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Forest protection and tenure status: The key role of indigenous peoples and protected areas in Panama

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ABSTRACT

Using recent land cover maps, we used matching techniques to analyze forest cover and assess effectiveness in avoiding deforestation in three main land tenure regimes in Panama, namely protected areas, indigenous territories and non-protected areas. We found that the tenure status of protected areas and indigenous territories (including comarcas and claimed lands) explains a higher rate of success in avoided deforestation than other land tenure categories, when controlling for covariate variables such us distance to roads, distance to towns, slope, and elevation. In 2008 protected areas and indigenous territories had the highest percentage of forest cover and together they hosted 77% of Panama's total mature forest area. Our study shows the promises of matching techniques as a potential tool for demonstrating and quantifying conservation efforts. We therefore propose that matching could be integrated to methodological approaches allowing compensating forests' protectors. Because conserving forest carbon stocks in forested areas of developing countries is an essential component of REDD+ and its future success, the discussion of our results is relevant to countries or jurisdictions with high forest cover and low deforestation rates.

1. Introduction

The proposal for reducing emissions from deforestation and forest degradation (REDD+), which was advanced by the United Nations Framework Convention on Climate Change (UNFCCC), is the first global mechanism to combat climate change using the forestry sector (Pistorius, 2012). Since 2005, it has been subject to negotiation at successive Conferences of the Parties (COPs) of the UNFCCC. In addition to activities to avoid deforestation and forest degradation, REDD+ also includes conservation, sustainable management of forests, and enhancement of forest carbon stocks in developing countries.

Lessons from forest conservation might help REDD+ avoid reinventing the wheel. Designation of protected areas (PA) is a widespread environmental policy tool that has been used to protect forests (Bertzky et al., 2012). Covering extensive areas at global scales, protected areas have been identified as being potentially efficient for preventing deforestation (Andam et al., 2008; Nelson and Chomitz, 2011). Latin America, for example, has a higher percentage of terrestrial protected areas (20.4%) than either developed countries (11.6%) or other developing regions (13.3%) (United Nations, 2012). In general, protected areas are more effective than other forms of land tenure in reducing deforestation (Nepstad et al., 2006; Clark et al., 2008; Joppa et al., 2008; Nelson and Chomitz, 2011; Porter-Bolland et al., 2012). Their success, however, generally depends upon location, governance, and budgets (Nelson and Chomitz, 2011).

While the creation of protected areas in Latin America and the Caribbean has been one of the most popular top-down instruments for protecting forests (Elbers, 2011), most of their recent expansion (1990 and 2000) has been associated with some previous level of protection or by the presence of indigenous areas (Nelson and Chomitz, 2011). The underlying assumption is that indigenous territories also can play an important role in forest conservation (Nepstad et al., 2006; Hayes and Murtinho, 2008). In several Latin American countries, forest-based peoples possess extensive areas of land, as is the case in Brazil (135 million ha), Bolivia (12 million ha), Mexico (39 million ha), and Colombia (36 million ha) (Larson et al., 2010). In Latin America, studies have shown that when the governments have recognized traditional local rights, indigenous people are better able to control deforestation than private land

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regimes and can successfully prevent incursions into their forested territories (Nepstad et al., 2006; Hayes and Murtinho, 2008). Across the tropics, apart from protected areas, lands under the control of indigenous peoples also exhibit low deforestation rates and have shown a high potential for conserving forests (Hayes and Murtinho, 2008; Lu et al., 2010; Porter-Bolland et al., 2012).

Using Panama as a case study, we specifically tested the hypothesis that protected areas and indigenous territories ensure forest conservation. We considered indigenous territories as geographic areas that are legally recognized, that are in the process of recognition, or that are claimed by indigenous peoples. Our study addresses two main questions: (1) What is the extension of forests in indigenous territories of Panama and how it has change through time? (2) Are protected areas and indigenous territories effective in reducing deforestation in Panama? To answer these questions, we first mapped indigenous claimed lands, then compared forest cover through time under three main land tenure regimes, viz., protected areas and indigenous territories versus non-protected areas. Evaluating the effects of forest conservation requires controlling for landscape characteristics (Joppa and Pfaff, 2010). For example, factors that are associated with remoteness, topography and access, such as distance from roads, distance from populated areas, slope steepness and soil fertility, affect land-use decisions (Joppa and Pfaff, 2010; Nelson and Chomitz, 2011). We devised an empirical test to support, or refute, the hypothesis that protected areas and indigenous territories are effective in reducing deforestation. To do so, we used matching methods (Rubin, 1973), a statistical impact analysis technique that allowed pairing protected and indigenous territories with unprotected areas with similar landscape characteristics. We also discuss the implications of our findings for the Panamanian REDD+ strategy, together with potential positive incentives that could reward forest conservation in high forest cover/low deforestation rate countries or subnational initiatives.

1.1. Panama's national context

The Republic of Panama is a small Central American nation that covers about 74,000 km^2, and is officially divided into nine provinces and five legally established indigenous territories, which are referred to as *comarcas*. Panama is a country that is rich in biodiversity, with western Panama being considered part of the Mesoamerican hotspot and eastern Panama, a part of the Chocó/Darién/Western Ecuador hotspot (Myers et al., 2000). The country is uniquely situated as a biological corridor between Central and South America. Panama's deforestation rate was about 413 $km^2\,yr^{-1}$ between 1992 and 2000, and 134 $km^2\,yr^{-1}$ between 2000 and 2008 (CATHALAC, 2008). Over the last 20 years, forest cover in Panama has decreased from 36,951 km^2 (49.3% of the total land area) in 1992, to 33,507 km^2 in 2000, and to 32,433 km^2 in 2008 (CATHALAC, 2008). In 2008, Panama started to work with two REDD+ multilateral readiness programs, viz., the Forest Carbon Partnership Facility (FCPF) of the World Bank and the REDD program of the United Nations, with the goal of developing a national strategy that could reverse deforestation, while developing an economic framework to do so (World Bank, 2011; UNDP, 2012). Panama's REDD+ readiness proposal to the FCPF identified six main causes of deforestation: traditional and mechanized agricultural practices; extensive cattle ranching practices; exploitation of forests in a disorderly and unsustainable manner; poorly planned urban development; inadequate practices for exploiting mineral resources; and low levels of education and environmental culture (World Bank, 2008).

Since the creation of Altos de Campana National Park in 1966, protected areas have represented the Panamanian government's principal strategy for *in situ* forest conservation within the country (ANAM, 2006). Protected areas have also played a role in preventing the loss of Panama's forests (Nelson et al., 2001; Oestreicher et al., 2009; Haruna, 2010), which currently represent 35.8% of the total land area (ANAM, 2009). However, many of Panama's protected areas overlap with indigenous territories, thereby creating a mosaic of different tenures and tenure overlap zones, which are a source of diverse land-use conflicts. Indigenous territories within the borders of Panama are constituted as legally recognized areas and as areas being claimed by indigenous groups who wish to obtain legal recognition. These areas are hereafter referred to as "legally recognized territories or comarcas" and "claimed lands," respectively. Claimed lands in Panama are based on customary ownership. As defined by Sunderlin et al. (2008), customary ownership is determined at local level and based on oral agreements by the community itself rather than the state or state law (statutory land tenure). However, under Law 72 (Gaceta Oficial, 2008), indigenous groups that are living outside of comarcas can request official recognition of their lands. According to official data, comarcas encompass 12% of the country and include ~27% of national forests (CATHALAC, 2008; ANAM, 2009). Official statistics only report forest cover and deforestation for three of the five comarcas because only three comarcas have provincial-level status, while the other two only have sub-provincial status (*corregimiento*). As a result, the remaining two comarcas are merged with provinces in national reports (ANAM/ITTO, 2003; ANAM, 2009). This situation prevents a complete understanding of the role that indigenous territories might play with respect to forest conservation in Panama.

The comarcas are located in the western and eastern sections of the country, and along the Caribbean coast. The first comarca, Guna Yala, was established in 1938, while the most recent one was legally recognized in 2000 (Velásquez et al., 2011). Outside of the comarcas, the precise location of most claimed lands in Panama had not been mapped prior to our study, and as a result, the extent and percentage of forests inside these claimed lands was unknown. Under the authority of the General Congresses of the Collective Lands of Alto Bayano, the General Congress of Emberá-Wounaan Collective Lands, and the National Congress of Wounaan People, which are located in eastern Panama, the claimed lands are currently in the process of legalization under the country's Law 72 (Gaceta Oficial, 2008) and Decree 223 (Gaceta Oficial, 2010). The three remaining claimed lands, which are attempting to gain official recognition as comarcas, include Dagarkunyala, which is in easternmost Panama, and the Bribri and Naso territories, which are in western Panama. Over the past two decades, many of these areas have experienced an increase in invasion by non-indigenous groups, which has generated greater deforestation and other environmental problems. Most of these invasions are related to the expansion of the agricultural frontier by cattle ranchers or farmers (*colonos*) from other areas of the country (Wali, 1993; Peterson St-Laurent et al., 2012).

2. Methods

2.1. Mapping indigenous claimed lands

The first step in our study was mapping the claimed lands of Panama to determine the location and size of these areas. We began by gathering existing documentation on GIS coverage of national administrative units (provinces and comarcas) and the national system of protected areas, together with land-use maps from 1992, 2000, and 2008. These data came from three Panamanian institutions: the National Authority for the Environment (ANAM), the National Land Program (PRONAT), and the National Geographic Institute Tommy Guardia. A detailed list of the information that we obtained can be found in the Table S1 of the Electronic supplementary material (ESM). Indigenous communities without a formal proposed boundary were not included in this study (e.g., the Chagres communities).

To identify the extent of indigenous claimed lands, we held meetings with the *Coordinadora Nacional de los Pueblos Indígenas de Panamá* (COONAPIP, National Assembly of Indigenous Chiefs of Panama) and the local traditional indigenous authorities of each claimed land. In June 2010, COONAPIP formally nominated their General Secretary, Mr. Germán Hernández, to assist us in identifying the indigenous areas to be mapped and to help contact local traditional authorities. Thereafter, meetings were held with the COONAPIP Secretary and local traditional authorities to explain the mapping project and obtain their authorization to visit the territories. Verbal authorization was the common way in which traditional authorities accepted participation in this project. We followed McGill University's protocols that are related to research conducted in indigenous areas and with indigenous peoples in Panama. Respect for intellectual property and the right of indigenous peoples to free, prior and informed consent were an essential part of this process. When available, geo-referenced maps of the claimed lands were provided by the traditional authorities and served as a starting point for our work. We visited four of the six claimed lands to collect qualitative and quantitative information about local land-use dynamics from indigenous peoples' own point of view at a local scale. The visit allowed us to determine, with the aid of local traditional authorities, the boundaries of claimed lands on 1:250,000 official topographical maps. The other two territories were not visited. One of these was not easily accessible, while we were unable to contact traditional authorities in the other.

The aforementioned information was amassed in ArcGIS (ESRI, 2011) to create a draft map of all of Panama's indigenous territories (including established comarcas and claimed lands). The draft map was validated by COONAPIP's traditional authorities and their technicians during a workshop, which was held in the Ngäbe Bugle comarca in August 2011. Representatives of ten of the 12 authorities of indigenous nations were present at this workshop; those of the Ngäbe and the Naso were not present. Printed maps with recognizable landscape features (e.g., rivers, roads, coastlines) were given to participants, who carefully examined the limits of their own areas and made comments. We used these comments to correct the draft maps where necessary. The resulting map was finalized at the end of August 2011 and officially approved by COONAPIP in October 2011. Printed and digital versions of the map were presented to each of the 12 traditional indigenous authorities through COONAPIP.

2.2. Forest cover in Panama

To identify forest cover among land tenure regimes of Panama, we used ANAM land cover maps for the years 1992 and 2000. In the absence of a more recent official land cover map, we used the digital land cover map that had been produced for 2008 by the *Centro del Agua del Trópico Húmedo para America Latina y el Caribe* (CATHALAC, Water Center for the Humid Tropics of Latin America and the Caribbean) (CATHALAC, 2008). Following the ANAM-International Tropical Timber Organization (ITTO, 2003) system of classification, we included all mature forests in the country, which consisted of mature, secondary mature, homogenous cativo (*Prioria copaifera* Griseb.), mixed cativo, homogenous orey (*Campnosperma panamensis* Standl.), mixed flooded, or mangrove forests. Note that this classification has been retained by Panama in the context of REDD+ readiness. All these categories are characterized as having more than 80% tree cover. Fallows, young secondary forest, and highly degraded lands were not included in the analysis.

We overlaid our GIS map of indigenous and non-indigenous territories with a digital coverage of ANAM's protected areas, together with the extent of mature forests, to determine forest cover in every sector. Nationally protected areas are the 89 areas that are included in the *Sistema Nacional de Áreas Protegidas* (SINAP, National System of Protected Areas), and which were centrally managed by the Panama's National Environmental Authority (ANAM) (ANAM, 2010). This overlay analysis allowed us to estimate mature forest cover in: (1) legally established comarcas that did not overlap protected areas (C); (2) overlap between legally established comarcas and protected areas (C-Over); (3) claimed lands that did not overlap with protected areas (Cl); (4) overlap between claimed lands and protected areas (Cl-Over); (5) nationally protected areas that do not overlap with indigenous territories (PA); and (6) other lands without protection in the country (OL) (Fig. 1).

The effects of land tenure regimes on the percentage of mature forest cover were analyzed using repeated measures ANOVA. The

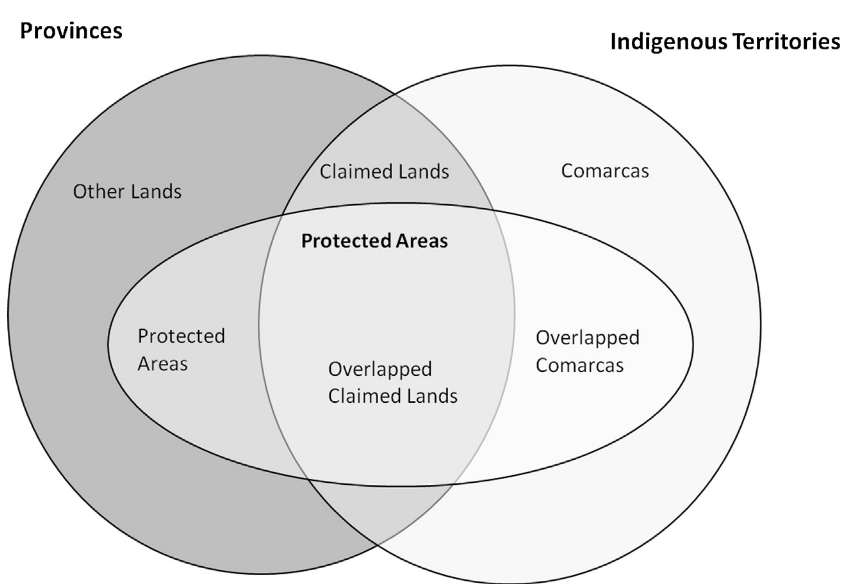

Fig. 1. Provinces, indigenous territories, and protected areas and their respective overlaps.

area that was covered by mature forest (log-transformed) in 1992, 2000 and 2008 were used as dependent variables. Tukey–Kramer post hoc multiple comparisons were used to test for significant differences among land tenure regimes and time. All statistical analyses were performed in the *car* package 2.0-16 of R (www.r-project.org).

2.3. Effectiveness of avoided deforestation: matching analysis

We assessed the effectiveness in avoiding deforestation by comparing protected areas and indigenous territories (the treated group) with non-protected areas (the control group) using matching methods (Rubin, 1973; Stuart, 2010). The response variable was the presence/absence of deforestation in at least one forested pixel (minimum area of 200 m x 200 m) during two evaluation periods. The country total area with approx. 1.8 million records was split in two separate categories to form the control and the treatment group for the analysis, including one record for every pixel. Two cohorts of pixels were prepared to compare the treated and control groups. The first cohort used 1992 as the base year, considering all protected areas that were created in or before 1992, with the response variable being the presence/absence of deforestation between 1992 and 2008. The second cohort used 2000 as the base year, including all protected areas that were created in or before 2000, with deforestation being estimated between 2000 and 2008 (Table S4 for details). We included all indigenous territories in both cohorts because indigenous peoples have permanently inhabited these areas, and we wanted to evaluate the potential effectiveness of these areas in avoiding deforestation against non-protected areas. Hence, the treated group considered five tenure categories (PA, C, Cl, C-Over, Cl-Over) to evaluate potential differences in avoided deforestation among these areas. The final control group was three or more times larger than the treatment group in the analysis, as a result, the 1992 cohort included 923,775 pixels with 642,840 pixels for the five tenure categories in the treatment group. The 2000 cohort was constituted of 837,675 pixels with 633,459 pixels for the same five tenure categories.

Matching allowed the pairing of the treated group with forested pixels that were similar in terms of topography and remoteness, but lacking "protection." Four matching covariates were selected to ensure the comparability of the treated and control groups. *Elevation* and *Slope* were used as proxies for topography, since agriculture and cattle ranching are mostly conducted on mild slopes and at lower elevations (Nelson and Chomitz, 2011). We used the CGIAR-CSI version of the 90-m resolution STRM (Shuttle Radar Topography Mission; Jarvis et al., 2008) digital elevation model to derive elevation and slope for the entire study area. *Distance to roads* and *Distance to towns* were proxies for remoteness (Kaimowitz and Angelsen, 1998; Geist and Lambin, 2002). Distance from roads and town was estimated using ArcGIS 10.1, considering all towns or cities with more than 5000 inhabitants, together with road systems, in 2000 for cohort pre-1992, and in 2008 for cohort pre-2000. Digital and hardcopy maps were used to extract cities and road networks for the two cohorts.

We used nearest-neighbour covariate matching with replacement -using the Mahalanobis distance metric- as an evaluation method (Rubin, 1973). Matching was applied without and with calipers (Rubin and Thomas, 2000) using 0.5 and 0.25 standard deviations; calipers indicate a tolerance level for evaluating the quality of matches. However, we do not report results with calipers because they did not produce any reduction in the number of treated/control matched pairs. The analysis tested several matching techniques until an adequate before- and after-matching balance was reached. Matching balance was evaluated using the set of balance statistics included by default in the R package *Matching* (version 4.7-14; Sekhon, 2011) and included the mean difference between control and treatment groups for each covariate before and after matching. Matching was considered satisfactory if the difference was ~0. The matching balance achieved was tested with the *t*-test of difference of means, the Kolmogorov–Smirnov test and quantile–quantile plots, to identify potential differences in covariate balance. It was deemed adequate if the difference of means for a covariate was not statistically significant between the two groups.

3. Results

3.1. Extension and forest cover of different land tenure in Panama

According to the GIS analysis, the indigenous territories that were legally established as comarcas, together with all of the claimed lands, represented 31.6% (23,470 km^2) of Panama's total area (Fig. 2). With a total of 27 separated areas, the newly mapped claimed lands represented 9.2% (6850 km^2) of the country's total area. Their sizes range from 231 km^2 for Alto Bayano to 3030 km^2 for the Collective Emberá Lands (more details in the ESM). With the exception of the Collective Emberá Lands, claimed lands are smaller in area than legally established comarcas. Only two indigenous territories, the Guna Yala and Madugandi comarcas (Table S2, ESM), do not overlap with existing protected areas. Otherwise, overlap with protected areas is high for all indigenous territories. Close to 1 million ha (979,850 ha) of the indigenous territories consequently have dual tenure, i.e., they are simultaneously both indigenous territory (comarcas or claimed lands) and protected areas (Fig. 3). Aggregate tenure overlay is higher in claimed lands (78.7%) than in comarcas (22.4%). A detailed description of all of the mapped claimed lands can be found in the ESM.

Mapping indigenous areas helped understand the comparative importance of forests in the six tenure regimes. Together, PAs and indigenous territories hosted 77% of Panama's total mature forest area in 2008. Our GIS analysis showed that about 725,300 ha of mature forests remain in PA, while 1,754,000 ha remained in indigenous territories, considering the forested areas of both comarcas and claimed lands. Indigenous territories, as a whole, represented 54% of mature forest cover of Panama in 2008. At that time, only three of the indigenous territories (the claimed lands of Alto Bayano and Collective Wounaan Lands, and the *comarca* Ngäbe Bugle) had less than 80% mature forest cover (Fig. 4). About 903,000 ha of the indigenous territories (comarcas and claimed lands) overlapped with protected areas, representing 28% of the total mature forest cover in 2008.

To analyze forest cover within Panama's provinces, we estimated their net areas and discounted claimed lands while including protected areas. The province with highest mature forest cover in 2008 were Bocas del Toro (166,000 ha), Colon (245,000 ha), and Darien (325,000 ha). Those provinces that had the lowest mature forest cover were Herrera (8000 ha) and Los Santos (25,000 ha). In 1992, four provinces (Chiriquí, Herrera, Los Santos, Coclé) had less than 20% forest coverage. The provinces that lost the most mature forest cover between 1992 and 2008 were Darien (141,000 ha) and Panama (92,000 ha).

In 2008, the tenure regime with the lowest proportion of mature forest cover (20%), compared to its total area (730,000 ha) was other lands (OL). Overlaps between indigenous territories and protected areas, i.e., overlapped comarcas (C-Over) and overlapped claimed lands (Cl-Over), had the highest proportion of forest cover (>90%) over a total area of 906,000 ha (Fig. 5). Net areas of comarcas (C) with 760,730 ha, claimed lands (Cl) with 85,240 ha, and protected areas (PA) with 725,300 ha had an intermediate proportion of mature forest cover (70–80%).

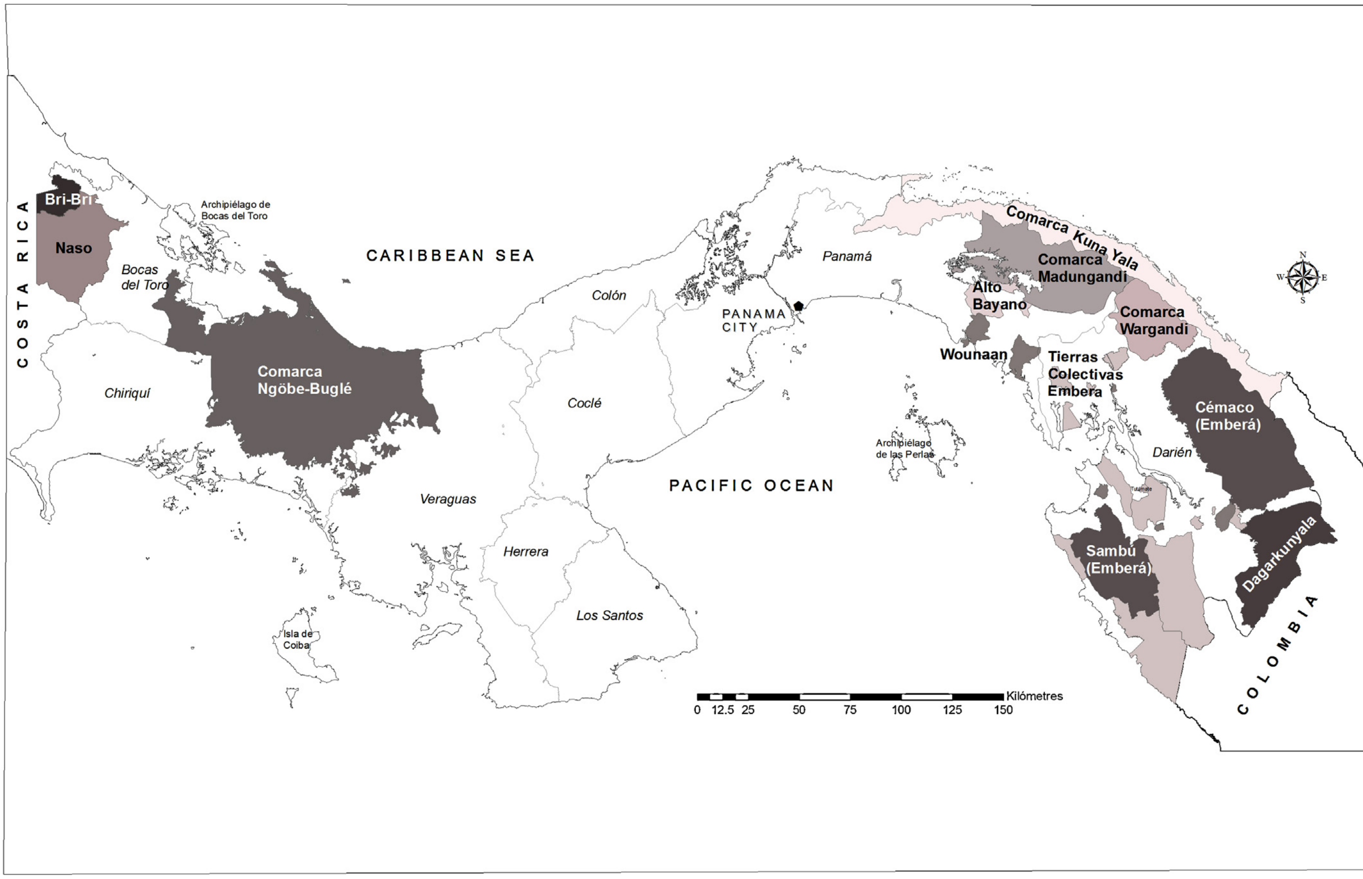

Fig. 2. Map of indigenous territories across Panama showing the five comarcas and the six indigenous claimed lands.

ANOVA showed significant differences in mean forest cover percentage among tenure regimes ($F_{5,32}$ = 14.58, P = 0.001). Tukey post hoc tests ($P < 0.05$) showed that the other lands (OL) regime (20.7 ± 17.8% forest cover) contained significantly less forest than all other tenure regimes. The percentage forest cover in comarcas (C) was 79.4% (±20.9% SD, P = 0.005), 76.7 (±23.3%, P = 0.005) in claimed lands (Cl), 93.7 (±5.35%, P = 0.005) in overlapped comarcas (C-Over), 93.8 (±10.2%, P = 0.005) in overlapped claimed lands (Cl-Over), and

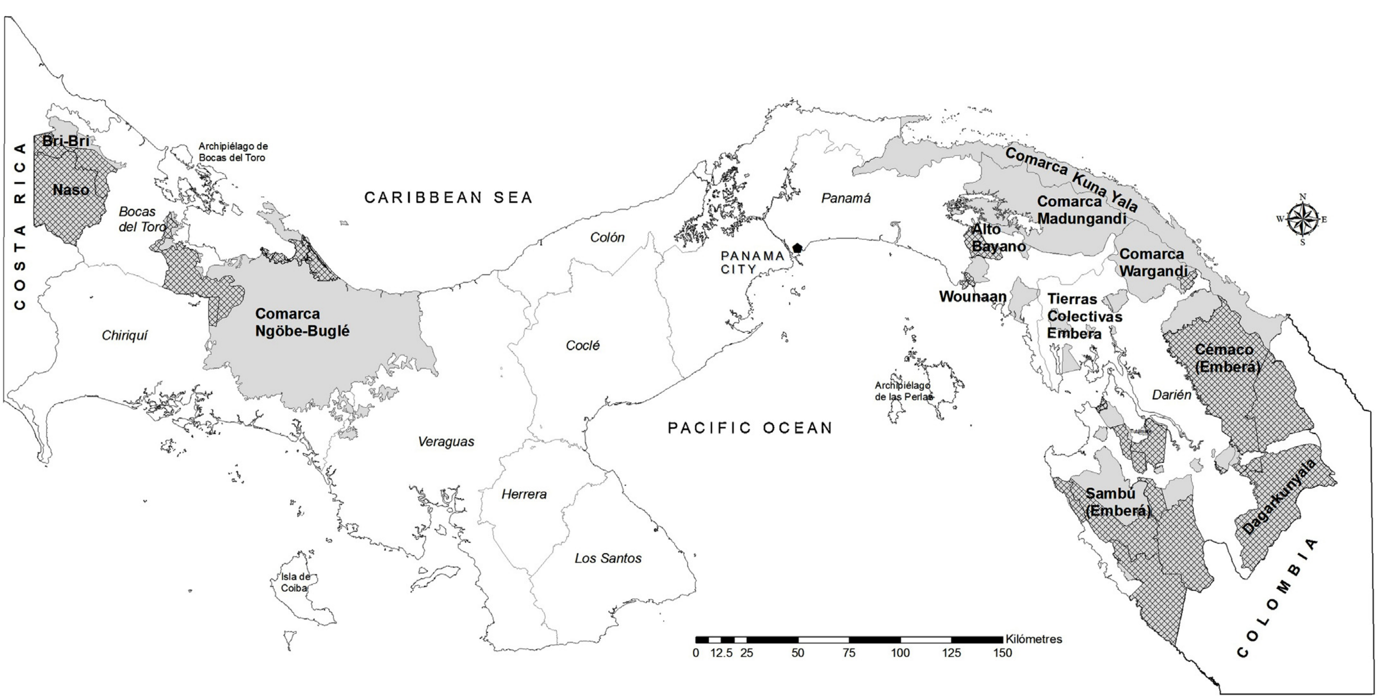

Fig. 3. Overlap between indigenous territories and protected areas in Panama (shaded areas).

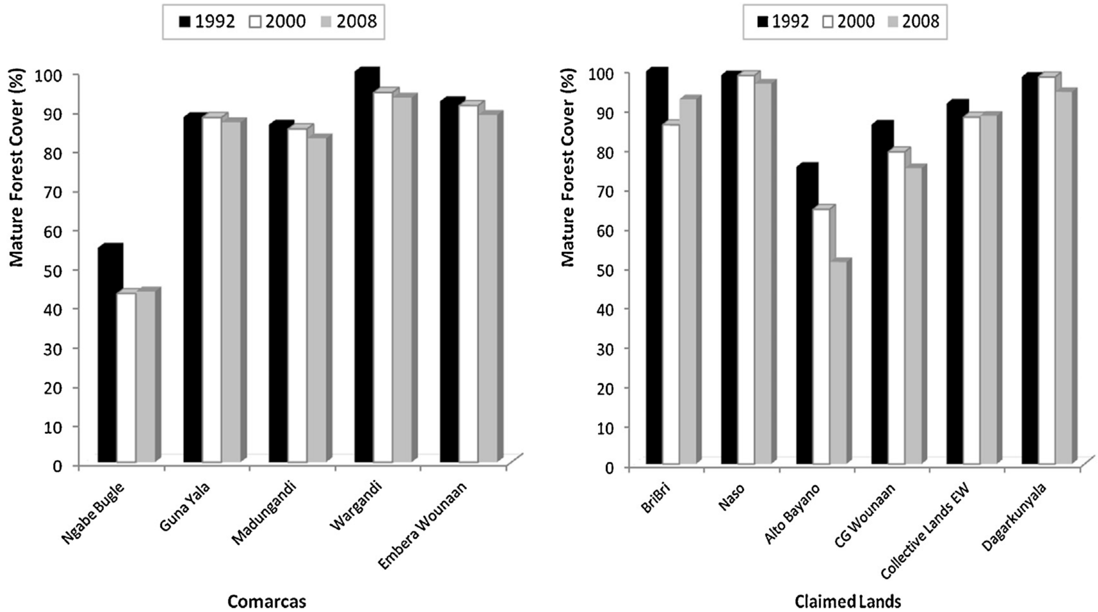

Fig. 4. Variation in forest cover (%) within the indigenous territories of Panama. Year 1992 (black), 2000 (grey), and 2008 (white). Left panel: comarcas, including overlapped areas (C-Over). Right panel: claimed lands, including overlapped areas (CL-Over).

71.6 (±24.2%, $P = 0.005$) in protected areas (PAs). In contrast, there were no significant differences among the tenure regimes of C, Cl, C-Over, Cl-Over and PA.

Across tenure regimes, the proportion of land that was covered by forests decreased significantly with time ($F_{2,64} = 7.62$, $P = 0.001$). Across the six tenure regimes, the proportion of forest decreased, on average, from 76.6% ± 26.7% in 1992 to 71.7 ± 27.6% in 2000 and to 69.8 ± 27.3% in 2008. Our analysis further revealed a significant interaction between time and tenure regimes for forest cover ($F_{10,64} = 2.3$, $P = 0.02$). Forest cover for claimed lands (Cls) showed a pattern of change that distinguishes it from the other tenure regimes. The high forest cover observed in 1992 decreased abruptly in 2000 due to high deforestation rates in this last period.

3.2. Matching as a way to assessing the effectiveness of avoiding deforestation

The general characteristics of the covariates that were used in the matching analysis indicate that overlapped areas, i.e., Cl-Over and C-Over, were more remote, and along with PA, had steeper

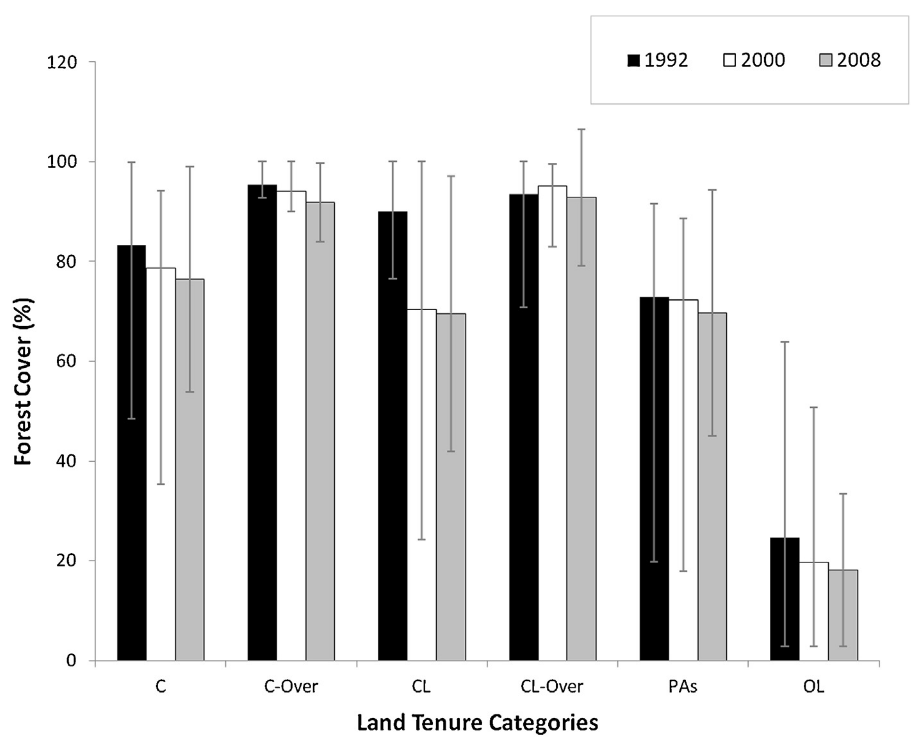

Fig. 5. Average forest cover (%) within six land tenure regimes for the period 1992–2008 in Panama (grey lines are ranges). C: comarcas, C-Over: overlapped comarcas, CL: claimed lands, CL-Over: overlapped claimed lands, PAs: protected areas, OL: other lands.

Table 1
Estimates of the proportion of treated pixels (in percentages) used in the matching analysis that retained forest cover between 1992–2008 and 2000–2008. The treated group included different forms of indigenous tenure as well as protected areas. By convention, negative signs reveal that the treatment resulted in avoided deforestation. The number of matched pairs is a measure of sample size, each matched pair including two pixels with similar covariates one from the treated and one from the control groups. For tenure: C-Over = overlap between *comarcas* and protected areas, Cl-Over = overlap between claimed lands and protected areas.

Tenure	Pre-1992 cohort		Pre-2000 cohort	
	Estimates* [SE]	Matched pairs	Estimates* [SE]	Matched pairs
Comarca	−5.7 [0.0011]	24,921	−6.1 [0.0009]	21,384
C-Over	−6.5 [0.0011]	10,149	−3.1 [0.0008]	9937
Claimed lands	−9.2 [0.0033]	3175	−8.3 [0.0027]	2361
Cl-Over	−4.8 [0.0008]	12,672	−2.1 [0.0007]	12,975
Protected areas	−18.1 [0.0013]	15,610	−10.8 [0.0010]	16,486

* All the estimates are statistically significant at pp < 0.01 and standard error (SE) was derived from the repetitions of the analysis.

slopes and higher elevations compared to the other tenure regimes (Table S3 in the ESM). Other lands (OL) and claimed lands (Cl), in contrast, showed greater proximity to roads, were located at lower elevations, and had lower slope gradients. The categories of OL and PAs showed also greater proximity to towns.

To answer the question: "Are protected areas and indigenous territories effective in reducing deforestation in Panama?" we used matching analysis. This technique allow controlling for covariate variables such us distance to roads, distance to towns, slope, and elevation all of which could explain why protected areas and indigenous territories retain the highest forest cover of Panama. We found that the tenure status of protected areas and indigenous territories (including comarcas and claimed lands) explains a higher rate of success in avoided deforestation than other land tenure categories. Matching analysis proceeded in two steps, after separating pixels in two groups, treated and control, it compared the proportion of areas in both groups that lost forests during each of the two time interval considered. Hence it provided estimates of avoided deforestation as a proportion of forest in the control group, set to 100%, with negative signs indicating less forest loss (Table 1). Matching analysis indeed showed that the most effective tenure regime for avoiding deforestation in Panama was protected areas (PAs) with 18.1 and 10.8% less deforestation, respectively for the 1992 and 2000 cohorts, than control areas with similar covariate characteristics (Table 1). Amongst the indigenous territories, claimed lands (Cls) was the most efficient tenure regime, reducing deforestation by 9.2% and 8.3%, respectively, for the 1992 and 2000 cohorts, compared to the control group. This is an important result because of the proximity of Cl to roads (Table S3 in the ESM). On average, indigenous territories without overlap (C, Cl) performed better than overlapped indigenous territories (C-Over, Cl-Over). In non-overlapped indigenous territories, deforestation was reduced in 7.45% in the pre-1992 cohort and 7.2% in the pre-2000 cohort, whilst clearing of overlapped indigenous territories was reduced in 5.65% and 2.6% for the same respective cohorts.

4. Discussion

4.1. Forest cover and tenure: insights from Panama

The question at the heart of our paper is: are protected areas and indigenous territories effective in reducing deforestation in Panama? We developed an empirical test to answer this question, and the result is an unequivocal. Yes, protected areas and claimed indigenous territories of Panama are the most effective tenure regimes for avoiding deforestation. Furthermore, these areas also possess high forest cover. Several authors have indicated resolution of issues that tenure and forest tenure should become an essential part of REDD+ readiness programs (Cotula and Mayers, 2009; Robinson et al., 2011; Angelsen et al., 2012; Holland et al., 2012). The evidence that is provided by this research on the effectiveness of protected areas and indigenous territories in avoiding deforestation certainly supports that recommendation.

Our results suggest that, because of their efficiency in conserving forests, both protected areas and indigenous territories could be part of the successful implementation of REDD+ in Panama. To date however, the relationship between Panama's Indigenous people and REDD+ has been bumpy. In 2013, three different bodies representing traditional indigenous authorities, the Comarca Guna Yala, the Comarca Madugandi and the COONAPIP, indeed rejected REDD+ and the UN-REDD program, respectively (Potvin and Mateo-Vega, 2013). In early 2014 however, the tensions between COONAPIP and ANAM apparently got resolved and a memorandum of collaboration. This memorandum does not resolve the issues raised by the two Kuna Comarcas where REDD+ remain, to date, banned. Carbon rights ownership was one of the demands that was established by COONAPIP when negotiating with the UNREDD program, stating: "Determining carbon property rights, and consequently those over carbon credits that may be generated, is crucial and a matter where differences persist" (COONAPIP, 2011, p. 14; Cuellar et al., 2013). In Panama, Article 10 of the Forest Law 1 (1994) indicates that the "forest patrimony of the state is constituted by all natural forests, the lands on which those forests are located, and state lands of preferably aptitude for forestry" (República de Panamá, 1994, article 10). This article of the Forest Law embodies the risk of exclusion that is feared by indigenous peoples in Panama and in Latin America (Griffiths, 2009; Velásquez, 2012).

While it is clear that attention should be given to resolving tenure conflicts and clarifying tenure rights in designing REDD+ strategies (Larson et al., 2013), many REDD+ strategies that are submitted by countries to the Forest Carbon Partnership Facility of the World Bank have not included a concrete proposal on how to implement or resolve tenure conflicts, even when the risks were mentioned in their proposals (Dooley et al., 2011; Westholm et al., 2011). Encouraging governments to clarify and resolve local forest tenure rights, and to remove the perverse legal incentives to deforest appears to be an unavoidable prerequisite for favouring indigenous peoples participation in REDD+ programs (Agrawal et al., 2008; CIRAD, 2012). Furthermore, local governance has been proposed as a way of conserving forests and ensuring local livelihoods in a cost-effective way compared to centralized governance (Sandbrook et al., 2010), which again suggests that clarifying land tenure is a key step for REDD+ success (Sunderlin et al., 2009).

4.2. Rewarding forest protectors

Although REDD+ was originally positioned primarily as carbon mitigation and offset mechanism, there is widespread expectation that REDD+ will also contribute to conserving and maintaining tropical forest biodiversity and other endangered forest ecosystems

(Angelsen et al., 2012). To do so, REDD+ needs to be able to compensate for forest conservation keeping in mind the principles of additionality and permanence (as defined by Parker et al., 2009) to produce real and credible reductions (Vallatin, 2011). The concern that a REDD+ mechanism largely structured to reward past deforestation has been plaguing the REDD+ discussion since its inception (Achard et al., 2005; Angelsen and Wertz-Kanounnikoff, 2008). Griscom et al. (2009), using FAO (2006) data to classify 56 tropical countries, showed that countries with high forest cover and low deforestation rates, and those with high forest cover and medium deforestation rates harboured 10.5% and 63.7% of tropical carbon stocks, respectively. The majority of countries in these two categories are Latin American (65% of the total). Given the importance of these high forest cover countries with medium to low deforestation rates, their broad participation in REDD+ is a required step to maximize the mechanism's mitigation potential, minimize international leakage, and promote equity (Eliasch, 2008). Over the past decade, diverse positive incentives to reward countries with high forest cover and low deforestation (e.g., Peru, Suriname, Belize) have been proposed (Achard et al., 2005; Mollicone et al., 2007; Prior et al., 2007; Gutman and Aguilar-Amuchastegui, 2012).

The challenges inherent to rewarding past conservation effort are likewise present at a jurisdictional and sub-national scale for example in protected areas and indigenous territories. It remains unclear whether protected areas that have already been established would be eligible for REDD+ (Larson, 2011) because their additionality is under question. Some would say that REDD+ funding should only apply to newly protected areas in areas where forests are at risk (Angelsen et al., 2012). In practice, deforestation frequently continues inside protected areas, particularly when funding, management capacity or political support is limited (Ricketts et al., 2010). If independent assessment shows that forest cover is being lost or degraded within an existing PA, and that additional resources could reduce these threats, PAs might present an attractive, previously overlooked opportunity to reduce emissions (Ricketts et al., 2010).

Consistent with our findings, several other studies have shown less deforestation within protected areas compared to other tenure regimes (Nagendra, 2008; Oestreicher et al., 2009; Haruna, 2010; Nelson and Chomitz, 2011), suggesting that the creation of new PAs or enhanced support for existing PAs could be important for successfully implementing REDD+ (Ricketts et al., 2010). Our results suggest that Panama's National REDD+ strategy could rely upon the enforcement of laws pertaining to national protected areas, and upon close collaboration with its indigenous peoples. This condition could be applicable to many other Latin American countries, where PAs and indigenous territories contain extensive forest resources. However, several questions arise. How do we reconcile the fact that these areas could represent the core of REDD+ national strategies with the possibility of using future carbon markets? If performance-based payments are adopted, how can incentives be provided to tenure regimes that already protect forests and have low deforestation rates?

Our results reinforce the idea that rewarding forest protectors is a necessary step for the global success of REDD+ because it can contribute to climate mitigation, reduce national and international leakage, and also promote a fair distribution of costs and benefits among and within countries (i.e., equity) (Meridian Institute, 2011). With the broadening of the scope of REDD+, three main approaches to performance-based payment for countries with medium to low deforestation rates have been suggested: (a) the strictly historical, (b) an intermediate historically based approach with adjustments, and (c) forward-looking approaches. The schemes could also apply at the jurisdictional level, e.g., provinces or indigenous territories.

(a) **Strictly historical:** Early proposals of performance-based payments are based on historical deforestation rates. One example of an historical proposal is "compensated reduction" (Santilli et al., 2005), which suggests that the strictly historical reference level (RL) be revised every 3 or 5 years to include more recent historical rates of deforestation. Joanneum Research et al. (2006) proposed the "corridor approach," which uses minimum and maximum RL values (based on observed past deforestation levels) instead of considering the average value for the reference period. In both of the aforementioned proposals, it is hard to envision how forest protectors who are engaged in forest conservation either at the national or jurisdictional level would be compensated, since conservation does not translate into any rates of change in forest cover nor emissions.In response to this challenge, the Government of India proposed, "compensated conservation" in 2007. Its intention is to compensate countries for maintaining and increasing their forests as carbon pools as a result of conservation, with increases and improvements to forest cover backed by a verifiable monitoring system (UNFCCC, 2011). India recommends measuring forest change with a previously set baseline, which could be fixed at 1990. This proposal intends to compensate countries for maintaining and increasing forest carbon stocks using a non-market based mechanism; however, it is not clear how this approach could resolve additionality issues regarding conservation payments.

(b) **Historical adjusted:** Concerns that compensation based on historical emissions would penalize forest protectors and favour past bad behaviour opened the door for the development of alternative proposals. The specific intention here is to address the issue of countries with high forest cover/low deforestation rates. Among proposals of this type is that of the Joint Research Centre (Achard et al., 2005), which presents a mechanism to account for preserved carbon if the country keeps its conversion rate below half of the global rate. This proposal also includes an accounting of forest degradation. Mollicone et al. (2007) proposed the "incentive accounting" approach, which recommends the establishment of a reference level for low deforestation countries at half of the global historical deforestation rate. In the same year, Prior et al. (2007) proposed an alternative, i.e., the "carbon stocks approach." It establishes a trading mechanism that allows participating Non-Annex I (developing countries with emission reduction targets) countries to sell "Carbon Reserve Units." These Carbon Reserve Units are linked to projects protecting forests that are under threat of degradation or deforestation, and which can be designed to include net increases of carbon stocks in degraded forests. Strassburg et al. (2009) have suggested the idea of "combined incentives," which explores the outcomes of establishing a universal benchmark that is equal to the global average rate of deforestation. This approach is intended to promote incentives that reduce deforestation and degradation, as well as stimulate forest conservation, while promoting reforestation and afforestation activities. Lastly, the "stock and flow approach" withholds a percentage of payments for emission reductions relative to historical deforestation levels to pay for conserving forest stocks (Cattaneo et al., 2010).

(c) **Forward-looking (projected):** The Terrestrial Carbon Group (2008) proposed that credit should be based upon the country's carbon stocks, but should differentiate between protected carbon areas and tradable carbon areas. In this proposal, protected areas that currently are not receiving compensation under REDD+ would be allowed to emit a certain quantity of tradable carbon stocks each year.

5. Conclusion: matching analysis as a novel approach

REDD+ performance-based proposals are primarily based on deforestation rates or on changes in forest cover (Gutman and Aguilar-Amuchastegui, 2012), making it difficult to apply them to forest conservation. Furthermore, the core of these performance-based proposals is also set at national scales while, in many developing countries, REDD+ actions are being developed at local or regional levels, including communities, civil society and regional governments. So-called nested approaches (Pedroni et al., 2009), for example, which support indigenous peoples' good forest stewardship, could facilitate early actions of local stakeholders. Standardized nested schemes have indeed been proposed by the Verified Carbon Standard (VCS) through the ''Jurisdictional and Nested REDD initiative (JNR)'' (VCS, 2012) and the ''Nested REDD+ standard,'' which were created by the American Carbon Registry (ACR, 2012). In nested schemes, countries could divide their territory according to biomes, political boundaries or tenure regimes, such as indigenous territories, protected areas and private lands, which could be considered sub-national jurisdictions. It has been suggested that sub-national jurisdictions could develop their own rewarding mechanisms (bottom-up approach) or, conversely, that countries could suggest standardized sub-national proposals for some regions (top-down approach) (Chagas et al., 2011).

We contend the matching analysis that we developed offers a statistically valid way of determining the effectiveness that is granted by protected areas and, therefore, their additionality. At jurisdictional levels, rewarding forest protectors could be resolved by matching the observed deforestation within a jurisdiction to land of similar area and characteristics outside the jurisdiction. A potential risk of stock-based payments, i.e., payments based upon the total carbon in the forest during a specific period, is that a part of these incentives could be made to areas that are under no ''threat'', which is also called passive conservation (Angelsen and Wertz-Kanounnikoff, 2008). We contend that matching methods could help to resolve this issue through the pairing of comparable protected and non-protected areas with respect to remoteness, topography or other relevant characteristics. From this perspective, the technique could help to demonstrate forest protectors' conservation efforts in a quantitative manner by estimating the impact in avoided deforestation of conservation areas. It could also serve to separate protected areas with real contribution to reduce deforestation from ''rock and ice'' areas, i.e., remote and unattractive areas for agriculture and raising cattle without real potential of being deforested. This approach is particularly important for PAs or other conservation areas, which could be biased towards areas that prevent land conversion the least (Joppa and Pfaff, 2009). Therefore, identifying areas under threat would also help us to compensate forest protectors in areas in which there are real pressures of forest clearing. Thus matching is a scientifically-sound, simple and elegant way to quantify the contribution of each jurisdiction to emissions avoidance.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.gloenvcha.2014.07.002.

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