Title: Scaling up conservation impact in Madagascar

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Abstract: Ten years ago, Madagascar's government committed to drastically scale up the nation's protected-area coverage from ~3% to 10% of its area. We ask how successful this PA expansion is likely to be in terms of reducing deforestation (and, thereby, increasing the conservation of biodiversity). We statistically evaluate the impact of the prior generations of Malagasy PAs and use those results to anticipate the conservation impacts of Madagascar's newest PAs. We find that deforestation was reduced by the prior PAs, although by less than suggested in simpler comparisons that lack explicit controls for land characteristics. Further, impacts are higher where deforestation pressure is higher, which often is closer to roads and cities (and which also may imply higher costs). We find Madagascar's newest PAs are sited where, if managed correctly, they can achieve impacts at least as high as prior conservation.

Keywords: Madagascar, tropical forest, biodiversity, deforestation, conservation, protected areas, siting, selection bias, impact evaluation, matching

1. Introduction

Held every ten years, the International Union for Conservation of Nature's (IUCN) World Parks Congress (WPC) is the global forum on protected areas (PAs). It sets the international agenda for site-based protection for the decade to follow. At the WPC in 2003, in Durban, South Africa, the then-president of Madagascar stunned the conservation community by embracing protection. In what became known as the "Durban Vision", former President Ravalomanana vowed to triple the area protected in Madagascar before the next WPC (i.e., to go from ~3% to ~10% of the nation). With this announcement came the creation of the new Malagasy PA network, i.e., the System of Protected Areas of Madagascar (Système d'Aires Protégées de Madagascar (SAPM)), consisting of the pre-existing PAs as well as all of the newly created PAs (Allnutt *et al.*, 2009; Raik, 2007).

While small in total land area, the Durban Vision was globally important. Madagascar hosts one of the most biologically diverse ecosystems in the world, with a variety of endemic taxonomic groups. However, despite global agreement and local efforts to conserve the region in light of this biological treasure − a global public good − there have been high rates of deforestation over time throughout the country (Harper *et al.*, 2007; Kremen *et al.*, 2008; Mittermeier *et al.*, 1990; Scales, 2012). Such land-use changes may threaten species but they have local economic benefit.

President Ravalomanana's 2003 decision to counter these threats by greatly increasing the area protected was surprising in its scale but not in its purpose. For almost a century, Madagascar has created protected areas (PAs) as part of achieving a balance between local need and protection of biodiversity.[1] Its PA network grew steadily, since its first PA was established, in 1927. Yet forest

[1] The history of Malagasy forest conservation policy is beyond our scope. Longer accounts are provided by Toillier *et al.* (2011), Consiglio *et al.* (2006), Miller and Porter Morgan (2011), Harper *et al.* (2007), and Raik (2007).

area declined − due to corruption, ineffective monitoring and subsistence use of forest resources by low-income rural communities (Ganzhorn *et al.*, 1997; Raik, 2007). The management of PAs remained largely unchanged until the collapse of the Soviet Union in the 1980s, at which point Madagascar shifted towards a more democratic style of government and foreign aid increased in an attempt to stimulate both development and conservation (Raik, 2007). In 1989, Madagascar ratified Africa's first National Environmental Action Plan, creating the Association National pour la Gestion des Aires Protégées (ANGAP) to manage its PA portfolio (Allnutt *et al.*, 2009).

Yet achieving conservation impact requires more than simply designating lands for conservation. There must be 'additionality' to the actions – for example, observed deforestation post-protection must be lower than deforestation would have been, at the same sites, in the absence of protection. Measuring 'in the absence' can be difficult. However, many observable land characteristics aside from protection – such as distances to roads, soil quality, management practices, or slopes – are relevant to and help to indicate deforestation outcomes in any scenario. Such measurable features can help to document that local development forces push back against PAs − a local constraint − for instance by pushing PAs away from where agricultural or other profitability would be high. Consequently, PA sites tend to be different from unprotected sites (Andam et al. 2008 in Costa Rica, Pfaff et al. 2014 in Brazil, and Joppa and Pfaff 2009 globally) and, by controlling for this, often we are able to get closer to understanding the true conservation impacts of PA legislation.

The most recent WPC in Sydney this year signaled the end of former President Ravalomanana's commitment. A retrospective analysis of Madagascar PA impacts can help to shed light on the future impact of the new Durban Vision PAs. We ask: did Malagasy PAs overall generally deter deforestation – i.e., one of the biggest threats to biodiversity − and, if so, do the locations of the

PAs appear to affect such deterrent impacts? Finally, if so, do these newest Durban Vision PAs appear to be located where PAs are likely to have lasting impact? We use matching to estimate PA impacts on deforestation in Madagascar − to our knowledge the first assessment of Malagasy PAs with controls for location (although see Gorenflo *et al*. 2013) and including the first use of matching in such evaluation (though Rosolofoson et al. 2015 provide an assessment of effects of community forest management with a similar approach, implemented simultaneous to this work). We assessed the impacts of PAs created before the Durban Vision, including the influence of key land characteristics on the magnitude of those impacts, and then documented Durban Vision PAs in terms of those characteristics. Specifically, to call attention to PAs' landscape characteristics, we analyzed not only all PAs but also subsets to assess if some resulted in higher PA impacts.

We find that PAs created prior to the Durban Vision significantly reduced deforestation, while the Durban Vision PAs were on sites that − if well managed − would yield impacts at least as high as earlier PAs. Consistent with other countries (see Pfaff et al. 2009, Joppa and Pfaff 2010), impacts in Madagascar can be higher when closer to roads and cities. These findings contribute to global conversations surrounding expansion of PA networks at multiple scales, as the world’s governments strive to achieve the Convention on Biological Diversity’s 11th "Aichi Target", i.e., that at least 17% of terrestrial and 10% of coastal and marine areas are effectively conserved. Below, Sections 2-5, respectively, present our Methods, Data, Results and finally Discussion.

2. Methods

Were PAs randomly sited it would suffice to compare deforestation rates inside and outside PAs to calculate PA impact. The protected and unprotected parcels would have similar characteristics and thus the deforestation on unprotected lands would provide a good estimate of what would have occurred at the PAs' locations had they not been protected. Many analyses compare PAs to all unprotected land or to the land nearby (Joppa and Pfaff 2010a provides a review), instead of controlling statistically for relevant location characteristics. When PAs differ in characteristics from unprotected lands − often facing lower pressure for deforestation (Joppa and Pfaff 2009) − this can lead to overestimates of the PAs' impacts. Here we address potential bias using ordinary least squares regression (OLS) to understand the drivers of deforestation, and then statistically controlling for biases in those drivers through OLS regression and propensity-score matching.

Ordinary Least Square Regression

Before getting to the matching analyses, and indeed motivating those analyses, we employ three types of OLS regressions for two types of outcomes, those being where protection is located and where deforestation occurs. We analyze the latter twice, starting with an analysis of unprotected lands in order to see what site characteristics have significant influence upon deforestation rates. We consider biophysical characteristics such as elevation, slope and distances to water, as well as socioeconomic characteristics like distances to roads, villages and large population centers, in addition to using indicators for large political units that differ in their geographies and processes.

Having confirmed the significance of those characteristics, we examine their effects on locations of protection in a regression for whether land has been designated as protected. As this confirms that protection is not randomly dispersed across the landscape, within a deforestation regression to test for the impact of protection we will include controls for influences of land characteristics. Thus, our third OLS regression is again for deforestation but considers all locations, i.e., not just unprotected locations, since we want to compare the unprotected and protected locations to infer the impacts of the PAs. We explain where deforestation occurs, including with a PA indicator.

Matching Methods

The last OLS regression considering deforestation for all locations offers one form of control for site characteristics when testing the impact of PAs. We control further using matching. When it is effective, matching generates control groups with characteristics very similar to treated sites. That reduces the challenge of removing characteristics' influences to infer PA impact. If treated and control groups have rather different characteristics, OLS may not strip out all the influences.

Matching focuses very explicitly on apples-to-apples comparisons, i.e., on similar characteristics. Of course it can employ only observable land characteristics, i.e., assumes that conditional on X (observable characteristics like slope), selection to treatment (here protection) is independent of potential outcomes (Rosenbaum and Rubin, 1983; Sekhon, 2009). If protected and unprotected are matched on observable covariates, they are assumed to differ only in terms of the protection.

For multiple continuous covariates, matching summarizes the characteristics using the predicted probability of a site being treated, i.e., protected (Rosenbaum and Rubin 1983). We match using that predicted probability or 'propensity score', in the sense of propensity for such characteristics to lead to protection. We match treated points with the untreated points with most similar scores. We also did robustness checks using calipers, i.e., rules for how similar those most similar scores have to be for that treated (i.e., protected) point to be included in the analysis (we used 0.01, 0.10 and 0.50 as maximum propensity-score differences). For each model, we also show whether and by how much the covariate balance improved, due to matching. We also address bias using post-match regressions to account for remaining differences in the X covariates between the matched pairs (Abadie and Imbens 2002; Rubin 1973; Sekhon 2011). Data analysis was performed with R 2.13.1 (R Development Core Team, 2011) including the Matching Package (Sekhon 2011).

3. Data

3.1 Land Cover

The land-cover data for 1990, 2000, and 2005 that we make use of were originally produced by Conservation International (CI) using Thematic Mapper (TM) and Landsat Enhanced Thematic Mapper Plus (EMT+) data. CI compiled the three raster images into one multi-date image with a 28.5m resolution (Harper *et al.*, 2007; Kremen *et al.*, 2008). The land-cover data used for this analysis was identical to the CI data, aside from minor preprocessing by Kremen *et al.* (2008), noting that pixels that were obstructed by clouds during imaging for one or more of the three study dates were excluded from analysis. The numbers of forested pixels that could be utilized, by year, are 124,252,074 for 1990, for 2000 114,507,467 and 111,536,234 for 2005. From these, we drew a random sample of 100,000 pixels for each of our two time periods of deforestation.

3.2 Protected Areas

The data we examine are a subset of the GIS file used by Kremen *et al.* (2008). We split PAs into three groups by year of creation: pre-1990; 1990-1999; and 2000-2008. We refer to the latter as 'Durban Vision PAs'. Lacking deforestation data for after they were created, we infer potential impact by comparing locations to PAs created prior to 2000, for which we do analyzed impacts. While PAs have different IUCN (International Union for Conservation of Nature) designations, the designations were not part of the dataset and, therefore, were not considered in this analysis. Some locations had missing data due to being outside of the raster grid's spatial domain. This is because raster data is formed with pixels while vector data consists of points, lines and polygons. The effect of these errors was minimal and the observations were removed. Table 1 shows some basic statistics on PA extent, for the endpoints of our periods, and its overlap with forested areas.

3.3 Key Landscape Characteristics

Elevation data are from the NASA Shuttle Radar Topographic Mission (SRTM) and have 90m resolution. We derived slope (degrees from horizontal) from the Digital Elevation Model (DEM). Data for streams and other inland water bodies (i.e., rivers, canals, and lakes) came from a 1992 publication of the Digital Chart of the World (DCW) and Urban Area was from the 1997 DCW. All DCW data has a scale of 1:1,000,000 and we note that these variables are constant over time. Also constant are ecoregions, classified by the World Wildlife Fund and accessed by means of an updated version of Olson *et al.* (2001) that was published in 2004. Madagascar Vegetation Map, which provides the Forest Classification data, had been produced for the Madagascar Vegetation Mapping Project (http://www.vegmad.org). The data were actually published in 2007, although the timeframe of the grid is 2001 (this is not a worry as the ecoregions do not shift on timescales relevant to this analysis). Here the data resolution is 30m (2007). Administrative Boundaries are from the global administrative area database (GADM, Version 1). Their scale is unknown and it could vary by country but, at roughly 30 Arc seconds, it is sufficiently precise for our purposes. The six original provinces in Madagascar (Antsiranana, Antananarivo, Mahajanga, Toamasina, Fianarantsoa and Toliara) were used as controls for regional differences, because our time frame predates their 2004 dissolution (was alongside the establishment of other administrative regions).

Villages and road-network data are from The National Geographic & Hydrographic Institute of Madagascar (www.ftm.mg), originally for 1964 and updated in 1990). These data are 1:500,000. The ‘Path Distance’ tool was used to process these data in order to derive distances to Primary and Secondary Roads. Population density comes from the 2000 Global Gridded Population Database of the Center for International Earth Science Information Network (CIESIN).

4. Results

Protected Area Locations and Deforestation

In Table 2 we provide a naïve estimate of the impact of PAs on deforestation by showing rates of deforestation for protected and unprotected locations, for PAs established prior to the year 2000. For the higher 1990-2000 deforestation rates, comparing deforestation in PAs to deforestation in all of the unprotected sites suggests a 7% reduction in deforestation due to those pre-1990 PAs. The 2000-2005 deforestation rate is lower. Comparing the deforestation rates in the PAs to all of the unprotected lands suggests about a 2% reduction in deforestation due to pre-1990 PAs. With slightly lower internal clearing, the PAs created in 1990-1999 had a greater impact (over 2.5%).

We call such estimates of PA impact 'naïve' because they ignore the differences in characteristics shown in Table 2 between the protected lands and unprotected lands on average in Madagascar. For instance, the protected sites are further from roads and on average also are on steeper slopes. That is consistent with results from Green *et al*. 1990 and Sussman *et al*. 1994, for Madagascar, and Joppa & Pfaff 2009 globally. Table 3a's multivariate regression summarizes the differences in sites by showing the effect of all our landscape characteristics on the probability of protection.

Drivers of Deforestation

The differences just documented, across protected and unprotected sites, matter for the rate of deforestation. Table 3b's OLS regression for deforestation for only unprotected locations shows this holds independent of any PA impacts. This shows important drivers of both 1990-2000 and 2000-2005 deforestation pressures. By implication, pressures varies greatly across the landscape (per time periods, coefficients tend to be smaller in later period given less deforestation overall).

For example, roads cause pressure to vary in both time periods, though not surprisingly there are shifts across time in where pressures are highest (Haruna et al. 2014 discuss the value, for policy, from an ability to anticipate shifts in pressure, while demonstrating shifts in pressure in Panama). For Madagascar, the secondary road network has consistent impacts but the pressure frontier is farther from primary roads in our second time period of deforestation, i.e., during 2000-2005. Slopes and provinces also have consistent effects − though again smaller in the second period.

Impacts of PAs – OLS Regression

As a first effort to control for differences in site characteristics in estimating PA impact, Table 3c combines Table 3b's factors with PAs to explain deforestation in unprotected and protected sites (we present OLS regressions for easy interpretation; Probit's marginal impacts are very similar). Controlling for site differences does affect impact estimates relative to naïve. Not surprisingly to control for the pre-1990 PAs' locations lowers the PA-impact estimate but it remains positive and statistically significant, although of course lower for the second time period given lower clearing. For 1990-2000 deforestation, the estimate of PA impact using controls is a bit more than 6% − i.e., lower than Table 2 difference in the raw means yet clearly significantly different from zero. For 2000-2005 deforestation, given lower pressure those same pre-1990 PAs avoid only ~ 1.4% deforestation. Interestingly, however, for the new 1990-1999 PAs the 2000-2005 impact estimate is ~ 2.5%, higher than for older PAs and, in fact, much like the difference in raw means. It could be that actors were better able to anticipate future clearing pressures when creating the later PAs.

Impacts of PAs – Matching

Table 4 shows that matching protected points to the most observationally similar unprotected ones clearly reduces the differences in characteristics between the protected and control points.

For instance, distances to roads and slope are significant factors in deforestation and both show significant differences between protected and unprotected locations that Table 4 shows both fall (this 'balance' table shows these reductions in difference as raw values and in standardized form).

Based on matched samples, Table 5 shows matching estimates for PA impacts on deforestation within the pre-1990 PAs (for both 1990-2000 and 2000-2005 deforestation) and 1990-1999 PAs (2000-2005 deforestation only). For the pre-1990 PAs, the additional (i.e., beyond OLS) control for differences in characteristics lowers the estimated impacts coefficients for both time periods. For the 1990-2000 deforestation, for instance, the estimate is on the order of 4% instead of 6%. Interestingly, suggestive of different dynamics over time in political economy of PAs' locations, for 2000-2005 deforestation matching correction raises (versus OLS) the estimate for later PAs. Thus, vis-a-vis pressure, location processes seemed to operate quite differently for the later PAs. Finally, addressing remaining differences in characteristics between the protected and matched control points, OLS regressions using only the post-matching protected and unprotected samples (also Table 5) support all of the conclusions derived from the standard matching impact analysis.

Varied PA Impacts Across The Landscape

Some subsets of PAs have reliably greater impact. From Pfaff et al. 2009 on Costa Rica, e.g., we might often expect dependable variation in clearing pressure as a function of variation in drivers and, thus, that well-enforced PAs vary in their impact (since without pressure there is no impact). Thus, all else equal, if PAs were to be located on flatter lands and to be closer to roads and cities while at least as well enforced − perhaps at a cost − then they could have higher forest impacts. That is the clear prediction from almost any static land-use model (see Pfaff and Robalino 2012, while Pfaff et al. 2013 and Pfaff et al. 2014 note that political economy modeling is needed too).

To demonstrate this for Madagascar, Table 6 presents variable 1990-2000 deforestation impacts of the pre-1990 PAs, as a function of where those PAs are located on the landscape. Specifically, Table 6 splits those pre-1990 PAs into subsets along three dimensions, or characteristics of sites that often matter for deforestation pressure: distance to primary road; distance to secondary road; and distance to urban area. Its two rows always split PAs into those with values: above the mean calculated for the entire sample, for the indicated landscape characteristic; and below that mean. The PAs closer to either type of road or the city have estimated impacts essentially twice as large as for typically lower-pressure locations. Such sites might have higher financial or political costs.

Potential Impacts of Durban Vision Protected Areas

Viewing the recent expansion of Madagascar's PA portfolio through the lens of the deforestation drivers and all the previous PA impacts is helpful for understanding how effectively Madagascar has scaled up their conservation efforts through the Durban Vision. From Tables 2 and 3 above, the characteristics of the sites of the newest PAs are associated with relatively high PA impacts. For instance, each successive generation of PAs has lower slopes and the PAs created as part of the Durban Vision are closer to each of the road types as are the averages for all of the prior PAs.

5. Discussion

For a country with important biodiversity, this analysis adds to a rapidly growing literature that demonstrates the importance of checking whether outcomes in PAs imply *impacts* of protection. For conservation organizations, and for other institutions with overlapping mandates for support, if good data exist such impact evaluations can be done quickly and cheaply to provide guidance.

However, data with appropriate spatial coverage, and resolution, for the time period of interest, will not always be immediately at hand. For instance, data for some potential driving factors in deforestation were not found for dates before 1990. If those factors responded to siting of PAs, that could bias our estimates of PA impacts. This motivates ongoing search for additional data − at the least facilitating robustness tests suggested by the consideration of many such possibilities.

Additional data could also permit extensions, for instance comparing impact across types of PAs or, with later deforestation data, evaluating not only the location but also the impact of new PAs. Earlier deforestation data also can help to understand whether the pool of forest shifted over time such that the currently standing forests, used as controls here, were those facing lower pressures.

Given those limitations, which we believe motivate attempts to extend what we have found here, we found that protection lowered the 1990-2000-2005 deforestation rates within PA boundaries in Madagascar, albeit by less than is estimated without matching methods' control for locations. Impacts are lower during the second time period because there is less clearing for PAs to block. Nearer to roads and cities, where there tends to be higher deforestation pressures on unprotected lands, PA impacts are indeed higher, although the same pressures could raise costs at these sites.

Finally, the characteristics of the many new 2003-2008 PAs − created after the Durban Vision − suggest at least an expansion of the significant PA impacts established by earlier Malagasy PAs. Maintaining or increasing this will not be easy, especially if global markets focus on resources found within Madagascar's PAs. For instance, the heightened demand for rosewood, as well the illegal extraction from Madagascar's forests that followed (see discussion in Barrett *et al*. 2010) highlights challenges for conserving Madagascar's biodiversity regardless of land characteristics. Wherever sources of pressure exist, effective monitoring, legislation, and enforcement will be required to capitalize on Madagascar's ongoing positive investment in lands worth conserving.

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<u>Figure 1</u>

Past Administrative Regions in Madagascar

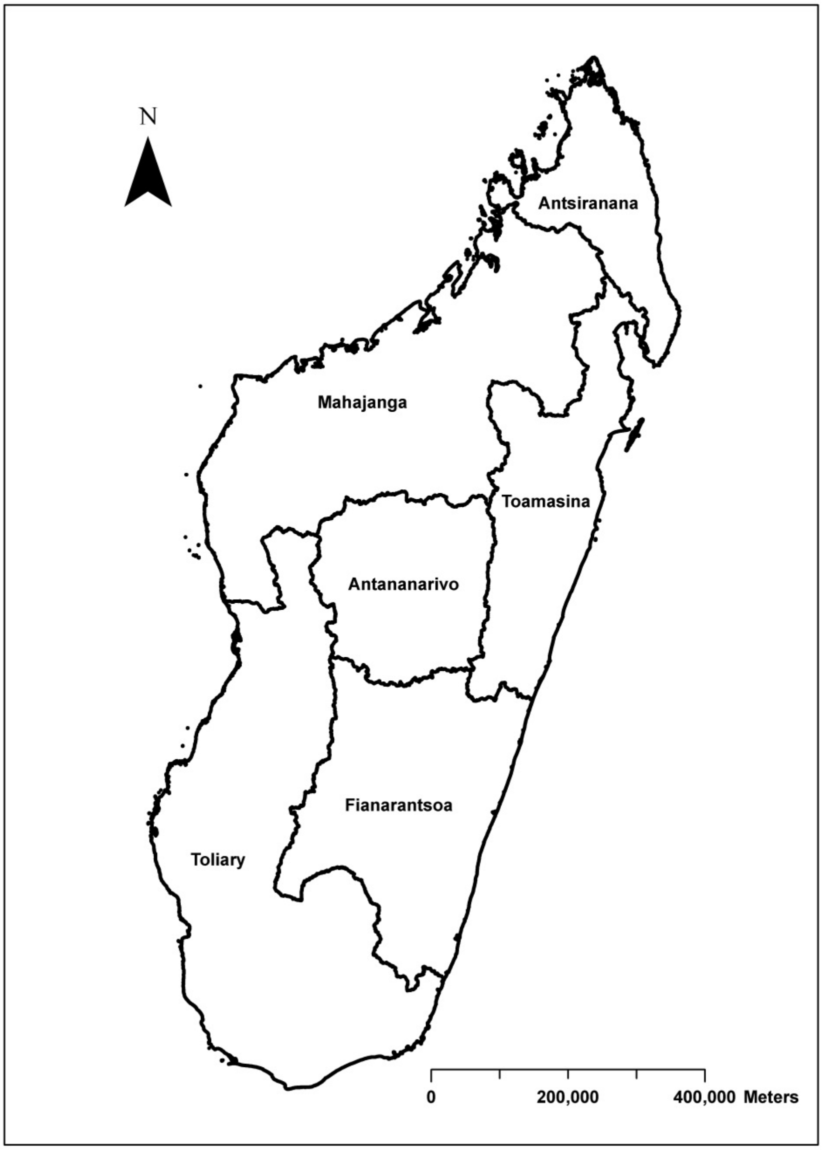

Figure 2

Malagasy Protected Areas Established Before 2000