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Titling community land to prevent deforestation: An evaluation of a best-case program in Morona-Santiago, Ecuador

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ABSTRACT

Assigning land title to collective landholders is one of the primary policies land management agencies use to avoid deforestation worldwide. Such programs are designed to improve the ability of landholders to legally exclude competing users and thereby strengthen incentives to manage forests for long-term benefits. Despite the prevalence of this hypothesis, findings about the impacts of land titling programs on deforestation are mixed. Evidence is often unreliable because programs are targeted according to factors that independently influence the conversion of forests. We evaluate a donor-funded land titling and land management program for indigenous communities implemented in Morona-Santiago, Ecuador. This program offers a close to best case scenario for a land titling program to reduce deforestation because of colonization pressure, availability of payments when titled communities maintain forests, and limited opportunities for commercial agriculture. We match plots in program areas with similar plots outside program areas on covariates that influence the conversion of forests. Based on matched comparisons, we do not find evidence that land titling or community management plans reduced forest loss in the five years following legal recognition. The results call into question land titling as a direct deforestation strategy and suggests land titling is better viewed a precursor to other programs.

1. Introduction

Assigning land title to customary and collective landholders is one of the primary policies used to avoid deforestation worldwide (Davis and Wali, 1994; Soule et al., 2000; Fearnside, 2001; Otsuka et al., 2001; Finley-Brook, 2007; ITTO, 2010; Larson, 2011; Larson and Dahal, 2012; Robinson et al., 2014). Upon receiving title, forest owners gain access to courts, law enforcement, and regulatory agencies that improve their ability to exclude competing users like colonists and extractive industries. Facing decreased risks that land will be expropriated and less of a need to signal tenure status by clearing forests, landholders may manage forest resources to secure a continuous stream of timber, game, forest products, or cultural amenities.

Based on these expectations, international aid donors, government agencies, and conservation organizations have embraced land titling as a way to reduce deforestation, especially where indigenous communities are landholders (Tucker, 1999). According to a search of a comprehensive database of international aid, development organizations have spent more than $7.8 billion on land titling programs since 1970 (Tierney et al., 2011). Some development organizations, like the United States Agency for International Development, maintain specialized offices to promote and manage land tenure programs worldwide (USAID/ARD, 2006). In 2012, USAID launched the $700 million, five-year Strengthening Tenure and Resource Rights program to expand and strengthen property rights to land worldwide (USAID, 2013). The World Resources Institute, a non-governmental organization with global reach, created the *Governance of Forests Initiative* to advise countries with extensive forests about land tenure. The clarification of land tenure—use and occupation rights to land that can be effectively enforced—through land titling in areas where indigenous populations reside also aligns with donor efforts to promote minority rights, credit markets, and pluralism in politics (Liverman and Vilas, 2006; Godoy et al., 1998; Robinson et al., 2014).

In addition, land title can provide access to incentive programs that pay for ecosystem services and the maintenance of forest cover. For example, in support of the United Nations REDD+

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program, international donors have increased their support of land titling programs (Naughton-Treves and Day, 2012). At the national level, incentives schemes that pay for the maintenance of forests require clearly delineated ownership. For example, Ecuador's flagship *Socio Bosque* program that pays landholders to maintain forests requires land title for eligibility (de Koning et al., 2011).

Despite the enthusiasm of forest managers and conservation practitioners about land titling as a way to prevent deforestation, little reliable evidence exists about how land titling affects forest cover. Existing research has generated mixed findings (Ferretti-Gallon and Busch, 2014) and often fails to isolate the direct effects of land titling programs from the background factors that drive targeting (Robinson et al., 2014). Because land titling programs are targeted or clustered based on factors that independently affect forest cover, such as remoteness or indigenous territory status, it is difficult to determine whether differences between program and non-program areas are a result of land titling interventions. This challenge is common for spatially explicit land management policies (Joppa and Pfaff, 2010). Additionally, as is the case with many areas of policy (Asian Development Bank, 2010; Pluye et al., 2004; Scheirer, 2005; Stirman et al., 2012), there is considerable uncertainty about medium to long-term effects of land titling programs because monitoring is not frequently pursued after programs are concluded.

Adding to the uncertainty, the effects of land titling programs are likely to be conditional on the governance environment and interactions with other programs (Barsimantov and Antezana, 2012; Mullan et al., 2011; Barsimantov et al., 2011; Paneque-Gálvez et al., 2013). Land titles may not change land management patterns without supporting institutions that enforce exclusion rules and legitimize claims to them (Kerekes and Williamson, 2010). Thus, land titling programs must be evaluated across different combinations of supporting institutions, such as land management programs, incentive policies for owners, and community decision-making procedures in the case of communal landholdings.

To produce reliable findings, we analyze a unique, parcel-level dataset of a USAID-funded land titling program for communal and indigenous areas in the heavily forested province of Morona-Santiago, Ecuador. We directly address the non-random spatial targeting of the program. We also evaluate variations in the effect of the program on forest cover when it is implemented with a complementary program of community management planning.

The Programa de Sostenibilidad y Unión Regional Sur (PSUR) was a $27 million, binational border integration and development program that was co-implemented by CARE (Cooperative for Assistance and Relief Everywhere) and other local and international organizations in three provinces between 2002 and 2007 (CARE, 2007). The program intended to support the post-conflict Peruvian-Ecuadorian Broad Agreement of Border Integration, Development and Good Neighborhood (*Acuerdo Amplio Peruano-Ecuatoriano de Integración Fronteriza, Desarrollo y Vecindad*) and aimed to increase the wellbeing of populations along the border (Donoso, 2009; Hocquenghem and Durt, 2002). CARE implemented an analogous program call *Frontera Norte* in the Peruvian border provinces, although it focused more on basic infrastructure (USAID, 2005). PSUR was also part of USAID's Conservation and Development Strategies with Lowland Indigenous Groups initiative, which aimed to support conservation of the nearby and overlapping Kutukú Protected Forest area, as well as to strengthen indigenous land rights (USAID, 2010, 2011; CARE, 2012). In Morona-Santiago province, PSUR claimed to benefit more than 24,000 people and to title more than 170,000 hectares of communal, indigenous lands, approximately 80% of which received complementary support for a community land management.

We identify matched counterfactual plots that are similar to the plots that received community titles and management plans, but that remain untitled through the end of our study period. This matching procedure allows us to isolate the impact of PSUR from the background factors that determined its targeting, a pressing need for research about land tenure programs (Robinson et al., 2014). After matching treatment plots to comparable control plots, we find that community land titles, whether or not coupled with community management plans, had no distinguishable impact on average on forest cover in the first five years after the recognition of legal tenure status. Our results raise important questions about the role of land titling and community management programs in directly reducing deforestation.

2. Theory of causation

Land titling programs attempt to increase the security of land tenure by improving *exclusion*—the ability of landholders to prevent potentially competing users from extracting value from land at present or in the future. Land titling increases the security of land tenure on average over time by facilitating access to the enforcement capabilities of the state and providing a "reference point" that can be used by traditional institutions to adjudicate land disputes (Fort, 2008; Jacoby and Minten, 2007; Bennett and Sierra, 2014). Past research finds that titles have been useful for improving exclusion of competing land claimants in Madagascar (Jacoby and Minten, 2007), for increasing land values in frontier areas in Brazil because of more secure alienation rights (Alston et al., 1996), and for decreasing the costs of enforcing boundaries (Mendelsohn, 1994). Exclusion is costly, which pushes community or individual landholders with insecure tenure to extract value from the land quickly or to engage in land uses that entrench their tenure. Land titling aims to strengthen land tenure and is thought to mitigate these incentives.

Improved exclusion through land titling can both increase and decrease the rate of forest conversion depending on the context. In a recent meta-analysis of 117 studies about deforestation, Ferretti-Gallon and Busch (2014) found that secure property rights to land do not have consistent effects on deforestation. Secure land rights only seem to reduce deforestation in studies where they are the primary variable of interest, rather than a control variable in a multivariate regression, potentially indicating publication bias in the scientific literature. In a different review, Robinson et al. (2014) find that most empirical studies about land tenure and forest cover do not have clear strategies to separate the direct effects of land titling programs from the background factors that drive their targeting. Improving the state of knowledge depends both on identifying the contextual factors that moderate the relationship between land titles and forest conversion and on employing methods that distinguish the direct effects of land titling programs from the background factors that drive their targeting.

Conceptually, it is useful to identify the ways that land titling influences the use of forests by competing users and landholders themselves. In many areas where indigenous communities reside, the poaching of forest resources by outsiders and encroachment into traditional territories are significant drivers of deforestation (Hayes, 2010). Indigenous lands are often expropriated by groups who wish to extract mineral resources or convert forests to agricultural or urban uses (White and Martin, 2002; Bebbington, 2013). Without formal title, communities are not able to avail themselves easily of legal remedies when colonists or extractive industries move onto their traditional lands (Brasselle et al., 2002; Hayes, 2010). Land tenure programs that provide legal property rights for indigenous communities have been found to reduce deforestation based on the improved exclusion of settlers (Nelson et al., 2001). To the extent that land titles improve the ability of landholders to exclude other users who are likely to deforest land, titling should be associated with the maintenance of forest cover.

Land titling may also affect land use decisions by communal landholders themselves, in particular by lengthening the time period they expect to obtain value from the land. Increasing the time horizon of landholders increases the expected value of benefits that accrue over multi-decadal periods, including timber, game, and cultural amenities. When landholders gain more secure tenure over long periods through titling, they are more likely to forego uses of forests that offer short-term benefits at the expense of these long-term benefits, such as low-productivity agriculture (see Araujo et al., 2009). When land contains a valuable natural resource that can be extracted, such as timber, having security from outside users through title can lengthen the time horizon for extraction and even promote investment in afforestation and sustainable forest management by forest owners (Nguyen et al., 2010).

More directly, the conversion of forests to agricultural and pastoral land uses is often a strategy to signal tenure to competing users and to relevant authorities when legal status is not established. Forest clearing has been used to successfully establish rights to land in different settings (Hayes, 2010; Fortmann, 1990). In the Brazilian Amazon, for example, settlers who cleared land have later gained recognition of land claims from the state. In response, indigenous people clear forests to signal their willingness to defend land claims against settlers when their tenure is not legally recognized (Araujo et al., 2009). Once land titles are in place, neither current nor competing landholders have incentives to convert forests as a way to achieve land tenure.

Options to raise revenue by maintaining forests also become available to landholders with title, which should reduce deforestation. Many incentives schemes pay owners for the values that forests provide to non-landholders, like water quality, air quality, biodiversity, and flood control (e.g., Arriagada et al., 2012). Access to incentives schemes for maintaining forests is often conditional on having title to land. These schemes depend on identifying the individual or group that is legally responsible for managing a certain forested area. As the international community moves to expand programs that provide payments for the ecosystem services that forests provide, such as the global REDD+ program that seeks to mitigate climate change, land titling programs often come first (Sunderlin et al., 2009; Duchelle et al., 2014). Land title can thus be a critical means of connecting landholders with incentive schemes that promote the maintenance of forests (e.g., de Koning et al., 2011).

While there are a number of ways that land titling can work to maintain forests by improving the security of tenure, it can also increase deforestation in certain contexts. When agricultural, pastoral, or urban land uses require significant upfront investment but offer long-term benefits, land titling may increase deforestation. With the secure tenure afforded by land titles, owners have increased certainty about being able to capture long-term benefits of new productive uses. Additionally, land titles can often be used as the collateral for credit, making investment in active land uses more likely for formerly subsistence farmers (Deininger and Chamorro, 2004; Otsuki et al., 2002; Marchand, 2012).

Of course, the returns to investment in alternative land uses are contextual. In a review of the drivers of land use by indigenous groups in the Ecuadorian Amazon, Gray et al. (2008) find that integration with commercial markets is the key predictor of conversion of forests to agriculture by indigenous groups. Since commercial opportunities for agricultural or pastoral uses are likely to be lowest in more remote areas (e.g., Alston et al., 1996), deforestation is a less likely outcome in these areas in response to land titling.

It is important to note that many factors apart from land titles and their resulting tenure security affect the incentives of landholders regarding resource extraction and the conversion of forests. Land titles for groups do not necessarily solve collective action or community management challenges that have been highlighted in the expansive literature on the commons (e.g., Agrawal, 2001; Poteete and Ostrom, 2004; Gibson, 2005). For example, Tucker (1999) argues that a community land title only improves a community's ability to exclude external users and does not necessarily deal with more challenging questions about community management of common resources. Other research finds that traditional, indigenous institutions are less effective at managing the use of forests by indigenous users as compared to outsiders (Bremner and Lu, 2006). In contrast, Hayes and Murtinho (2008) show that indigenous groups with stronger community property management institutions are more likely to prevent agriculture expansion. Taken together, this body of research suggests that land titling programs will only be effective at reducing deforestation by landholders when supported by strong, collective decision-making processes.

Additionally, land titling programs are not always insulated from political influence and can themselves result in the expropriation of customary lands. Wealthy and powerful individuals can use their influence to capture disputed lands (Broegaard, 2009). Because land titling programs can set off competition for title among competing users, it is possible that land titling programs focus appropriation effort on nearby lands that remain untitled, resulting in more deforestation or "leakage" in those nearby lands (Jacoby and Minten, 2007). Thus, analyses about the effects of land titling on forest cover must be careful to consider impacts on equity and nearby areas (Wainwright and Bryan, 2009).

While past research about the effects of land titling on forest conversion has been based on the theoretical expectations we outline, little reliable evidence exists that accounts for the targeting of programs. Little research exists that examines how land titling affects forest cover over time. Land title might have both positive and negative effects on forest cover, but the net effects are thought to be substantially positive in relatively remote areas occupied by indigenous landholders (Fearnside, 2001; Holland et al., 2014). We tackle the theoretical and empirical challenges that have limited existing research by examining a unique land titling program that offers close to a best case for land titling to reduce deforestation.

3. Study context: PSUR as a close to best-case land titling program

Almost all of the contextual factors that help land titling programs reduce deforestation are present over much of the area covered by PSUR (Table 1). Thus, the findings of this research can be interpreted in light of a best case study design. If the program is found to reduce deforestation, the next step would be to disentangle the most important factors or combinations of factors that contribute to this effect. If the program does not reduce deforestation, the promise of land titling as a direct intervention to reduce deforestation comes into question more generally, given the preponderance of supporting factors.

Morona-Santiago is approximately 24,346 km^2 and had an estimated 2001 population of 120,487 rising to 214,786 by 2010. At between 8 and 9 people per km^2, the population density is one of the lowest in Ecuador, far below the national average of 58.2 people per km^2. The province is dominated by tropical rainforest in the eastern and southern portion and Andean mountain areas in the far west. Shuar indigenous groups dominate the lowland regions with between 60,000 and 85,000 members as of 2010. The Achuar nation located in the southeastern portion of the region has

Table 1
Factors that moderate the effect of land titling on forest cover.

Land titling will *reduce* deforestation when these conditions are present	Land titling will *increase* deforestation when these conditions are present
● *Colonization and extraction pressure from competing users*; ● *Land clearing is used as a strategy to assert rights under insecure tenure*; ● *Forests have high economic and cultural value for landholders*; ● *Complementary land management programs and training*; ● *Access to payments for ecosystem services programs.*	● Opportunities for commercial agriculture based on proximity to markets; ● Traditional landholders are able and likely to sell land to new user groups; ● Opportunity to receive title sets off competition for land by competing users; ● *Increased extractive capacity because of reduced effort devoted to exclusion.*

Notes: Conditions that are present in the study area are italicized.

approximately 4000 members. The rest of the population is comprised of non-indigenous colonists that typically practice agriculture and raise livestock (see SI, Appendix A for more background information). The region is known for its high ecological value and the entire study area is recognized as one of the top 25 biodiversity hotspots globally (Myers et al., 2000).

PSUR offered Shuar Indigenous organizations the opportunity to codify the exclusivity of traditional lands and prevent further encroachment by mestizo and quichua colonizers. Since the 1950s, colonization was common in the study region due to publicly supported road building and formal colonization policies that tied land rights to converting land into agricultural and pastoral uses. Although land claims where pursued by the Shuar from the 1970s, it was not until decades later that some of these claims were acted upon, especially in the north of the province, along the access road (Rudel et al., 2002). In many other cases however, unclear legislation and hostile authorities prevented the formalization of claims, even when the local population thought that their tenure was secured by title. PSUR offered the Shuar Indigenous organizations a chance to finally achieve secure land tenure and access to enforcement by state agencies (CARE, 2007).

As part of PSUR, Shuar communities gained collective title after undergoing a legalization process that produced Land Legalization Plans (*Plan de Manejo para Legalización* or PMLs) with the assistance of CARE-Ecuador and local partner PRODEPINE (The Project for the Development of the Indigenous and Afro-Ecuadorian People of Ecuador). These plans detailed the location and boundaries of claimed land, claimant status, and zoning designations for forest protection, agriculture, and pasture. All of the 52 communities that received title in our study area completed PMLs. It is possible that some of these lands were included in an earlier formalization efforts conducted in the 1970s and 1980s, but it appears that these titles were either never fully recognized by the state or limited in scope. Hence, a new titling program was required by government agencies in the early 2000s.

All communities that took part in the PSUR program from 2003 onwards completed supplementary management plans (*Plan de Manejo Integral* or PMIs) that contained a general diagnosis of the socio-economic and environmental status of the community and a plan for managing human, natural, and physical resources. For a PMI to be approved by the Ministry of Environment, it had to have been discussed and accepted by the communal assembly. PMIs were initially designed and co-implemented by non-profit partners of USAID, but eventually trained local personnel from the Shuar Federation produced them. Because only 41 of the 52 communities that received title through the PSUR program produced these plans, we are able to compare the efficacy of land titling with and without supporting land management planning activities (Fig. 1).

In terms of securing access to the long-term value of forests, the land titling made available through PSUR provided Shuar communities the opportunity to reaffirm their identity and the validity of their way of life. Land use zoning within PMIs contained provisions to establish areas of no agricultural use to facilitate the maintenance of areas for hunting, plant gathering and recreation. According to the CARE (2007) evaluation of PSUR, 66 percent of Shuar communities reported improvements in maintaining their traditional ways of life as a result of land titling, which includes the household division of labor, the use of natural resources, and the preservation of spirituality. Recent studies echo this evaluation and suggest that in spite of decades of progressive acculturation, the Shuar in the Trans-Kutuku area have generally maintained their traditional land use systems (CARE, 2007; López et al., 2013). The traditional zoning, corresponding to land use 'rings' around a village center dedicated to agriculture, ranching, gathering, hunting and fishing, was formalized in PMIs along with technical requirements to meet government standards. Furthermore use standards (*acuerdos mínimos de uso*) were established as part of PMIs to ensure that Shuar families would manage their land according to the Ministry of Environment's guidelines.

PSUR also offered later access to payments for the maintenance of forests in many of the communities in our sample. Ecuador's flagship state program that provides payments for forest conservation, *Socio Bosque*, began in 2008. Communities or individuals voluntarily enroll by pledging to maintain "native" vegetation intact for 20 years. In exchange of each hectare of conserved land, landowners receive payment that must be invested in local development projects. Land title is a prerequisite for accessing *Socio Bosque* (Krause and Nielsen, 2014). Even though *Socio Bosque* did not begin activity in the study area until late 2008, the program had been in negotiations with local organizations like FICSH for a several years. Shuar communities in the southern section of the PSUR intervention area were among the first to enroll. By 2011, slightly less than half of communities legalized by PSUR had land enrolled in *Socio Bosque*. By 2012, about 100,000 hectares of Shuar territory were registered in *Socio Bosque* according to the program's own statistics (Socio Bosque, 2012).

In summary, the contextual factors that should support the reduction of deforestation following land titling are present in the program area, while almost all of the conditions that would cause land titling to increase deforestation are absent. The PSUR program offers a close to best case scenario for a land titling program to reduce deforestation.

4. Data and methods

We obtained spatial data on the intervention areas of all waves of PSUR from USAID Ecuador and their partners Ecolex, the *Bosques y Costas* Project, and CARE International. These partners provided a portion of the data on titles in digital format. We digitized and georeferenced other title boundaries from PSUR documentation and paper maps. We approximated three community boundaries based on hard copy and digital documentation we obtained during field visits with partners in May 2013, including management plans completed as part of the PSUR program. For nine communities where no data was available, we used existing settlement names to estimate the corresponding community lands (Fig. 1).

To assess whether land titles and management plans achieved conservation goals we divided Morona-Santiago province into 27,984 0.87 km^2 grid cells. A grid approach is preferable to a

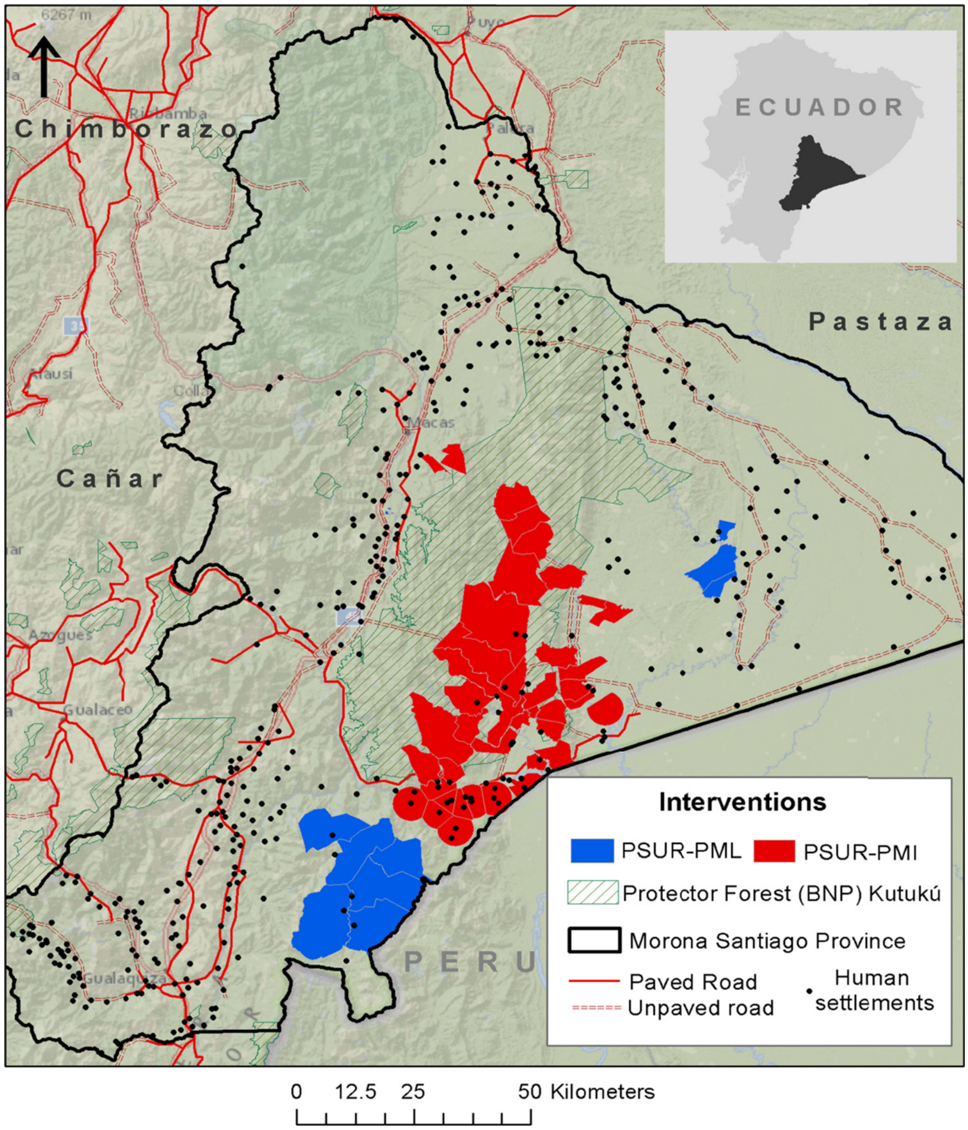

Fig. 1. The study area and locations of titling and management planning treatments. *Notes*: The blue areas of the map represent communities that underwent legalization planning (PML) as part of PSUR. The red areas of the map represent communities that underwent both legalization and management planning (PMI) as part of PSUR. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

community object-based approach in our application, since pixels can capture factors that make deforestation more or less likely within a community object, such as slope or pre-existing land cover. Additionally, compiling data at the level of the pixel allows for aggregation into objects like communities, but compiling data at the level of objects does not allow disaggregation to pixels. We chose pixel size based on a combination of our coarsest input dataset (population density by Landscan) and the desire to have multiple Global Forest Change (GFC) pixels that we use as the primary outcome variable feed into each grid cell (Hansen et al., 2013).

We examined the amount of forest loss in each grid cell in the five years following legalization and management planning. For our main analysis, we use the GFC measure of forest loss to generate post-treatment forest loss in each of our grid cells. The GFC data provides a measure of the conversion of forest cover to non-forest cover each year, with forest defined as vegetation reaching at least 5 m height (SI, Appendix C contains a discussion of the strengths and weaknesses of these data). In supplementary analyses, we verify our findings using enhanced vegetation index (EVI) derived from MODIS, which can be more sensitive to forest degradation (SI, Appendix B).

The GFC data show that Morona-Santiago was 89% forested with 21,713 km^2 of forest cover immediately before our study period in 2000. By the end of our study period in 2012, 315 km^2 or 1.45% of the baseline forest had been converted to non-forest. Although deforestation is relatively low across the province, two distinct areas experienced significant deforestation, both of which partially overlap the PSUR intervention area. The first is the western portion of the province along the only major road (E40) in the region. Along this corridor, approximately 3.2% of the forests were converted during the study period. The second is at the intersection of the Rio Morona and E45 near the Peruvian border. Approximately 3.8% of forests in this corridor, which is within Shuar indigenous territory, were converted during the study period. Fig. 2 depicts the two corridors of deforestation (panel A) and the common pattern of agricultural clearing alone E40 in the Rio Morona corridor (panel B). The PSUR inventions are mostly located between these two corridors, which may indicate either the successful reduction of deforestation or the strategic targeting

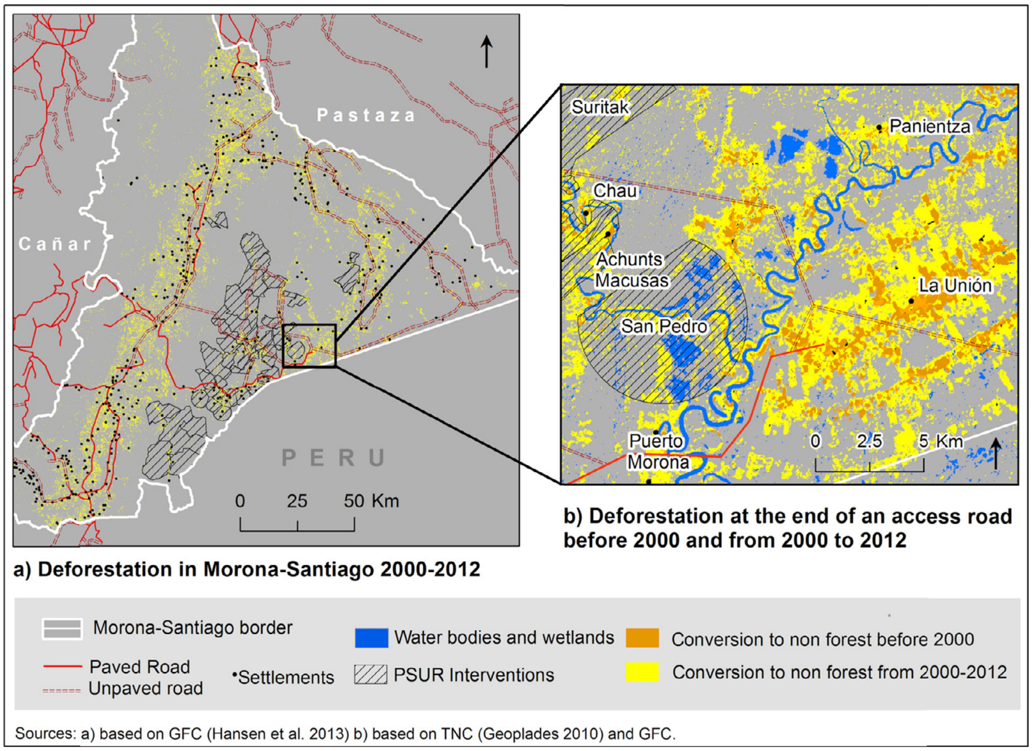

Fig. 2. Study area and patterns of deforestation. Panel A depicts the two zones of deforestation in the intervention areas. Panel B depicts the fishbone deforestation pattern observed when settlers covert forests along transportation corridors, which is common in the Amazon region.

of the program to areas with lower background rates of deforestation.

Disentangling the direct effects of land management interventions from the background factors that drive their targeting is a major challenge (Ferraro, 2009; Joppa and Pfaff, 2010). Both observable and unobservable differences between treatment areas that receive an intervention and control areas that do not receive an intervention can confound estimates of the effects of an intervention. We employ a matching approach to construct a set of control plots that have similar pre-treatment characteristics to the plots in the PSUR program. We compile spatial data on other variables that have strong associations with forest loss in the extant literature (Table 2). We then iteratively search through sets of control observations outside of the PSUR intervention area to select a set of control units that have observed distributions of each covariate that are not observationally different from the distributions of the same covariates in the treatment plots as described in Equation 1, where ρ is the observed values in the selected set of treatment and control groups, X is a matrix of covariate values, and T is the treatment state (see Appendix C for the full statistical derivation).

$$\rho(X_i|T_i = 1) \approx \rho(X_i|T_i = 0) \quad (1)$$

Our first set of covariates are measures of forest loss in pre-treatment time periods: the amount of forest cover in the subject plot and the pre-treatment rate of forest loss within 5 km^2 of the plot. These variables attempt to capture background rates of deforestation that cannot be explained by the other observable covariates, which alleviates some concerns about unobserved differences between the treatment and control plots. Indeed, matching studies are frequently able to reproduce the results of more reliable experimental studies when a pre-treatment measure of the outcome is used for matching (Cook et al., 2008).

Our second set of covariates—distances to roads, rivers, electricity grids, and disturbed lands—all account for the increased value of production and ease of colonization on lands that are more connected with built infrastructure. Within the Amazon region, a large majority of studies cite roads as a driver of deforestation (Arima et al., 2005; Rudel et al., 2009). Thus, it is necessary to

Table 2
Control variables used to balance treatment and control plots and for regression adjustment.

	Source	Temporal granularity	Native resolution
Forest loss	Hansen et al. (2013)	Annual	30 m
Forest loss within 5 km^2 ($t-1$)	Hansen et al. (2013)	Annual	30 m
Forest cover percent ($t-1$)	Hansen et al. (2013)	Annual	30 m
Distance to major roads	OSM, VMAP1, MAE	Various, 1993, 2012	Vector
Distance to electric grid	VMAP1, MAE	1993, 2012	Vector
Distance to river	VMAP1, MAE	2012	Vector
Distance to disturbed land classification	MOD12Q1	Annual	.5 km
Indigenous Shuar land	TNC	2012	Vector
Protected area status	WDPA, MAE, TNC	Annual	Vector
Population density within 5 km^2 ($t-1$)	Landscan	Annual	1 km
Elevation/slope	Souris (2008), IRB	2001	30 m

identify a set of control plots that have similar levels of access to infrastructure and connection to settlements. The western portion of our study region lacks access to roads and utility infrastructure, and the dominate form of transport occurs by river, so we also match on this covariate. In addition, the distance to land that has already been converted from forest is one of the most important predictors of forest conversion, through population diffusion and frontier effects (Walker et al., 2002; Geist et al., 2006; Rudel et al., 2009). The majority of disturbed lands in our study area are farmlands, with limited urban settlements, both of which are important covariates for creating a balanced control set.

Our third set of covariates for matching—the indigenous status of landholders, protected area status, and population density—are demographic and institutional variables that may impact rates of forest conversion. The PSUR program in Morona-Santiago was explicitly targeted to secure land title for Shuar communities. Past research shows that ethnic backgrounds can predict land use because of cultural practices, particular skills, or institutions that govern collective action (Bray et al., 2006; Stocks et al., 2007). Thus, we match plots based on whether they are occupied by Shuar indigenous communities. Likewise, land use inside protected areas is managed under different rules than non-protected areas, often with legal penalties for the conversion of forests. For Shuar communities in our study area that reside in ''soft'' protected areas, rates of deforestation might be lower owing to additional restrictions on the use of forests, which is a common pattern in many areas (Andam et al., 2008; Nelson and Chomitz, 2011; Joppa and Pfaff, 2011). Additionally, because population density is associated with the intensity of forest use (Laurance et al., 2002), we seek to find a set of control plots with the same localized population density as PSUR treatment plots.

Finally, we match on two geophysical covariates that affect the suitability of forest areas for other land uses—elevation and slope. Both the desirability of timber species and land's suitability for agriculture depend on elevation. Additionally, areas of high slope are difficult to access, deforest and use for productive agriculture as compared to relatively flat areas (Yackulic et al., 2011). Table 2 contains a more complete description of characteristics of the full set of covariates used in our matching procedure.

Before executing the matching procedure, we discard control observations that fall outside the range of values observed for treatment units for each of the covariates. We carry out statistical matching using a genetic algorithm that both weights and discards control plots that do not serve as comparable units to the treatment plots (Sekhon, 2007; Diamond and Sekhon, 2013). We apply a genetic algorithm that iteratively searches through many sets of potential control plots to maximize balance on the observed covariates. Matched sets with good balance, those that have a large *minimum* p-value on paired t-test for differences of means between treatment and control observations across all covariates are passed onto the next generation, along with mutated sets to ensure the full space of sets of control observations are explored.

Matching does not ensure that treatment and control observations are similar for unobserved variables. We rely on the assumption that matching on pre-treatment measures of the outcome reduces unobserved heterogeneity and often reproduces causal estimates (Cook et al., 2008). A more complete description of the matching procedure and a justification of our assumption about capturing unobserved heterogeneity in the pre-treatment value of the outcome can be found in Supporting information, Appendix C.

We estimate difference-in-differences between treatment and control plots using ordinary least squares regression with aggregated forest loss over the five years following the PSUR interventions (Eq. (2)).

$$a_i(Y_i(t = x) - Y_i(t = 0)) = a_i(\alpha + \tau T_i + \beta X_i) \quad (2)$$

where Y_i is the amount of forest cover at different times, a_i is the square root of the weight for each observation, α is the regression intercept, τ is the treatment effect of the PSUR intervention, and β is a vector of coefficients for control variables. To check the assumption that the treatment indicator is observationally independent from covariates X, we compare estimates of treatment effects dropping the βX_i for all specifications. If the PSUR interventions have the intended effect, we will observe smaller losses in forest cover in the treatment plots than the control plots, both aggregated over several years and on a year-to-year basis.

The methods we employ have two distinct advantages over cross-sectional regression approaches that are common in the literature on forest policy (see also Blackman, 2013). Regression approaches without matching adjust treatment and control observations based on modeling assumptions about how the chosen covariates affect the outcome. By selecting a set of control observations that are already similar to treatment observations without significant statistical adjustment, matching renders estimates less sensitive to model assumptions that cannot be easily tested (Ho et al., 2007). The difference-in-difference method has the added benefit of generating more precise estimates by removing time-invariant, cross-sectional variation in the outcome measure and accounting for common trends in the outcome across treatment and control observations (for another application, see Arriagada et al., 2012).

5. Results

We first examine the results of legalization plans and titles without enhanced community management plans on forest loss during the following five years. As part of the first wave of land titling in 2002, nine Shuar communities that worked with CARE and the local non-governmental organization PRODEPINE received titles after completing a legalization plan or PML. Although these communities are Shuar, they did not follow the same selection criteria as the later wave of PSUR. In particular, they were not inside or adjacent to the Kutukú Protected Forest and did not receive the same support to create natural resource management plans and other livelihood activities (Fig. 3, panel C).

Difference-in-difference least-squares regression without pre-matching (Fig. 4), model (a) provides an estimate of the treatment effect of legalization planning and land titling on deforestation over five years, after controlling for the other factors that drive deforestation in the area. As shown in the corresponding bar (a), the aggregate treatment effect of land titling and the legalization plan over five years is estimated to be a reduction of more than 1000 m^2 of forest loss for each approximately 1 km^2 study plot. The challenge, however, is that the targeting of the titling program is associated with a number of other factors that reduce deforestation. For example, PML-only treatment plots are on average further away from major roads and more likely to have high slopes than other regions of the study area, both of which tend to decrease forest loss (Technical Appendix, Table A1 contains balance statistics). In a simple regression, the estimated treatment effects will be highly dependent on the model assumptions used for statistical adjustment (e.g., linear effects of the covariates) and the assumption that covariates affect the outcome independent from the treatment (e.g., additive effects), which is not substantiated in this case since targeting occurred purposefully.

After matching to find a set of plots that did not receive a PSUR intervention, remained untitled through 2012, and had similar observed distributions of covariates, we do not find any evidence that having a legalization plan and communal title reduces forest loss over the next five years. Fig. 4, models (b)/(c) show that this result is consistent across post-matching models that include and

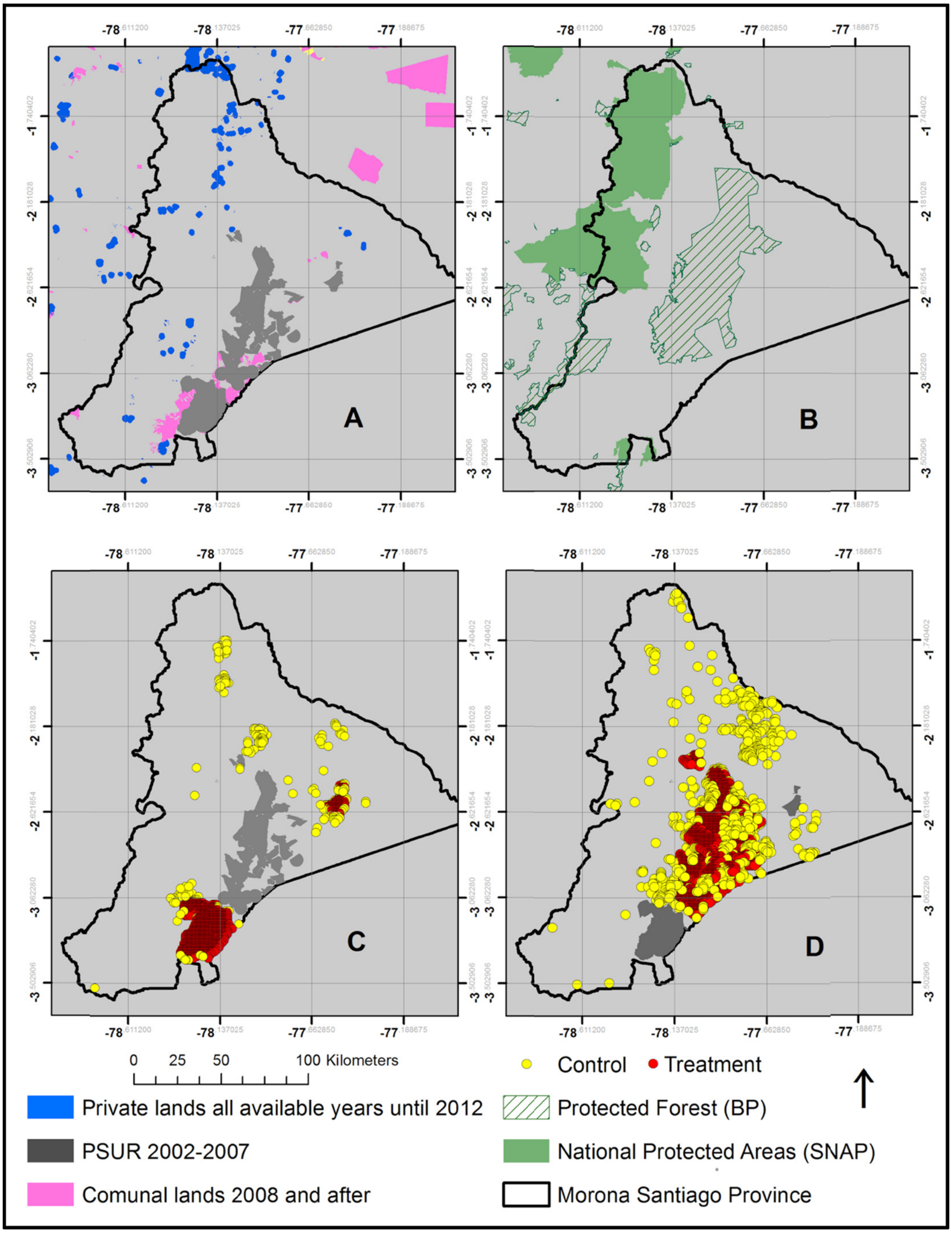

Fig. 3. *Panel A.* Land tenure on type of property based on Secretaría Nacional de Planificación y Desarrollo (SENPLADES). *Panel B.* National Protected Area (hard conservation) and Protected Forest (*Bosques Protectores*). *Panel C.* PML-only treatment and control areas generated by matching. *Panel D.* PMI treatment and control areas generated by matching.

do not include covariates for regression adjustment that were balanced through the matching procedure. We do not present coefficient estimates for the control variables, since they correspond to a non-representative set of observations created to isolate the effect of the treatment variable. The point estimate in both models is similar and indicates higher rates of deforestation in areas following land titling, but this result is not statistically distinguishable from variation that would occur by random chance. The consistency of the point estimates in models (b) and (c) is an indication that matching has made the treatment variable observationally independent from the covariates.

We also considered the possibility that the effects of land titling could be realized at different points in time after the intervention. For example, titling might focus attention on land management immediately after the legal process, resulting in decreased deforestation only in early years. Alternatively, it may be several years until new management plans take effect given the challenges of reforming existing institutions and practices. Thus, we examine the effects of land titling in each year following the PSUR intervention. The results are similar to the aggregated estimates (Fig. 5). The difference-in-differences point estimates of the treatment effect without pre-matching indicate reduced deforestation, though this result is only statistically significant in two of

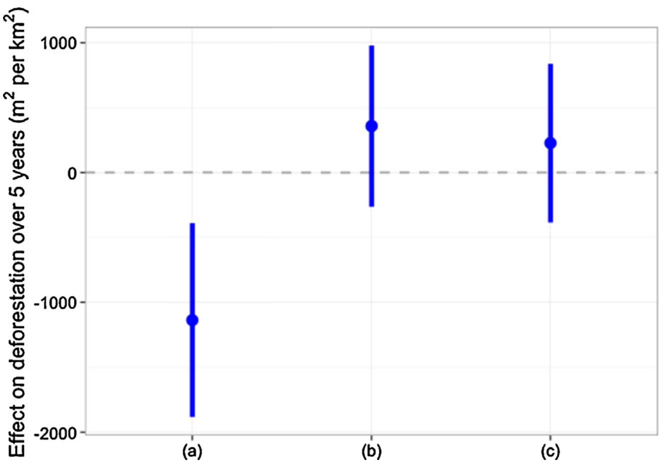

Fig. 4. Difference in differences over five years for PSUR plots with legalization plan (PML) and title versus non-PSUR plots with no plan or title, 2002–2012. *Notes*: Figure shows treatment effect of tenure status for models as follows: (a) covariates, no pre-matching; (b) no covariates, pre-matching; (c) covariates, pre-matching.

the five years (black line). In contrast, the point estimates of the treatment effect after pre-matching, both with and without matched covariates used for regression adjustment, are never statistically distinguishable from results that are likely to be realized by random chance (blue lines). Thus, we find no evidence that land titling alone reduces deforestation within five years of the intervention when comparing treatment areas to similar areas that remain untitled.

As mentioned earlier, the second wave of PSUR from 2003 onwards included a variety of management and training activities in addition to legalization. Activities included funding of the Shuar Federation operations and training for its staff, supplemental income generation programs related to handicrafts, animal husbandry, and agriculture, as well as planning low-impact forestry and agroforestry operations. Many of these activities were articulated in an Integrated Management Plan (PMI), which aimed to support the success of the land titling program by strengthening local institutions of collective decision-making and complementing titles with activities that promoted sustainable use of the land.

In light of the synergy between PMIs and land titles, we pre-match and then estimate the impact of the second wave of PSUR, which includes all programs implemented from 2003 onward, compared to similar non-program areas that did not receive title during the study period. Like the first wave, all program areas have a PML and land title. Like the results we report for PML-only plots, the full PMI treatment appears to reduce forest conversion in the difference-in-difference regression model without pre-matching (Fig. 6, model a). However, like the regression model for the PML-only treatment, the plots that received title and management plans have background characteristics associated with lower levels of forest loss, including lower population densities and greater distance from disturbed land classifications (Technical Appendix, Table A1 contains balance statistics). This raises the possibility that the estimated effect is driven by collinearity with these covariates and modeling assumptions, rather than an actual treatment effect.

Again, we conduct a search for a set of control plots using a genetic matching algorithm that are similar on observable covariates to the treatment plots. In the post-matching models both with and without the covariates, we estimate that the treatment effect of titling and management plans on forest loss is approximately zero (Fig. 6, models b/c). Because the post-matching models with and without covariates have similar estimates, we are confident that in the post-matching dataset the treatment variable is observationally independent from the covariates that have an effect on forest loss, reducing or eliminating bias in estimates due to collinearity and modeling assumptions.

Similar to the PML-only analysis, we disaggregate the effect of the PMI treatment and estimate treatment effects for individual years following the program (Fig. 7). The results of this analysis mirror those reported for the PML-only analysis. The difference-in-differences point estimates of treatment effects without pre-matching indicate reduced deforestation, with a statistically significant result in four out of five years (black line). In contrast, the point estimates of the treatment effect after pre-matching, both with and without matched covariates included in the difference-in-differences regression, are never statistically distinguishable from results that are likely to be realized by random chance (blue lines). Thus, we find no evidence that land titling plus

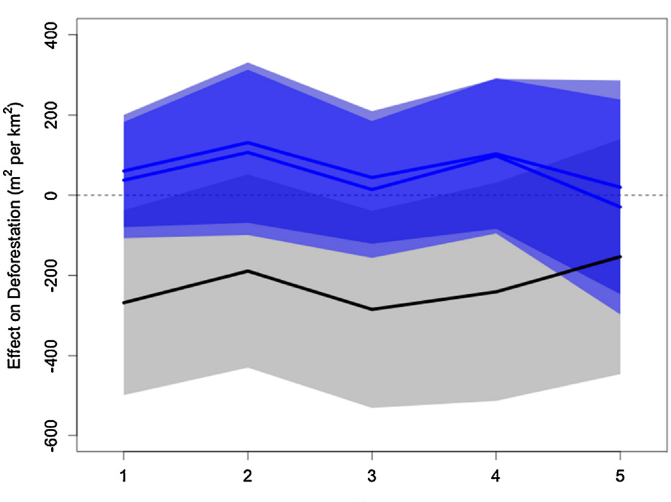

Fig. 5. PML-only effects on an annual basis following treatment. *Notes*: The black line/gray error bars are regression without pre-matching; the blue lines and error bars are regression estimates with pre-matching both with (dark blue) and without (light blue) covariates. The error bars show two standard errors. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

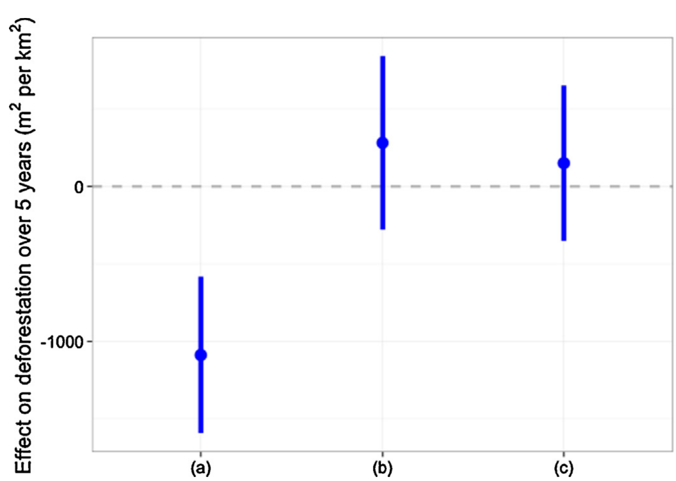

Fig. 6. Difference in differences over five years for PSUR plots with title and USAID-funded management plan versus non-PSUR plots with no title, 2002–2012. *Notes*: Figure shows treatment effect of PMI treatment for models as follows: (a) covariates, no pre-matching; (b) no covariates, pre-matching; (c) covariates, pre-matching.

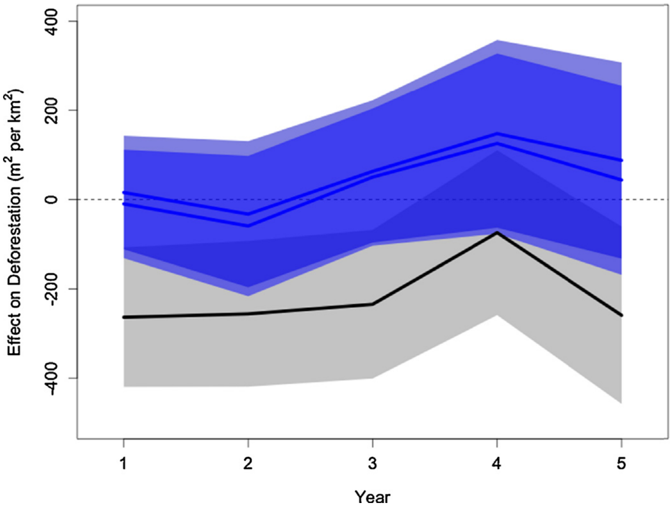

Fig. 7. Titling and PMI effects on an annual basis following treatment. *Notes*: The black line/gray error bars are regression without pre-matching; the blue lines and error bars are regression estimates with pre-matching both with (dark blue) and without (light blue) covariates. The error bars show two standard errors. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

community management planning reduces deforestation within five years of the intervention when comparing treatment areas to similar areas that remain untitled, either cumulatively over five years or annually.

In addition to these main results, we report a number of additional results and robustness checks in the Supporting Information. First, we report the balance statistics for the covariates used in the matching procedure for both the PML-only and PMI models (SI, Table B1). Next, we report results of the same empirical procedure reported above, but only for study plots that are inside Shuar lands as reported by the Nature Conservancy Ecuador (SI, Figs. B1–B4). Because some of the land titling occurred in areas that are not exclusively Shuar according other datasets, we restrict our analysis to areas where titling and other datasets agree about indigenous status. We also examine these results using EVI as the outcome variable (SI, Figs. B5 and B6). The main results do not change. We also tested for the possibility that legalization and management plans (PMIs) interact with protected status where they overlap, given that past research highlights interactions between land tenure types (Holland et al., 2014). We did not find an interaction in our sample and report only main effects in our main text and appendix results. Finally, we add a technical appendix that describes the derivations and sources of our covariates in greater detail (SI, Appendix D).

6. Discussion and conclusion

We find no evidence that land titling with or without management planning reduces deforestation in the five years following treatment for the PSUR program in Ecuador. This result is robust across different subsets of the data and at different periods of time following treatment. Our findings are some of the first evidence about the effects of land titling programs on forest cover that compare program areas to similar non-program areas. Our finding of a near zero effect has important implications for a number of research areas and policy decisions about land tenure programs being implemented around the world.

First, no previous research that we are aware of uses matching techniques to address the factors that are likely to confound the relationship between land titling and forest outcomes. This has left much of the research on land titling and land tenure programs on weak empirical footing (Robinson et al., 2014). The dangers of relying on simple regressions to estimate the effects of land tenure and community forest management on environmental outcomes are highlighted by our results. For both PML-only and PMI treatment plots, simple difference-in-difference regressions with control variables generate estimates that indicate reduced forest loss as a result of PSUR. These results are similar to other studies that do not address selection and collinearity in regression (e.g., Barsimantov and Kendall, 2012). The PSUR intervention in our study area is implemented in areas that already have lower background rates of deforestation as compared to non-program areas. Our results speak to the need in the empirical literature to take on selection and targeting challenges more directly.

Second, the literature on common property and the collective management of forests has been generally positive on the potential for secure land tenure to support customary, local institutions. The literature is filled with examples of community management institutions successfully managing land, especially when receiving formal recognition from the state (e.g., Bray et al., 2006; Ojha et al., 2009). Many of the most cited examples provide rich descriptive inference about the design and operation of community-level institutions, but do not necessarily contain explicit counterfactuals that allow for estimates of the impact of land tenure programs. By comparing titled plots with similar plots that do not have land title or forest management plans, we have contributed to a growing body of literature that considers land tenure and community management institutions based on comparative methods (see Agrawal, 2001). Since we do not find that land titling and forest management planning reduce forest loss as compared to similar plots outside intervention areas, our results suggest that scholars should base claims on explicit comparisons of areas and communities that differ on tenure status.

Third, development organizations are spending tens of millions of dollars each year on land titling programs to achieve conservation goals. Our results suggest this spending may be insufficient or perhaps even misguided if reducing the rate of forest loss is a primary goal of the program itself. These programs should carefully consider the effects of exclusion on colonization, time horizons, investment opportunities, and access to incentive schemes. The presence of *de facto* land tenure institutions has been reported in some areas of our study region, which may have promoted successful exclusion apart from formal land tenure through land title (Rudel, 1995). However, promoting “land security” in light of pressures from competing users was stated goal in PSUR documents (CARE, 2007).

As the global community scales up its support of land titling and land tenure interventions to achieve environmental and development goals, land titling programs need to be carefully considered for their connections to other processes and incentives. With opportunities for investment in agriculture expanding in many frontier areas, for example, land titling programs may actually accelerate changes in land use (Gray et al., 2008). Future research that connects land titling programs and formal incentive schemes for maintaining forest cover offers a promising direction. In particular, geospatial impact evaluations like ours combined with behavioral experiments and field surveys might be used to link incentives, institutions, and land use decisions to outcomes such as deforestation.

Fourth, we can only speak to effects that are realized in the years immediately after the PSUR intervention. Given that other parts of southeastern Ecuador have experienced deforestation as a result of colonization and less so extractive industry activity, it may be the case that the PSUR program will reduce deforestation as these processes approach the intervention areas. In a political climate where program impacts need to be immediate and large, the challenge of programming for long-term benefits is pronounced. We must be careful to reinforce that just because benefits on forest cover have not been realized to this point, we take no position on whether they will be realized over a longer period of time. We intend to follow this program over time, overcoming the challenge of measuring the long-term effects of policy interventions. Using remotely sensed data, we introduce the possibility of following the time path of policy effects with limited field presence and little additional cost. We expect that the use of remotely sensed data can have broad applicability to measuring the long-term impacts of agriculture, industrial development, aquaculture, and forestry policies. Thus, we advocate greater incorporation of these tools into the work of program evaluation.

Finally, we must recognize that our results speak only to the effects of land titling and forest planning on forest cover. It may be the case (or not) that the PSUR program had a large and positive effect on local livelihoods and income or on the ecological properties of forests that are not measurable by a categorical land conversion or degradation measured by leaf greenness. Our analysis cannot and does not intend to speak to these questions. Likewise, it is possible that land tenure programs will succeed in reducing forest loss in settings unlike those that we consider as part of this study, though we do believe our study offers a close to best case scenario. We cannot rule out this possibility until more evidence that takes selection effects seriously accumulates.

Many of the implementing partners that reviewed the results of this study emphasize that PSUR increased local and national capabilities related to land management. We recognize that these effects are more difficult to quantify. For example, local paralegals trained as part of PSUR continued their work in other areas and projects. Ecuadorian NGOs gained capacity to fill legal loopholes and advocate for the correction of ambiguous legislation. The sense among implementing organizations is that PSUR generated clarity in land rights generally, with spillover effects to subsequent programs. These claims, while intuitive and deeply held in the development community in Ecuador, would require very different study than we present here.

We offer an empirical analysis of a land titling program that explicitly addresses targeting, modeling assumptions, and collinearity between the intervention and other background characteristics due to spatial clustering. A recent review of the land tenure literature suggests that research progress will be based on the accumulation of results from research that takes these challenges seriously (Robinson et al., 2014). In providing a step in this direction, we hope to persuade the conservation and development community to improve the evaluation of land tenure interventions and consider the promise of these interventions to be testable hypotheses.

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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.2015.04.001.

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