessity by considering them as moderators of the effect, defining a moderator as "a variable that is unaffected by the intervention and whose value affects the magnitude of an impact" (Ferraro and Hanaueur 2014).

The full model we estimate is

$$Def_{i,t} = \alpha + \beta_1 Tr + \beta_2 Tr \times Ttreat + \beta_3 Tr \times \mu_t + \beta_4 Tr \times Police + \beta_5 Tr \times Poverty + x'_{i,t} \gamma + z'_i \zeta + v_{i,t} ; v_{i,t} = u_{i,t} + c_i \quad (4)$$

μ_t represents a year fixed effect, $x'_{i,t}$ a 2-dimensional row vector of time varying explanatory variables, z'_i a K-dimensional row vector of time invariant explanatory variables $u_{i,t}$ a normally distributed error term and c_i a random effect.

We expect for a current efficiency of PAs $\hat{\beta}_1|_{Tr=1} > 0$, that it deforestation in unprotected areas higher than inside PAs everything else being constant ; and $\hat{\beta}_1|_{Tr=2} = 0$ i.e. no remaining difference in deforestation rate between PAs and NPAs after treatment. For NPAs, we can at least expect a dynamic efficiency, that it is even if $\hat{\beta}_1|_{Tr=2}$ remains positive, $\hat{\beta}_2|_{Tr=2} < 0$ in order to β to become null in the long run.

4.3.2 Regression Results

Regression results are presented in Table 3. We present several specifications of the model that enrich progressively the definition of the impact. These results confirm the additionality of PAs whatever the specification is ($\beta_1|_{Tr=1} > 0$), and the uncertain additionality of NPAs: for half of specifications, a significant difference remains between NPAs and PAs after their creation ($\beta_1|_{Tr=2} > 0$) and no clear sign of dynamic impact after creation yet ($\hat{\beta}_2|_{Tr=2} = 0$)

Table 3: Regression results

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Binary Tr	Tr x Year	Tr x Time_Tr	Tr x Policemen	Tr x Poor + Des	Tr x Policemen + Tr x Poor + Des	Mechanisms / Tr x Time_Tr
Treat (base = Historic PAs)							
Unprotected ($\beta_1 _{Tr=1}$)	0.00287** (0.00131)	0.00378** (0.00185)	0.00211 (0.00246)	0.00550* (0.00310)	0.00868* (0.00463)	0.0107** (0.00472)	0.0117*** (0.00345)
NPA ($\beta_1 _{Tr=2}$)	0.00475*** (0.00177)	0.00214 (0.00194)	0.00150 (0.00270)	0.00395 (0.00372)	0.0112** (0.00567)	0.0124** (0.00606)	0.0160*** (0.00531)
Unprotected x Time Tr			0.000913** (0.000419)	0.000916** (0.000422)	0.000903** (0.000416)	0.000906** (0.000419)	
NPA x Time Tr			4.65e-05 (0.000442)	4.09e-05 (0.000443)	6.39e-05 (0.000446)	6.02e-05 (0.000447)	
Unprotected x Policemen				-0.00701*** (0.00261)		-0.00626** (0.00257)	-0.00632** (0.00259)
NPA x Policemen				-0.00504 (0.00367)		-0.00401 (0.00359)	-0.00409 (0.00360)
Unprotected x Poverty rate					-0.000102* (5.37e-05)	-8.61e-05* (5.19e-05)	-0.000102** (5.00e-05)
NPA x Poverty rate					-0.000158** (7.14e-05)	-0.000146** (6.96e-05)	-0.000164** (6.80e-05)
Time Tr			-1.00e-04*** (3.37e-05)	-9.49e-05*** (3.50e-05)	-8.05e-05** (3.42e-05)	-7.82e-05** (3.50e-05)	
Policemen	0.000368 (0.00140)	0.000470 (0.00140)	8.86e-05 (0.00142)	0.00319* (0.00189)	-0.000143 (0.00143)	0.00253 (0.00185)	0.00279 (0.00191)
Poverty rate	-0.000164 (0.000136)	-0.000165 (0.000136)	-0.000129 (0.000138)	-8.84e-05 (0.000130)	-4.68e-05 (0.000123)	-2.14e-05 (0.000119)	-3.61e-05 (0.000120)
Poverty rate ²	1.40e-06 (1.20e-06)	1.41e-06 (1.20e-06)	9.19e-07 (1.23e-06)	4.91e-07 (1.18e-06)	7.83e-07 (1.18e-06)	4.35e-07 (1.15e-06)	7.73e-07 (1.12e-06)
Tree Cover	-1.65e-08*** (3.52e-09)	-1.64e-08*** (3.51e-09)	-1.58e-08*** (3.57e-09)	-1.52e-08*** (3.39e-09)	-1.54e-08*** (3.57e-09)	-1.49e-08*** (3.42e-09)	-1.54e-08*** (3.42e-09)
Slope	-0.000460* (0.000235)	-0.000488** (0.000236)	-0.000371 (0.000247)	-0.000446* (0.000257)	-0.000338 (0.000245)	-0.000407 (0.000254)	-0.000480** (0.000242)
Elevation	6.76e-06** (2.84e-06)	6.54e-06** (2.80e-06)	6.19e-06** (2.85e-06)	6.40e-06** (2.81e-06)	6.05e-06** (2.77e-06)	6.24e-06** (2.74e-06)	6.61e-06** (2.69e-06)
Population district	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Population locality (2001)	3.45e-08 (1.06e-07)	1.92e-08 (1.06e-07)	2.05e-08 (1.08e-07)	1.49e-08 (1.07e-07)	8.00e-09 (1.03e-07)	4.66e-09 (1.03e-07)	8.12e-09 (1.01e-07)
Share irrigated rice	-7.85e-05** (3.74e-05)	-7.43e-05** (3.69e-05)	-8.62e-05** (3.87e-05)	-8.54e-05** (3.86e-05)	-8.92e-05** (3.83e-05)	-8.83e-05** (3.84e-05)	-8.21e-05** (3.71e-05)
Travel time nearest city (rainy season)	-1.70e-05 (2.54e-05)	-2.13e-05 (2.59e-05)	-2.34e-05 (2.54e-05)	-2.76e-05 (2.69e-05)	-2.21e-05 (2.52e-05)	-2.58e-05 (2.65e-05)	-2.21e-05 (2.66e-05)
Constant	0.0164*** (0.00448)	0.0165*** (0.00433)	0.0205*** (0.00434)	0.0190*** (0.00410)	0.0157*** (0.00428)	0.0150*** (0.00409)	0.0112*** (0.00424)
Observations	2,853	2,853	2,841	2,841	2,841	2,841	2,853
Number of id	248	248	247	247	247	247	248
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year x Tr	No	Yes	No	No	No	No	No
Time Treat x Tr	No	No	Yes	Yes	Yes	Yes	No

Clustered standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Overall, the impact of PAs has been quite limited. Deforestation in historic PAs is only 0.2% lower than the one in unprotected ones, that corresponds to a one-fifth decrease in deforestation directly attributable to PAs. For the 561 localities from our whole sample that were covered by 2 290 156ha in 2000, the annual saved forests through PAs is of 6 573 ha according to our estimates. Knowing that humid forests in Madagascar are able to store $2.24 \text{ tCo}_2 \text{ y}^{-1} \text{ ha}^{-1}$ (Vieilledent et al. 2014), it would correspond to a modest annual avoided contribution of $14 724 \text{ tCo}_2 \text{ y}^{-1}$ or $\$73 615 \text{ y}^{-1}$ for the current value of $\$5 \text{ tCO}_2^{-1}$.

We find that generally the time to exposure to the treatment tends to decrease deforestation. It is only altering the impact of PAs on deforestation before their creations. In other words, before PAs are created, as long as we got closer to the official date of creation ($T_{treat} \rightarrow -1$), the larger the difference in deforestation rate between existing PAs and unprotected PAs. After their creation, another year spent under protection does not increase so far the impact. A kind of anticipation seems to play a role, pushing first deforestation upward before creation of PAs.

Year differentiated impact: same results, differences in the impact. Create Table with only Yr x

Table 4: Yearly variations of the impact (Details of Column (2) - Table 3)

	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Unprotected x Year	Baseline	-0.00141 (0.00202)	-0.00712*** (0.00271)	-0.00134 (0.00176)	0.000474 (0.00216)	-0.00187 (0.00192)	0.00422 (0.00362)	0.0180** (0.00861)	0.000331 (0.00243)	0.00185 (0.00206)	-0.0136** (0.00602)	-0.00162 (0.00182)
NPA x Year				-0.00363 (0.00358)	-0.00475 (0.00350)	0.000522 (0.00159)	0.00143 (0.00194)	-0.000217 (0.00179)	0.00227 (0.00210)	0.00570*** (0.00191)	0.00817*** (0.00309)	Baseline

From Section 2, we have stated that the intrinsic logic of establishing PAs in a quasi law-less state like Madagascar was to increase law enforcement on the ground to tackle opportunistic deforestation. We test how the impact varies regarding initial variations in law enforcement measured by the presence of policemen in the locality. We find that in unprotected areas, the difference of deforestation with PAs is lower when there is policemen in the localities: where initial law enforcement was lower, the additional impact of PAs is larger. However, when having a PA in the locality, the additional presence of policemen does not decrease even more deforestation or when having policemen in the locality, the addition of PA does not bring more impact. PAs and policemen might appear as substitutes here. Both can increase the effectiveness of laws on the ground but only to a certain point. The extent of the territories under consideration are generally large, located in extremely remote areas and the means put in place to achieve protection are limited. The median locality impacted by a PA is reported to be located at about 14 hours driving from the nearest city during the rainy season in the ILO-Cornell database. More, 35% of these localities even are reported to be at more than 24h driving. For them, enforcing law appears as a particular challenge. Regarding the lack of means, Madagascar has one forestry officer for approximately 30,162 hectares of natural forest compared for example with one to every 421 hectares in the neighboring La Reunion Island ¹⁴. Despite this dilution, the lack of an upsurge in deforestation throughout the period, as politically unstable

¹⁴Environment Secretary, presentation during PHCF Day - 18 September 2012, quoted by Brimont 2004: p 68.

as it was, is the evidence of the achievement of a certain degree of an environmental effectiveness of PAs.

We also have pointed out that deforestation was caused by a necessity to access some new lands for marginalized households. PAs managers have developed ICDP programs to tackle this issue of higher reliance on resources from the poorest households. Results are showing a weaker impact of PAs as long as poverty rates increase. The persistence of weaker but yet existent opportunities to deforest allowed locals to continue to deforest to satisfy their needs. The establishment of a PAs and ICDP seems to have had little effectiveness on the improvement of local populations' living conditions as it is recognized by some conservation actors themselves [22].

ICDPs' have notably been financed by incomes generated from visitor entrance fees to the PA-NPAs. However, these incomes turned out to be paltry and unequally distributed. Of the 30 PAs managed by Madagascar National Parks open to public visits, two of them accounted for almost 45% of total visits between 2005 and 2010, and 5 other parks generated a further 45% of visits. The rest, more than two thirds of PAs, generated less than 10% of visits (Figure 5). The margins for leeway to directly compensate on a commune wide-level and to finance programs were very fine for almost all the PAs¹⁵.

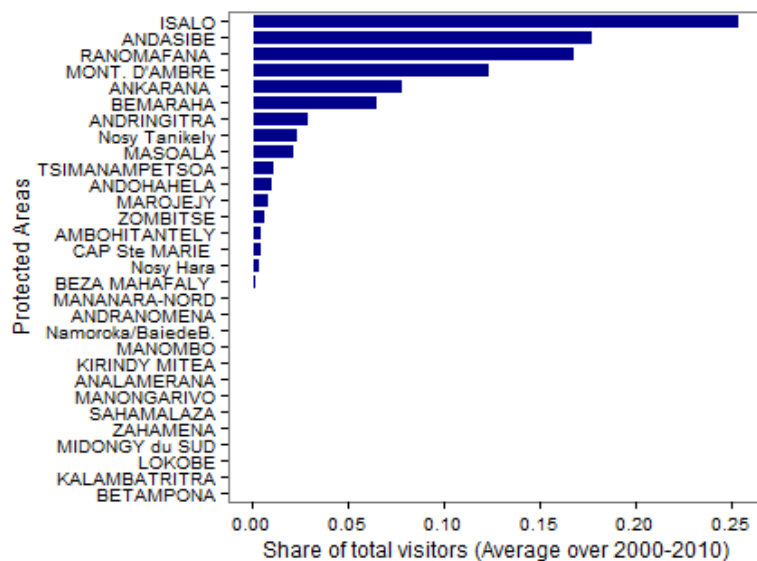


Figure 5: An unequal repartition of visitors

Beyond the lack of means, development programs haven't always had the expected effects due to deficiencies in the way they have been set up and because of strong local resistance to adopting new practices. In this way, several ICDPs have aimed to replace *tavy* by sedentary modes of rice farming. The number of farmers

¹⁵So that the Zahamena National Park which has an average of 5 visitors a year was only just capable of refunding \$7 a year to the affected communes (Personal communication, Manistra Razafintsalama). Data cited here are the courtesy of MNP

accepting to give up *tavy* has been rarely consequential [39] and, even when an improvement in yields is observed, once the project is completed, the number of farmers abandoning the alternative method is high. Other programs aim to replace rice farming by alternative animal-rearing activities (fish or poultry farming) or cash cropping. In these cases, the remoteness of a population can represent a hindrance to the sale of their produce. Such programs, without any insurance mechanisms have exposed farmers to important fluctuations of commodities prices Price slumps in the 1980s and in the price of vanilla since 2004 have jeopardised farmers' livelihoods, preventing them from accessing basic goods and necessities, in turn exposing them to food insecurity. These situations have driven farmers to react by increasing forest clearance to make way for new *tavy* as is the case in the Mananara Nord Reserve, as well as illegal felling or overfishing and poaching¹⁶. Over and above the implementation of restrictions associated with access to markets and price fluctuations, some authors have highlighted the intrinsic restrictions of these "conservation by distraction" mechanisms [21], which bear the inherent causes of future upsurges in deforestation (rebound effects) by virtue of the increased costs of conservation opportunities created automatically by the programs' success [42].

As a consequence, the addition of development activities for populations living adjacent to PAs appears not to have succeeded in reducing their reliance on forestry resources to a sustainable level. Consistently sustained demographic growth showing hardly any signs of slowing down, the absence of social programs in the strategies of conservation stakeholders, and the *de facto* lack of incentives designed to compensate for weaknesses in the control mechanisms and state sanctions contribute to explaining the continued stable deforestation rate over the period.

5 Discussion: A Necessary Reorientation Of Conservation Policies To Stop Deforestation

Deforestation in Madagascar is a persistent feature despite the establishment of PAs. Whilst our results show that PAs have helped to slow down its rate at least by blocking the upsurge effects inherent to the country's political instability, they also indicate that this public intervention strategy has failed to entirely curb deforestation. Our analysis leads us to conclude that this incapacity will persist, than halting deforestation will at least requires some ambitious agricultural reforms which would need to be tethered to the conservation agenda.

Despite certain affirmations [16, 47], it is hard to believe that the ten of thousands of farming households who still depend today on access to forests to fulfil their basic subsistence needs will convert to tour guides and eco-tour operators. Taking account of the inadequacies of amenities, tourism will continue to concentrate in the few suitably adapted zones and will remain strongly linked to the national, if not international, political setting. It appears then necessary to implement a true agricultural

¹⁶For examples, see Huttel C., Toubel L., Clüsner-Godt, M., 2002, La Réserve de Biosphère de Mananara-Nord –un défi pour la conservation et le développement intégrés, Rapport d'étude de l'Association Nationale pour la Gestion des Aires Protégées, UNESCO/ANGAP

transition, an unavoidable condition for the improvement in living conditions of local populations [36], and investment by the institutions in a rule of law.

Yet, the means mobilized by conservation stakeholders often are insufficient to meet this challenge. In the Ankeniheny-Zahamana Corridor (CAZ), the management documents allow for only around \$13 per household per year (average between 2007 and 2012) to bring about agricultural transition. In the *Programme Holistique de Conservation des Forêts* (PHCF) in the south of the country, the sums are even lower: \$3 in 2010 and 2011 [13]. Meanwhile, even projects which have invested \$100 per household haven't managed to make the implemented transition last¹⁷. Pointing at the failure of small rural development programs is not new but rather dates back from the end of the first phase of the first ambitious conservation policy of the early 1990s, the National Environmental Action Plan (Pollini 2011). Yet, nothing has really changed up to now.

5.1 Promote A Greater Articulation Of Sectoral Policies

In Madagascar, not only public expenditure targeting the agriculture sector is low (around 8% of public expenditures¹⁸), agricultural development programs as well are concentrated in places where maximization of food production is the most likely (suitable soils, infrastructures and climatic conditions). In the eastern region of Madagascar, one of the only projects of "ecological intensification" is the one of the Alaotra Lake, one of the largest rice production areas of the country, where no-tillage practice are developed and proposed to farmers. Recent official document as the *Readiness-Preparation Proposal* (R-PP) submitted by the Government of Madagascar to the *Forest Carbon Partnership Facility* for REDD+ emphasizes the need to promote more intensive agriculture practices in order to settle slash-and-burn-oriented farmers, but fails to recognize the need to combine important investments in applied research and the adoption of new agro-silvo-pastoral practices by farmers surrounding the PAs. Moreover, the R-PP seems hesitant to engage this way, as it mentions just after the risk of rebound effect, through the possibility that an increase of the agricultural intensity raises the pressure of forest resources. Such a concern is widespread within the environmental NGOs – especially the non-Malagasy ones – operating in Madagascar and explains why they frequently give priority to non-agricultural "revenues-generating activities" (such as beekeeping, ecotourism...) over efforts towards what is called agricultural ecological intensification [15] around the core of the PAs. This concern is also reflected in publications by Angelsen and Kaimowitz who suggested strategies of agriculture intensification only in areas far away of forests [5].

To address this issue about potential rebound effect, we would suggest combining investment for ecological intensification of agriculture (in a large sense, including husbandry and agroforestry) and direct incentives for conservation. A potential instrument for this, would be a program of investment-oriented PES [33], which could integrate in a single instrument conditional payments for conservation and control,

¹⁷We refer here to the COGESFOR project and its interventions in the area of Didy. See the project's capitalization material [38].

¹⁸see Alliance for a Green Revolution in Africa, *Africa Agriculture Status Report : Focus on Staple Crops*

and additional investments for introducing more productive and sustainable agriculture practices. These last would be conditioned also to conservation efforts but the investment component would be separated from the direct payments associated with conservation results – which is not the case, today, with the few PES-like experienced by some REDD+ projects.

A pre-requisite for this strategy to work is the clarity and the security of land and resource tenure for the targeted farmers. The transfer of the management of resources to local communities is an instrument available for this. As well, Madagascar received from 2006 assistance from the Millennium Challenge Account to undertake a large program of land securization, through simplified and decentralized land titling (“certificats fonciers”). This program nonetheless terminated with the 2009 coup. While this effort might resume with the new political situation, it would be appropriate that such initiative also targets forested areas, taking account the specificity of the PAs legal status but contributing to increase the legal security of local farmers.

Given the hybrid dimension of such investment-oriented PES, the funding of such programs would not have to rely only to conservation-oriented budget and international aid (such as a national REDD+ fund). As one can expect a revitalization of investment in the agriculture sector, it would be critical that the efforts to implement ecological intensification of agriculture through PES in forested areas will be supported largely by public expenditures for agriculture.

6 Conclusion

In this article, we have outlined the processes which, according to us, explain deforestation in the east of Madagascar, allowing a better appreciation of the effectiveness of current conservation policies. We suggest that current deforestation originates from a combination of a need to clear the forest (*deforestation by necessity*) and opportunities left by the deficiencies of the legal and institutional framework (*opportunistic deforestation*). We find that the establishment of PAs appears to succeed in minimizing these opportunities. NPAs efficiency is not yet certain but time might still be necessary to observe first impacts. We find that PAs do act as a mean to better enforce law on the ground but that their additionality decrease with the rate of poverty inside localities. Consistent with the later finding, the persistence of a stable deforestation trend testifies to the failure observed of local development programs [22] and of the persistence of *deforestation by necessity*.

Let’s note that deforestation data as the ones used here are not precise enough to capture fully activities like selective timber extraction or small scale mining activities. Such activities rather are a source of forest degradation than deforestation but still have impacts on biodiversity losses. Deforestation is only the visibly detectable part of the problem and halting, or curbing it cannot directly ensure the maintenance of the whole panoply of services rendered by forestry ecosystems. We unfortunately cannot say with our study in which extent PAs have altered these activities.

We believe that in order to permanently eradicate deforestation in Madagascar, an adjustment in the conservation policy strategy must be applied. The response to the necessary transition in agricultural practices is far too often a secondary measure and

used by conservation stakeholders to buy social peace following the implementation of access restrictions. It is crucial however that these issues be made a primary objective forcing an articulation to be found between the agendas of development and conservation. Obviously, achieving this agricultural transition is not simply a matter of means and will not be without its challenges. The failure of the agricultural transition towards new practices is also not the only fault of conservation actors but also the failure of agronomists and development actors to propose credible alternatives to peasants. At this juncture, we do not have all the available answers to develop the best strategy for implementing it. In a very hierarchical almost caste-based society, it is a challenge to know how to reach the most vulnerable families through collective programs and to avoid funds being siphoned off by the local elite. The same applies to the social acceptability of more individualized programs and the transaction costs generated. All this remains nonetheless in the domain of design problems to be removed and these difficulties should not serve as a pretext for the adjustment of the national policy strategy.

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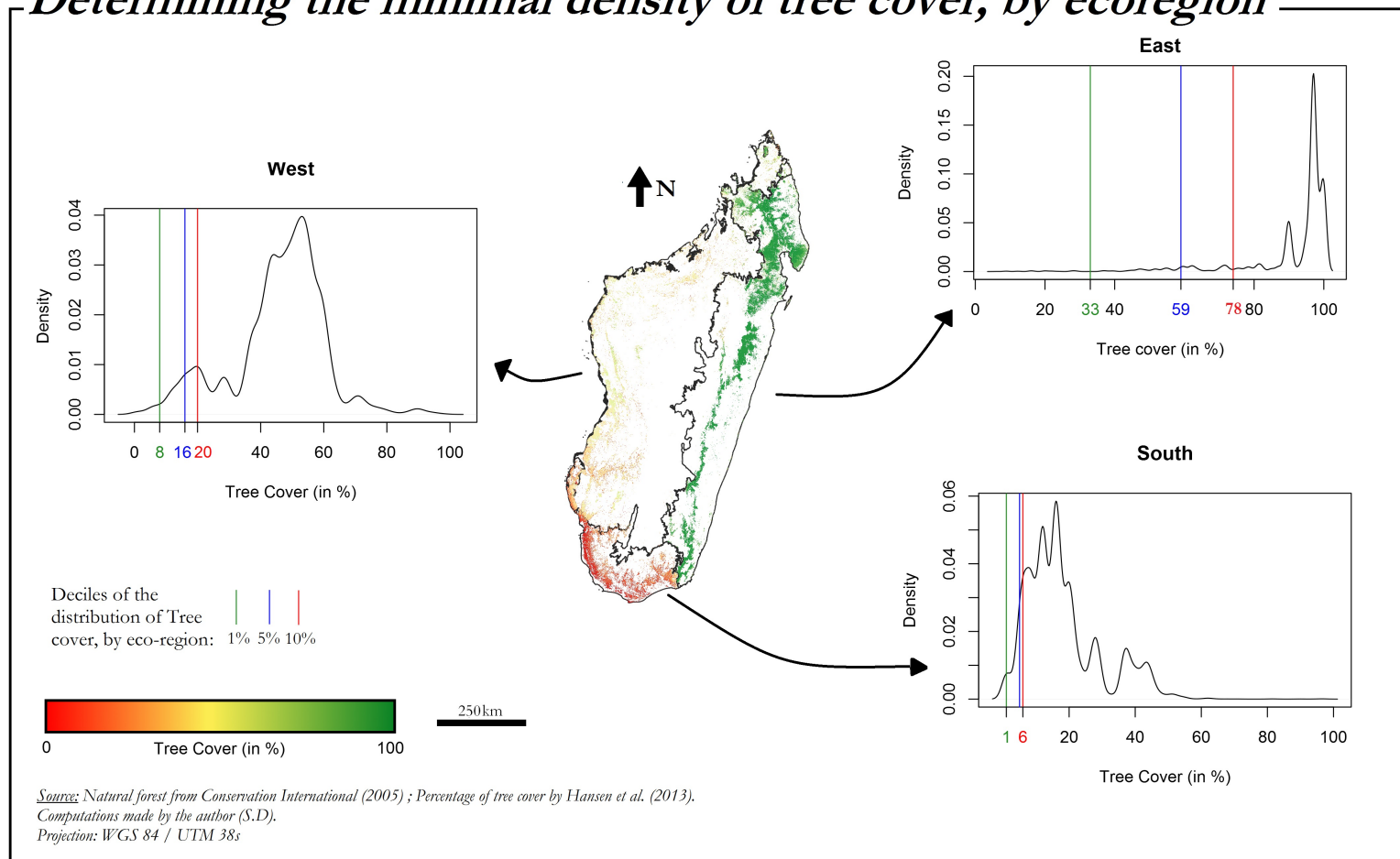
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7 Appendix

7.1 Defining Forest With Hansen et al. (2013)

Determining the minimal density of tree cover, by ecoregion



Note: Depending on each eco-region, the tree cover of a natural forest differs. From Hansen et al. (2013) data, we have to select different thresholds of tree cover cover to define a natural forest. We select these thresholds using Conservation International's map of natural forests and determine for the three eco-regions what is the minimal tree cover density that defines a natural forest. Vertical lines represent the deciles of the distribution of tree cover for each area. The red one represents the 10th decile. It means that 10% of the area has a tree cover density inferior to this threshold and that 90% of the area has a tree cover superior to this threshold.

7.2 Balance

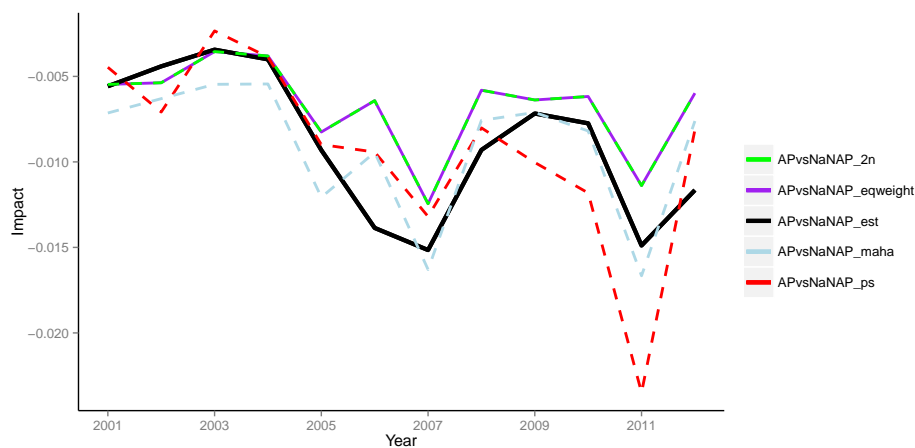
Table 5: Balance of the matching

	(a) PAs, mean difference		(b) NPAs, mean difference	
	Before	After	Before	After
Population 2001	-22.3	-1,6	-10	12
Slope	96***	14***	63***	9*
Slope square	125***	18***	52***	9
Elevation	51***	3	21**	8
Travel time to nearest city (rainy season)	16**	3	7	5
Population in agricultural sector (%)	-10	-12	56	-15
Irrigated rice paddy per inhabitant (%)	2	10	-1	11
Poor people (%)	-12	-4	-22	-14
Destitute people (%)	-28**	3	-3	-0.3
Pop district 2005	-55***	-0,7	-30***	-6
Pop district 2011	-61***	1	-39***	-1
Irrigated rice paddy per inhabitant (%) * slope	13	11	6	8

*Mean difference between treated and control. Bootstrapped p-value used (1000 iterations). * : significant at 10%
** : sign at 5%*** : sign at 1%.*

7.3 Robustness Checks 1: Different Matching Procedures

7.3.1 Cross Section Matching



7.3.2 Panel Results

Table 6: 2 nearest neighbors pre-matching

VARIABLES	(1) Binary Tr	(2) Tr x Year	(3) Tr x Time_Tr	(4) Tr x Policemen	(5) Tr x Poor + Des	(6) Tr x Policemen + Tr x Poor + Des	(7) Mechanisms / Tr x Time_Tr	(8) Mechanisms / Tr x Time_Tr
0.Treat_NAPvsAP	0.00381*** (0.00130)	0.00325* (0.00190)	0.00469** (0.00236)	0.00703** (0.00280)	0.0135*** (0.00449)	0.0147*** (0.00442)	0.0131*** (0.00322)	0.0131*** (0.00322)
2.Treat_NAPvsAP	0.00601*** (0.00180)	0.00328* (0.00193)	0.00365 (0.00263)	0.00505 (0.00348)	0.0157*** (0.00560)	0.0160*** (0.00584)	0.0178*** (0.00519)	0.0178*** (0.00519)
0.Treat_NAPvsAP#c.time_treat			0.00100** (0.000417)	0.00101** (0.000419)	0.000987** (0.000413)	0.000991** (0.000416)		
2.Treat_NAPvsAP#c.time_treat			0.000219 (0.000443)	0.000215 (0.000443)	0.000234 (0.000446)	0.000233 (0.000447)		
0.Treat_NAPvsAP#1.pres_policiers				-0.00511** (0.00222)		-0.00406* (0.00223)	-0.00381* (0.00220)	-0.00381* (0.00220)
2.Treat_NAPvsAP#1.pres_policiers				-0.00317		-0.00183	-0.00161	-0.00161
0.Treat_NAPvsAP#c.pauvres_dem					-0.000132*** (4.97e-05)	-0.000121** (4.93e-05)	-0.000128*** (4.58e-05)	-0.000128*** (4.58e-05)
2.Treat_NAPvsAP#c.pauvres_dem					-0.000189***	-0.000182***	-0.000191***	-0.000191***
time_treat			-5.56e-05* (2.89e-05)	-5.68e-05** (2.88e-05)	-2.64e-05 (3.01e-05)	-2.87e-05 (2.97e-05)		
1.pres_policiers	-0.00103 (0.00133)	-0.000947 (0.00132)	-0.00106 (0.00135)	0.000991 (0.00146)	-0.00142 (0.00140)	5.83e-05 (0.00150)	-9.95e-06 (0.00150)	-9.95e-06 (0.00150)
pauvres_dem	-0.000128 (0.000134)	-0.000128 (0.000134)	-0.000117 (0.000135)	-9.88e-05 (0.000130)	-3.92e-06 (0.000123)	2.84e-06 (0.000120)	2.74e-06 (0.000120)	2.74e-06 (0.000120)
pauvres_dem2	1.18e-06 (1.14e-06)	1.18e-06 (1.14e-06)	9.67e-07 (1.16e-06)	7.65e-07 (1.12e-06)	6.70e-07 (1.09e-06)	5.42e-07 (1.08e-06)	6.38e-07 (1.07e-06)	6.38e-07 (1.07e-06)
Tree78_	-1.20e-08*** (3.18e-09)	-1.18e-08*** (3.16e-09)	-1.17e-08*** (3.22e-09)	-1.13e-08*** (3.04e-09)	-1.10e-08*** (3.25e-09)	-1.08e-08*** (3.12e-09)	-1.09e-08*** (3.11e-09)	-1.09e-08*** (3.11e-09)
pent_e_mean	-0.000409* (0.000209)	-0.000436** (0.000210)	-0.000361* (0.000217)	-0.000388* (0.000218)	-0.000324 (0.000215)	-0.000347 (0.000216)	-0.000378* (0.000208)	-0.000378* (0.000208)
altitude_mean	5.61e-06* (2.92e-06)	5.37e-06* (2.88e-06)	5.43e-06* (2.97e-06)	5.38e-06* (2.89e-06)	5.11e-06* (2.85e-06)	5.10e-06* (2.79e-06)	5.08e-06* (2.72e-06)	5.08e-06* (2.72e-06)
pop_dist200	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
pop2001	4.09e-08 (9.30e-08)	2.51e-08 (9.34e-08)	4.50e-08 (9.59e-08)	4.88e-08 (9.62e-08)	2.93e-08 (9.11e-08)	3.29e-08 (9.18e-08)	1.83e-08 (9.03e-08)	1.83e-08 (9.03e-08)
pourcentage derizires irrigues prb	-7.28e-05* (4.02e-05)	-6.82e-05* (3.97e-05)	-8.21e-05* (4.20e-05)	-8.26e-05** (4.17e-05)	-8.56e-05** (4.15e-05)	-8.59e-05** (4.14e-05)	-7.93e-05** (3.98e-05)	-7.93e-05** (3.98e-05)
dure du voyage vers lecupensaisonds	-3.16e-05 (2.50e-05)	-3.59e-05 (2.56e-05)	-3.17e-05 (2.49e-05)	-3.40e-05 (2.60e-05)	-3.15e-05 (2.46e-05)	-3.33e-05 (2.53e-05)	-3.56e-05 (2.54e-05)	-3.56e-05 (2.54e-05)
Constant	0.0155*** (0.00422)	0.0163*** (0.00406)	0.0185*** (0.00429)	0.0177*** (0.00412)	0.0122*** (0.00440)	0.0120*** (0.00424)	0.00989** (0.00398)	0.00989** (0.00398)
Observations	2,853	2,853	2,841	2,841	2,841	2,841	2,853	2,853
Number of id	248	248	247	247	247	247	248	248
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year x Tr	No	Yes	No	No	No	No	No	No
Time Treat x Tr	No	No	Yes	Yes	Yes	Yes	No	No

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table 7: Matching with Equal weights

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
VARIABLES	Binary Tr	Tr x Year	Tr x Time_Tr	Tr x Policemen	Tr x Poor + Des	Tr x Policemen + Tr x Poor + Des	Mechanisms / Tr x Time_Tr
0.Treat_NAPvsAP	0.00381*** (0.00130)	0.00325* (0.00190)	0.00469** (0.00236)	0.00703** (0.00280)	0.0135*** (0.00449)	0.0147*** (0.00442)	0.0131*** (0.00322)
2.Treat_NAPvsAP	0.00601*** (0.00180)	0.00328* (0.00193)	0.00365 (0.00263)	0.00505 (0.00348)	0.0157*** (0.00560)	0.0160*** (0.00584)	0.0178*** (0.00519)
0.Treat_NAPvsAP#c.time_treat			0.00100** (0.000417)	0.00101** (0.000419)	0.000987** (0.000413)	0.000991** (0.000416)	
2.Treat_NAPvsAP#c.time_treat			0.000219	0.000215	0.000234	0.000233	
0.Treat_NAPvsAP#1.pres_policiers				-0.00511** (0.00222)		-0.00406* (0.00223)	-0.00381* (0.00220)
2.Treat_NAPvsAP#1.pres_policiers				-0.00317 (0.00336)		-0.00183 (0.00332)	-0.00161 (0.00329)
0.Treat_NAPvsAP#c.pauvres_dem					-0.000132*** (4.97e-05)	-0.000121** (4.93e-05)	-0.000128*** (4.58e-05)
2.Treat_NAPvsAP#c.pauvres_dem					-0.000189*** (6.83e-05)	-0.000182*** (6.78e-05)	-0.000191*** (6.54e-05)
time_treat			-5.56e-05* (2.89e-05)	-5.68e-05** (2.88e-05)	-2.64e-05 (3.01e-05)	-2.87e-05 (2.97e-05)	
1.pres_policiers	-0.00103 (0.00133)	-0.000947 (0.00132)	-0.00106 (0.00135)	0.000991 (0.00146)	-0.00142 (0.00140)	5.83e-05 (0.00150)	-9.95e-06 (0.00150)
pauvres_dem	-0.000128 (0.000134)	-0.000128 (0.000134)	-0.000117 (0.000135)	-9.88e-05 (0.000130)	-3.92e-06 (0.000123)	2.84e-06 (0.000120)	2.74e-06 (0.000120)
pauvres_dem2	1.18e-06 (1.14e-06)	1.18e-06 (1.14e-06)	9.67e-07 (1.16e-06)	7.65e-07 (1.12e-06)	6.70e-07 (1.09e-06)	5.42e-07 (1.08e-06)	6.38e-07 (1.07e-06)
Tree78_	-1.20e-08*** (3.18e-09)	-1.18e-08*** (3.16e-09)	-1.17e-08*** (3.22e-09)	-1.13e-08*** (3.04e-09)	-1.10e-08*** (3.25e-09)	-1.08e-08*** (3.12e-09)	-1.09e-08*** (3.11e-09)
pente_mean	-0.000409* (0.000209)	-0.000436** (0.000210)	-0.000361* (0.000217)	-0.000388* (0.000218)	-0.000324 (0.000215)	-0.000347 (0.000216)	-0.000378* (0.000208)
altitude_mean	5.61e-06* (2.92e-06)	5.37e-06* (2.88e-06)	5.43e-06* (2.97e-06)	5.38e-06* (2.89e-06)	5.11e-06* (2.85e-06)	5.10e-06* (2.79e-06)	5.08e-06* (2.72e-06)
pop_dist200	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
pop2001	4.09e-08 (9.30e-08)	2.51e-08 (9.34e-08)	4.50e-08 (9.59e-08)	4.88e-08 (9.62e-08)	2.93e-08 (9.11e-08)	3.29e-08 (9.18e-08)	1.83e-08 (9.03e-08)
pourcentagederiziresirriguesprb	-7.28e-05* (4.02e-05)	-6.82e-05* (3.97e-05)	-8.21e-05* (4.20e-05)	-8.26e-05** (4.17e-05)	-8.56e-05** (4.15e-05)	-8.59e-05** (4.14e-05)	-7.93e-05** (3.98e-05)
dureduvoyageverslecupensaisonsds	-3.16e-05 (2.50e-05)	-3.59e-05 (2.56e-05)	-3.17e-05 (2.49e-05)	-3.40e-05 (2.60e-05)	-3.15e-05 (2.46e-05)	-3.33e-05 (2.53e-05)	-3.56e-05 (2.54e-05)
Constant	0.0155*** (0.00422)	0.0163*** (0.00406)	0.0185*** (0.00429)	0.0177*** (0.00412)	0.0122*** (0.00440)	0.0120*** (0.00424)	0.00989** (0.00398)
Observations	2,853	2,853	2,841	2,841	2,841	2,841	2,853
Number of id	248	248	247	247	247	247	248
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Table 8: Matching with Propensity Score Matching

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
VARIABLES	Binary Tr	Tr x Year	Tr x Time_Tr	Tr x Policemen	Tr x Poor + Des	Tr x Policemen + Tr x Poor + Des	Mechanisms / Tr x Time_Tr
0.Treat_NAPvsAP	0.00381*** (0.00130)	0.00325* (0.00190)	0.00469** (0.00236)	0.00703** (0.00280)	0.0135*** (0.00449)	0.0147*** (0.00442)	0.0131*** (0.00322)
2.Treat_NAPvsAP	0.00601*** (0.00180)	0.00328* (0.00193)	0.00365 (0.00263)	0.00505 (0.00348)	0.0157*** (0.00560)	0.0160*** (0.00584)	0.0178*** (0.00519)
0.Treat_NAPvsAP#c.time_treat			0.00100** (0.000417)	0.00101** (0.000419)	0.000987** (0.000413)	0.000991** (0.000416)	
2.Treat_NAPvsAP#c.time_treat			0.000219 (0.000443)	0.000215 (0.000443)	0.000234 (0.000446)	0.000233 (0.000447)	
0.Treat_NAPvsAP#1.pres_policiers				-0.00511** (0.00222)		-0.00406* (0.00223)	-0.00381* (0.00220)
2.Treat_NAPvsAP#1.pres_policiers				-0.00317 (0.00336)		-0.00183 (0.00332)	-0.00161 (0.00329)
0.Treat_NAPvsAP#c.pauvres_dem					-0.000132*** (4.97e-05)	-0.000121** (4.93e-05)	-0.000128*** (4.58e-05)
2.Treat_NAPvsAP#c.pauvres_dem					-0.000189*** (6.83e-05)	-0.000182*** (6.78e-05)	-0.000191*** (6.54e-05)
time_treat			-5.56e-05* (2.89e-05)	-5.68e-05** (2.88e-05)	-2.64e-05 (3.01e-05)	-2.87e-05 (2.97e-05)	
1.pres_policiers	-0.00103 (0.00133)	-0.000947 (0.00132)	-0.00106 (0.00135)	0.000991 (0.00146)	-0.00142 (0.00140)	5.83e-05 (0.00150)	-9.95e-06 (0.00150)
pauvres_dem	-0.000128 (0.000134)	-0.000128 (0.000134)	-0.000117 (0.000135)	-9.88e-05 (0.000130)	-3.92e-06 (0.000123)	2.84e-06 (0.000120)	2.74e-06 (0.000120)
pauvres_dem2	1.18e-06 (1.14e-06)	1.18e-06 (1.14e-06)	9.67e-07 (1.16e-06)	7.65e-07 (1.12e-06)	6.70e-07 (1.09e-06)	5.42e-07 (1.08e-06)	6.38e-07 (1.07e-06)
Tree78_	-1.20e-08*** (3.18e-09)	-1.18e-08*** (3.16e-09)	-1.17e-08*** (3.22e-09)	-1.13e-08*** (3.04e-09)	-1.10e-08*** (3.25e-09)	-1.08e-08*** (3.12e-09)	-1.09e-08*** (3.11e-09)
pente_mean	-0.000409* (0.000209)	-0.000436** (0.000210)	-0.000361* (0.000217)	-0.000388* (0.000218)	-0.000324 (0.000215)	-0.000347 (0.000216)	-0.000378* (0.000208)
altitude_mean	5.61e-06* (2.92e-06)	5.37e-06* (2.88e-06)	5.43e-06* (2.97e-06)	5.38e-06* (2.89e-06)	5.11e-06* (2.85e-06)	5.10e-06* (2.79e-06)	5.08e-06* (2.72e-06)
pop_dist200	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
pop2001	4.09e-08 (9.30e-08)	2.51e-08 (9.34e-08)	4.50e-08 (9.59e-08)	4.88e-08 (9.62e-08)	2.93e-08 (9.11e-08)	3.29e-08 (9.18e-08)	1.83e-08 (9.03e-08)
pourcentagederiziresirriguesprb	-7.28e-05* (4.02e-05)	-6.82e-05* (3.97e-05)	-8.21e-05* (4.20e-05)	-8.26e-05** (4.17e-05)	-8.56e-05** (4.15e-05)	-8.59e-05** (4.14e-05)	-7.93e-05** (3.98e-05)
dureduvoyageverslecupensaisonsds	-3.16e-05 (2.50e-05)	-3.59e-05 (2.56e-05)	-3.17e-05 (2.49e-05)	-3.40e-05 (2.60e-05)	-3.15e-05 (2.46e-05)	-3.33e-05 (2.53e-05)	-3.56e-05 (2.54e-05)
Constant	0.0155*** (0.00422)	0.0163*** (0.00406)	0.0185*** (0.00429)	0.0177*** (0.00412)	0.0122*** (0.00440)	0.0120*** (0.00424)	0.00989** (0.00398)
Observations	2,853	2,853	2,841	2,841	2,841	2,841	2,853
Number of id	248	248	247	247	247	247	248
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Table 9: Matching with Mahanobolis distance

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
VARIABLES	Binary Tr	Tr x Year	Tr x Time_Tr	Tr x Policemen	Tr x Poor + Des	Tr x Policemen + Tr x Poor + Des	Mechanisms / Tr x Time_Tr
0.Treat_NAPvsAP	0.00377*** (0.00124)	0.00327* (0.00185)	0.00462* (0.00240)	0.00730** (0.00296)	0.0148*** (0.00433)	0.0159*** (0.00436)	0.0139*** (0.00314)
2.Treat_NAPvsAP	0.00587*** (0.00172)	0.00277 (0.00169)	0.00338 (0.00270)	0.00510 (0.00365)	0.0168*** (0.00546)	0.0171*** (0.00579)	0.0185*** (0.00503)
0.Treat_NAPvsAP#c.time_treat			0.000987** (0.000414)	0.000990** (0.000416)	0.000971** (0.000410)	0.000974** (0.000412)	
2.Treat_NAPvsAP#c.time_treat			0.000255 (0.000439)	0.000251 (0.000439)	0.000272 (0.000443)	0.000270 (0.000444)	
0.Treat_NAPvsAP#1.pres_policiers				-0.00522** (0.00224)		-0.00371* (0.00219)	-0.00365* (0.00216)
2.Treat_NAPvsAP#1.pres_policiers				-0.00323 (0.00340)		-0.00143 (0.00330)	-0.00140 (0.00327)
0.Treat_NAPvsAP#c.pauvres_dem					-0.000153*** (4.90e-05)	-0.000141*** (4.83e-05)	-0.000145*** (4.55e-05)
2.Treat_NAPvsAP#c.pauvres_dem					-0.000210*** (6.74e-05)	-0.000202*** (6.64e-05)	-0.000208*** (6.41e-05)
time_treat			-5.39e-05** (2.63e-05)	-4.83e-05* (2.64e-05)	-2.07e-05 (2.72e-05)	-1.89e-05 (2.72e-05)	
1.pres_policiers	-0.00107 (0.00132)	-0.000995 (0.00131)	-0.00130 (0.00135)	0.000854 (0.00144)	-0.00178 (0.00139)	-0.000439 (0.00143)	-0.000336 (0.00145)
pauvres_dem	-0.000115 (0.000126)	-0.000115 (0.000126)	-0.000106 (0.000127)	-9.87e-05 (0.000122)	7.91e-06 (0.000109)	6.40e-06 (0.000108)	7.33e-06 (0.000108)
pauvres_dem2	1.16e-06 (1.08e-06)	1.16e-06 (1.08e-06)	9.74e-07 (1.09e-06)	8.68e-07 (1.05e-06)	8.00e-07 (1.01e-06)	7.44e-07 (9.91e-07)	7.94e-07 (9.77e-07)
dureduvoyageverslecupensaisonsds	-3.90e-05 (2.62e-05)	-4.31e-05 (2.66e-05)	-4.15e-05 (2.59e-05)	-4.18e-05 (2.69e-05)	-3.87e-05 (2.57e-05)	-3.92e-05 (2.63e-05)	-4.11e-05 (2.64e-05)
Tree78_	-1.18e-08*** (3.18e-09)	-1.16e-08*** (3.14e-09)	-1.09e-08*** (3.18e-09)	-1.11e-08*** (3.02e-09)	-1.10e-08*** (3.28e-09)	-1.12e-08*** (3.17e-09)	-1.14e-08*** (3.13e-09)
pente_mean	-0.000710*** (0.000220)	-0.000735*** (0.000220)	-0.000667*** (0.000230)	-0.000685*** (0.000232)	-0.000594*** (0.000225)	-0.000611*** (0.000227)	-0.000632*** (0.000215)
altitude_mean	6.59e-06** (3.16e-06)	6.34e-06** (3.11e-06)	6.30e-06* (3.23e-06)	6.33e-06** (3.15e-06)	5.86e-06* (3.05e-06)	5.91e-06** (3.02e-06)	5.87e-06** (2.91e-06)
pop_dist200	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
pop2001	1.05e-07 (9.60e-08)	9.07e-08 (9.57e-08)	1.04e-07 (9.95e-08)	1.07e-07 (9.93e-08)	8.89e-08 (9.14e-08)	9.21e-08 (9.20e-08)	7.89e-08 (8.95e-08)
pourcentage deriziresirriguesprb	-7.94e-05* (4.30e-05)	-7.46e-05* (4.24e-05)	-8.83e-05** (4.49e-05)	-8.86e-05** (4.43e-05)	-9.12e-05** (4.37e-05)	-9.13e-05** (4.36e-05)	-8.54e-05** (4.19e-05)
Constant	0.0164*** (0.00410)	0.0172*** (0.00397)	0.0197*** (0.00423)	0.0187*** (0.00404)	0.0125*** (0.00398)	0.0123*** (0.00390)	0.0105*** (0.00359)
Observations	2,853	2,853	2,841	2,841	2,841	2,841	2,853
Number of id	248	248	247	247	247	247	248
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes

7.4 Robustness Checks 2: Results At The Pixel Level

The *Conservation Evaluation 2.0* literature has both relied on aggregate scale and pixel scale analyzes. As robustness checks, we redo the statistical work on PAs' efficiency at pixel scale and show that our results at locality scale remain consistent (Table 4).

We have drawn a random sample of around 60 000 forested pixels in 2000. Each pixel represents a surface of around 30m².

PAs appears to have decreased deforestation following a similar pattern as the one presented in Figure 2. When taking every unprotected pixels as a control, we find that if Year 2002 at locality scale just pass the significance test, it appears now not to. Interestingly, we find an overall effect over the period 2001-12 of $-4,47\%$ which is close from the 5% from Gorenflo et al. (2011) over 1990-00. It would suggest that the magnitude of the impact has been similar for the 1990's and the 2000's.

The lower impact we find when focusing solely on PAs v.s. NPAs not yet established -our strategy to control stronger unobservables, is also confirmed here. Its magnitude at pixel scale appears even weaker than at locality scale.

Table 10: Robustness checks

Y= Impact of PAs on the probability for a pixel to be deforested		
Year	(a) PAs vs NAs	(b) PAs vs NAP
2001	-0,45%***	-0,03%
2002	-0,60%***	-0,03***%
2003	-0,04%	-0,04%
2004	-0,43%***	-0,43%***
2005	-0,59%***	
2006	-0,56%***	
2007	-0,46%***	
2008	-0,36%***	
2009	-0,29%***	
2010	-0,90%***	
2011	-0,40%***	
2012	-0,34%***	
2001-12	-4,47%***	
2001-04		0%

Standard deviations in brackets. * : significant at 10% ** : sign at 5%
 *** : sign at 1%. We control here for the same covariates as before
 , plus the euclidean distance to roads, slope and elevation at pixel level.