It's not only poverty: uncontrolled global trade and bad governance are responsible for unceasing deforestation in Western Madagascar

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Summary

Madagascar is recognized for both its unparalleled biodiversity and its high level of threat, associated in particular to anthropogenic deforestation. Despite the efforts to fight poverty and curb deforestation, forest cover in Madagascar is rapidly decreasing. To try to explain why it is so difficult to stop deforestation in Madagascar, we analysed further the recent deforestation process in western Madagascar through satellite image analysis and field surveys. We showed that average deforestation increased from 0.85%.yr-1 on 2000-2010 to 2.35%.yr-1 on 2010-2014. We identified two major causes of deforestation, which were not associated to agriculture for auto-consumption: slash-and-burn agriculture for the cultivation of cash crops (maize and peanut) and uncontrolled fires to open pastures. Crop production is mainly exported outside Madagascar and the money earned by farmers is invested into zebu herd acquisition. Export of agricultural commodities benefit to several intermediaries, some of who having political responsibilities. On the other hand, agents from institutions in charge of the management of the protected areas have no means to enforce law against deforestation. In the absence of an efficient strategy to stop deforestation, we predicted that half of the forest present in 2000 will have disappeared in 2050. Forest loss, apart from biodiversity loss and climate-change global issues, will be at the expense of local population. In order to stop deforestation, international aid should be used at improving local governance to enforce the environmental law and pressure should be put on international companies to buy certified agricultural commodities not derived from deforestation.

Keywords: biodiversity, conservation, conflict of interest, cyclones, dry deciduous forest, fires, illegal logging, Madagascar, protected areas, slash-and-burn agriculture, tropical deforestation.

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1. Introduction

Tropical forests provide important ecosystem services at the global scale, such as biodiversity conservation and climate regulation (Costanza et al. 1997), and at the local scale for people livelihood (Anderson et al. 2006; Jeannoda et al. 2007; Gardner & Davies 2014). On the island of Madagascar, three types of tropical forests, covering about 15% of the country area, can be found: the moist forest in the East, the xerophytic forest in the South, and the dry forest in the West (Humbert 1955). Among all the ecosystem services they provide, Malagasy forests are particularly important for the unique biodiversity they shelter, both in terms of species diversity and endemism in many taxonomic groups (Goodman & Benstead 2005; Brooks et al. 2006).

However, a large part of the original tropical forest is thought to have disappeared since the arrival of the humans on the island around 2000 years ago (Green & Sussman 1990; Harper et al. 2007), some studies advancing that 90% of the island was originally covered by forest (Burns et al. 2016). From 1950 to 2000, a loss of about 40% of the forest cover has been estimated, conducting to an estimated extinction of 9% of the species present at that time in Madagascar (Allnutt et al. 2008). Common narrative attributes the deforestation to the extreme poverty of the country and subsistence farming through slash-and-burn agriculture (Jarosz 1993; Scales 2011; Gardner et al. 2013). About 81% of the population leave below the international poverty line of 1.25$ per day in 2010 and more than 70% of the population of Madagascar, of 24 million people in 2015 (The World Bank 2015), heavily rely on forests for their livelihood (Anderson et al. 2006). Moreover, Malagasy population is rapidly increasing, with population growing at a rate close to 3%.yr-1, thus doubling each 25 years.

To curb deforestation, several conservation and rural development programs have been implemented in Madagascar since the establishment of the first protected areas in 1927. The Madagascar Protected Area System (SAPM) has seen both an increase in the number of protected areas and an increase in the place taken by rural development programs to accompany conservation actions (Virah-Sawmy et al. 2014). Rural development programs aimed at alleviate poverty, increase agriculture productivity, education, health and local governance in the periphery of the protected areas (Freudenberger 2010). Since 2003, Madagascar's protected area coverage expanded from 1.7 to 6.4 million hectares (11% of the country area) (Kremen et al. 2008; Corson 2014). In parallel to the development of the SAPM, the REDD+ (Reducing Emissions from Deforestation and Forest Degradation) mechanism have emerged in Madagascar to avoid deforestation combining conservation and development actions (Ebeling & Yasue 2008). Five REDD+ pilot projects have been initiated since 2004 over a total of 1.76 Mha of forest (Demaze 2014).

Most of these actions were funded by the donor community, led by the USAID (United States Agency for International Development) and the World Bank (Freudenberger 2010). The total funding of the NEAP from 1990 to 2010 has been estimated at approximately $450 million for environment activities, with another 50% for related development programs (e.g. agriculture and health interventions) (Freudenberger 2010). Other bilateral donors (mainly Europe, France and Germany) have also funded specific socio-environmental projects ($102 million on the period 2005-2011) (Critical Ecosystem Partnership Fund 2014). The main international NGOs (WWF, CI, WCS) and international research centers (such as Cirad and IRD French research centers) also contributed significantly to the financial effort by providing their own resources to support conservation and development programs (Critical Ecosystem Partnership Fund 2014). Regarding REDD+ activities, the private sector also provided substantial fundings. As an example, Air France supported the first phase of the PHCF REDD+ project (2008-2012) with $5 million. Annually, this represent a rough estimate of about $60 million per year from the donor community to fund environmental and related development activities in Madagascar (80% of the annual budget) (Critical Ecosystem Partnership Fund 2014).

Despite all the efforts and money invested in conservation and development programs over the past 30 years (1985-2015), deforestation has not stopped on the island. Out of the 10.8 Mha of tropical forest in 1990, around 1.5 Mha (13% of the forest) has been deforested on the period 1990-2010 (Harper et al. 2007; Hansen et al. 2013), which corresponds to an average annual deforestation rate of 75,000 ha.yr-1 (0.72%.yr-1). More worryingly, Madagascar has seen an acceleration of the deforestation recently. Madagascar was the third country with the fastest acceleration of tree cover loss (+8.3% of ha.yr-1) on the period 2001-2014 (see Hansen et al. (2013) and http://ow.ly/RBbgw). On the period 2010-2014, deforestation reached an average rate of 100,000 ha.yr-1 (1.09%.yr-1). Forest cover in 2014 was estimated at 8.9 Mha (https://bioscenemada.cirad.fr/forestmaps). The conclusion is unfortunately rather clear: conservation and development programs since mid 1980s have failed to save Madagascar forests. It is therefore legitimate to wonder why such initiatives have not been successful and what could be the alternative solutions to stop deforestation. Also, the recent deforestation might be attributable to new factors, independent of local human activities, such as global climate change, cyclone and natural fires, which would imply conservation measures different to the ones used in the past.

To try to answer these questions, we analysed more in depth the deforestation process in two study areas in the Menabe region, west Madagascar. The studies areas were located around two protected areas: the Kirindy-Mite National Park (KMNP) and the Menabe-Antimena New Protected Area (MANPA). These two protected areas are characteristic of the dry deciduous forest in Madagascar which is home to a unique biodiversity both in animal and plant (Fig. 1). Many species are endemic to the region such as the symbolic *Adansonia grandidieri* of the Avenue of the Baobabs or *Microcebus berthae*, the smallest species of primate in the world. In the two study areas, we derived historical deforestation maps from satellite image analysis on the period 1990-2010-2014. We validated these maps with field observations. To identify the causes of the deforestation, we also conducted local household and environmental stakeholder surveys. A much clearer scheme, explaining why environmental actions currently fail to stop deforestation, has emerged from this analysis. Finally, based on a spatial deforestation model, we predicted the likely extent of the tropical dry forest in 2050 in the absence of any efficient solution to curb deforestation.

2. Materials and Methods

2.1 Historical deforestation maps

We derived 30m cloud-free forest maps for Madagascar for the years 1990, 2000, 2010 and 2014 combining the 1990 and 2000 forest maps by Harper et al. (2007) and the 2000-2014 tree percent cover map by Hansen et al. (2013). On Harper's map, ~200,000 ha clouds are present over the ~4.2 million ha moist forest ecoregion (4.8% of clouds). To remove these clouds, we used the 2000 cloud-free tree percent cover map provided by Hansen et al. (2013) (also at 30~m resolution) and we chose a threshold of 75% of tree cover to decide whether to replace cloud pixels with forest or non-forest pixels (Achard et al. 2014). We thus obtained a cloud-free year 2000 forest map for Madagascar. From this map, using tree cover loss data from 2000 to 2014 by Hansen et al. (2013), we obtained cloud-free forest maps in 2010 and 2014 at 30~m resolution. Finally, we corrected the cloudy 1990 Harper forest map assuming that if forest was present in 2000, it was also present in 1990. Doing so, all clouds were removed and we obtained a cloud-free 1990 forest map for Madagascar. These maps are freely available at http:/bioscenemada.cirad.fr/forestmaps. We then used these national maps for our regional study around the Kirindy-Mite National Park (E: 43.67555, W: 44.35067, S: -21.36469, N: -20.50137, in decimal degrees) and the Menabe-Antimena New Protected Area (E: 44.20934, W: 44.8185, S: -20.3644, N: -19.55838, in decimal degrees). Field work was conducted during a ten days mission in June 2016 to verify the presence of the recent (2000-2010-2014) patches of deforestation in the two study areas. We validated the deforestation maps on this period and identified the main causes of deforestation in the two study areas.

2.2 Deforestation model

Following Vieilledent et al. (2013), we considered two processes for modelling deforestation, a first one describing the intensity of deforestation (number of hectares of forest deforested each year) and a second one describing the location of the deforestation (spatial probability of deforestation). For the intensity of deforestation, we used two historical means at the study area level assuming a conservative scenario (S1) and a worst-case scenario (S2). The conservative scenario assumed a lower deforestation rate corresponding to the mean annual deforestation observed on the period 1990-2010. The worst-case scenario assumed a higher deforestation rate corresponding to the mean annual deforestation observed on the period 2000-2014, during which the deforestation has dramatically increased (Table 3). For the location of the deforestation, we estimated the parameters β of a Binomial logistic regression linking the spatial probability of deforestation θ_i for forest pixel i to a set of spatial explicative factors X_i computed at the pixel level. To account for unexplained spatial variation in the probability of deforestation, we added a spatial random effect $\rho_{j(i)}$ at the level of the 10km resolution cell j including the pixel i: $\text{logit}(\theta_i) = X_i\beta + \rho_{j(i)}$. To account for spatial autocorrelation, these spatial random effects were structured with a conditional autoregressive (CAR) model (Besag et al. 1991) where ρ_j depends on the values of $\rho_{j'}$ for the neighbouring cells j'. We used the deforestation data on the period 2000-2010 to fit the model. We used altitude, distance to forest edge, distance to main town, distance to main road, inclusion into a protected area and distance to past deforestation (period 1990-2000) as spatial explicative factors of the probability of deforestation (Vieilledent et al. 2013). These factors described the accessibility, the land policy and the historical deforestation of the forest. Model parameters were estimated in a Bayesian framework using the function `hSDM.binomial.iCAR()` from the hSDM `R` package (Vieilledent et al. 2014). The 10km spatial random effect estimates were interpolated at 1km using a bilinear interpolation. Using the results of the statistical model, we derived a map of the spatial probability of deforestation at 30m resolution for the year 2010 for Madagascar. The map is freely available at https:/bioscenemada.cirad.fr/forestmaps. We used this national map for our regional study (Fig. S1). To forecast the forest cover in 2050 for our two study areas, we removed the 2010 forest pixels with the highest probability of deforestation following the annual deforestation rate of the two intensity scenarios considered (conservative scenario S1 and worst-case scenario S2). To validate our projections, we computed the percentage of observed deforestation on the period 2010-2014 included in the predicted deforestation on the period 2010-2050.

2.3 Surveys

During a ten day period in June 2016, we conducted surveys among local farmers and environmental stakeholders (Table 1) around the Kirindy-Mite National Park and the Menabe-Antimena New Protected Area. The objectives of the surveys were first to identify the causes of the deforestation and second to assess the efficiency of the conservation actions implemented by the NGOs in charge of the management of the protected areas, either Fanamby for MANPA or Madagascar National Parks for KMNP. Surveys were qualitative and included non-directive questions (no "yes-or-no" questions). Discussing with the *"Fokontany"* chief at Lambokely, we also obtained rough population estimates on the period 2010-2015 for the two villages of Kirindy and Lambokely. The *"Fokontany"* is a Malagasy administrative unit under the level of the township. Information from field surveys was cross-checked and complemented by a review of technical reports on the maize and peanut sectors in Madagascar (Fauroux 2000; Ministère de l'Agriculture, de l'Elevage et de la Pêche de Madagascar 2004; Youssi 2008; Chan Mouie 2016) and scientific studies on the deforestation process in south-east Madagascar (Fauroux 2000; Réau 2002; Casse et al. 2004; Scales 2011; Gardner et al. 2013; Zinner et al. 2014).

3. Results

3.1 Intensity and pattern of deforestation

Deforestation rates have continuously increased since 1990 for the two study areas (Table 2). We estimated that 3,960 ha and 3,295 ha of forest have disappeared annually on the period 2010-2014 in the study areas around KMNP and MANPA, respectively. This represent annual deforestation rates of about 2.35%.yr-1. The annual deforestation has more than doubled on the period 2010-2014 compared to the period 2000-2010 (0.85%.yr-1). In the study area around KMNP, mosaic deforestation associated to slash-and-burn agriculture occurred outside the protected area, showing a relative effectiveness of the protected area to prevent deforestation (Fig. 2b, label A). Much larger patches of deforestation have been observed on the period 2010-2014 on the east part of the protected area associated to uncontrolled fires after cyclone events (Fig. 2b, label B). Dispersed and small-scale deforestation has also been observed in the northern and western part of the park associated to illegal logging activities (Fig. 2b, label C). In the Menabe-Antimena New Protected Area, large patches of deforestation associated to slash-and-burn agriculture were identified around the Kirindy and Lambokely villages and at the south of Belo-sur-Tsiribihina town (Fig. 2a).

3.2 Deforestation drivers

3.2.1 Proximate causes of deforestation: slash-and-burn agriculture, uncontrolled fires and illegal logging

In the study area around the Menabe-Antimena New Protected Area, the main cause of deforestation was the slash-and-burn agriculture (locally known as *"hatsake"*) for maize (*Zea mays* (Linné)) and peanut (*Arachis hypogaea* (Linné)) crop (Fig. 2a). The burning of forest provides nutrient rich ash and light for crops. Peanut is cultivated as cash crop and is transformed into peanut oil. A part of the production is at the destination of the national market but most of it is exported outside Madagascar, mainly for the Chinese market (Fig. 3). Maize is cultivated for auto-consumption and as cash crop. The production of maize is at the destination of the national and regional market (Fig. 3). Peanut and maize are sold by farmers to resellers at the price of 1400 Ariary (MGA) and 400 Ariary per kilo, respectively. For 2016, the production for a household was of 1.6 T of peanut and 2.5 T of maize, thus providing an annual income of about 3.24 millions MGA. With the money earned from the sale of the maize and peanut harvest, farmers invest in zebu herd acquisition.

We identified three causes of deforestation in the study area around the Kirindy-Mite National Park (Fig. 2b). Slash-and-burn agriculture for maize crops was identified as the main cause of deforestation in several areas at the periphery of the protected area (Fig. 2b, label A). Inside the protected area, uncontrolled fires were identified as the main cause of deforestation (Fig. 2b, label B). People repeatedly set fire on former grasslands (*"bozake"*) outside the protected area to obtain flush of green pasture for their livestock. When uncontrolled, fires can spread on large areas of the forest and cross the boundaries of the protected area. In 2009, the cyclone named *"Fanele"* impacted a large area of the forest in the Kirindy-Mite National Park leaving a lot of wood fuel on the ground. This has allowed uncontrolled fires to spread on large areas of the park in the years following the cyclone (Fig. 2b, label B). These fires were difficultly stopped with water and sand by the agents of the park with the help of the local villagers. Illegal logging was also identified as a cause of deforestation in Kirindy-Mitea (Fig. 2b, label C). Timbers are mainly used for house and boat construction and sold in local markets in Belo-sur-Mer and Morondava towns.

3.2.2 Ultimate causes of deforestation

Demographic growth and migration

Population increase in central Menabe, associated to demographic growth and migration, have accentuated the pressure on forest. The population of Kirindy and Lambokely villages (Fig. 2a) has been roughly multiplied by 5 between 2010 and 2015 (from about 600 to 3000 inhabitants for Kirindy and from 1000 to 5000 for Lambokely). This was both due to demographic growth and migration. The demographic rate in Madagascar is close to 3%.yr-1 (Vieilledent et al. 2013) which means that the population doubles each 25 years on average. In Lambokely and Kirindy villages, the families we surveyed had all more than six children. Also the possibility of cropping cash crops have attracted many people from the south of Madagascar during the last years, in particular from the *"Androy"* region (southeastern Madagascar). First migrants arrived in the central Menabe to work in large agricultural concessions authorized by the French colonial government. Notably, many *"Tandroy"* migrants have arrived in the 1960s and established near the Beroboka village (located between Kirindy and Lambokely villages) to work in the sisal (*Agave sisalana* (Perrine, 1838)) plantation of the de Heaulme family which is now abandoned. Moreover, consecutive droughts reported in southeastern Madagascar resulted in severe famines there, that forced several thousand *"Tandroy"* families to migrate to Menabe region in search for new farming land.

Limits in the application of conservation policy

Forest clearance is illegal in Madagascar since 1987 (Décret n°87-143, 20 April 1987), even outside the protected areas. However, the law is not respected nor applied. Almost nobody is prosecuted for forest clearance. During our stay in the field, seven people were arrested for doing slash-and-burn agriculture but were relaxed a few days later. The political crisis of 2009, followed by several years of political instability, has reinforced this state of lawlessness. Moreover, authorities commonly have economic interests in not curbing deforestation as they are often involved in the trade associated with cash crops. Indeed, many politics in Madagascar are also business leaders. Regarding the structures in charge of the management of the protected areas, such as Fanamby and Madagascar National Parks NGOs, they have no legal enforcement powers which are retained by local Government agencies. Thus, their unique role concerning forest conservation in the field is limited to population awareness of the forest conservation issues, to inventory and monitor the biodiversity in the parks, and to organize patrols to discourage forest clearance or report offences. But in any case they have the right to arrest people or to draw up a report and decide on a fine. NGOs also engage people as conservation partners (then named *"polis ny ala"*) to try to make them stewards of their forest but they have practically no power and will difficultly report illegal acts from known neighbours or relatives.

3.3 Projected deforestation

Following the conservative scenario S1 (projecting 1990-2010 mean annual deforestation) and the worst-case scenario S2 (projecting 2000-2014 mean annual deforestation), we predicted that 36-55% of the forest present in 2000 will have disappeared in 2050 (Table 3). On the period 2000-2014, around 17% of the forest have already disappeared. Forest in 2050 should remain preferentially in the protected areas but deforestation should not stop at the boundaries of the parks (Fig. 2c and 2d). The model predicted that deforestation in the future should occur close to places were deforestation occurred in the past, thus correctly simulating the contagious process of deforestation (Fig. 2). Deforestation is also more likely to occur at short distances to villages and roads and at the forest edge (Fig. 2c and 2d). Forest fragmentation is also predicted to increase in association to deforestation (higher number of disconnected forest patches in Fig. 2c and 2d). Most of the deforestation observed on the period 2010-2014 was included in the deforested area predicted by the model on the period 2010-2050, (60-82% for MANPA and 51-72% for KMNP for scenarios S1 and S2, respectively) thus validating partly the predictions regarding the location of the future deforestation (Fig. 2c and 2d).

4. Discussion

4.1 Historical deforestation, projections and consequences on livelihoods, biodiversity and climate-change

For the two study areas, we have shown a strong increase of the annual deforestation rates on the period 1990-2014. This increase, also observed by Scales (2011) and Zinner et al. (2014) in the region, clearly demonstrate the inefficiency of the recent environmental policies to reduce deforestation. In the absence of any efficient future policy to curb deforestation, we predicted a 36-55% forest loss on the period 2000-2050. This scenario, confirmed by the results of Zinner et al. (2014), would be terrible for both local villagers in terms of livelihoods and at the global scale for biodiversity and carbon emissions. In term of loss of biodiversity, Allnutt et al. (2008) estimated a 9% decrease in the number of species after a deforestation of 40% on the period 1950-2000. In our case, given a forest loss of 36-55%, we can assume that the biodiversity loss would be of the same order of magnitude on the period 2000-2050. Many species endemic to the region, such as *Hypogeomis antimena*, *Mungotictis decemlineata*, *Microcebus berthae* and *Pyxis planicauda* could experience a dramatic demise of their populations resulting in a rapid tailspin toward extinction. Dry forests sequester an average of 52 Mg.ha-1 (1Mg=106g) (Vieilledent et al. 2016). Considering the predicted forest cover loss of 94,702-163,162 ha on the period 2010-2050, deforestation would lead to emissions of 4.9-8.5 Tg (1Tg=1012g) of carbon in the atmosphere, thus contributing to climate change.

4.2 Deforestation is not associated directly to poverty but to uncontrolled global trade and bad governance

Our field observations and surveys indicated that a large part of the deforestation was attributable to slash-and-burn agriculture for cash crops (maize and peanut). The major part of the maize production is exported, in particular to the Reunion island to feed the pig farms (Fauroux 2000; Ministère de l'Agriculture, de l'Elevage et de la Pêche de Madagascar 2004; Scales 2011). Most of the peanut production is also exported outside Madagascar, previously to the neighbour islands of Mauritius, Reunion and Mayotte (Ministère de l'Agriculture, de l'Elevage et de la Pêche de Madagascar 2004; Youssi 2008) and now increasingly to the Chinese market (Chan Mouie 2016). The annual household income we computed associated to the selling of cash crops (about 3.24 millions MGA) was relatively high compared to the estimated median household income of 2.02 millions MGA (Gallup World Poll from the Gallup Organization) With the money earned from the sale of the maize and peanut harvest, farmers invest in accumulating zebu herd (Réau 2002; Casse et al. 2004). Buying zebu herd is a way for farmers of saving money such as a bank would do it (Réau 2002). In Madagascar, cattle also represent status, wealth, and cultural identity (Hobbs 2016). In the Menabe region, people's diet is mainly composed of manioc (*Manihot esculenta* (Crantz)), wild and cultivated yams (*Dioscorea spp.*), and maize (Falola & Jean-Jacques 2015). The main purpose of the slash-and-burn agriculture is thus not to obtain food for subsistence but to cultivate cash crop in order to invest in livestock acquisition and to secure new farming lands (Fauroux 2000). In line with other studies (Grandin & others 1988; Jarosz 1993; Scales 2011; Gardner et al. 2013), we underline that it would be simplistic to reduce the causes of the deforestation to the poverty of local population.

Of course, Malagasy farmers do not make large profits and do not harvest most of the benefits associated to the culture of maize and peanut. Many intermediaries, such as storers, domestic transporters, resellers, exporters and corrupt officials reap most of the profits. Foreign entrepreneurs (European and Chinese) as well as entrepreneurs from the Malagasy elite (including *"Karana"*, the descendants of Indo-Pakistani migrants) connect rural households to international markets, the ports of Morondava and Tulear being important centers for the export of agriculture commodities (Fauroux 2000; Scales 2011). Field surveys reported that several officials in the army or with political responsibilities, who are at the same time business men or entrepreneurs, are involved in this trade. As a consequence, stopping deforestation would go against the economic interest of some people having decisional and political power in Madagascar. In previous studies, Jarosz (1993) and Scales (2011) have clearly shown how economic booms of agricultural commodities and policies have driven deforestation in Madagascar during French colonization. Nowadays, deforestation in central Menabe is driven by the increasing demand in maize and peanut on the national and international markets and by the possibility of making economic profits in these sectors.

Slash-and-burn agriculture for cash crops and the economic profits are made possible by the non-application of the environmental law in Madagascar. Forest clearance is illegal in Madagascar since 1987 (Décret n°87-143, 20 April 1987). In the field, the agents of MNP and Fanamby have no legal enforcement powers to arrest offender even when apprehended. Under-resourced local Government agencies that retain such legal powers are generally corrupt and have a low technical capacity, making their actions virtually ineffective. As a consequence, illegal activities such as slash-and-burn agriculture or setting fire to open pastures continue in full sight of everyone. This situation has been accentuated by the political crisis of 2009-2012 in Madagascar (Ploch & Cook 2012). Madagascar is a fragile State country (the Fund for Peace 2016). Common characteristics of a fragile State include a central Government so weak or ineffective that it has little practical control over much of its territory. Our study confirms that the deforestation problem in Madagascar is more a governance problem in a context of unregulated global economy than an economic development problem. Interestingly, two global studies have recently shown that corruption (Venter et al. 2016), overexploitation and agriculture (including crop farming and livestock farming) (Maxwell et al. 2016) were responsible for a major part of the biodiversity loss, thus reflecting our results.

4.3 Enforcing law and controlling agricultural sector to stop deforestation in western Madagascar

If we want to stop deforestation in western Madagascar, it seems necessary to rethink the conservation strategies we adopted during the last 30 years, which was based on extended the protected area network and alleviating poverty. One solution we see would be that foreign companies engage into ecological certification for agriculture commodities in Madagascar (Kiker & Putz 1997; Laurance et al. 2010). It seems indeed contradictory for developed countries to provide economic environmental aid on one hand and to allow companies to buy low cost deforestation-derived agriculture commodities from developing countries on the other hand. Relative to estimates of conservation costs in the developing world, it has been shown that existing levels of environmental aid are insufficient (Miller et al. 2013). If the amount of the environmental aid have to be increased, the targets have also to be redefined and improving governance in Madagascar should be considered a priority (Smith et al. 2003). Brazil, which have reduced by two third the Amazon deforestation on 2005-2011 compared to 1996-2005, is a good example to show that both law enforcement (enforcement of the Brazilian Forest code) and control of the agricultural sector (voluntary moratoriums by the soy bean and beef industries) are efficient ways to rapidly curb deforestation (Nepstad et al. 2009; Boucher et al. 2013). This success, even if temporary, should inspire conservationists working in Madagascar and in other developing countries facing tropical deforestation in general.

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Data availability statement

All the data and codes used for this study are made available publicly in the `menabe` repository on the GitHub platform at the following web address: https://github.com/ghislainv/menabe.git. The results and the manuscript are fully reproducible running the R script `menabe.R` from the `menabe` git repository.

Tables

Id	Type	Name	Institution	Position	Date	Duration
1	Migrant and farmer	Farmer 1	Kirindy village	Chief of a family with a woman and eight children	10/06	1h30
2	Woman	Woman 1	Kirindy village	Wife of a farmer living in the Kirindy village	10/06	30min
4	Migrants and farmers	Farmers 2 and 3	Lambokely	Two family chiefs with women and children	10/06	1h
5	Administration	Chief 1	Lambokely	Fokontany chief	10/06	30min
8	Government representative	Cynthia Raveloson	DREEF Menabe	Chief of the regional forest service	09/06	1h
6	National Parks	Mamy Rakotobenandrasana	MNP	Director of the conservation program for KMNP	07/06	1h30
7	Environmental NGO	Roland Eve	WWF	Landscape Planning and Management advisor for KMNP	08/06	1h
9	Environmental NGO	Tahina Riniavo	Fanamby	Director of the conservation program for MANPA	10/06	30min

Table 1: **List of surveys conducted among local farmers and environmental stakeholders**. Surveys were conducted around the Kirindy-Mite National Park and the Menabe-Antimena New Protected Area.

The *"Fokontany"* is a Malagasy term defining an administrative territory under the level of the township. In Madagascar, the management of the protected areas is under the responsibility of Madagascar National Parks (MNP) or delegated to another environmental Non-Governmental Organisation (such as Fanamby for Menabe-Antimena New Protected Area).

Site	D90-00	D00-10	D10-14	D10-50,S1	D10-50,S2
KMNP	833 (0.43%)	1565 (0.85%)	3960 (2.34%)	1205 (0.80%)	2238 (1.78%)
MANAP	1042 (0.64%)	1301 (0.87%)	3295 (2.38%)	1162 (0.98%)	1840 (1.79%)

Table 2: **Evolution of the annual deforestation with time in the Kirindy-Mite National Park (KMNP) and the Menabe-Antimena New Protected Area (MANPA).** *D90-00*, *D00-10*, *D10-14* and *D10-50*: annual deforestation (in ha.yr-1) for the periods 1990-2000, 2000-2010, 2010-2014 and 2010-2050 respectively, followed by the annual deforestation rate in parenthesis (in %.yr-1). The annual deforestation has more than doubled on the period 2010-2014 compared to the period 2000-2010. The two last columns of the table indicate the mean annual deforestation on the period 2010-2050 resulting from the projection of the forest cover in 2050 following the two deforestation intensity scenarios S1 (conservative scenario: 1990-2010 mean annual deforestation) and S2 (worst-case scenario: 2000-2014 mean annual deforestation).

Site	Area	F1990	F2000	F2010	F2014	F2050,S1	F2050,S2
KMNP	388491	198988	190655	175006	159166	126803	85469
MANAP	349360	166647	156223	143208	130028	96711	69598

Table 3: **Evolution of the forest cover with time in the Kirindy-Mite National Park (KMNP) and the Menabe-Antimena New Protected Area (MANPA).** *Area*: land area (in ha). *F2000*, *F2010* and *F2014*: forest area (in ha) for the years 2000, 2010 and 2014, respectively. *F2050*: projected forest area (in ha) for the year 2050. About 17% of the forest have disappeared on the period 2000-2014 in the two sites and we predict the loss of around 36% and 55% of the forest on the period 2000-2050 for the two sites assuming a conservative (projecting the 1990-2010 annual deforestation) or a worst-case scenario (projecting the 2000-2014 annual deforestation), respectively.

Figures

Supplementary materials

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Figure 1: Figure 1: **Emblematic species representative of the biodiversity of the central Menabe.** The dry forest of the central Menabe is home to a very large number of species, many of which being endemic to the region. We present here some examples of this biodiversity for different taxonomic groups: Plants, Birds, Mammals (including Lemurs), Amphibians and Reptiles. From top-left to bottom-right: 1. *Adansonia grandidieri* (Baillon, 1888), 2. *Adansonia rubrostipa* (Jumelle & Perrier, 1909), 3. *Aglyptodactylus laticeps* (Glaw, Vences & Böhme, 1998) 4. *Cryptoprocta ferox* (Bennett, 1833), 5. *Falco newtoni* (Gurney, 1863), 6. *Furcifer labordi* (Grandidier, 1872), 7. *Hypogeomis antimena* (Grandidier, 1869), 8. *Leptosomus discolor* (Hermann, 1783), 9. *Mesitornis variegata* (Geoffroy Saint-Hilaire, 1838), 10. *Microcebus berthae* (Rasoloarison, Goodman & Ganzhorn, 2000), 11. *Mimophis mahafaliensis*, 12. *Mirza coquereli* (Grandidier 1867), 13. *Mungotictis decemlineata* (Grandidier 1867), 14. *Propithecus verreauxi* (Grandidier, 1867), 15. *Pyxis planicauda* (Grandidier 1867), 16. *Uroplatus guentheri* (Mocquard, 1908). Sources: 1,2,5,8,10,11: authors; 3: Miguel Vences; 4,6,7,9,13,14,15,16: Wikipedia; 12: Louise Jasper.

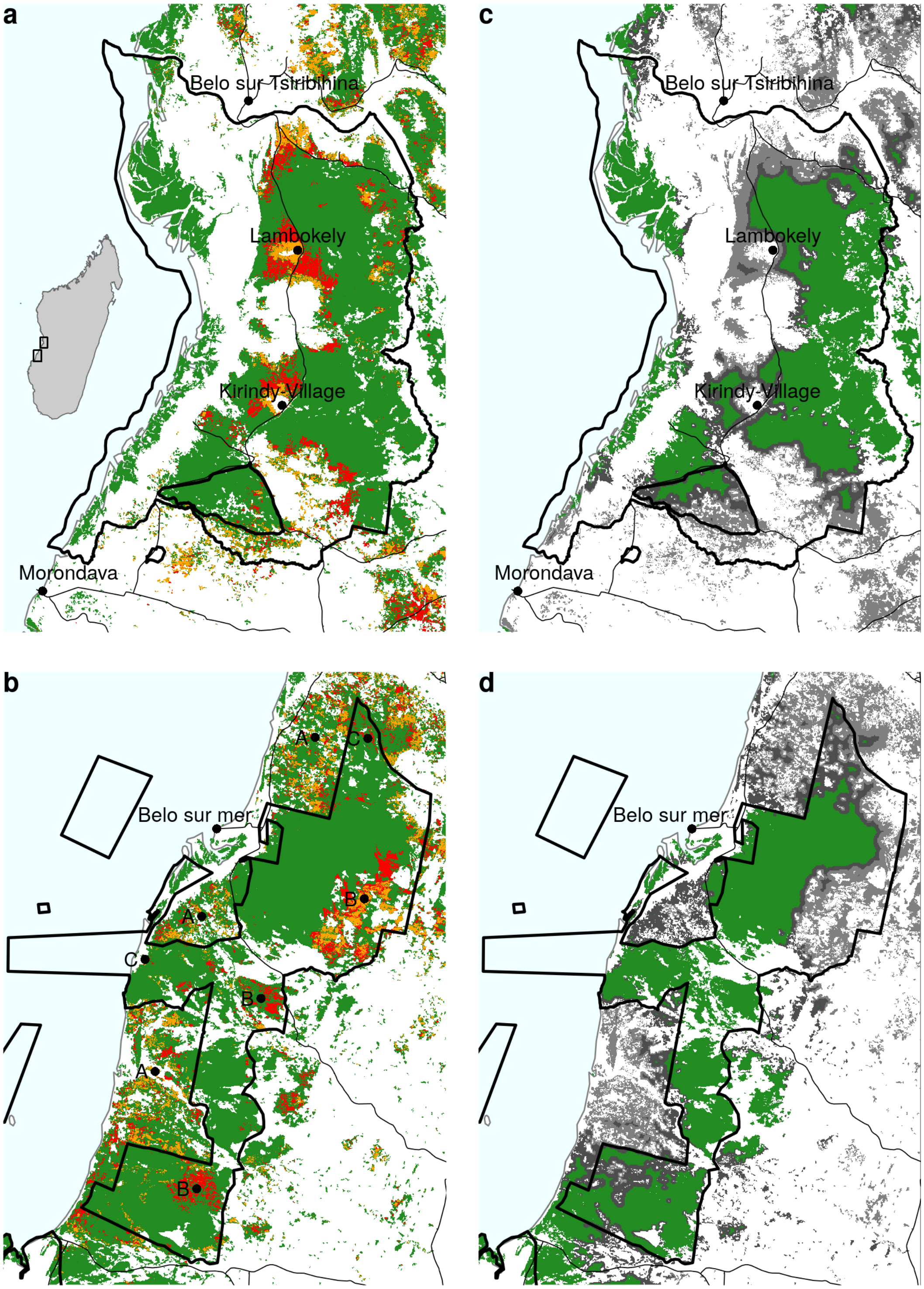

Figure 2: Figure 2: **Historical and forecasted deforestation in the study areas around the Kirindy-Mite National Park (KMNP) and Menabe-Antimena New Protected Area (MANPA).** Madagascar map is represented on the top left panel (a), with the Menabe-Antimena study area at the north and the Kinrindy-Mitea study area at the south (black rectangles). On each of the sub-panels, the boundaries of the protected areas are represented with black polygones (source: Rebioma project at http://rebioma.net). Main roads are represented with thin black lines (source: FTM BD500). Coast line is represented with a thin grey line. Morondava and Belo-sur-Tsiribihina are the main cities located near MANPA. Belo-sur-Mer is the main village located near KMNP. **a-b**: *Historical deforestation on the period 2000-2010-2014 for the Menabe-Antimena and Kirindy-Mitea study areas, respectively.* Green: forest cover in 2014, orange: 2000-2010 deforestation, red: 2010-2014 deforestation (source: BioSceneMada project at http://bioscenemada.cirad.fr). In the Menabe-Antimena study area, the main cause of the deforestation is the slash-and-burn agriculture (*"hatsake"*) for maize and peanut crops. Most of the 2000-2014 deforestation occured around the villages

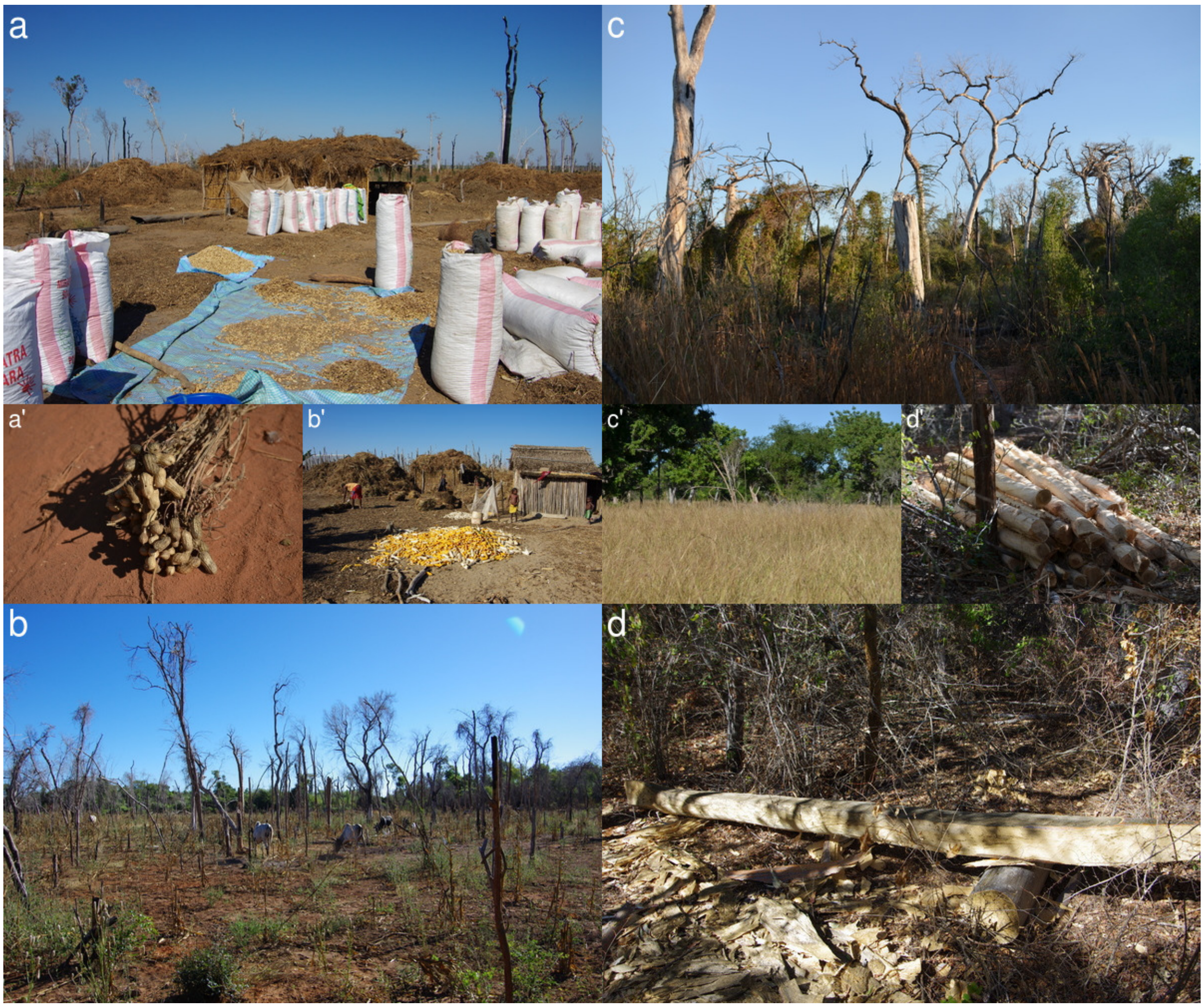

Figure 3: Figure 3: **Main causes of deforestation in central Menabe. a-a'**: *Slash-and-burn agriculture (*"hatsake"*) for peanut crop.* Peanut (a') is cultivated as a cash crop. Part of the production is at the destination of the national market but most of it is exported outside Madagascar, mainly for the Chinese market. **b-b'**: *Slash-and-burn agriculture for maize crop.* Maize (b') is cultivated for auto-consumption and as a cash crop. The production of maize is at the destination of the national market and is used in particular to brew the national beers. **c-c'**: *Cyclone followed by uncontrolled fires.* Cyclone *"Fanele"* (2009) caused tree mortality and accumulation of wood fuel on the ground. As a consequence, uncontrolled fires set on nearby pastures (c') spread over large areas of forest after 2009. **d-d'**: *Illegal logging.* Timbers are used for house and dugout canoe construction.

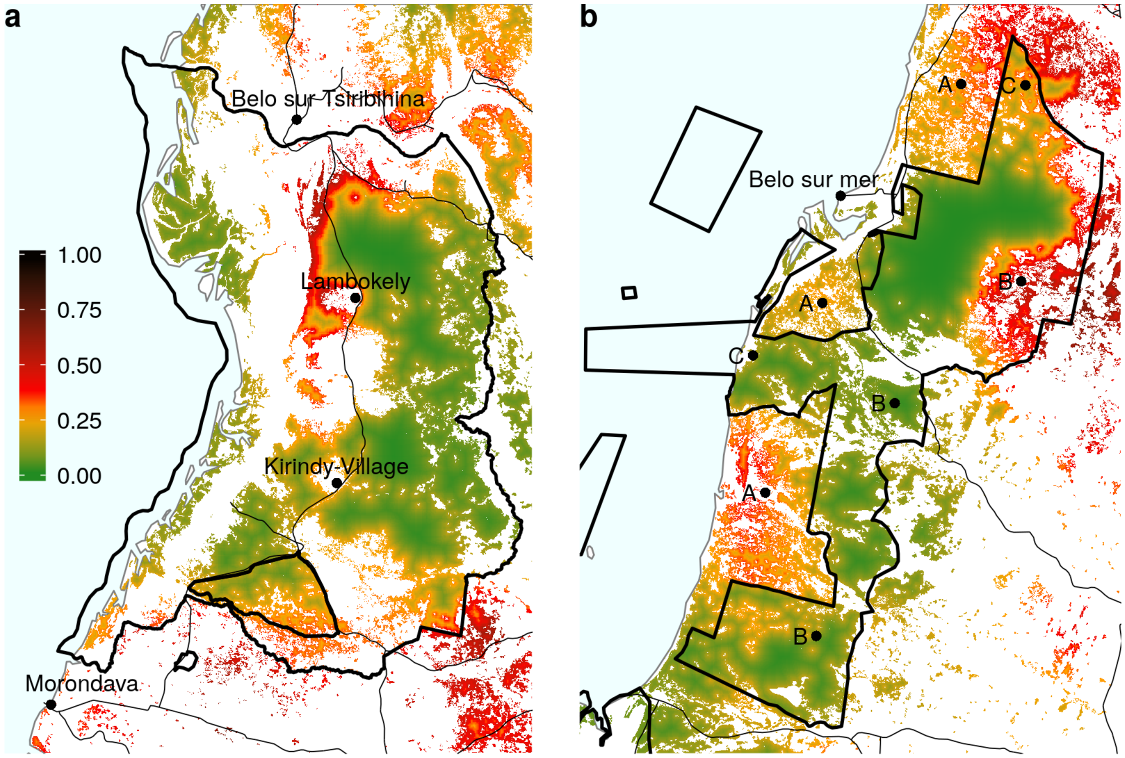

Figure 4: Figure S1: **Spatial probability of deforestation for the year 2010.**

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