Assessing the Role of Group Heterogeneity in Community Forest Concessions in Guatemala's Maya Biosphere Reserve

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ABSTRACT. *We use land use data from Guatemala to estimate the impact of a community forest concession policy on avoided deforestation when accounting for group heterogeneity. Our analysis includes communities with significant forestry experience, along with communities comprising recent settlers with primarily agricultural backgrounds. Employing a matched difference-in-differences approach, we compare deforestation in community concessions relative to a matched control area. We find the concession policy reduced deforestation throughout the study region, with the most significant effects in the recently settled concessions. While there is also evidence of leakage in this group, overall, there is a net reduction in deforestation.* (JEL Q57)

I. INTRODUCTION

The role for community management of publically owned forests, which comprise 80% of forestland throughout the world, has expanded in recent years, particularly in South America and Southeast Asia (Food and Agriculture Organization 2010). This move toward decentralization largely results from increased pressure on governments to acknowledge that many forest-based communities, especially indigenous groups, depend on local resources for their livelihoods. In addition, shifting management responsibility to community groups can reduce the burden on governments (both financially and administratively) of managing and protecting forestland (Agrawal, Chhatre, and Hardin 2008). Given the trend toward increasing areas under community forest management (CFM), along with the prominent role CFM plays in international climate negotiations through the United Nations program on Reducing Emissions from Deforestation and Forest Degradation (REDD), it is critical to better understand how community characteristics influence deforestation rates (Agrawal, Chhatre, and Hardin 2008; Larson and Soto 2008; Bowler et al. 2010; Phelps, Webb, and Agrawal 2010; Hayes and Persha 2010).

Typically, CFM involves granting some form of property rights (either formal or informal) to local communities as incentive for more sustainable resource management. This approach is especially compelling where an imbalance between expansive governmental claims on natural habitats and modest public expenditures on management and administration creates de facto open access. While the long-term, sustainable management of timber and nontimber forest product (NTFP) extraction likely serves in the best interest of the community members living in and around the forest, individuals have incentives to convert the land for short-term, personal gains at the expense of long-term sustainability. Through the assignment of shared property rights, CFM projects require communities to overcome these types of collective action problems. Numerous studies have assessed factors that influence successful collective action in forest settings (Ostrom 1990; Poteete and Ostrom 2004; Gautam and Shivakoti 2005; Alix-Garcia 2007), as well as the outcomes of various CFM projects to date (Bowler et al. 2012; Porter-Bolland et al. 2012). However, few

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studies have analyzed factors affecting the success of CFM, and those that have are often inconclusive or face limitations to their empirical estimation strategies, such as failing to control for selection bias (see Bowler et al. 2010 for further discussion).

Bray et al. (2008) observe that the case for CFM consists largely of "anecdotal evidence and case studies," many of which compare and contrast CFM and officially protected parks and reserves. In a survey of various conservation initiatives, Porter-Bolland et al. (2012) conclude that there is less deforestation where local communities have some form of property rights than in parks and reserves. In contrast, Nepstad et al. (2006) identified mixed outcomes in the Brazilian Amazon, finding less encroachment on natural habitats inside parks than in indigenous reserves. However, the parks they examined were also under less external pressure than the indigenous holdings, which typically are located in the vicinity of active agricultural frontiers. The same researchers found that, in the face of similar outside pressures, parks and indigenous lands were comparable in their capacity to restrict deforestation.

Additionally, most research on CFM to date has concentrated on long-term forest dwellers, including indigenous populations (see, e.g., Nelson, Harris, and Stone 2001; Gautam, Webb, and Eiumnoh 2002; Kumar 2002; Somanathan et al. 2009; Nelson and Chomitz 2011). One reason for this focus is that few CFM projects involve recent migrants, who likely have significantly less knowledge about forest management compared to long-established communities. This has resulted in a potential selection issue, where communities that are most likely to be successful in community-based forest management initiatives are also more likely to be chosen to participate in such projects (Bowler et al. 2010). Furthermore, when considering the broader potential of CFM, agricultural migrants cannot be ignored, since a large portion of forest loss in Africa, Asia, and Latin America is due to agricultural expansion (Barbier 2004; Gibbs et al. 2010). If recent migrants are unwilling or unable to engage in effective forest management, then CFM may ultimately provide limited protection for forests.

Of the many tropical and subtropical settings where CFM has been undertaken, the Maya Biosphere Reserve (MBR) in northern Guatemala is among a handful where groups of recent settlers have received land for forest management under a policy that created 12 community-based forest concessions. The legal framework for the policy does not vary across the concessions, but there is substantial variation among the participating communities (Maas and Cabrera 2008; Bray et al. 2008; Radachowsky et al. 2012). Some of these communities are made up of individuals whose families have been in the region for generations and who consequently are prepared to benefit from CFM. Other participating groups comprise recent settlers from outside the region with primarily agricultural backgrounds. These groups tend to have limited forest experience, though CFM appeals to them insofar as it is a route to land ownership. Additionally, some of the concessions dedicated to CFM have residents, while others do not, typically because they are remote and lack road access. Under these circumstances, a rare opportunity exists to examine how much CFM is influenced by the heterogeneous characteristics of the participating communities (Bray et al. 2008).

In this study we use land use data from the MBR to estimate the impact of the community forest concession policy on avoided deforestation for three categories of participating communities: long-term inhabitants, recent settlers, and nonresidents. We employ a matched difference-in-differences approach to compare deforestation in each of the three types of community concessions with forest loss in matched control areas that are made up of nearby habitats that are inside the reserve but are unmanaged. Comparisons are made both before and after the concessions were established to estimate the amount of avoided deforestation that can be attributed to the policy. A further contribution of this study is our analysis of leakage, which might occur if reduced deforestation inside community concessions can be linked to forest loss in adjacent areas not under management. To our knowledge, no existing CFM study addresses leakage. If CFM programs simply shift deforestation to regions that are not under management, either locally or through market prices, then the impact of CFM projects as a whole is undermined because overall deforestation rates are not reduced.

Based on our analysis, the community forest concession policy appeared to reduce deforestation in all three types of concessions, with the largest impact in the recently settled concessions. Leakage was insignificant in the nonresident and long-inhabited concessions; however, we find evidence of leakage in areas inhabited by more recent migrants. This is not surprising given that the majority of the inhabitants come from agricultural backgrounds and had little experience with forestry prior to moving to the MBR. These concessions have experienced significant challenges since their inception, and the deforestation rates over the period of analysis are higher in these regions relative to other areas in the reserve; however, our results suggest that the concession policy still significantly reduced deforestation compared to what would have happened in the absence of the policy. This result is meaningful since forests in areas where such migrants normally settle are also under greater threat of land use change. While leakage was detected in these concessions, the increased forest loss in surrounding areas that can be categorized as leakage is not enough to negate the larger reductions in deforestation attributed to the policy. Overall, we conclude that the community forest concessions were effective in reducing deforestation throughout the MBR, which suggests that this may be a promising approach to CFM for a variety of participants and is not limited to indigenous groups and other well-established forest communities.

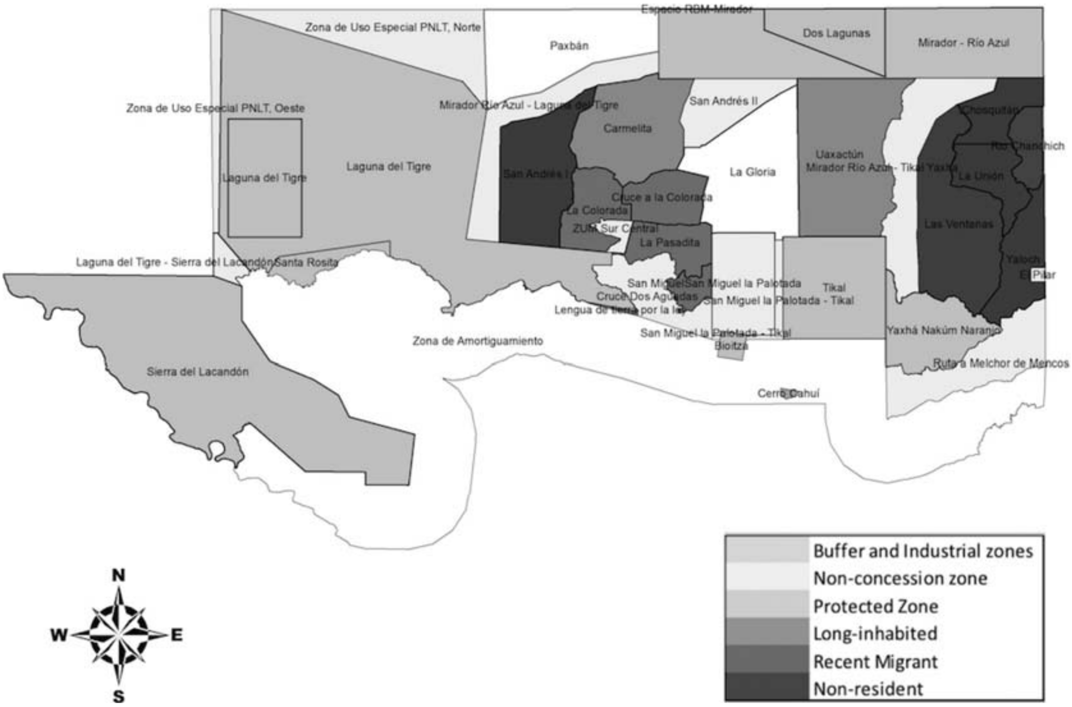
II. BACKGROUND

The MBR was established in the Petén lowlands of northern Guatemala in 1990 by the National Council of Protected Areas (CONAP) in response to wasteful logging, an encroaching agricultural frontier, and mounting threats to historical and cultural resources. Encompassing 2.1 million ha, the reserve is divided into three zones, each with its own environmental objectives and management strategies (Figure 1). The core zone, which accounts for 36% of the reserve, is strictly protected and includes national parks, biotopes (areas of uniform habitat), and Mayan ruins—most prominently, El Tikal National Park, which the U.N. Educational, Scientific, and Cultural Organization designated as a World Heritage Site in 1979. The remainder of the MBR is divided between a buffer zone (24% of the MBR), which separates the reserve from the rest of Guatemala farther south, and a multiple-use zone (40% of the MBR), which allows for sustainable resource extraction and is home to the community forest concessions (CONAP 1996; Nittler and Tschinkel 2005; Gómez and Méndez 2007).

While the MBR was established in 1990, the community concessions were introduced later due to pressure from both conservation groups that wanted to keep the forests out of the hands of private logging firms and local populations that wanted legal access to the reserve and its resources. Left unchecked, the forests within the multiple-use zone presented a collective action problem. Given the vast resources of the forests, local communities could manage the land collectively for long-term sustainability through the selective harvesting of high-value timber (primarily cedar and mahogany) and nontimber forest products (NTFPs) such as *chicle* (a natural ingredient in chewing gum) and *xate* (used in floral arrangements). There is ample evidence that forests in the MBR have long provided income for households living in the region (Schwartz 1990). However, new migrants with different skills, or even individuals within long-established communities, could also take advantage of insecure property rights and illegally clear the land for farming or cattle ranching to maximize short-term rents.

To address the collective action problem and to satisfy the interests of both the conservation groups and resident communities, a system was set up in which community associations worked with NGOs to create a sustainable forest management plan and an environmental impact evaluation, both of which had to be reviewed by CONAP (Nittler and Tschinkel 2005; Gómez and Méndez 2007). The management plans were based on extracting timber, for commercial purposes, from a selected area of the concession one year and

FIGURE 1
Zones and Concessions in the Maya Biosphere Reserve



then rotating to another section each subsequent year, allowing time for regrowth in the initial sections by the end of the contract period. Once the management plan and environmental evaluation were approved, CONAP granted the community property rights to a forest concession area for a renewable period of 25 years. Resource ownership was a key component of the policy since many of the more recently settled communities inside the MBR were concerned that they would be relocated (Radachowsky et al. 2012). The assignment of property rights to participating communities secured the forest area for member use and provided legal grounds for the groups to prevent outsiders from encroaching on the land (Nelson, Harris, and Stone 2001). In addition to providing property rights, the concession model provided a framework for communities to collectively benefit from the resources provided by the forest.

In 1994, a pilot concession, San Miguel, was established which was followed by the creation of 11 other concessions between 1997 and 2002 (Table 1). The staggered timing in the formation of the concessions was primarily due to administrative and technical limitations. It took several years to conduct the feasibility studies for the first concessions, which also had to coincide with assessments of the biological corridors within the reserve. Additionally, the availability of technical support staff assigned to work with the community groups was limited, which prolonged the approval process.

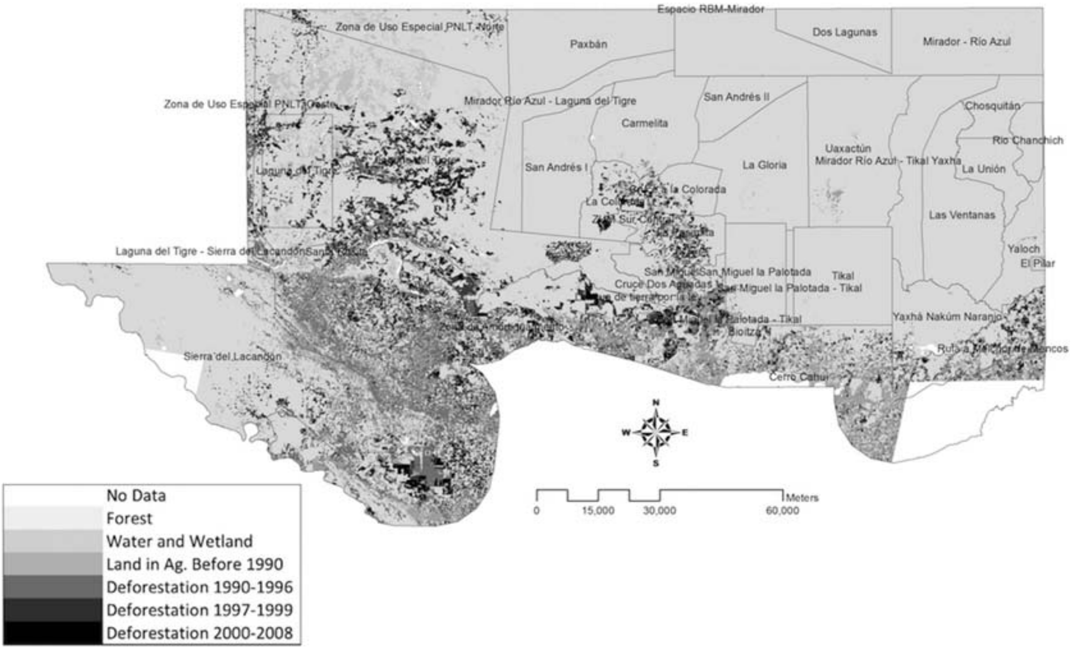
While the procedures for securing property rights to a forest concession area were uniform, the participating communities and their respective land holdings differ substantially (Bray et al. 2008; Maas and Cabrera 2008; Radachowsky et al. 2012). With respect to spatial and environmental characteristics, several of the concessions are remote, without road access, and are relatively farther away from villages and larger population centers. As has been observed in various parts of the world, remote forests are under less pressure for land use change (Pfaff 1999; Cropper,

TABLE 1
Overview of the Three Types of Community Forest Concessions

Concession Category	Concession Name	Year Formed	Number of Members	Concession Area (ha)
Resident, long-inhabited	Carmelita	1997	122	53,797
	Uaxactún	2000	244	83,558
Resident, recently settled	San Miguel	1994	30	7,039
	La Pasadita	1997	110	18,817
	La Colorada	2001	39	27,067
	Cruce a la Colorada	2001	65	20,469
Nonresident	Suchitecos (Río Chanchich)	1998	27	4,607
	Laborantes (Chosquitán)	2000	78	19,390
	San Andrés (AFISAP)	2000	174	51,940
	Arbol Verde (Las Ventanas)	2001	364	64,973
	El Esfuerzo (Yaloch)	2002	39	25,386
	Custosel (La Unión)	2002	96	21,176

Source: Data from Gómez and Méndez 2007.

FIGURE 2
Deforestation in the Maya Biosphere Reserve: 1990–2008



Puri, and Griffiths 2001; Man, Wu, and Deng 2013). In the MBR, areas lacking road access have had historically low deforestation rates (less than 1% per annum), thus even after concessions were established in such areas, the likelihood of forest loss remained small (Maas and Cabrera 2008; Radachowsky et al. 2012). In contrast, the central and western portions of the reserve are more easily accessible and consequently have experienced more settlement and economic activity, leading to greater environmental disturbance. As indicated in Figure 2, which displays patterns of land use from 1986 through 2008, deforestation has been particularly severe in the western reaches of the MBR, which has absorbed a large number of refugees during and since the civil war that Guatemala endured from 1960 to 1996, and more recently has become a route for international drug trafficking (McSweeney et al. 2014). General lawlessness and violence have impeded CONAP operations, including the creation of concessions, which exist only in the central and eastern regions of the MBR (Gómez and Méndez 2007; Radachowsky et al. 2012).

The communities themselves also have substantial differences, which likely influence their respective incentives for managing their concession holdings sustainably. Other research supports this hypothesis. For example, Alix-Garcia (2007) examined the impact of spatial and community characteristics on deforestation rates in communal land holdings in Mexico, commonly referred to as *ejidos,* and found that more educated communities had lower rates of deforestation. Other work by Alix-Garcia, Shapiro, and Sims (2012) found that Mexico's forest conservation program was more effective in reducing deforestation in areas with lower poverty levels. We hypothesize that given the large disparities in education and income among the concession communities that coincide with their respective backgrounds in primarily agricultural or forest-related activities, the incentives of each type of community group will vary based on these characteristics and thus need to be accounted for in the analysis. These differences among the concession communities are widely recognized in the literature on the MBR (Bray et al. 2008; Maas and Cabrera 2008; Radachowsky et al. 2012). In keeping with previous work, we categorize the concessions into the following three groups: nonresident, long-inhabited, and recently settled (Table 1).

The nonresident category comprises six concessions made up of members with various backgrounds in farming and forestry. The key distinguishing features of this group are that the members all live outside the concession boundaries and, on average, report higher income and education levels relative to the other two groups. Five of the six nonresident concessions are located in the more remote, eastern half of the reserve, which is mostly uninhabited. The members typically live in larger towns along major roads in the southern portion of the MBR and travel seasonally to and from the concession areas to extract timber, while often maintaining other jobs that provide their main source of income throughout the year. In a 2012 survey of 271 concession members (Fortmann 2014), participants of the nonresident concessions had the highest income and education of the three groups, and over half of the members surveyed reported having another job outside of farming or forestry as their primary occupation (Table 2). The main benefit from joining these concessions was that it allowed members to complement their primary earnings with income from the seasonal extraction of timber and other forest products, and in some cases members received significant dividend payments from concession profits. In addition to having the largest income on average among the three groups, these concession members also reported receiving the largest dividend payments from concession profits, providing further incentives for these members to collectively work together to keep their concessions in good standing.

We expect that leakage in these concessions would be minimal given the remoteness of the forest and the corresponding higher costs due to increased travel time, poor road access, and greater distance to markets. The members that are engaged in farming or ranching typically maintain landholdings outside of the concession areas in the southern portion of the reserve. Thus, there is little incentive for members of these nonresident communities to clear land within the concession boundaries.

One limitation in our analysis of the nonresident concessions is that they are both more remote *and* managed by communities with higher levels of education and income (relative to the other concession groups). These combined attributes predict that these concessions would experience the least forest disturbance; however, we are not able to establish the differential impacts of remoteness verses income and education.

The second group, long-inhabited, consists of two concessions, Uaxactún and Carmelita,

TABLE 2
Member Summary Statistics Separated by Concession Group

Variable	Nonresident	Long-Inhabited	Recently Settled
Age of head	49.6	47.8	51.0
Education of head (years)	5.0**	4.1**	2.5***
Born in Petén (percent)	52***	76***	29***
Daily food expenditures[a] (dollars)	11.87**	8.77	7.41
Annual income[a] (dollars)	7,928*	3,867*	2,413**
Own land (percent)	47***	76.8**	82**
Personal landholdings (ha)	13.8**	7.6**	48.8***
Dividend payment (2011 dollars)	350***	48***	0***
Farmer (percent)	34.2	37.1	86***
Forest job (percent)	7.9**	25.8***	1.7**
Other job (percent)	52.6**	35.5**	10.5***
Observations	152	62	57

Note: Concession membership ranged from 20 members to more than 300. Twenty to twenty-five percent of members were randomly selected for interviews.

[a] Income and food expenditures are converted from quetzales to dollars based on October 2012 exchange rates (when the survey was conducted), Q1.00 = $0.1253 (source: www.freecurrencyrates.com/exchange-rate-history/GTQ-USD/2012). Significant difference from the other two groups based on independent sample *t*-tests.

*Significant at 10%; ** significant at 5%; *** significant at 1%.

with members coming from *petenero* communities that have been established in the region since the early 1900s (Schwartz 1990). Given their history of harvesting timber and nontimber forest products (*chicle* in particular), the communities are largely dependent on the surrounding forest for their livelihoods and most closely represent the typical communities that are the focus of much of the previous research on CFM. While *chicle* collection peaked in the 1940s and has since dwindled (Schwartz 1990), a number of the residents in these communities currently are *xateros,* collecting *xate* as a primary source of household income. Additionally, the communities use the extensive tracts of forest that the concession policy has provided to earn additional income from ecotourism. All of these income-generating activities depend on the forest remaining intact, which provides additional incentives for the concession members not only to refrain from illegal land clearing, but also to monitor and enforce the rules among the local populations of members and nonmembers alike. While these two communities are located inside the concession boundaries, they are more remote than the recently settled concessions to the south. The close proximity in which they live, and isolation from other villages further enable enforcement of the concession policies. Uaxactún, in particular, is protected by Tikal National Park, where there is only one road from which to access the village and it runs directly through the park, with guards monitoring all transportation entering and exiting the park.

In a survey of members from long-inhabited concessions, 76% of the people reported being born in the Petén (Fortmann 2014). Among the three concession types, this group has the largest percentage of members that claim a forest-related job as their primary occupation (26%). A number of members also reported farming as their primary occupation (37%); however, this tends to be on land that was previously cleared and allocated to members for agricultural purposes when the concessions were first established. Given that these communities have existed within the Petén for multiple generations and have greater reliance on forest resources for their livelihood, they are more likely to successfully engage in collective action and thus have lower deforestation rates in their respective concession areas compared to groups with less forest experience (Baland and Platteau 2000, 255; Poteete and Ostrom 2004).

The four recently settled concessions, in contrast, are primarily comprised of individuals from agricultural backgrounds who were born in other parts of Guatemala and who continue to rely heavily on farming for their livelihood. These concessions are located in the central region of the reserve, and the members live inside the concession boundaries. Compared to the other two concession groups, surveyed members of recently settled concessions reported the lowest income and level of educational attainment, and farming was reported as the primary occupation for 86% of this group (Fortmann 2014). Moreover, members of these concessions are not entitled to dividend payments, since they were registered as nonprofit associations at the time of formation and are eligible only for in-kind benefit distributions (e.g., life insurance, scholarships). The nonresident and long-inhabited concessions, on the other hand, are allowed to distribute annual dividends to their members based on concession profits.

We suspect that the recently settled concessions are the most susceptible to leakage for a number of reasons. Relative to the other groups, these concessions are surrounded by a number of rural settlements populated primarily by migrants who are not participating in CFM and come from agrarian backgrounds, placing these concessions under considerable pressure for land clearing. Residents of these communities also have fewer outside options for alternative work, given their greater distance to towns and relatively low levels of education. Part of the concession contract includes forming vigilance committees that are responsible for monitoring the concession area and keeping out encroachers; this added enforcement may further result in shifting deforestation from inside the boundaries to surrounding areas not under the purview of concession management. Survey data indicate that members of the recently settled concessions have the largest private landholdings, with the members reporting 47.5 ha on average compared to the other two concession groups, which averaged 13.8 and 7.6 ha for the nonresident and long-inhabited members, respectively (Fortmann 2014), further suggesting that these communities have previously engaged in land-clearing activities and thus making these concessions more prone to leakage.

The recently settled concessions are further distinguished from the nonresident and long-inhabited groups in that the majority of these concessions formed under pressure from the government and NGOs. Many of the members were initially reluctant to join and did so only out of fear of being removed from the land they were currently settled on after the establishment of the reserve (Nittler and Tschinkel 2005; Radachowsky et al. 2012). This provides for a unique treatment group in which the members were not inclined toward forest management and thus there is not the potential for selection bias that may be present in the long-inhabited concession areas that would likely have lower deforestation rates regardless of concession status. Given the circumstances, it is not surprising that the recently settled concessions have struggled more than the other two groups; two concessions (San Miguel and La Colorada) were canceled as of 2009, and another (Cruce a la Colorada) has been under suspension (see Radachowsky et al. 2012 for more details).[1] The reluctance to form groups and lack of initial interest in forestry are a departure from many other CFM studies that focus on long-term, forest-dwelling communities. The addition of migrant communities in this study provides new analysis on how these types of groups will fair in future CFM programs and whether they can be effective in forest management and conservation initiatives.

To account for the differences among the concession communities in our assessment of CFM, we separate the concessions into the three categories described above, each comprising a different treatment group that is matched to a separate control group. The control areas consist of surrounding nonconcession forestland that is part of the multiple-use zone within the MBR but is not under a management plan. The core and buffer zones are not included in this analysis since they are under different management strategies and thus do not make a suitable control group for the concessions. In addition to the features we have highlighted, there are a number of other differences among the concessions, including

[1] In La Colorada, a number of the members illegally sold their land to cattle ranchers and fled the area. In 2008, a large area of clear-cut forest was discovered and the concession was canceled shortly thereafter (Radachowsky et al. 2012; Wildlife Conservation Society 2013).

size of membership and landholdings, profit distribution (based on whether they are a for-profit or nonprofit association), and level of engagement in NTFP collection. While many of these community characteristics are of interest in determining the success of the concessions and the role of community heterogeneity, we are unable to account for these differences in the analysis, since the characteristics are not isolated to one type of concession group (Table 1).

III. DATA

Land use data for this study come from satellite imagery of the MBR compiled by the Center of Monitoring and Evaluation (CEMEC) under CONAP.[2] CEMEC classified the images into various land uses at 30 m resolution. The data format is similar to that of survival (or hazard) data. Each 30 $\times$ 30 m pixel is coded as "forest" if it remained forested from 1986 through 2008. If at some point it was determined that the parcel of land experienced forest disturbance, based on satellite images, that pixel is coded based on the year the disturbance took place. Thus, reforestation of a parcel in later periods is not accounted for in the data set. A further limitation is that we are not able to ascertain the density or quality of the forest area, only whether a parcel is considered forested or not (see Sader et al. 2001 for more details). As a result, the dependent variable of interest is binary, equal to 1 if the pixel of land was deforested during a given time period, 0 otherwise. Due to the large number of observations in the study area, we randomly selected 100,000 observations from each type of concession area to create three separate treatment groups. The corresponding control groups comprised 200,000 randomly selected observations from the surrounding areas in the multiple-use zone that were not under concession management or part of the core or buffer zones.[3]

Environmental covariates used to match observations between the concession areas and the control areas include elevation, slope, soil acidity (pH), and aspect. The slope and elevation measures come from digital elevation models (DEM) created by Guatemala's Ministry of Agriculture, Livestock, and Food and are analyzed using ArcGIS (ESRI 2011). Data on distances to roads and settlements (established prior to 1990 when the reserve was formed) were obtained from the National Institute of Statistics. Spatial covariates used in the analysis include distances to the nearest road, pixel of land cleared prior to 1990, archeological site, major town, and medium-sized village. Major towns are defined as having a population over 10,000 people.[4] Medium-sized villages are defined as having a population greater than 200 people or existing within the reserve prior to its establishment in 1990 (Grunberg and Hugo 1998).[5] These villages are included in the analysis separately from towns since populations in smaller settlements are more likely to be involved in subsistence agriculture and have different incentives for land clearing. Distance to the nearest major town serves as a proxy for transportation costs and distance to markets and is more likely to influence land use change on a commercial scale. To account for regional differences in the reserve (discussed in the background section), a dummy variable is included in the matching models based on whether the observed parcel is in the eastern or western half of the reserve. For the four recently settled concessions, only observations in the western half of the multiple-use zone are included in the control group since all of the concessions are located in this region.

Given that the primary unit of observation is a parcel of land and whether it was deforested or not, our analysis is driven by envi-

[2] All of the data used in this analysis originated from the National Institute of Statistics and the Ministry of Agriculture and were complied by CEMEC. The data are available upon request from the authors and CEMEC.

[3] The total dataset including all observations in the concession and nonconcession areas of the multiple-use zone contains 10,557,972 observations.

[4] There are four towns in the Petén that meet this requirement: Flores, San Benito, Melchor de Mencos, and Poptun. However Poptun is located farther away from the reserve than the others, so no parcel of land included in the analysis is closer to this town than compared to the other major towns.

[5] Medium-sized villages within the reserve prior to 1990 are based on a census report by Grunberg (1998) and correspondence with Dr. Norman Schwartz, an anthropologist and scholar of the Petén.

TABLE 3
Comparison of Summary Statistics for Three Forest Concession Groups

Variable	Nonresident	Long-Inhabited	Recently Settled
Road distance (km)	21.4	8.8	6.6
Slope (degrees)	3.7	3.5	5.0
Elevation (meters)	194	226	230
Cleared distance[a] (kilometers)	9.4	5.7	1.6
City distance (kilometers)	49.5	69.5	51.6
pH	6.8	7.1	7.3
Archeo distance[b] (kilometers)	21.4	16.4	22.7
Aspect (degrees)	175	159	185
Village distance (kilometers)	25.3	13.1	5.1

Note: Data are from remote sensing satellite images. Observations are based on 30 m × 30 m parcels of land. See Data section for more details. All of the variables for each concession group are significantly different from the other groups at the 99% level for all covariates.
[a] Cleared distance is the distance to the nearest pixel of land cleared prior to 1990.
[b] Archeo distance is the distance to the nearest Mayan archeological site in the reserve.

ronmental and spatial covariates. The limitation of using spatial variables for matching as a proxy for differences in the concession groups is that each treatment parcel is influenced by the characteristics of its respective type of concession community. The control areas, however, do not account for these differences among the communities, which might affect land use outside the concession boundaries. While we cannot directly control for community variation in the control regions, we believe that many of the important differences are captured by the spatial variables (Table 3). For example, the distinction between the three types of concessions is evident when looking at the average distance to the nearest road and village in the nonresident concessions (21 km and 25 km, respectively) compared to the long-inhabited (9 km and 13 km) and recently settled concessions (7 km and 5 km). The greater distance to roads and villages in the nonresident concessions reflects the remoteness of the land and higher costs of land clearing. These characteristics are captured by this distance variable when finding a suitable matched parcel in the control group. Additionally, the covariate for distance to the nearest land clearing (prior to 1990) further highlights how the spatial characteristics of the parcels reflect differences among the concession communities. In the recently settled concessions, the nearest clearing is 1.6 km away on average, compared to 5.7 km and 9.7 km in the long-inhabited and nonresident concessions, respectively. Thus, when observations in the recently settled concessions are matched to control areas, parcels that are closer to land clearings are also likely to be closer in proximity to other, recently settled communities located in the MBR.[6]

The main limitation that we see in the matching process is the comparison between the long-inhabited concessions and their matched control group, since the surrounding control areas are mostly inhabited by recent settlements and there are no similar forest-dwelling communities without concessions to draw comparisons. For these long-standing concessions, we hypothesize that the pressure for land conversion is reduced, since these communities have been relying on forest resources for multiple generations. So, comparing these communities with control areas that are mostly inhabited by recent migrants will overestimate the effectiveness of the concession policy, since treated areas are less likely to experience deforestation compared to their matched control areas. While this is a concern, we believe that the main group of interest in our study is the recently settled concessions, since little research has been done on how these types of communities would fare in CFM projects. The majority of settlements in the control areas are made up of recent migrants who moved to the region in search of land for farming and ranching and have many

[6] The distance to the nearest clearing is based on cleared areas prior to 1990, before the reserve was established.

similarities to the recently settled concession communities. Therefore, we expect that the unobservables due to community influence are similar in both the treatment and control groups. Regarding the nonresident category, since these concession areas are remote and there are very few settlements in the eastern half of the reserve outside of the main town (Melchor de Mencos) where the majority of the population lives, the unobservables for both the treatment and control areas are likely to be similar after controlling for remoteness and location,

Finally, without baseline survey data, we cannot control for changes in the communities that may have occurred due to the policy. However, we believe that it is unlikely that the defining characteristics of the three community types, such as forest experience or migrant status, changed significantly between the formation of the concessions and the time the survey took place. Thus, we assume that the key differences among the concession communities are time invariant over the period of analysis.

IV. METHODS

We use a matched difference-in-differences (DID) approach to assess the effectiveness of the three different concession communities on avoided deforestation in the MBR. The final data sets used in the postmatching regression analysis are based on nearest-neighbor matching with Mahalanobis distance metrics and calipers to limit poor matches (Guo and Fraser 2010, 147; Ho et al. 2007, 2011; Arriagada et al. 2012).

Approach to Matching

The first part of the analysis involves matching treatment group observations from each of the three forest concession areas with control observations from the nonconcession areas. The objective is to create a control group of observations that resembles the treatment group to estimate how much deforestation would have taken place in the absence of the concession policy. Matching methods are based on the assumption that all of the factors that affect selection into the treatment group are observable and controlled for in the matching process; this is often referred to as selection on observables or the conditional independence assumption (Guo and Fraser 2009). Failure to take into account differences between the two groups may lead to biased estimates of the treatment effect. The second necessary requirement for estimating causal effects is referred to as the stable unit treatment value assumption (SUTVA), which requires that the treatment of one unit does not impact the outcome of other units. To satisfy the SUTVA, the selection of forests into concession management would have to have no impact on deforestation in surrounding, nonconcession areas, which make up the control units in this case. This may not be true if leakage is an issue, which occurs if increased management in one area results in deforestation shifting to nonprotected areas. Given that leakage is a concern, our sensitivity analysis includes estimates of spillover (increased deforestation) after the policy was implemented in nearby buffer areas surrounding the concession boundaries.

In the case of the MBR, we believe the results would potentially be affected if we did not account for differences among the three types of concessions (i.e., treat all the concessions the same), since the heterogeneous community characteristics likely lead to variation in the effectiveness of the concession policy across participating groups. To address this possibility, we matched each of the three groups separately under the assumption that differences in the types of communities applying for concessions and the spatial characteristics of the forest area will also influence the ability of each group to manage the land and successfully engage in collective action.

Following Ho et al. (2007), we focus on nearest-neighbor matching, which allows for postregression analysis with the matched data sets (Guo and Fraser 2009). The final samples used in the DID analysis are matched based on nearest-neighbor propensity score matching with Mahalanobis distance metrics. Propensity scores are estimated with a logit model that predicts the probability of treatment (being selected into one of the three concession areas) based on a set of environmental and spatial covariates (see Appendix Table A1 for logit results). The propensity score is used to narrow down the range of possible matches between the treatment and control observations. For each treatment observation, only control observations that have propensity scores within a quarter of a standard deviation of the treatment observation's score (caliper = 0.25) are eligible for matching. After the potential control observations are narrowed down, they are matched to the treatment observation with the smallest distance metric based on a vector of covariates (see Guo and Fraser 2009 for further details).[7] Balance is assessed by measuring the difference in means between the treatment and control groups for each covariate and the median difference in the quantile-quantile (QQ) plots between groups, where zero indicates that the empirical distributions are the same for each covariate (Ho et al. 2011) See Appendix Table A2 for results on balance between matched treatment and control groups for each concession type.

Difference-in-Differences

After matching the data, we conduct DID regression analysis with two cross-sections of the matched data to estimate the average treatment effect on the treated (ATT) observations, which is defined here as the expected difference in deforestation in forest areas under community concession management compared to the deforestation that would have taken place had there been no concession policy. The DID model compares differences in the outcome variable between the treatment and control groups before and after the policy was implemented. The regression equation can be written as

$$y_{it} = \beta_0 + \beta_1 Treat_{it} + \beta_2 Post_{it} + \beta_3 Treat_{it} \times Post_{it} + \beta_4 X_{it} + \varepsilon_{it},$$

where y is a binary dependent variable equal to 1 if the parcel was deforested in a given period, i indexes the observed parcel of forest area, and t indexes the time period, 0 before the concessions, or 1 after the concessions were established. The coefficient of interest is b_3, the DID estimate, which can be interpreted as the impact of the concession policy on avoided deforestation.

An advantage of using DID is that the method controls for unobservable, time-invariant factors that might affect the outcome of interest and selection into the treatment group. However, this method rests on the parallel trends assumption, which requires that the trends in deforestation for treatment and control group areas would have been similar if the policy had never been implemented (Wooldridge 2002). To test this assumption we reformat the data to represent a panel that includes three periods of observation for each parcel before the concession policy was in place and the concessions were actively managing the forest, from 1990 to 1997.[8] We then compare differences in deforestation in the control group with treated concession areas before the policy was implemented using interaction variables ($Control \times Time\_period$) that can be interpreted as the difference in deforestation between the treatment and control groups prior to the concession policy. If there were no differences in deforestation trends, we would expect the interaction variables to be statistically insignificant, which is what we find for all three types of concessions (see Appendix Table A3 for results).

For the DID estimation, the prepolicy time period used for this analysis is 1990 to 1997, after the reserve was created but before the community groups were actively managing their concession areas. The first pilot concession (San Miguel) formed in 1994, which overlaps with the prepolicy period; however, given the relatively smaller size of the concession area compared to the other recently settled concessions, we believe that the overlap in time does not have a significant impact

[7] Mahalanobis distance metric is measured as $D(i,j) = (\mathbf{u} - \mathbf{v})^T \mathbf{C}^{-1} (\mathbf{u} - \mathbf{v})$, where i and j are treatment and control observations, respectively, and **u** and **v** are vectors of covariates for the treatment and control observation. **C** is the sample covariance matrix (Guo and Fraser 2010).

[8] Panel data format is based on periods where deforestation was observed. There are three preconcession periods: 1990–1993, 1993–1995, and 1995–1997. Each pixel was coded as 1 if it experience deforestation during that period, and then remained 1 for all subsequent periods.

on the results.[9] The postpolicy period varies slightly based on the concession group. For the nonresident concessions the postpolicy period is 2002 to 2008, so the analysis does not include the interim years when the concessions were being formed. For the long-inhabited concessions the postpolicy period is 2000 to 2008, since Carmelita and Uaxactún were both established as of 2000. For the recently settled concessions the postpolicy period is 2001 to 2008.[10]

For the main regression analyses, we use a linear probability model, since the dependent variable is binary, equal to 1 if the parcel of land was deforested in the period of analysis. The results include standard errors clustered on regional management boundaries to control for potential spatial correlation among observations. We also conduct a number of other robustness tests discussed in the results section that follows.

V. RESULTS

The results indicate that the concession policy reduced deforestation in all three types of community concession areas relative to what would have occurred had the policy not been implemented. The results are robust to tests for unobserved bias using Rosenbaum's bounds (Rosenbaum 2002). Given that we detect leakage in the recently settled concessions, to control for the impact of the concession policy on nearby forest areas we report two sets of results. Column (2) includes the entire matched control group and column (3) excludes control observations inside the 2 km buffer area surrounding the forest concession boundaries.[11] The results from both models are similar in magnitude, and the statistical significance is improved when the 2 km buffer observations are excluded.

Referring to the results from column (3), all three types of concessions experienced less deforestation compared to their control areas. The nonresident concessions had the smallest effect, with a 4.3% reduction. This is not surprising given that these areas had the lowest deforestation rates even prior to the concessions forming. The long-inhabited concessions reduced deforestation by about 6.4% compared to the matched control group, and the recently settled concessions reduced deforestation by approximately 7.7%. Table 4 presents the DID results with clustered standard errors, though some limitations on the clusters should be noted. Clustered standard errors ideally control for correlation in the error terms and reduce the reliance on the assumption of the errors being identically and independently distributed. However, given the data set, the best available variable on which to cluster the errors is based on regional management boundaries (concessions, biological corridors, national parks, etc.; see Figure 2), which cover large tracts of land that have significant spatial variation and provide a limited number of clusters (25 when including all concessions and control areas).

We use the DID results to estimate the area of avoided deforestation that can be attributed to the concession policy for each type of concession. The long-inhabited concessions cover approximately 133,576 ha of forest, and the resulting avoided deforestation is estimated to be 8,548 ha. In the nonresident concessions, avoided deforestation amounts to approximately 8,348 ha (based on 194,157 total ha), and 4,955 ha in the recently settled concessions (out of 64,361 total ha).

As a further robustness check for the DID results, we also compare differences in mean deforestation rates between the matched treatment and control groups (ATT) before and after the concession policy was established using data matched with kernel and bias-corrected matching estimators (Abadie and Imbens 2002).[12] The results are comparable with

[9] We believe the inclusion of a concession in the latter years of the prepolicy period would result in lower deforestation rates in the "pre-" period, which would bias the results downward, underestimating the impact of the concession policy. In our analysis we also run a model without San Miguel and the results do not change appreciably.

[10] San Miguel was canceled in 2007; however, the deforestation data is recorded in two-year increments to show deforestation during the period of 2007 to 2008, so our analysis extends to the end of 2008 for the recently settled concessions.

[11] We exclude only the 2 km buffer and not the 5 or 10 km buffer areas since those results are inconclusive regarding leakage.

[12] Smaller sample sizes (50,000 rather than 300,000) are

TABLE 4
Results of Difference-in-Differences (DID) and Probit Marginal Effects (ME)

	Unmatched (1)		Matched[a] (2)		Matched without 2 km Buffer (3)	
Model	Coeff.	Clustered Std. Err.	Coeff.	Clustered Std. Err.	Coeff.	Clustered Std. Err.
All Groups						
DID	− 0.02	0.024	− 0.042	0.038	− 0.046	0.037
Probit ME	0.022**	0.011	0.004	0.008	0.0098	0.009
Observations	295,001		169,666		134,192	
R-squared	0.12		0.15		0.14	
Nonresident						
DID	− 0.04**	0.02	− 0.033	0.02	− 0.043**	0.02
Probit ME	0.003	0.02	− 0.014**	0.007	− 0.014*	0.007
Observations	293,248		90,190		73,159	
R-squared	0.13		0.47		0.098	
Long-inhabited						
DID	− 0.043**	0.02	− 0.050*	0.028	− 0.064*	0.033
Probit ME	− 0.018	0.013	− 0.022**	0.011	− 0.024**	0.012
Observations	294,679		94,204		84,471	
R-squared	0.13		0.11		0.12	
Recently settled						
DID	0.026	0.022	− 0.078*	0.047	− 0.077***	0.019
Probit ME	− 0.001	0.013	− 0.040**	0.016	− 0.015	0.014
Observations	296,262		43,116		25,682	
R-squared	0.08		0.25		0.065	

Note: Standard errors are clustered at the "concession" region level with 25 clusters for "all groups" and 17 clusters in the subgroups.
[a] Matched samples are based on nearest-neighbor propensity score matching with Mahalanobis distance metric with calipers set to 0.25 standard deviations taken from the sample with 300,000 observations. Results based on a linear probability model where the dependent variable equals 1 if pixel is deforested, 0 otherwise.
*Significant at 10%; ** significant at 5%; *** significant at 1%.

the DID results (Table 5). Kernel matching estimates indicate that deforestation was reduced across all three types of concessions, with a 7.8% reduction in the recently settled concessions (compared to a 7.7% reduction using the DID estimates). Results from the bias-corrected matching show that the recently settled concessions reduced deforestation by 8.4%, and the long-inhabited concessions reduced deforestation by 8.5% (results for the nonresident concessions are not significant). These results are also robust to unobserved or "hidden" bias; see Appendix Table A4 for results and discussion on robustness tests (Rosenbaum 2002; Becker and Caliendo 2007).

As a final robustness check we transform the data to a panel format, similar to the parallel trends analysis, and test DID including a time trend (see Appendix Table A5 for results). The results do not change substantially, and in all cases, the estimated treatment effects for the concessions are negative, further supporting the conclusion that the concession policy reduced deforestation in all three categories of concessions.

used for these matching estimators due to the computational complexity of the matching process.

Leakage Analysis

We test for leakage that would occur if the concession policy resulted in deforestation shifting from inside concessions to areas outside their boundaries. If such negative spillovers occur, then the estimates of avoided deforestation, based on the results from Table 4, will be upward biased. Positive spillovers could occur, as well, if the implementation of the concession policy and improved forest management discourages deforestation out-

TABLE 5
Average Treatment Effect on the Treated (ATT) Results for Kernel and Bias-Corrected Matching Estimators

		Unmatched		Kernel		Bias-Corrected	
Concession Group	Time Period	ATT	Std. Err.	ATT	Std. Err.	ATT	Std. Err.
Nonresident	Pre	− 0.036	0.002	− 0.0028	0.004	− 0.013	0.0006
	Post	− 0.070	0.003	− 0.025	0.009	− 0.015	0.004
	Difference	− 0.034***	0.004	− 0.022**	0.010	− 0.0015	0.004
Long-inhabited	Pre	− 0.036	0.002	− 0.041	0.009	0.0080	0.004
	Post	− 0.068	0.003	− 0.144	0.011	− 0.077	0.009
	Difference	− 0.032***	0.004	− 0.103**	0.014	− 0.085***	0.010
Recently settled	Pre	− 0.019	0.002	0.013	0.02	0.038	0.002
	Post	0.068	0.004	− 0.065	0.034	− 0.046	0.020
	Difference	0.087***	0.004	− 0.078**	0.039	− 0.084***	0.020

Note: Kernel matching performed in Stata Version 12 with "psmatch2" using clustered standard errors. Bias-corrected performed in Stata using the "nnmatch" command. The number of observations for each sample varies but is based on 50,000 total observations in the unmatched sample, then split up into 25,000 each for pre and post samples. The standard errors for kernel results do not take into account estimated propensity scores, but we choose not to bootstrap given the potential for errors (see Abadie et al. 2004; Abadie and Imbens 2006), since these are robustness checks. The bias-corrected ATT estimates do not include clustered standard errors.
*Significant at 10%; ** significant at 5%; *** significant at 1%.

side of the concession boundaries. Following the approach of Andam et al. (2008), we estimate leakage from the community concessions by creating buffer areas around the outside boundaries of the three concession areas (2 km, 5 km, and 10 km) and then match randomly selected observations from within the buffer areas to observations outside the buffers, farther away from the concession borders.[13]

Leakage is estimated based on the coefficient for a buffer dummy variable, which indicates if an observation is within the designated buffer area in the postconcession policy period. We estimate the model with ordinary least squares including the full set of environmental and spatial covariates (Table 3). A positive buffer coefficient indicates that leakage may have occurred, since observations in the buffer zones had higher rates of deforestation compared to matched observations farther away from the concessions. This approach captures leakage due to local residents involved in smaller-scale agriculture or ranching. If the presence of the concessions discouraged large landowners and cattle ranchers from settling near concession boundaries, but they moved elsewhere in the region and deforested outside the buffer areas, then this method would underestimate the total amount of leakage taking place due to the concession policy.[14]

We find that leakage primarily occurred near concessions managed by recent migrants. The results for these concessions indicate that leakage varied across buffer distances, with areas closer to the concession boundaries experiencing more deforestation than areas farther away. Deforestation inside the 2 km buffer surrounding the recently settled concessions was 13% higher compared to matched control areas outside the buffer region. In the 5 km and 10 km buffer areas, the magnitude and sign (positive or negative) of leakage varies, thus the extent of the leakage outside of the recently settled concessions beyond the 2 km buffer is not clear (Table 6). Leakage estimates in the other two concession groups for all three buffer distances are, for the most part, negative (indicating positive spillovers) or not significant (Appendix Table A6).

The presence of leakage in areas surrounding the recently settled concessions is not surprising. We would expect to see leakage in

[13] Andam et al. (2008) matched unprotected forest plots within a 2 km buffer surrounding the protected area (treatment) with unprotected plots beyond the 2 km radius (control) and compared deforestation in the two areas to test whether there were any spillover effects due to the designation of protected area status in Costa Rica.

[14] Our model estimates leakage only from activity shifting and not market-based leakage that would occur if the size of the projects changes any prices (we assume prices are exogenous). Other studies that estimate market leakage include those by Murray, McCarl, and Lee (2004) and Sohngen and Brown (2004).

TABLE 6
Leakage Estimates for Buffer for Recently Settled Concessions

	2 km Buffer		5 km Buffer		10 km Buffer	
Model	Unmatched	Matched	Unmatched	Matched	Unmatched	Matched
OLS	0.089	0.145	0.078	− 0.057	0.057	0.039
Robust Std. Err.	(0.004)***	(0.008)***	(0.003)***	(0.009)***	(0.004)***	(0.014)***
Clustered Std. Err.	(0.031)***	(0.003)***	(0.027)***	(0.005)***	(–0.054)	(0.055)
Kernel	—	0.068***	—	− 0.13***	—	− 0.0004
Std. Err.	—	(0.018)	—	(0.013)	—	(0.036)
Observations	96,899	7,230	97,756	5,582	98,014	5,004
R-squared	0.19	0.28	0.16	0.29	0.15	0.17

Note: Matched results are based on nearest-neighbor matching without replacement with Malahanobis distance metrics. Matching was done in *R* using "MatchIt" (Ho et al. 2011). Kernel results are from Stata Version 12 using "psmatch2." Standard errors are in parentheses. Dependent variable is binary, equal to 1 if observation is within the designated buffer zone. OLS, ordinary least squares.
*Significant at 10%; ** significant at 5%; *** significant at 1%. Significance designations based on clustered standard errors.

this area in particular for a number of reasons. The recently settled concessions are located in a more densely populated area of the reserve, which includes a number of settlements that are not a part of the community forest concessions. The majority of these settlements comprise more recent migrants that come from farming backgrounds, and as a result, the main source of deforestation in this area is due to land clearing for subsistence farming and cattle ranching. Furthermore, the local populations in this region have few alternatives to farming since they do not have backgrounds in forestry and live inside the reserve, farther away from towns and cities that would provide alternative employment opportunities. Residents in these communities also are less educated, further limiting their options for work outside of agriculture. In a survey of both recently settled concession members and neighboring nonmembers, participants from this region of the reserve reported the lowest educational achievement levels (2.6 years of schooling on average for the head of household) relative to survey participants in the nonresident and long-inhabited communities (5.1 and 4.1 years, respectively).

Despite the negative spillovers, we still find that overall, the concession policy reduced deforestation. Taking into consideration the increased amount of deforestation in the 2 km buffer area that we attribute to leakage, we calculate that avoided deforestation amounts to 3,233 ha in the recently settled concessions (compared to 4,955 ha in gross). Other studies estimating leakage surrounding protected areas or land enrolled in payment for ecosystem services programs found minimal leakage that was, if anything, positive. (Andam et al. 2008; Honey-Roses, Bayliss, and Ramírez 2011). The only study, to our knowledge, that finds evidence of negative leakage is by Alix-Garcia, Shapiro, and Sims (2012). The authors examined slippage due to farmer enrollment in a payment for ecosystem services program in Mexico that compensates farmers who conserve forestland. They found that in more remote areas with high program enrollment and low road density, deforestation is higher in buffer areas surrounding enrolled land compared to areas that are less remote and have better access to markets. These results parallel our findings, where leakage is greater in areas where the residents live farther away from markets and have few alternatives to farming. Among other studies that examine community-managed forests, none address leakage in their analyses (Nelson and Chomitz 2011; Somanathan et al. 2009; Bowler et al. 2010)

VI. CONCLUSION

The majority of the literature on CFM has been focused on indigenous or long-standing communities of forest dwellers. Given that these communities are more willing to engage in CFM projects, a selection bias problem arises, since they are also more likely to be successful given their background and dependence on forest resources (Bowler et al. 2010). The MBR presents a unique situation where multiple types of communities have been granted property rights to forest concession areas, including long-time forest dwellers, as well as more recent migrants with primarily agricultural backgrounds. This allows us to compare the two types of groups and their relative effectiveness in reducing deforestation. The third group of nonresident concession communities experienced the least amount of deforestation, both before and after the concession policy was implemented. This follows previous research, which mainly finds that remote, uninhabited forests experience lower deforestation rates compared to ones with settlements (Nepstad et al. 2006; Joppa, Loarie, and Pimm 2008).

The members of the nonresident concessions come from mixed backgrounds, some with prior forest experience, others without. They are also distinguished from the other two community types by their relatively higher levels of education and income (Fortmann 2014). This further supports previous research that deforestation rates are lower in communities with more educated and wealthier populations (Alix-Garcia 2007; Alix-Garcia, Shapiro, and Sims 2012). Our findings indicate that allowing nonresident community concessions access to remote forests for the purpose of harvesting timber and NTFPs does not lead to increased deforestation in uninhabited reserves, but it does provide an alternative source of income generation for local communities. However, this may be contingent on these communities also having alternative employment opportunities outside of agriculture and/or separate landholdings set aside for farming, as the nonresident communities in this study do, which reduces their incentives to illegally harvest timber.

The main group of interest in our study is the recently settled concessions. These communities primarily comprise migrants who where displaced from their previous landholdings due to the civil war in Guatemala, or moved to the MBR in search of land for farming (Schwartz 1990). We find that despite their lack of forestry experience, and in some cases, initial reluctance to join a community forest group, the forest areas under concession management by these communities still fared better than the matched control areas in terms of avoided deforestation, as predicted, though these concessions also experienced leakage in areas adjacent to the concession boundaries (whereas the other two types of concessions had minimal or positive spillover). The estimated leakage was not enough to negate the avoided deforestation attributed to the concession policy though, so overall, we find net avoided deforestation in the recently settled concessions. These findings have broader policy implications considering that a significant portion of tropical deforestation taking place is happening at the agricultural frontier. While on the whole, these areas experienced higher rates of deforestation than other areas in the reserve, our results suggest that deforestation would have been significantly higher in the absence of the concession policy. The long-term viability of these concessions, however, is still in question. These communities have experienced more conflict and have ultimately struggled with concession management more than the two other types of community groups, with two concessions being canceled and another under suspension. Given the location of these concessions, there was a host of internal and external factors that likely contributed to this outcome, including corruption within the organizations and external pressure from outside actors that resulted in land grabbing and illegal land clearing for cattle ranches (Nittler and Tschinkel 2005; Wildlife Conservation Society 2013). Also, the historically weak governance of CONAP likely contributed to the termination of these concessions, where illegal activities within the MBR have long gone unchecked and unpunished (see Radachowsky et al. 2012 for more details). On the whole, our evidence suggests that the agricultural migrant–based concessions did achieve some success with reducing deforestation, though more research will need to be conducted to develop a longer-term, sustainable model for these groups. On the other hand, in the two other types of concessions, we find that both groups were able to reduce deforestation with no signs of leakage, suggesting that the community concession model can be effective in similar settings of uninhabited reserves and the more traditional, long-term forest dwelling populations.

APPENDIX

Test for Unobserved Bias

TABLE A1
Logit Results from Estimating Propensity Scores for Matching

	Nonresident		Long-Inhabited		Recently Inhabited	
Variable	Odds Ratio	Clustered Std. Err.	Odds Ratio	Clustered Std. Err.	Odds Ratio	Clustered Std. Err.
Distance to road	1.41	0.209**	0.83	0.13	2.13	0.56***
Distance to road^2	1.00	0.005	0.99	0.005	0.97	0.008***
Distance to major city	0.91	0.076	4.74	1.44***	2.34	0.745***
Distance to major city^2	1.00	0.0006	0.99	0.002***	1.00	0.004
Elevation	1.00	0.0045	1.03	0.009***	1.02	0.008***
Slope (degrees)	1.05	0.02***	1.04	0.016**	1.06	0.015***
Distance to cleared parcel	2.08	0.28***	1.62	0.314 **	0.40	0.13***
Distance to cleared parcel^2	0.97	0.97***	0.97	0.009***	0.93	0.07
Distance to nearest village	1.35	0.106***	0.62	0.106***	0.33	0.22*
Distance to nearest village^2	1.00	0.0016**	1.00	0.003	1.04	0.04
Distance to archeo site	0.97	0.024	1.16	0.083**	0.47	0.04***
pH	2.32	0.40***	0.63	0.102***	0.95	0.61
Aspect	1.00	0.002	1.00	0.0002***	1.00	0.0002
West (dummy)	424.5	642***	0.25	0.25	—	—
Constant	2.2e–6	5.2e–6***	2.6e–23	2.7e–22***	8.2e–7	8.9e–6
Observations	293,248		294,208		232,984	
Pseudo R^2	0.5828		0.7794		0.8384	
Log likelihood	− 78,344.1		− 41,589.9		− 25,643	

Note: Logit results from Stata Version 12. The nonresident observations include 19 clusters, long-inhabited 15 clusters, and the recently settled 7 clusters (since only western concessions and controls are included).
*Significant at 10%; ** significant at 5%; *** significant at 1%.

TABLE A2
Comparison of Balance between Matched Data Sets

Variable	NonResident				Long-Inhabited				Recently Inhabited			
	Unmatched		Matched		Unmatched		Matched		Unmatched		Matched	
	Mean Diff.	eQQ Med.[a]	Mean Diff.	eQQ Med.[a]	Mean Diff.	eQQ Med.[a]	Mean Diff.	eQQ Med.[a]	Mean Diff.	eQQ Med.[a]	Mean Diff.	eQQ Med.[a]
Distance to road	6.86	6.75	1.81	1.72	−5.71	6.82	−0.03	0.67	−8.93	8.13	1.06	1.45
Distance to city	−23.48	24.92	−0.96	6.60	−3.48	23.16	5.96	19.98	−14.98	21.95	5.20	6.86
Distance to village	6.62	6.52	0.88	2.65	−5.60	6.60	−0.99	0.90	−9.66	10.11	0.48	0.81
Distance to village^2	305.9	217.7	32.06	71.17	−231.9	262.1	−40.10	21.99	−240.3	200.0	12.31	5.74
Distance to clearing	1.90	2.10	−0.59	1.36	−1.80	1.34	−0.14	0.56	−8.68	10.67	0.86	0.19
Distance to clearing^2	18.69	19.14	−19.24	27.82	−46.52	13.78	−5.32	3.91	−152.4	133.1	7.37	0.38
Distance to archeo site	−0.86	5.22	−1.89	2.01	−5.85	3.27	−0.97	2.94	3.64	5.53	−3.19	2.87
Aspect	12.88	10.01	1.01	4.40	−2.60	6.34	−0.36	1.30	20.27	14.04	−4.02	4.07
pH	0.34	0.36	0.10	0.05	0.55	0.50	−0.09	0.00	0.51	0.36	−0.13	0
Elevation	29.90	48.25	12.22	11.00	62.14	69.00	−4.29	36.00	29.93	35.00	14.7	16
Slope (degrees)	0.57	0.87	−0.36	0.00	0.38	0.46	−0.11	0.00	2.20	1.90	−1.86	1.97
West (location dummy)	−0.29	0.29	0.00	0.00	−0.16	0.16	0.00	0.00	0.32	0.00	0.00	0.00
Observations	293,248		90,190		294,208		94,204		296,262		43,116	

Note: Matching methods for all three data sets are nearest neighbor without replacement, with Mahalanobis distance metric for select variables.
[a] Median values for the quantile-quantile (QQ) plot differences are used for all ordinal covariates and the mean is used for categorical covariates (west). Matching is conducted in *R* using "MatchIt" (Ho et al. 2011).

TABLE A3
Panel Test for Parallel Trends in Deforestation Preconcession Policy

Variable	Recently Settled Coeff.	Recently Settled Std. Err.	Long-Inhabited Coeff.	Long-Inhabited Std. Err.	Nonresident Coeff.	Nonresident Std. Err.
Control	0.004	0.007	0.013	0.008	0.007	0.005
Year 90_93	− 0.003**	0.001	− 0.0008*	0.0004	− 0.00002**	0.00001
Year 93_95	− 0.002**	0.001	− 0.0008*	0.0004	0.00000	0.00000
Control*90_93	− 0.004	0.005	− 0.010	0.007	− 0.005	0.003
Control*93_95	− 0.003	0.004	− 0.003	0.002	− 0.004	0.003
Constant	0.007**	0.003	0.0008*	0.0004	0.00007**	0.00003
Observations	129,099		282,537		270,564	
Groups	43,033		94,179		90,188	

Note: Results based on a random effects linear probability model with panel data from three preconcession periods: 1990–1993, 1993–1995, and 1995–1997. Each pixel was coded as 1 if it experienced deforestation during that period, and then remained 1 for all subsequent periods. Results based on a linear probability model where the dependent variable equals 1 if pixel is deforested, 0 otherwise.

*Significant at 10%; ** significant at 5%; *** significant at 1%.

The results for the Mantel-Haenszel test statistic (Table A4), which tests the null hypothesis that the treatment effect is overestimated for the given levels of Γ. We can reject the null hypothesis in all cases. The results are robust to unobserved bias for Γ up to five ($p < 0.001$). Thus the significance of the treatment effect would not change even in the presence of a sizable unobserved, confounding variable. The upper bounds on the significance levels for Γ are essentially zero ($p < 0.001$) for all levels of Γ, for all subgroups (not shown in the table).

TABLE A4
Test for Unobserved Bias Using the Mantel-Haenszel Test Statistic

Γ	Nonresident Pre	Nonresident Post	Long-Inhabited Pre	Long-Inhabited Post	Recently Inhabited Pre	Recently Inhabited Post
1	12.2	21.5	10.3	15.1	6.2	4.4
2	17.4	30.3	14.8	21.6	11.1	13.1
3	21.3	36.9	18.3	26.5	14.6	18.8
4	24.6	42.4	21.2	30.6	17.4	23.2
5	27.5	47.2	23.8	34.2	19.8	26.9

Note: Results were obtained using "mhbounds" in Stata Version 12 used for testing unobserved bias with binary dependent variables (see Becker and Caliendo 2007). Reported values are for the Mantel-Haenszel statistic Q+mh (assumption: *overestimation* of treatment effect). *p*-Values for all test statistics are less than 0.001 and thus are not displayed in the table. Pre indicates the prepolicy period from 1990 to 1996, post indicates the postpolicy period from 2000 to 2008. Γ is a measure of the degree of hidden bias required to change results of the estimated treatment effect from the kernel matching results (Table 5).

TABLE A5
Panel Data Results with Time Trend

Variable (Dependent deforest = 1)	Recently Settled: With 2 km Buffer	Recently Settled: Without 2 km Buffer	Long-Inhabited: With 2 km Buffer	Long-Inhabited: Without 2 km Buffer	Nonresident: With 2 km Buffer	Nonresident: Without 2 km Buffer
	Coef.	Coef.	Coef.	Coef.	Coef.	Coef.
Treat	− 0.003	− 0.013***	− 0.011*	− 0.014*	− 0.005	− 0.008
	(0.006)	(0.002)	(0.006)	(0.007)	(0.004)	(0.005)
Post	0.018	0.085***	0.015	0.023	0.007	0.016
	(0.035)	(0.024)	(0.015)	(0.019)	(0.010)	(0.013)
Treat × Post	− 0.081	− 0.134***	− 0.041**	− 0.052**	− 0.024	− 0.034**
	(0.059)	(0.013)	(0.021)	(0.023)	(0.015)	(0.017)
Time Trend	0.026***	0.023***	0.007*	0.008	0.004*	0.005
	(0.008)	(0.006)	(0.004)	(0.005)	(0.003)	(0.003)
Constant	− 0.057***	− 0.038***	− 0.006	− 0.005	− 0.005	− 0.003
	(0.016)	(0.015)	(0.008)	(0.010)	(0.005)	(0.006)
Observations	344,264	204,832	753,432	675,576	721,504	585,256
Groups	43,033	25,604	94,179	84,447	90,188	73,157

Note: Data are from remote sensing satellite images. Observations are based on 30 m × 30 m parcels of land. Panel format is based on periods where deforestation was observed. There are eight periods from 1990 to 2009. Each pixel was coded as 1 if it experience deforestation during that period and then remained 1 for all subsequent periods. Results based on a linear probability model where the dependent variable equals 1 if pixel is deforested, 0 otherwise.
*Significant at 10%; ** significant at 5%; *** significant at 1%.

TABLE A6
Leakage Estimates for "Buffer" Coefficient for Concession Groups

Model	2 km Buffer: Unmatched	2 km Buffer: Matched	5 km Buffer: Unmatched	5 km Buffer: Matched	10 km Buffer: Unmatched	10 km Buffer: Matched
Resident Indigenous						
OLS	− 0.0411	− 0.037	− 0.027	− 0.028	0.0008	− 0.010
Clustered Std. Err.	(0.012)***	(0.014)***	(0.012)**	(0.013)**	(0.019)	(0.015)
Observations	96041	47246	95480	42136	94648	26932
Pseudo R^2	0.181	0.1474	0.1757	0.119	0.167	0.0896
Nonresident						
OLS	0.0115	0.0056	0.015	− 0.0014	0.015	− 0.010
Clustered Std. Err.	(0.011)	(0.009)	(0.013)	(0.008)	(0.034)	(0.032)
Observations	95,007	38,176	94,723	29,674	94,602	24,568
Pseudo R^2	0.168	0.239	0.164	0.236	0.164	0.242

Note: Clustered standard errors in parentheses. OLS, ordinary least squares.
*Significant at 10%; ** significant at 5%; *** significant at 1%.

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