MEASURING PROTECTED AREAS' IMPACT ON DEFORESTATION IN PANAMA

by

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December 2010

Masters project submitted in partial fulfillment of the
requirements for the Master of Environmental Management degree in
the Nicholas School of the Environment
Duke University
2010

Abstract

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Throughout the last century, protected areas (PAs) have been the major policy instrument for forest conservation worldwide, as well as in the Republic of Panama. The country has strived to lower the decline in its tropical forest cover which is rich in biodiversity. The importance of evaluating existing forest policies has been increasing, especially with emergence of financial incentives given to mitigation of deforestation. Few studies, however, have examined the effectiveness of forest policies in Panama, including the adoption of PAs.

This study evaluates the impact of PAs on deforestation rates in Panama through the use of matching methods. The methods are used to adjust observable selection bias of PAs location. The conventional evaluation methods for protected areas failed to consider such bias, thus results using matching methods were expected to give less distorted estimates of the impact. Two types of matching methods were applied to obtain the estimated impacts of PAs, namely propensity score matching and covariate matching. The results were compared with those from the conventional evaluation methods. Countrywide forested plots in two time periods, 1992-2000, and 2000-2005 were examined.

The results indicated positive effects of PAs on prevention of deforestation. They also revealed that conventional evaluation methods overestimated the impact of PAs. Such results agree with the previous matching analysis done for other geographic regions. It seems that the magnitude of the impact was enhanced in areas where high deforestation pressure existed. There was an indication of a geographical shift of deforestation frontiers toward remote areas with time. Bias-adjusted estimates for evaluation of PAs will be critical for formulation of future policy. With PAs being effective in avoiding deforestation, the future focus should be on where to put major resources for protection. As deforestation drivers make the deforestation frontier shift geographically, PAs will need to meet needs of covering forests under large threat in the present and the future.

Masters project submitted in partial fulfillment of the requirements for the Master of Environmental Management degree in the Nicholas School of the Environment,

Duke University 2010

Acknowledgements

This research couldn't have been realized without guidance and support of all the following individuals and organizations. The author would like to thank Dr. Alexander Pfaff for advising, Dr. Lucas Joppa for making data available and valuable comments, Dr. Richard Condit, the staffs of the Panama Canal Authority, the ministry of environment in Panama(ANAM) and U.T.A Capira, Panama, for providing information about the country's policies, Dr. Lynn Maguire for supporting the research process, and lastly, my family and friends for continuous support and encouragement. Any errors remain the sole responsibility of the author.

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I. Introduction

Evaluation of effectiveness of protected areas

Tropical deforestation has been one of the most critical global environmental problems for a number of decades now. Factors which scientists have argued contribute to deforestation include poverty, population factors, demands for timber, energy and agricultural commodities, infrastructural development, mining, urbanization, tenure rights, etc (Benhin, 2006; Binswanger, 1991; Defries et al., 2010; Rudel et al., 2009) . Various policy instruments have been adopted to tackle the problem, but the speed of loss of the tropical forests has been continuously high. Recently, the role of the tropical forests in climate change mitigation has added to the urgency of the forest conservation. Deforestation, most of which occurred in tropical forests, is estimated to contributes most of the 17% of the current total global green house gas (GHG) emission that is derived from the forestry sector (IPCC, 2007).

In response to the urgency of reduction of carbon emission from loss of and damage to tropical forests, financial incentives have been proposed in national and international climate change regimes. The system of incentives is known as REDD (Reduced Emissions from Deforestation and forest Degradation), a mechanism of international assistance and funding provided by developed nations to developing nations in order to reduce GHG emission caused by deforestation and forest degradation. This mechanism was originally proposed in the UNFCCC Conference of Parties (COP) 11 in 2005 by Coalition of Rainforest Nations. After the REDD mechanism was included in the Bali roadmap COP 13 in 2007, the scheme began to be a subject of explicit consideration in the GHG mitigation mechanism of UNFCCC and national governments. The scale of the mechanism may be expanded if it covers a wider range of activities such as forest management and carbon stock enhancement, as has been discussed (new mechanism called REDD+). Furthermore, REDD is not limited to only the international level: bilateral REDD mechanisms at state or country level have also been examined or developed . We see such examples in recent climate change registration drafts submitted to the US congress, or the state of California's pilot REDD project in provinces of Brazil and Mexico.

As the financial instruments for tropical forest conservation and finance have attracted the interests of a wider range of stakeholders than before, it also becomes more important to evaluate the effectiveness of existing forest conservation policies, including the establishment and management of protected areas. Throughout the last century, protected areas have been played a central role in the forest conservation policy of most nations worldwide, a role which can certainly continue in the future. Therefore, it is critical to analyze the reasons for the failures in forest conservation and identify major threats, in order to create effective forest conservation policies in future.

Current methodologies that measure the effectiveness of forest conservation in protected areas have room for improvement. Joppa and Pfaff (2010-a) summarize the problems of several common types of evaluation methods of protected areas and show the biases included in the results. Recent studies with improved methodologies have changed the way we view the protected area impacts that were based on such conventional methods (Joppa and Pfaff, 2010-a). Some of the recent studies used a new approach where biases from selecting the locations of protected areas were countered with a methodology called matching analysis. These analyses have shown that the impacts of the protected areas on deforestation mitigation tend to be lower than what had been described previously on a worldwide scale and in the country of Costa Rica (Andam et al., 2008; Pfaff et al., 2008; Joppa and Pfaff, 2010-b).

Evaluating protected areas of Panama

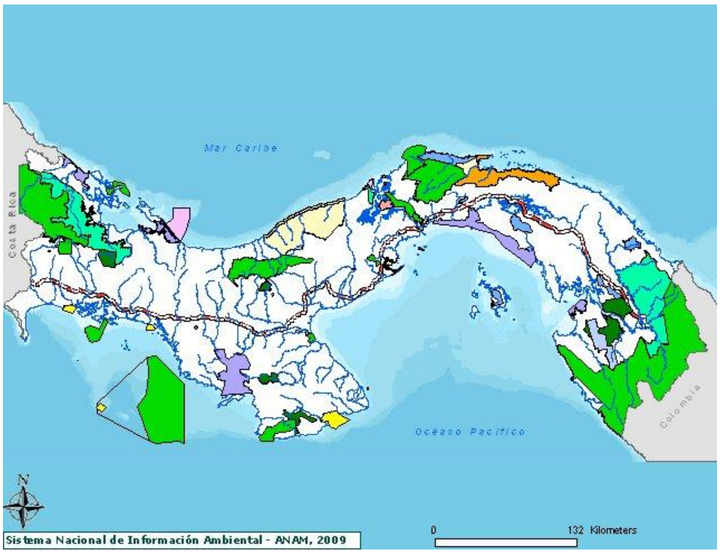
The republic of Panama comprises 75,717 km^2 of landmass, located in the far south of Central America, in a tropical climate, and its forests have extremely rich biodiversity. Panama has more vertebrate species than any other Central American nation, and 21 times more plant species per square km than Brazil. A significant number of species are endemic to the country: from 1,300 to 1,900 plants, 23 amphibians, 24 reptiles, 8 birds and 10 mammals. In addition to their rich biodiversity, the forests in Panama also play an important role in the Mesoamerican biological corridor; for example, they share about 120 migratory bird species with other American countries (Government of Panama, 2009).

In the year 2000, Panama’s forest cover accounted for 45% of the country’s landmass. Between 1992 and 2000, its deforestation rate was 1.1% per annum, comparatively high among global deforestation rates. According to the National Environment Authority (hereafter ANAM), most loss of forest cover occurred in mature forests. ANAM identifies major causes of the deforestation as: unsustainable agricultural practices, ranching, forest exploitation, urban development, exploitation of mining resources, and education levels and culture which affect people's behavior. The most recent deforestation rate of Panama, reported by FAO is lower than that of the previous decade (0.1% per annum between 2000 and 2005) (FAO, 2009). The government of Panama, however, claims in a recent report submitted to the World Bank that conservation strategies and measures are needed to tackle continual threats of deforestation (Government of Panama, 2009). ANAM, which was established in 1998, is the current state entity in charge of natural resource management, environment related policy, and law enforcement, including management of the country's forest cover.

For decades, the Panamanian government has been putting its major regulatory and enforcement effort into the establishment and management of protected areas. As seen in Table 1, the area under protection has been expanding since 1960. In the 1980's, major national parks were established, including Darien national park (579,000 ha), which lies next to the border of Colombia, La Amistad international park (207,000 ha) in collaboration with Costa Rica, and Chagres national park (129,000 ha), which includes the headwater regions of the Panama Canal. In 2000, Panama's protected areas covered 26% of the national territory; by 2008 the area had increased to 36%. Map 1 shows the geographic locations of protected areas as of 2006. Many of the protected areas are located in comparatively remote areas, far from city centers and roads.

Despite of the expansion of the scale of the protected areas, however, lack of resources is considered to be a major obstacle to conservation. Oestreicher et al. (2009) points out that there has been a large variation among national parks in available resources such as government budgets. Such limitation may have restricted the impact of some protected areas on forest conservation. According to the authors, they also imply a problem with the ban on illegal logging that ANAM enforced in the 1990's; such a command and control type of policy became difficult to implement because the police force also lacks resources.

Map 1: Location of protected areas in Panama (as of 2006)



*Protected areas:areas in colors

Table 1: Establishment of the protected areas (1960-2004)

Period of establishment	Area(km^2)
1960's	1,906
1970's	972
1980's	10,914
1990's	1,404
2001-2004	1,312

Panama's forest policy, which originally focused on command and control, had recently shifted to incentive-based approaches. The executive decree that ANAM promulgated in 2003 characterized the nation's forest policy as an "integral part of policies for the economic and social development of the country". The National Environment Strategy for the period of 2004 to 2009 also mentioned "conservation for sustainable development". ANAM has been incorporating the incentive mechanism represented by ecosystem services into their actions too. In 2007 Panama adopted the Kyoto Protocol of the UNFCCC, which allowed the country to participate in the GHG offset programs of afforestation/reforestation under the Kyoto mechanism. The government is currently participating in the REDD+ readiness project facilitated by World Bank Forest Carbon Partnership Facility (FCPF) during the term between 2009 and 2012. This project supports participant countries' preparation in REDD by developing reference scenarios, adopting a REDD+ strategy, designing monitoring systems and setting up REDD+ national management arrangements. Participation in this project will give the government an important opportunity to evaluate and reform the country's forest policy, strategy and actions.

Considering the current status of the country, review of the past policy seems critical to formation of effective schemes of forest conservation in the future. A few number of studies have evaluated either forest policy or effectiveness of protected area in mitigation of deforestation. Oestreicher et. al. (2009) analyzed protected area effectiveness in Panama in terms of resource input, governance and community involvement. They compared the deforestation rates among multiple protected areas; however they did not measure the impact of the protected areas. Rompre et al. (2008) examined potential threats of land conversion within the Panama Canal watershed, and suggested the need to study deforestation threats in other regions such as rural areas. An analysis of Nelson et al. (2001) for Darién national park concluded less impact of legal protection in the area, emphasizing importance of tenure right. There are no studies, however, for countrywide scale evaluation of protected areas in Panama.

This thesis aims to provide a countrywide analysis of the effectiveness of protected areas in preventing deforestation. I have adopted the matching method and evaluated the results with a comparison between estimations using conventional deforestation analysis. My results show that the analysis for the protected areas in Panama exhibits patterns similar to previous analyses using the matching method for other geographic areas, yet distinctive on some points. These results suggest some future directions for effective forest conservation policy in Panama.

II. Methodology

Selection bias in location of protected areas

Previous studies using the matching method revealed that protected areas had a general tendency to be established in places where a low probability of deforestation pressure existed. These studies proved that areas with a low probability of deforestation tend to have steep slopes, high elevation and greater distance from roads and urban areas (Andam et al., 2008; Pfaff et al., 2009; Joppa and Pfaff, 2010-a). Such land characteristics in protected areas are also intuitively understandable. That is to say, the major objective of the establishment of many protected areas might have been the preservation of intact and scarce ecosystems. Such ecosystems may tend to be located in remote areas which are less susceptible to land conversion, and therefore may have remained intact or less degraded even before protection. Another intuitive result is that remote areas with a low potential for utilization are preferred for protection because of lower rent potential of the lands.

Conventional methods to evaluate the effect of protected areas on deforestation have had some limitations, considering the above bias in selecting land for protection. A typically used evaluation method compares protected areas with unprotected areas in general. In this case, the locations of protected areas may originally be under less threat of deforestation. Therefore, the actual contribution of the protected area to the control of deforestation may have been smaller than calculated by comparison with unprotected areas in general. In other word, the effect of the protected areas will be overestimated.

This is why comparing lands with different characteristics may distort the estimator. Another common evaluation method compares the deforestation rates between protected areas and “buffer zones”. Buffer zones are areas adjacent to protected areas, often 10km or so in width, set up for the purpose of allowing local inhabitants sustainable resource use and management. Such a comparison assumes that the characteristics of the buffer zones are similar to those of protected areas. However, the buffer zones can be influenced by the protected areas in either a positive or a negative way for deforestation. The buffer areas can have lower deforestation rates because of being assigned as “buffer zones”, or on the contrary, can be subject to deforestation leakage (forest clearing shifts from protected areas to buffer zones because of the restriction). Therefore this estimator can be skewed. There is also a method which compares different protected areas. This method has two problems. First, individual protected areas could have different attributes. Second, the comparison has no reference point from which to measure effectiveness of the policy. Finally, a method exists which makes a temporal comparison of specific protected areas. This method is susceptive to temporal factors such as economic growth that will influence the deforestation rate (Joppa and Pfaff, 2010-b).

Treatment effect and matching method

Let {Yi(0),Yi(1)} denote the two potential outcomes of a policy intervention. Yi(1) is the outcome of individual i when exposed to the treatment Ti=1 (designated as protected area), and Yi(0) is the outcome of individual i when not exposed to the treatment Ti=0. The treatment effect for a single unit τ_i is defined as τ_i = Yi_1 - $Y_{i0.}$ The treatment effect in a non-experimental setting, which is the expected treatment effect for a single unit τ_{i} , is defined as

$\tau^e = E(Y_{i1} \mid T_i = 1) - E(Y_{i0} \mid T_i = 0)$.

With full sample *N*, the sample average treatment effect is

$$\tau^{sample} = \frac{1}{N}\sum_{i=0}^{N}\{Y_i(1) - Y_i(0)\}$$

The average treatment effect is the standard measurement of policy effectiveness. In the case of measuring the effectiveness of protected areas, the outcome is whether the land plot i is deforested or not during specific period of time, and the treatment is whether the land plot i is designated as a protected area or not. As an impact of the policy, we measured the difference of average deforestation rates between the sample treated and control groups as an estimator of the population average treatment effect (Abadie et al., 2004). However, this estimator of treatment effect is distorted when the random sampling assumption is breached.

Matching is an econometrics methodology first developed by Rubin (1973). It was created for the purpose of obtaining an average treatment effect with less bias in the process of sample selection. The bias exists when the sampling framework is not randomized, as the treated group is selected conditional on observable variables. Such bias is called observable selection bias. This bias in sample selection distorts the estimator of treatment effects, when the determinants of the sample selection also affect the treatment effect. The matching method corrects observable selection bias among the sample, so that the estimator of the treatment will be less distorted. The matching method is widely used to measure impacts of interventions in various academic disciplines, in cases where a randomly sampled data set is not obtainable, and the bias is observable and adjustable throughout the method. In the case of protected areas' effectiveness, the sample selection bias (location selection for protected areas) is accounted for in the land characteristics. The past typical methodologies introduced above lack consideration of this bias. Recent studies using a matching method have tried to measure the bias-adjusted effectiveness of protected areas on deforestation.

In the matching method, the observable selection bias is corrected as follows: First, a set of variables which determined the selection of the treated group is defined. Second, a set of treated and control samples are chosen which share similar values of the covariates, and are paired. Matching samples, is expected to diminish bias in observable variables. Lastly, statistical analysis is done using this bias-adjusted and matched sample set. Currently there are two matching methods available for statistical inference: the propensity score matching, and the covariate matching method. In my analysis, I primarily use propensity score matching, and also use covariate matching as a sensitivity analysis.

1. Propensity score matching

The propensity score was first proposed by Rosenbaum and Rubin (1983). This score, an index for matching samples, is used to reduce the dimensionality in matching based on multiple covariates. The propensity score is “the conditional probability of assignment to a particular treatment given a vector of observed covariates” (Rosenbaum and Rubin, 1983). This methodology requires two stages of regression analysis. The first regression is a probit regression that estimates propensity scores (probability of protection for each unit of observation) and assigns one to each observation. An untreated sample is matched to a treated sample which has the closest propensity score. A second regression on the set of matched samples calculates the average treatment effect (Dehejia and Wahba, 2002).

2. Covariate matching

Covariate matching pairs up samples between treated and untreated groups, based on a measurement unit called Mahalanobis distance. In contrast to Euclidean distance which is a scale-invariant, Mahalanobis distance measures multi-dimensional distance that is mapped within the space of covariates. This unit of measurement is useful when we treat multiple variables which are represented by different units of measurement. The average treatment effect is calculated by regression on the matched sample set (Guo, 2005; Abadie et al., 2004).

Data

Two datasets were used to analyze the temporal change in country-wide land use over the two periods of time: 1992 - 2000, and 2000 - 2005. These were the latest sets of the land cover data available at the time of analysis. The data were primarily collected and organized by Dr. Lucas Joppa, my resource collaborator. Because the 1992 dataset was not compatible with the 2005 one, two datasets were used for 2000, one paired with the 1992 data and one paired with 2005 data. The source for the 1992-2000 pair of datasets was land cover inventories created by the government of Panama. The 2000-2005 pair was organized using two global data-sets of land cover (Data from year 2000 was Global Land Cover(GLC) 2000 project by the European Commission Global Environmental Monitoring Unit for data, and data from year 2005 was from the GLOBCOVER project by an initiative of the European Space Agency (ESA).). The data for the second period adopted the land use classification of UN Land Cover Classification System (UN LCCS). The landmass of the whole country was divided into 1 km squared plots, which was used as a unit of observation.

UNFCCC's Marrakech Accords in 2001 defined deforestation as "the direct human-induced conversion of forested land to non-forested land". On the other hand, FAO defines it as "the conversion of forest to another land use or the long-term reduction of the tree canopy cover below the minimum 10 percent threshold". The definition of deforestation used by each country can vary. In the present analysis, deforestation was defined as a change of land from forested to non-forested in each 1km squared plot during a time period. For protected area boundaries, the 2008 World Database on Protected Areas was used as a source of data. As seen in Table 2, most of the protected areas of Panama are categorized as national parks.

Table 2: Category of protected areas of Panama (as of 2004)

	Area(km^2)
Nature Reserve and Wilderness Area	166
National Park	10,540
Habitat/Species Management Area	197
Protected Landscape/Seascape	109
Managed Resource Protected Area	1,169

(Followed with the IUCN category of protected area)

After the land plots were obtained, the corresponding land use variables and deforestation variables were organized. Areas that were non-forested at the first measurement time (1992 for the first set and 2000 for the second set) were dropped from the observation, in order to exclude the effect of reforestation or natural vegetation recovery. In addition to that, protected areas established after the beginning of each measurement period (after 1992 for first set and after 2000 for second set) were excluded from observation for that period, since I needed to measure the effect after their establishment. Furthermore, the only areas to be chosen as a treated group were those which were considered to be under the most rigorous protection, such as national parks, natural reserves and wilderness areas. With these criteria, 37,066 km^2, representing 49% of the total landmass of Panama became a population for analysis between 1992 and 2000, and 35,563km^2, 47% of the total landmass for analysis between 2000 and 2005.

The previous studies using the matching method assumed the following variables as determinants of protected area site selection: geographic variables such as distance from roads, distance from cities, slope, elevation, and agricultural suitability. In the present study, these variables were used as determinants of observable selection bias along with several economic and geopolitical variables that I considered might have had impact in the site selection. Hereafter I will call all the variables I used “land characteristics variables”.

The geographic variables include elevation, slope, distance from roads, distance from urban areas, ecoregion and agricultural suitability. Elevation and slope were calculated with Shuttle Radar Topography Mission elevation data from the Global Land Cover Facility. Locations of roads were identified with the VMAP Level0 dataset. Locations of urban areas were identified with the Gridded Rural Urban Population dataset. Ecoregion categories were included to take into account the ecosystem types of the land plots. The definition of ecoregion is “relatively large units of land containing a distinct assemblage of natural communities and species, with boundaries that approximate the original extent of natural communities prior to major land-use change” (Olson et al., 2001). Finally, data regarding agricultural suitability was collected from the International Institute for Applied Systems Analysis for Agricultural Suitability. The institute estimated the suitability of land for agriculture based on variables such as climate, soil type, land cover and slope of terrain. The suitability was expressed as a discrete variable ranging between 0 (most suitable) and 9 (least suitable) (Joppa and Pfaff, 2010-a).

I considered the following economic and geopolitical variables for use in my analysis: district average household income, location in indigenous reserves (indicated with a dummy variable), and location in the watershed which supplies water to the Panama Canal. (hereafter called the Panama Canal watershed) The household income data was taken from the national census administered by the Panamanian government in 2000. The district level average income was calculated and allocated to each unit of observation as an economic index of the unit. Both the data of indigenous reserve territories and the Panama Canal watershed boundaries were quoted from the public GIS database of the national government. The Panama Canal watershed, located in the central areas of the country's terrain, covers approximately 4% of the nation's landmass. The Panama Canal watershed had been a subject of implementation of various policy instruments for forest conservation by the government because the Panama Canal plays a central role in the country's economy as a keystone of the world's maritime trade routes. The government has designated maintenance of the forest cover in the Panama Canal watershed as a critical factor for the operation of the Canal, since soil erosion and decreasing water supply as a result of deforestation could negatively affect the Canal's function.

Indigenous reserves are another political influence which covers more than 20% of the territory of the country. Five indigenous groups, Kuna Yala, Emberá-Wounann, Ngöbe-Buglé, Madugandí and Wargandí govern their own territories, and the lands within the territories are collectively owned. The General Environment law of Panama indicates that anyone carrying out any activity, work, or project within their territories must consult with and secure the agreement of community representatives. Thus, I expected that the authority of the national government over indigenous territories in terms of forest conservation may be restricted. I also assumed that indigenous institutional enforcement and individual behaviors might have a unique influence on causes or patterns of deforestation, compared to those in the areas outside their territories.

III. Result

When I compare the lands located in the protected areas with the ones located outside of the protected areas, they had significant differences in the mean of the deforestation rate, the geographic variables and the socioeconomic and political variables, as seen in Table 3. The following tendencies are evident: First, within the protected areas, the mean deforestation rate is lower than in the unprotected areas. Second, the protected areas tend to be located farther from urban areas and roads, and at higher elevations, than the unprotected areas. They are also located in terrains with sharper slopes, and have lower agricultural suitability. In short, the protected areas tend to have low accessibility and low suitability for land conversion. Such differences between protected and unprotected areas have been also explained in the previous studies conducted for other countries (Andam et al., 2008, Pfaff et al., 2009, Joppa and Lucas, 2010-a.).

Differences in socioeconomic and political variables are also significant between the two groups. Some unique features are observed with these variables. The mean district average household income is higher in the protected areas than the unprotected areas, which is contrary to the typical pattern of high poverty levels among communities in forested areas that is frequently observed in different parts of the world. A possible reason for this discrepancy is my use of the average regional income for all land plots in a region. Thus, the local income status at the local levels may be under- or overestimated. Another difference in variables is that the majority of areas in the indigenous reserves are located outside of protected areas, while in the Panama Canal Watershed the pattern is the opposite.

Table 3: Pre treatment characteristics (Forested areas in 1992)

	Protected areas (protected before 1992)	Unprotected areas	Anova P-value (α=0.05)
Deforestation (dummy) mean (1992-2000)	0.007 (0.0008)	0.16 (0.002)	0.00
Deforestation (dummy) mean (2000-2005)	0.06 (0.003)	0.31 (0.003)	0.00
Elevation (m) mean	757.93 (6.48)	302.00 (2.18)	0.00
Slope (degree) mean	6.23 (0.04)	3.24 (0.02)	0.00
Distance from urban areas (km) mean	59.71 (0.41)	51.45 (0.17)	0.00
Distance from roads (km) mean	19.97 (0.12)	17.41 (0.09)	0.00
Agricultural suitability (0-9) mean	4.96(0.01)	4.49 (0.01)	0.00
District average household income (USD) mean	166.89 (0.88)	122.01 (0.37)	0.00
Indigenous reserve area (dummy) mean	0.13 (0.003)	0.28 (0.002)	0.00
The Panama Canal watershed (dummy) mean	0.10 (0.003)	0.02 (0.001)	0.00
Observation (observation in 2000-2005)	9,467(8,372)	27,559(27,191)	

Parenthesis: Standard Error

To see the impact of protected areas on deforestation rates, I tested OLS regression models with multiple regressors. The dependent variable is the deforestation dummy (1:deforested, 0:forested) and the independent variable is the protection dummy (1:protected, 0:unprotected). This is also one of the typical conventional evaluation methods: the comparison of deforestation rates between protected areas and unprotected areas in general. I used the geographic variables and the economic and geopolitical variables as control variables, assuming they would affect the outcome of protection. Three different models were used for sensitivity analysis: the first one used only geographic variables, the second one used all covariates, both geographic and economic and geopolitical variables, and the third one had no controls for any covariates. As the results in Table 4 show, the coefficients of protection have negative values for both periods of measurement (from -0.063 to -0.162 in 1992-2000, and from -0.159 to -0.243 in 2000-2005). These coefficients are all statistically significant at the 5% significance level.

Another feature in the table is that estimators in 2000-2005 are larger than those in 1992-2000. In the data, the deforestation rates in both protected and unprotected areas are much higher in 2000-2005 compared to1992-2000 (for forested protected and unprotected areas, 16% and 0.7% in 1992-2000; 31% and 6% in 2000-2005.). As a result, the estimated difference in deforestation rate in 2000-2005 looks much larger. This phenomenon may imply success in continuous deforestation control inside the protected areas, with the impact increasing over time. There is also a possibility that the estimators are inflated due to inaccurate calculation of deforestation rates in the 2005, since this data mainly served for analysis on a global scale rather than a single country. We would like to wait for the country scale land use map for the new period to confirm this temporal trend between the two time periods.

The coefficients of geographic variables - elevation, slope, distance from urban areas and distance from roads - are almost all negative at the 5% significance level. In other words, lands with low accessibility tend to be less subject to deforestation pressure than those with high accessibility. Such a result agrees with arguments of some previous studies about correlation between the deforestation rate and land characteristics. Some of the data, however, vary from this general tendency. First, the covariate of distance from urban areas has positive coefficients in the period between 1992 and 2000. This might be a result of the trend towards intensified deforestation at the forest frontier lines in remote areas. Also, the positive coefficients of distance from roads between 2000 and 2005 differ from the usual negative coefficients for this variable. This may be the result of expansion of the deforestation frontiers in interior areas away from roads.

Regarding the coefficients of socioeconomic and geopolitical variables, first, the income level has only a small impact on deforestation. For the indigenous reserve dummy, the coefficients are mostly positive, which means that more deforestation occurred within the indigenous reserves. By contrast, the Panama Canal watershed dummy has all negative coefficients, showing low deforestation within the areas. When the covariates are controlled, the scale of the impacts of the protected areas on deforestation is lowered (Compare Models 1,2 and 3). This shows the importance of covariate control. Another point worth noting is that OLS regression models assume a randomized sample. Therefore, my biased sample may make the estimators of the above models inaccurate.

Table 4: OLS models of the impact of protection on deforestation

	Period between 1992-2000			Period between 2000-2005		
Dependent var=Deforestation	Model1	Model2	Model3	Model1	Model2	Model3
Protection	-0.092**	-0.063**	-0.162**	-0.159**	-0.181**	-0.243**
	(0)	(0)	(0)	(0)	(0)	(0)
Elevation	-0.000**	-0.000**		-0.000**	-0.000**	
	(0)	(0)		(9.86e-06)	(2.52e-09)	
Slope	-0.005**	-0.007**		-0.003**	-0.002**	
	(0)	(0)		(0.000655)	(0.00200)	
Distance from urban areas	0.002**	0.002**		-0.002**	-0.001**	
	(0)	(0)		(0)	(0)	
Distance from roads	-0.003**	-0.004**		0.002**	0.002**	
	(0)	(0)		(0)	(0)	
District average income		0.000**			0.001**	
		(0)			(0)	
Indigenous reserve dummy		0.131**			0.038**	
		(0)			(5.21e-09)	
Panama Canal watershed dummy		-0.125**			-0.090**	
		(0)			(2.00e-10)	
Ecoregion dummy	-	-		-	-	
Agricultural suitability dummy	-	-		-	-	
Constant	0.057	-0.030	0.169**	0.462**	0.317**	0.312**
	(0.136)	(0.443)	(0)	(6.24e-07)	(0.000643)	(0)
Observations	37,066	36,630	36,630	35,563	35,563	35,563
R-squared	0.146	0.164	0.045	0.134	0.140	0.056

Robust p-values in parentheses

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

As the first step of matching, I examined determinants of the protected areas' selection using Probit maximum likelihood regression models. Based on the previous studies of protected areas, I hypothesized that geographic variables determines the choice of lands for protection – the less accessible the land is, and the less suitable for land conversion, the more it tends to be subject to protection. In addition, I also hypothesized that the presence of the Panama Canal watershed and indigenous reserve influenced the decision of protection. Therefore, except for the district average household incomes, the same geographic and socioeconomic variables tested in the OLS regression models were used, in order to estimate the probability of protection for each land plot. I tested two models: the first one using only geographic variables, and the second one using all covariates including both geographic and sociopolitical variables. Table 5 shows the results of the estimation. The results largely support my original assumptions about the influence of the covariates on probability of protection in both periods of measurement. All coefficients of the covariates are statistically significant at the 5% significance level. Except for the indigenous reserve dummy, as the values of covariates increase, the probability of protection also increases. In contrast, the indigenous reserve dummy has a negative impact (The areas tend to be not protected). Therefore, together with the results of the OLS regressions, the impact of the covariates on both deforestation and probability of protection are presented.

Based on the probit regression result, I estimated the propensity score as a probability of protection for each land plot. I used Model2. The same set of covariates in this model was used to match samples in the covariate matching. Figure A shows the distribution of the estimated propensity scores. The figures show that the treatment group is more likely to be protected, while the control group has the opposite tendency.

Also as shown in the figures, there is thin common support between the treatment and control groups, which would create a potential bias by letting samples with fewer common characteristics be matched. Therefore, in propensity score matching, I conducted a sensitivity analysis with further control for the sample.

Table 5: Probit models of probability of protection

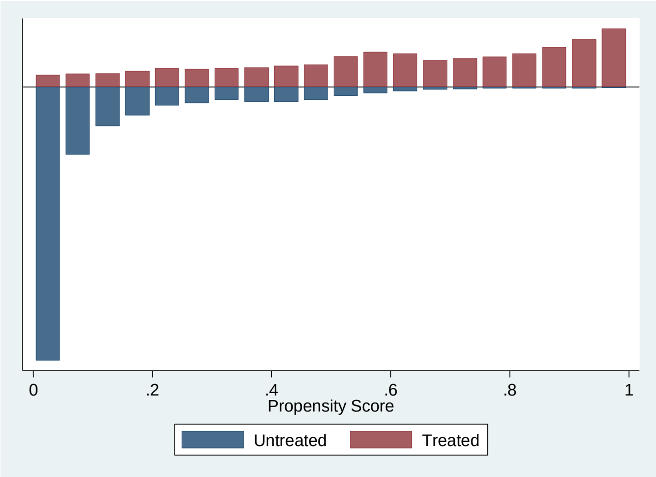
	Protected or not between 1960 – 1991		Protected or not between 1960 - 1999	
Dependent variable=Protection	Model1	Model2	Model1	Model2
Elevation	0.001**	0.001**	0.001**	0.001**
	(0)	(0)	(0)	(0)
Slope	0.042**	0.086**	0.035**	0.088**
	(0)	(0)	(0)	(0)
Distance from urban areas	0.007**	0.006**	0.009**	0.007**
	(0)	(0)	(0)	(0)
Distance from roads	0.008**	0.014**	0.013**	0.017**
	(0)	(0)	(0)	(0)
Indigenous reserve dummy		-1.365**		-1.477**
		(0)		(0)
Panama Canal watershed dummy		2.716**		2.276**
		(0)		(0)
Ecoregion dummy		--		--
Agricultural suitability dummy		--		--
Constant	-1.850**	-8.267**	-2.030**	-2.611**
	(0)	(0)	(0)	(1.70e-08)
Observations	37066	36556	35563	35149
R-squared	0.178	0.449	0.190	0.463

Robust p-values in parentheses

** $p<0.01$, * $p<0.05$, + $p<0.1$

Figure A: Distribution of propensity scores

1. Protected or not between 1960 -1991



2. Protected or not between 1960 – 1999

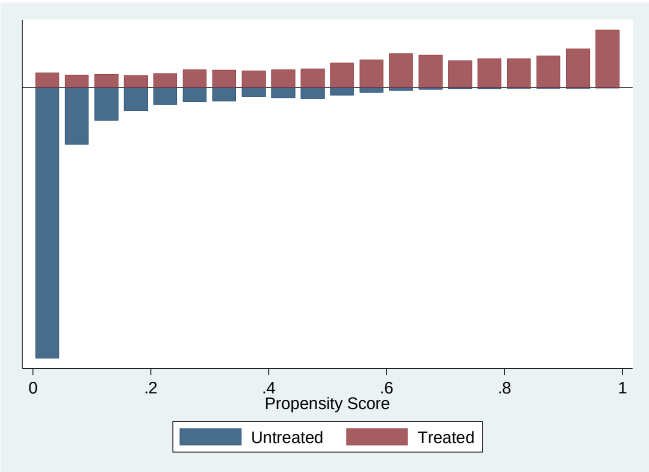


Table 6 shows the mean comparison of samples between the treated and control group before and after propensity score matching. We can see that matching reduced the difference between the means of the two groups, thus reducing bias in the sample. Nevertheless, p-values for some covariates show that the differences are still significant after matching. The reason is the large discrepancy in land characteristics between the treated and control groups, which could not be sufficiently compensated for by matching.

Table 6: Pre treatment test comparison, before and after propensity score matching

		Protected areas (protected before 1992)	Unprotected areas	T-test P-value (α=0.05)
Elevation (m)	Before	524.46	298.86	0.00
	After	523.81	568.08	0.00
Slope (degree)	Before	4.95	3.22	0.00
	After	4.95	5.25	0.00
Distance from cities (km)	Before	58.92	51.93	0.00
	After	58.93	55.74	0.00
Distance from road (km)	Before	20.10	17.67	0.00
	After	20.10	18.94	0.00
Agricultural suitability	Before	4.84	4.51	0.00
(0-9, lower = less constraint)	After	4.49	4.96	0.06
Ecoregion	Before	454.39	458.16	0.00
	After	454.38	453.81	0.12
District average household income	Before	159.38	120.74	0.00
(USD)	After	159.30	135.42	0.00
Indigenous reserve area dummy	Before	0.17	0.29	0.00
(0/1)	After	0.17	0.16	0.14
Panama Canal watershed dummy	Before	0.10	0.02	0.00
(0/1)	After	0.10	0.10	0.66
Observation	Before	27,006	7,804	
	After	26,761	6,301	

After obtaining the matched dataset, I estimated the average treatment effect of protected areas on deforestation and compared the estimators with those from the two typical conventional methods, i.e., comparison with general unprotected areas and comparison with buffer zones. For both the propensity score and covariate matching, I conducted a sensitivity analysis of the controls for the samples. In the sensitivity analysis of the propensity score matching, first, I set a limit to the difference of propensity score that the matched sample can have (Score difference limit 0.01.). Second, I allowed matching to have redundancy in so-called “replacement”. It allows samples in the control group to be matched with samples in the treatment group that are already matched with another sample, if they have the closest score that the controlled sample can have. I also cut off samples with propensity scores larger than 0.8 since above a score of 0.8 there is little common support. In covariate matching, I sampled 5% of the whole dataset and repeated it ten times to obtain an average, since covariate matching using the full sample was beyond the capacity of the statistics software. The averaged estimates are sample average treatment effect (SATE), as opposed to the population average treatment effects (PATE) measured by propensity score matching. In the sensitivity analysis of covariate matching, I used two matches. As I expected that tighter controls of samples would produce more accurate estimates, I used the same controls in the case of comparison with buffer zones.

The estimators in Table 7 signify what percentage of deforestation would be avoided by the presence of protected areas. For example, -0.162, the first figure in the top left row means that on the average, without protection, deforestation of the total area would be estimated to be 16% greater between 1992 and 2000. All the estimators in the table are negative, implying that the establishment of protected areas had contributed to prevention of deforestation during both time periods. Estimates in 1992-2000 have especially good statistical precision with small range of 95% C.I. This represents a favorable result considering the past resources devoted to the protected areas. Also, comparison with buffer zones gave lower impacts of protection than comparison with general unprotected areas, regardless of whether matching methods or conventional methods were used. This difference may suggest that the government controls on sustainable resource use in these zones had been successful.

Compared to the two conventional evaluation methods, the protection impact estimators from the methods using matching estimators were conservative. In other words, when conventional evaluation methods are applied, the impact of the protected areas will be overestimated. For example, in 1992-2000, the matching method gave a 3 to 4% lower impact of protection than the figure estimated by the conventional method. This tendency holds for both periods, 1992-2000 and 2000-2005, and also for comparison with buffer zones. The large 95% C.I. of some of the matched estimators, however, make the conclusion less definite. Lastly, the matching estimators in the comparison with the buffer zones in 2000-2005 are larger than those in 1992-2000. This result may suggest increasing effectiveness of control over deforestation in the buffer zones with time. Alternatively, the estimators may be inflated as I mentioned for the estimators of the OLS models.

Table 7: Impact of protected areas on deforestation

	Period between 1992-2000		Period between 2000-2005	
	Average treatment effect	Number of matched sample	Average treatment effect	Number of matched sample
A. Comparison with unprotected areas in general				
Conventional inside/outside analysis	-0.162 (±0.007)	37,066	-0.243 (±0.010)	35,563
Propensity score matching: *2	-0.152 (-)	36,556	-0.124 (-)	34,570
Propensity score matching (sensitivity analysis) *3	-0.136 (-)	33,062	-0.121 (-)	31,685
Covariate matching *4	-0.126 (±0.024)	37,510	-0.150 (±0.098)	17,780
Covariate matching (sensitivity analysis) *5	-0.121 (±0.019)	37,510	-0.152 (±0.079)	17,780
B. Comparison with buffer zones (within 10km of parks)				
Conventional inside/outside analysis	-0.088 (±0.006)	19,734	-0.219 (±0.010)	18,692
Propensity score matching *3	-0.061 (-)	16,221	-0.120 (-)	15,677
Covariate matching, within 10km of parks *5	-0.049 (±0.037)	18,565	0.126 (±0.065)	9,439

Parenthesis: 95% C.I. 95% C.I. of propensity score matching estimators were not obtainable from the limitation of software program.

*1 OLS estimation, without using covariates.

*2 Without replacement.

*3 With replacement, samples with p-score<=0.8 only, p-score difference <0.01.

*4 Single match, bias adjusted.

*5 2 matches, bias adjusted.

In an additional analysis using propensity score matching, I measured how protection would impact areas with different land characteristics. The purpose of the analysis was to see the protected areas' impact in more details. Variables such as distance from cities, distance from roads, elevation and gradient were used to examine such variation. Samples were separated into two subsample groups, either lower or higher than the average in the values of the above attributes. The sample average treatment effects on the treated group (SATT) were measured for this analysis in order to obtain the 95% C.I. that the software produced. Let SATT be defined as:

$\tau^{sample,\, t} = \frac{1}{N1} \sum_{i|Wi=0}^{N} \{Y_i(1) - Y_i(0)\}$ Where W_1 indicates the treatment received.

The focus of this additional analysis was to reveal any possible difference in protected areas' effects among the different land characteristics. As ATTs and ATEs are supposed to show different results in the same estimation, we cannot compare the scale of the ATTs with the ATEs in Table 7.

Results are shown in Table 8. Coefficients in 1992-2000 in general are intuitive - protection shows larger impact on areas with easier access. There is an exception in the case of distance from urban areas. The impact became smaller when the lands were located closer to urban areas. This pattern coincides with what we saw in the OLS estimation, which reinforces the hypothesis of more deforestation occurring in rural areas. The estimators in 2000-2005 show a more characteristic pattern. Areas generally considered to be under low deforestation pressure - areas closer to roads or urban areas, with lower elevations or with smaller slopes – all have smaller impact of protection. Such tendency may reflect a shift of deforestation pressure towards remote areas. This result is supported by a recent analysis by the government of Panama which specifies several key deforestation spots in rural areas (Government of

Panama, 2009). Many estimators of this matching analysis in 2000-2005, however, have quite a wide range of C.I., which makes it difficult to confirm such a conclusion.

Table 8: Impact of protected areas on lands with different characteristics

	Period between 1992-2000		Period between 2000-2005	
	Average treatment effect on treated	Total number of matched sample	Average treatment effect on treated	Total number of matched sample
Closer to roads	-0.096 (0.010)	18,394	-0.150 (0.016)	18,083
Farther from roads	-0.008 (0.007)	14,668	-0.282 (0.020)	14,086
Closer to urban areas	-0.047 (0.009)	17,509	-0.186 (0.020)	17,429
Farther from urban areas	-0.073 (0.009)	15,553	-0.223 (0.017)	14,740
Lower elevation	-0.071 (0.008)	24,038	-0.188 (0.015)	23,008
Higher elevation	-0.028 (0.008)	9,024	-0.230 (0.021)	9,161
Smaller slopes	-0.059 (0.009)	22,926	-0.200 (0.020)	19,919
Steeper slopes	-0.047 (0.009)	10,136	-0.212 (0.017)	12,250

Parenthesis: S.E.

IV. Discussion

This analysis attempted to make a less biased estimate of the effectiveness of protected areas in Panama using matching methods. Several key findings are apparent. First, from 1992 until 2005, protected areas have had a certain positive effect on mitigation of deforestation. When the impacts were measured by less biased sample sets provided by matching methods, their scale became smaller than those measured by conventional evaluation methods. Second, the impact of the protected areas may have increased over time, especially in buffer zones. This point will need finer data for further investigation. Third, the locations of the largest impact may have changed over time perhaps due to a geographical shift in the last decade in deforestation pressure towards more remote and rural areas in the last decade. Thus for protected areas originally located in remote areas, the impact increased over time.

Previous studies in other regions using matching methods produced conservative values for effectiveness of the protected areas compared to conventional methods. The overall finding of my analysis is consistent with these precedents. Here I have extended the use of the matching method to another geographic region, Panama, and shown it to be effective. The finding of spatial variation in the impact of protected areas in the country emphasizes the importance of analyzing the protected area system on a countrywide scale.

There are limitations in this study in terms of data availability and methodology. In terms of data availability, first, the time dependence of some variables was not treated. For example, the political influence of indigenous reserves over decisions on protection may have changed during the period of measurement; the date of official establishment of the reserve territories varied, and some were not established until the 1990's. Also, protected areas had been established in different years before the measurement, and thus their different historical background might have had different impact on deforestation. I observed from the data that the earlier the protected areas were established, the lower recent deforestation rates were inside the areas. Second, there is a possibility of bias from omitted variables. My choice of covariates mainly followed those of previous studies. Also due to limited resources for the research, the variety of socioeconomic variables which I obtained was small. There may be some variables such as population density or immigrant ratio which may have affected selection of locations and deforestation (Andam, 2008). Third, the definition of forested areas in the data for 1992-2000 is slightly different from 2000-2005 since the data sources are different. This factor makes comparison of the results difficult. The accuracy of the data in 2000-2005 is also a problem, as previously stated.

In terms of the methodology, first, although the bias in land characteristics was greatly improved by the matching, the differences in several attributes were still statistically significant after matching. Further analysis using more controls on variables (such as further narrowing the range of matching) may solve the problem, or some improvement may be seen if some covariates are dropped, if they may have had less influence on decision making for protected areas' selection and also deforestation. Second, the covariates used here have some degrees of correlations with each other. Although these correlations are generally small, the correlation between slope and elevation was high enough (correlation coefficient 0.65) that it may be reasonable to drop one of the two variables to test the impact for the other coefficient. Third, I didn't measure time-dependent effects between the beginning and end years of each time period (for example, between1992 and 2000). The difference in difference estimators could be added to treat such a factor. Finally, the increasing scale of protected areas can influence the demand for land in the country, as the protected areas have occupied a large portion of the nation's landmass. Therefore, matching may not treat such differences between the treated and control groups if the control group as a whole had been under stronger deforestation pressure.

The results of these matching methods show the necessity of examining the methodology for measuring the effectiveness of protected areas in Panama. They also provide some suggestions for policies for forest conservation in the country. With new opportunities to tie forest conservation to financial incentives, policy makers are expected to integrate the financial schemes into current conservation policy instruments. Protected areas, which have gathered major resources for forest conservation, must meet such needs. As my analysis showed, the effectiveness of protected areas may have changed along with geographic shifts in deforestation pressure. The effect may call into question how a protection scheme such as protected areas which has comparatively low mobility can respond to geographically mobile demand for lands with changing socioeconomic conditions. At the least, effective schemes for covering and weighting effort on areas with serious deforestation threat should be considered further.

The objective of protected areas is not only to maintain the forest covers within them, but also to maintain ecosystem integrity and biodiversity. Therefore, inclusion of different indices of evaluation may be needed to make a complete picture of the protected areas' effectiveness. Quantitative analysis of financial ROI will also be an important part of evaluating the policy instruments. These other indices were not within the scope of this study, and should be a subject for future research.

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