How Protected Areas Reduce Deforestation? An Exploration of the Economic and Political Mechanisms for Madagascar's Rainforests (2001-12)*

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Résumé

Madagascar's notoriously high level of biodiversity is currently threaten by deforestation. Protected Areas (hereafter "PAs") remain until now the central instrument to protect it whilst little is known about their environmental effectiveness in the country. With a matching approach in a quasi-natural experiment setting, we demonstrate for the entire island's rainforest that PAs' additionality has been limited from 2001 to 2012. PAs have made it possible for deforestation to be stabilized in a trend and has restricted the upsurge of deforestation resulting from the country's late political instability. Nonetheless, post-matching analyzes reveal that PAs have only contained some of the causes of deforestation. Effectively stopping the latter will require further ambitious policies to trigger the necessary agricultural transition for the country.

JEL Codes : Q2, Q28, Q58, 013

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1 Introduction

Impact evaluation of conservation policies still lags behind many other fields such as education, health of development policies (Baylis et al. 2015). Impact evaluations of PAs has attracted attention of many scholars (Systematic review Geldmann et al.) but few of these studies are meeting best practices standards which has often lead to overstestimmaiton of impacts (Joppa). Another area is also only burgening now : a more careful analysis of the mechanisms behind these results (Ferraro).

This paper presents an analysis of the impact of Protected Areas on deforestation in Madagascar, annually between 2000 and 2012.

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* [1, 2].

This threat to Madagascar's unique biodiversity can be explained by the reduction and fragmentation of natural habitats, most notably generated by a continuous process of deforestation over the past decades [3, 4] . Whilst it would be difficult to estimate precisely the original surface area of the island's forests [5], it is possible that half of the forests have disappeared, particularly since the middle of the 1950s [6]. 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 [7].

From 1927, PAs have started to be established as a mean of conserving a "few specimens of the fauna and flora" [1]. 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 from 1996 to 2014 [2] 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 forests [3]

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

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

3. Authors' 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.

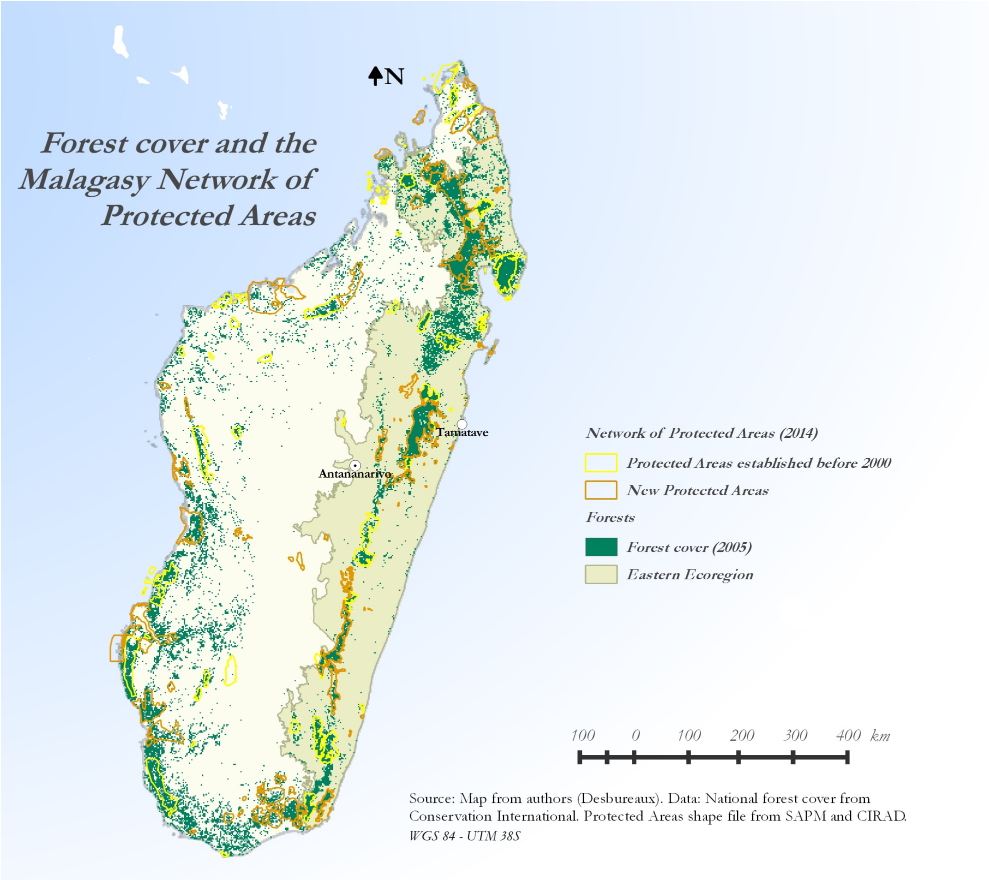


FIGURE 1 – PAs and Forest cover

and number of the interested parties involved in conservation is continuing to press for the extension of this network [8] [4]. Yet, we know very little of the real effectiveness of these PAs in Madagascar.

A few studies, in fact, show that the establishment of PAs across the tropics has contributed to reducing deforestation [9, 10, 11, 12, 13, 14]. Overall, estimates show that their additionality might have been limited [15]. To our knowledge, two studies reveal the environmental impact of PAs in Madagascar [16, 17] and both 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 [17]. 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 third study [18] 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 in these three studies and that the authors offer little explanation of the nature of a causal mechanism that would explain this limited effect. Moreover, the implicit exogeneity assumption of PAs location made by the authors have been challenged in the literature [19]. If not

4. Going 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".

satisfied, results would be inconsistent.

In the present article, we clarify the causes of deforestation in Madagascar and draw up an analytical 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 [20, 21] , and an opportunistic deforestation following the difficulties of the fragile authorities to enforce law. We 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. This stabilization suggests that PAs have helped in reducing opportunistic deforestation. Nonetheless, the persistence of a positive trend of deforestation and post-matching analyzes revealing a lower impact among poorer localities indicate that PAs have failed in haltering deforestation by necessity. To this end, it seems policies would need to be readjusted and to develop further for real agricultural transition to take hold in the country if the goal is to effectively stop deforestation.

We believe the contribution of this paper to the literature to be threefold. First, our analysis is extending the scope of the "*Conservation Evaluation 2.0*" research program [15] geographically to a new 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. Second, the new time series of deforestation data compiled by Hansen et al. (2013) [22] 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, in a methodological perspective, the Malagasy context allows us to go further than previous comparable studies regarding the possibility to control for unobserved biases between treated and control groups. The extension of the network of PAs represent for us a context of a quasi-natural experiment that allow to control for pre-treatment differences in outcomes in a DID-matching model. If some impact evaluations of Payments for Environmental Services (PES) have been able to use this kind of data [23], most studies regarding PAs lack them. Here, we show that controlling for pre-treatment differences in outcomes attenuates the impact.

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 discuss in Section 5 why a readjustment of conservation policies and strategy is crucial to curb deforestation in Madagascar.

2 Understanding deforestation in Madagascar

2.1 Different anthropic factors

Deforestation in Madagascar can be attributed for the most part to two major types of human activities : small scale agriculture on the one hand and the extraction of timber and non-timber forest products on the other hand. Rice farming by itinerant slash and burn, known as *tavy*, is the primary economic activity of most rural households in the east of the country, despite being officially prohibited since the 1860s. It has been recognized as the main source of pressure on the forests in this region since the beginning of the colonial era [24]. 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 [25]. 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 [26]. Likewise, farming the slopes allows farmers to reduce their exposure to the high risk of cyclone damage in this part of the island [5]. Finally, over and above a simple economic activity, *tavy* is a socially-rooted practice which replicates a certain type of social organization [27].

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 households [6].

2.2 The "Poverty-environment trap" situation : deforestation by necessity

These various pressures show that households are almost entirely dependent on the access to the resource 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 [28]. There are also

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

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

economic factors : households are directly exposed to the strong volatility of markets for agricultural commodities, whether it be rice, vanilla or cloves. They are physically isolated by their remoteness from the major markets thus limiting 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. Finally, there are also the climactic factors (the frequent passage of cyclones). Households respond to this by clearing the forest, which leads to a situation that we call here a *deforestation by necessity*, one which enables households to fulfil their subsistence requirements in response to their state of socio-economic fragility. This situation fully corresponds to the well-known "poverty-environment trap" [29, 21].

2.2.1 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 [30], the legal and regulatory framework is often misunderstood or disregarded by citizens [31], whilst government officials often come up against numerous flaws and inconsistencies [32].

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 year 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. 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 [33]. 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 checkpoints [7].

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

7. Estimates 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.

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 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) [34], 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.

2.3 Curbing deforestation

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. 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 [35], various local development compensatory programs have been initiated. 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 envisaged [8]. These development programs are often launched on a community-wide level, based on management transfers that NGOs generally create to accompany NPAs. We will now study whether or not this strategy has effectively made it possible to reduce deforestation in the eastern part of the country.

8. See, 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)

3 Data and empirical strategy

3.1 Data

This paper is concerned with assessing the environmental effectiveness of the PAs and NPAs located inside Madagascar's network of protected areas (SAPM) in 2014, both temporary and permanently [9]. Our study deals with their environmental effectiveness with respect to the additional deforestation their presence has or has not enabled to avoid in areas initially moderately or not at all degraded (i.e. in places with major biodiversity and carbon issues) within the island's eastern ecoregion. To that end, we used data from Hansen et al. (2013), who compiled more than 740,000 Landsat images for analysing annual global deforestation between 2000 and 2012 [22].

We define little or slightly degraded tropical rainforest as areas presenting a forest canopy greater than or equal to 78% in 2000 [10]. We aggregated this data on a commune-wide level ; a scale for which we have detailed socio-economic data collected by the ILO-Cornell project (2001) and INSTAT data. We retained only the communes where the surface area of forest is at least 50ha as PAs are aiming at protecting sufficiently large forest patches. Likewise, we incorporated a selection of biophysical data. The list of covariates, the origins of data and summary statistics are presented in Table 1. In total, the information was gathered for 561 communes, 109 of which are concerned by the existence of PAs and 126 by NPAs.

3.2 The fundamental problem of evaluation

We questioned whether the establishment of PA has brought about a significant reduction in the rate of deforestation in the communes concerned. We formalize the problem using the framework of potential outcomes [36]. Let' denote by PA, the presence of a PA -the treatment, and Def_i the rate of deforestation in locality i -the outcome. Def_i^T correspond to the outcome for a locality i with a PA (treated) while Def_i^C correspond to the outcome in the same locality i but without the PA (control). The expected impact of PAs can thus be expressed as :

$$E[Def_i^T - Def_i^C] \tag{1}$$

The fundamental issue of policy evaluation is that Def_i^T and Def_i^C cannot be observed simultaneously. All the analyzis for us hence consists in finding the best counterfactual scenario that simulates deforestation that would have happened at

9. What in fact interests us is that the local residents should in practice perceive the notion of a protected status.

10. The 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 already degraded areas, where rainforest is concerned. 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, [6].

Table 1 – Data and summary statistics

Source	Data & Variables	Mean (Standard Deviation)
SAPM-CIRAD	Network of protected areas	
Hansen/UMD/Google/USGS/NASA (2013)	Deforestation rate (commune, here for the total period 2000-12, in %)	18 (17)
ILO-CORNELL	Travelling time to nearest town – rainy season (hours)	22 (24)
	Population in agricultural sector (%)	88 (16)
	Irrigated rice paddy per inhabitant (%)	13 (24)
	Poor people (%)[a]	51 (25)
	Destitute people (%)[b]	9 (13)
INSTAT	Population commune 2001	13451 (8202)
	Population district 2005	193486 (67929)
	Population district 2011	216291 (79484)
DEM data	Average slope (%)	8,42 (3,53)
	Average elevation (meters)	580 (515)

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)

time t in a locality with a PA if the later was absent. We can for that use a before-after and/or a with-without comparison. It is not possible to obtain the impact only by naive comparison in a with-without framework. Indeed, if we decompose 1, a well-known result is :

$$E[Def_i^T - Def_i^C] = E[Def_i^T - Def_i^C|PA = 1] - E[Def_i^T - Def_i^C|PA = 0] \quad (2a)$$
$$+ E[Def_i^C|PA = 0] - E[Def_i^C|PA = 1] \quad (2b)$$
$$+ E[Def_i^T|PA = 0] - E[Def_i^T|PA = 1] \quad (2c)$$

2.a corresponds to the impact we identify in a with-without framework. For 1 to be unbiased, we therefore have to got 2.b plus 2.c to equal 0 ; that is, the expected outcome of controls if they had been impacted by a PA would have been the same as the outcome of actual treated, and the expected outcome of treated if they had not been impacted by a PA would have been identical to the outcome of actual controls. PAs are generally located in areas with fewer anthropic pressures, that is to say in more remote, higher, less populated areas, that are less prone to deforestation than unprotected ones [19]. 2.a equal 0 would hence not hold in a naive with-without comparison. As well, in a before-after framework, a naive comparison would make us miss temporal trends in the outcome that we know is erratic. We have to construct more reliable counterfactuals.

3.2.1 The impact of existing PAs and Genetic Matching

Around half of PAs studied here have been established before 2000, the year we start to measure outcomes. For them, it is impossible to use pre-traetment observations. This problem has been the one faced by all previous "conservation evaluation 2.0" 's studies detailed in Miteva et al. (2012) [15].

We recreate statistically a more comparable reference scenario of what would happened without PAs by selecting through matching unprotected forests which are close to protected ones regarding observable variables denoted X_i we believe they influence the probability of deforestation. We select these covariates in light of the findings from the literature studying the determinants of tropical deforestation [37, 38] and hypothesize that we are taking into account all the variables that are affecting deforestation. This is the so-called unconfoundedness hypothesis [36] :

$$Def_i^T, Def_i^C \perp PA|X_i \tag{3}$$

However, the more covariates we control for, the more difficult it is to find similar matches in a finite size 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/smaller locality scale [11]. To face the curse of dimension problem, we instead use the Genetic Matching approach developed by Diamond and Sekhon (2012) [39]. Genetic Matching finds the optimal weight to give to each covariate 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 and use as a metric of similarity Mahalanobis distance. 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 in our analysis this limit to half of the standard deviation of matching covariates. As robustness checks, we also conduct analyzes at pixel level.

We estimate the annual *Average Treatment of the Treated* (ATT) of PAs over the years 2001-12 [12]. We use two different control groups. First, all the communes that have never been impacted by any PA over the period. Second, we also incorporate localities that will be impacted by a PA but that yet don't have one the year we make the estimation.

3.2.2 The issue of unobservables, the impact of NPAs and DID-matching

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 factors biasing the results and their causal interpretation. Particularly, what if matches before the treatment had different rates of deforestation ?

Previous studies from the *Conservation Evaluation 2.0* program on PAs were unable to control for pre-treatment differences in outcomes because of data limitations. Here,

11. As an example, the remoteness measure of the locality we have might be more informative than a euclidean distance to roads we could have construct at a pixel scale. Such measures would fail to take into account places' relief, the presence of footpaths, of some navigable rivers *etc*. There is here a trade-off between having a larger sample and risking to face a classical mismeasurement bias.

12. ATT instead of Average Treatment Effect (ATE) allow to relax partially 3 to :

$$Def_i^C \perp PA|X_i$$

the extension of the network of PAs with NPAs from 2004 represents for us an interesting natural experiment to evaluate more carefully the impact of PAs though a Difference-in-Difference (DID) matching approach. With DID, because only a part of observations will receive the treatment, the control group will allow us to control for time variations that are not caused by the exposure to treatment. The unconfoundedness hypothesis is restrained to :

$$(Def_{i,t_1} - Def_{i,t_0}) \perp PA|X_i \tag{4}$$

With t_0 and t_1 the pre-treatment and post-treatment moments. We simply have now a conditional parallel trend assumption in which we assume that unobserved heterogeneity can be present among observations but is time invariant. We match localities impacted by a NPA to localities that never have been and evaluate the annual DID impact :

$$E[(Def^T_{i,t+1} - Def^T_{i,t})|PA_{t+1} = 1] - E[(Def^C_{i,t+1} - Def^C_{i,t})|PA_{t+1} = 0] \tag{5}$$

For the pre-treatment outcome, we use the average annual deforestation rate for the years 2001-03. To get a sufficient sample size, we start to measure the impact from the year 2006 to 2012. We present two sets of results. First, we incorporate on a rolling base every NPA the year after they have been created. Second, because there might be some delay between the creation and the first effects, we only focus on the first NPAs created before 2006.

4 Results : The impact of the establishment of PAs and NPAs on deforestation rates

4.1 The impact of PAs on deforestation

The results of the environmental effectiveness of PAs created before 2000 are synthesized in Figure 2 and Table 2 columns (a) and (b). In Figure 2.a, the control group is composed of every localities without protection the year of the estimation which means both localities that have never been impacted by a PA and localities that will have in the following year (but not yet) a PA. In Figure 2.b, we restrict the control group to localities that have not been impacted by any PA. The balance is presented in Appendix 7.1. We present the mean difference with the control group that only contains localities that have never been under PA since adding to them not yet created NPAs can only increase the quality of the balance. We hence present the worst balance we attain.

The average deforestation rate in treated areas are in red (plain) and the average deforestation rate in control areas are in green (long dash). In blue (small dash), we draw the deforestation rate for every unprotected areas (matched ones and non matched ones). The ATT is in black.

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

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

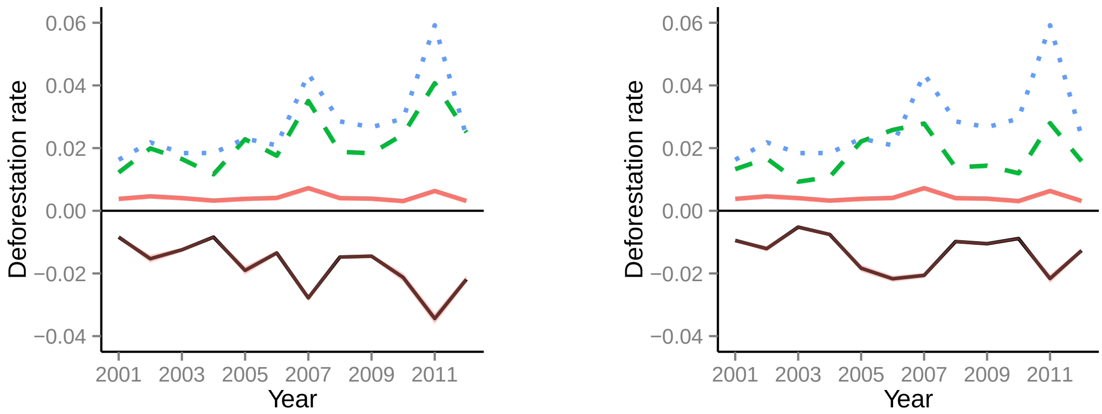


FIGURE 2 – The impact of PAs on deforestation in the Eastern forest corridor, 2001-12

TABLE 2 – Effectiveness of PAs NPAs (2001-2012)

	PA vs Na & NPA (*a*)	*PA vs NAs* (*b*)	*NPA vs Na* (*c*)	*NPA (<2006) vs NA* (*d*)
Year	*ATT*	*ATT*	*DID matching*	*DID matching*
2001	-0,0072*** (0,0024)	-0.0084*** (0,0022)		
2002	-0,0105*** (0,0048)	-0,0153*** (0,0063)		
2003	-0,0043*** (0,0026)	-0,0124*** (0,0034)		
2004	-0,0090** (0,0038)	-0,0084*** (0,0022)		
2005	-0,0183*** (0,0057)	-0.0190*** (0,0069)		
2006	-0,0175*** (0,0042)	-0.0134*** (0,0039)	-0.0199** (0,0601)	-0.0199** (0,0601)
2007	-0,0162*** (0,0037)	-0.0278*** (0,0052)	-0.0195*** (0,0054)	-0.0195 (0,0054)
2008	-0,0111*** (0,0027)	-0.0147*** (0,0029)	-0.0043 (0,0272)	-0,0055* (0,0270)
2009	-0,0066*** (0,0021)	-0.0144*** (0,0032)	-0,0021 (0,0272)	0,0038 (0,0271)
2010	-0,0089*** (0,0019)	-0.0212 (0,0071)	-0,0053 (0,0651)	0,0053*** (0,034)
2011	-0,0210*** (0,0071)	-0.034*** (0,0087)	-0,0112 (0,0722)	0,0167** (0,0651)
2012	-0,0102*** (0,0033)	-0.0218*** (0,006)	-0,0107* (0,0692)	0,0178** (0,0806)

Standard deviations in brackets. * : significant at 10% ** : sign at 5%*** : sign at 1%

For the period 2001-2012, Figure 2 strongly suggests that PAs have helped to curb, without halting, annual deforestation. Deforestation in unprotected areas has been erratic, with a major upsurge in overall deforestation from 2007, the year which marked the beginning of the disintegration of state power, leaving even greater windows of opportunity for deforestation. On the contrary, deforestation within PAs has been stable, only wavering marginally from one year to another in a consistently positive direction (around 0.5% per year). 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.

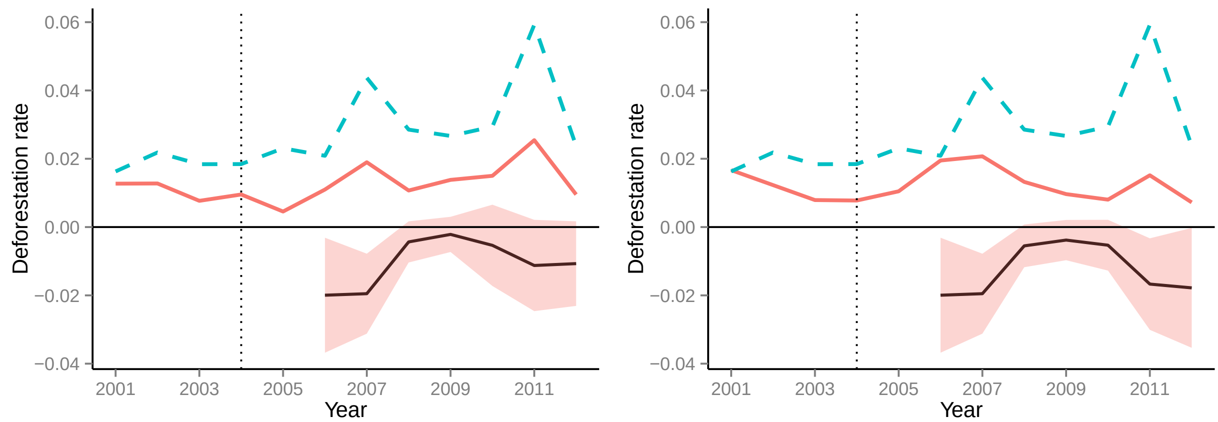
Figure 2 also confirms that matching estimates lead to a smaller impact than a naive comparison. Especially for the years 2007 and 2011 when the upsurge of deforestation was important, the impact using matching is up to 2 times lower than in a naive comparison. Controlling for deforestation drivers hence appears as crucial. We now show that controlling further for unobserved heterogeneity lower even less the impact.

4.2 Controling for unobserved heterogeneity : the early impact of NPAs on deforestation

Figure 3 provides the DID-matching estimate of the impact of NPAs. The blue dashed curb is the control group, the red plain one the treated group and the black one the estimated impact. Results suggests that the impact of PAs previously found might be overestimated because of a difference in initial outcomes despite the matching on observed covariates.

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

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



Note : For the treated group in 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 3 – The impact of NPAs on deforestation in the Eastern forest corridor, 2007-12

Taking every NPAs on a rolling basis the year after they have been created, we do not find a systematic additionality anymore. Because it might take some time to make effective the creation of a PA on the ground, we restrict the analysis to the first NAP created (the ones before 2007). With this specification, we find a slightly better impact. Similarly as in Figure 2, we also find that PAs are helping in stabilizing an erratic deforestation. Meanwhile, when national deforestation rates are moderate, the additionality of NPA is uncertain.

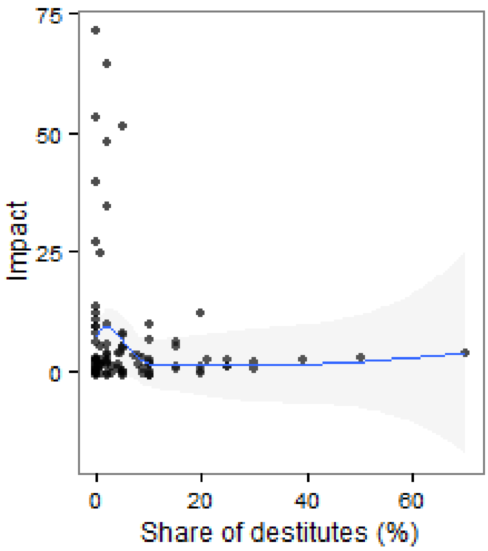
We proposed in Section 2 to differentiate two processes to explain deforestation : a deforestation by necessity and a opportunistic deforestation. Finding this stable trend od deforestation within PAs might suggest that their creation indeed blocked opportunities of deforestation (no upsurge) but did not solve the dependency to the resource (letting the trend to be positive). We confirm this interpretation through post-matching analyzes.

4.3 A heterogeneous impact across communes

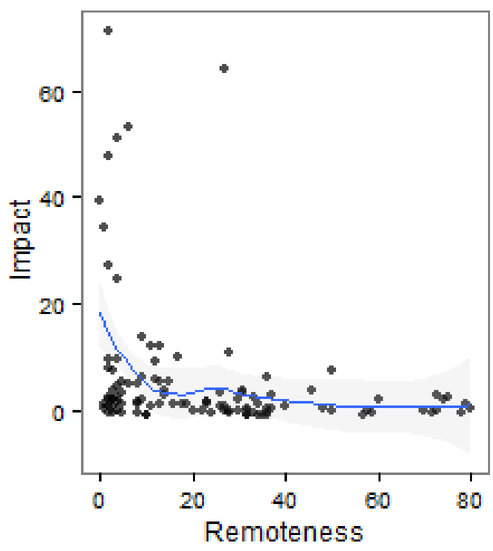
Regarding the distinction we have drawn between deforestation by necessity and opportunistic deforestation, we are particularly interested in how the impact of PAs varies when poverty and opportunities differ. Indeed, poorer households are the most likely to be dependent on the access to forests : the higher is poverty in locality, the more important is the issue of deforestation by necessity. As well, the more remote is a commune, the higher are the opportunities to deforest because of a weaker enforcement of law.

We analyze how the impact of PAs vary by level of high poverty and of remoteness through LOESS [14, 40]. To control for original differences between deforestation rates, we express the additionality in terms of the share of original deforestation PAs have allow to reduce by community Figure 4. For robustness, we present the results based on regressions techniques in Table 3. Both provide similar insights : firstly, the more remote is a locality, the weaker has been the impact of PAs. Secondly, the higher is the share of destitute people, the weaker again has been the effect of PAs.

Hence, have PAs been able to curb opportunistic deforestation in eastern Madagascar ? We have found that probably yes ; but LOESS results nuance by confirming that it is not the case everywhere. What's about deforestation by necessity ? The joint finding of a persistent trend of deforestation over the period within PAs, and of a decreasing additionality with higher poverty strongly suggest that no. We discuss these results in Section V.



(a) Impact of PAs by poverty levels, 01-12



(b) Impact of PAs by remoteness, 01-12

FIGURE 4 – LOESS analyzes

TABLE 3 – Post-matching analysis

Y= -Treatment of the treated/Deforestation_2001		
	(1)	(2)
Constant term	7,11 (6,07)	10,344 (6,47)
Population 2001	0 (0)	0 (0)
Slope	0,284 (0,236)	0,278 (0,22)
Elevation	0,001 (0,002)	0 (0,002)
Travelling time to nearest town – rainy season (hours)	-0,100** (0,039)	-0,292*** (0,1)
Travelling time^2		0,002** (0,001)
Population in agricultural sector (%)	-0,04 (0,045)	-0,035 (0,038)
Irrigated rice paddy per inhabitant (%)	0,036 (0,035)	0,028 (0,033)
Poor people (%)	-0,027 (0,029)	-0,015 (0,12)
Poor people^2		0 (0)
Destitute people (%)	-0,119** (0,058)	-0,324** (0,13)
Destitute people^2		0,004** (0,002)

Note : *** p<0.01, ** p<0.05, * p<0.1. OLS estimation. Robust standard errors in parenthesis (Eicker-White correction).
Despite the squares, the marginal relationship between on the one hand poverty and remoteness, and additionality never become positive.

5 Discussion

5.1 PAs, *opportunistic deforestation* and *deforestation by necessity*

5.1.1 A partially achieved reduction in the failure of the forestry management system

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. But in reality, these two objectives are tempered by the extent of the territories under consideration and the means put in place to achieve them [13].

Despite this dilution, the lack of an upsurge in deforestation throughout the period, as politically unstable as it was, is the evidence of the achievement of a certain degree of a environmental effectiveness of PAs. Has the effectiveness been complete ? The fact that the impact of PAs is decreasing with the degree of remoteness of the locality would indicate that it is not the case. If PAs have allowed to decrease deforestation in easily accessible communes, they failed in more remote ones. This is not surprising. The median commune impacted by a PA is reported to be located at about 14 hours driving from the nearest city during the rainy season. More, 35% of these communes even are reported to be at more than 24h driving. For them, we thus understand that enforcing the law appears as a particular challenge and that adding a PA *de jure* hardly change reality on the ground.

Let's also 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.

5.1.2 PAs and associated programs have probably not reduced deforestation by necessity

Have we seen a decrease in the dependency of locals on the resource ? The consistent and continuous stable deforestation trend suggests probably not entirely. The weaker impact of PAs in poorer communes, i.e. in communes where the share of people deforesting by necessity is higher, confirm this intuition. PAs in poorer communes has not been an efficient way to curb deforestation. 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 seems to have had little effectiveness on the improvement of local populations' living conditions as it is recognized by some conservation actors themselves [41].

In the ICDPs' initial policy scheme, there was the ambition to reduce local residents' reliance on the resource by installing local development programs, notably 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 4). The margins for leeway to directly compensate on a commune wide-level and to finance programs were very fine for almost all the PAs [14].

13. One figure illustrates this well : Madagascar has one forestry officer for approximately 30,162 hectares of natural forest compared with one to every 421 hectares in the Reunion Island (Environment

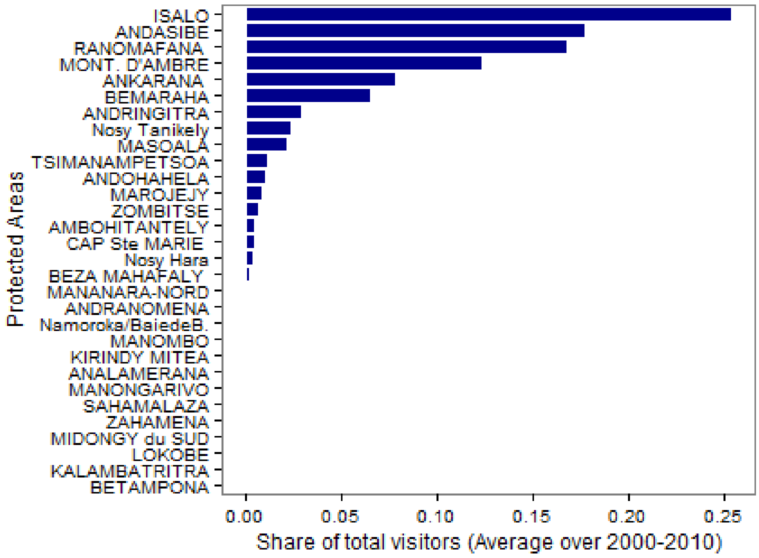


FIGURE 5 – An unequal repartition of visitors

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 accepting to give up *tavy* has been rarely consequential [42] 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 poaching [15]. Over and above the implementation restrictions associated with access to markets and price fluctuations, some authors have highlighted the intrinsic restrictions of these "conservation by distraction" mechanisms [43], 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 [44].

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

14. So 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

15. For 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

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.

5.2 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 [8, 45], 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 transition, an unavoidable condition for the improvement in living conditions of local populations [46], 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 [47]. Meanwhile, even projects which have invested $100 per household haven't managed to make the implemented transition last [16].

5.3 Promote a greater articulation of the sectoral policies

In Madagascar, not only public expenditure targeting the agriculture sector is low (around 8% of public expenditures [17]), 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

16. We refer here to the COGESFOR project and its interventions in the area of Didy. See the project's capitalization material [48].

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

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 Partneship 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 [49] 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 [20].

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 [50], which could integrate in a single instrument conditional payments for conservation and control, 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*). Using a DID-Matching approach, we find that the establishment of PAs appears to succeed in minimizing these opportunities but a persistent stable deforestation trend testifies to the failure observed of local development programs [41]. 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. 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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7 Appendix

7.1 Balance

Table 4 – 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. Bootstraped p-value used (1000 iterations). * : significant at 10% ** : sign at 5%*** : sign at 1%.*

7.2 Robustness checks : Results at the pixel level

The *Conservation Evaluation 2.0* literature has both relied on agregate 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 $30m^2$.

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 5 – 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.