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Forest cover change and land tenure change in Mexico's avocado region: Is community forestry related to reduced deforestation for high value crops?

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ABSTRACT

Forest cover change in highland pine-oak forests of Michoacan, Mexico is due to a process of conversion of natural forests to avocado orchards. Privately-owned avocado orchards are found on land that was common forest before the 1992 Reform of the Mexican Constitution. We ask how forest cover change was facilitated by policy changes that affected land tenure rules and existing community forestry programs. We use a comparative case study of four communities, an analysis of forest cover change, and interviews and household surveys. Results show that 33.1% of forest cover was lost over a 16-year-period across the region. However, two forestry case study communities lost 7.2% and 15.1% of forest cover, while two adjacent non-forestry communities lost 86.5% and 92.4%, respectively. Interview data show that the Reform of Article 27 combined with the 1992 Forestry Law led to collapse of local governance, illegal division of common forests, and illegal logging in the two non-forestry communities.

Introduction

Rapid land cover change observed in highland pine-oak forests of Michoacan, Mexico is due to a process of conversion of natural forests to avocado plantations (CEF, 2007). This contrasts with tendencies observed in the majority of pine-oak forests in Mexico, in which the land cover change rate (1.0%) is lower than that of tropical broadleaf forests (2.1%) (Velazquez et al., 2002). Little has been documented about the ecological, social or economic implications of avocado expansion and associated deforestation, as well as the process by which communally owned forests are converted into privately-owned orchards.

Anecdotal evidence of forest cover change processes in the region led to two observations. First, land cover change is not evenly distributed among communities; certain communities have deforested over half of their communal forests in recent years while the forests of adjacent communities remain intact. Second, according to historical accounts of community members and government officials, rapid deforestation occurred in the region several years before avocado production expanded and began coincidentally with two policy changes: the Reform of Article 27 of the Mexican Constitution (Government of Mexico, 1992a), which allowed the individualization and private titling of commonly held lands under certain conditions, and the 1992 Forestry Law (Government of Mexico, 1992b), which reduced government oversight of timber transport to improve efficiency and liberalize the sector.

How were the expansion of avocado production and forest cover change facilitated by policy changes that affected systems of common property management? To address this question, we conducted a formal analysis of forest cover change using Landsat TM and ETM satellite imagery in a set of four case study communities and in the larger avocado production region. We then explored the histories of forest use and cover change in the four communities to understand how policy changes in the early 1990s were related deforestation in certain communities and rapid expansion of avocado production in the early 2000s. While these are certainly not the only policies that have affected the forestry sector in Mexico, and changes in forestry laws prior to 1992 played an important role in defining community forestry, this paper focuses on the effects of these policy changes. Finally, we compare results of interviews and household surveys of case study communities to determine underlying differences that created varied outcomes for forest cover.

This study aims to further our theoretical understanding of how policy change affects local management of the commons. We conclude that if efforts to maintain and enhance forest cover in Mexico's common forests are not made in a policy context that favors common property institutions, the outcome may not be beneficial for forest cover. In our analysis, policy changes in the agrarian, forestry, and agricultural sectors have been a determining

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factor in debilitating local institutions and creating the opportunity for subsequent forest cover change.

Background

Common forests and community forestry in Mexico

Community forestry in Mexico began in the late 1970s when concessions to timber companies were nearing expiration and a handful of communities in Oaxaca and Durango organized to attain the right to harvest timber from land under their control (ASETECO, 2002; Bray & Merino, 2004). The Forestry Law of 1986 established community forestry in Mexico by canceling concessions and formally recognizing the rights of communities to manage forest resources and contract forestry services (Merino, 2004). Most of Mexico's highly successful community forestry programs (Bray et al., 2004; Chapela Mendoza, 1999; Velazquez, Torres, & Bocco, 2003) were initiated in the late 1970s and early 1980s as a result of the grassroots community forestry movement and subsequent government sponsored community forestry development programs. Currently, roughly 2000 federally issued permits for timber extraction exist nationwide, most of which are in pine-oak forests where timber value is relatively high (Bray, Merino-Perez, & Barry, 2005).

Roughly 80% of Mexico's forests are governed under a common property regime by *ejidos* and *comunidades indigenas*, two types of common property landholdings created by the Mexican government after the Mexican Revolution (Bray et al., 2005; Yates, 1981). Given this high percentage of common property, effective local governance of commonly owned forests is crucial to maintain ecosystem services and create economic benefits for forest communities. Collective action theory (Olson, 1965) as applied to common property (Ostrom, 1990) aims to understand the conditions under which groups of people cooperate to manage commonly owned resources. Effective collective action in the commons is influenced by three sets of factors: characteristics of the user group, characteristics of the resource, and external influences (Ostrom, 1990).

Most research on management of commonly owned forests has focused on the first two sets of factors, including extensive work on rule-making and enforcement, leadership, group size, and heterogeneity, and characteristics of resources (Gibson, McKean, & Ostrom, 2000; Ostrom, 1990; Poteete & Ostrom, 2004; Wade, 1988). In Mexico, community forestry research has done so as well, with many case studies examining the organization and functioning of community forest enterprises (Garibay Orozco, 2007; Klooster, 2000; Merino, 2000; Orozco-Quintero & Davidson-Hunt, 2010; Velazquez et al., 2003). These studies have used the Mexican community forestry context to examine theoretical and practical issues related to the management of common pool resources. Yet commons management invariably takes place within a political economic context whose influence in some cases may matter more than internal organization (Agrawal, 2001; McCay & Jentoft, 1998), which is the focus of this paper.

In Mexico, research on the external context of community forestry has focused on failures in management resulting from the lack of coordination between state and local authorities in the Monarch Butterfly Reserve in Michoacan (Tucker, 2004); on a local logging ban that created disincentives for sustainable timber management in the Lake Pátzcuaro basin in Michoacan (Klooster, 2003); and on federal reforms of land tenure and forestry laws in Durango and Quintana Roo (Taylor & Zabin, 2000; P. Taylor, 2000; P.L. Taylor, 2003). Recent research has also looked at the attitudes of members of communities (Merino & Martićnez, 2009) as well as how communities make partnerships with outside organizations (Orozco-Quintero & Berkes, 2010). This analysis aims to deepen our understanding of external influences on the commons by exploring whether and how specific policies have changed incentives for forest cover maintenance and affected the ability of user groups to effectively manage resources.

Avocado production in Michoacan, Mexico

The avocado region of Michoacan is defined by climatic characteristics that provide adequate moisture and temperature for intensive production of the Haas avocado variety. According to the Avocado Commission of Michoacan (COMA), adequate conditions occur in areas between 1050 and 2600 m above sea level that receive between 120 and 160 cm of annual precipitation and have a temperature of between 8 and 21 °C. This represents roughly 12.9% of the surface area of the state of Michoacan (COMA, 2007).

While orchard production with improved varieties began as early as 1957 in Michoacan, rapid expansion did not occur until more recently. In 1968, total surface area of avocado production in the state was 13,350 ha, a figure which grew to 23,000 ha in 1975, 78,500 ha in 2000, and over 86,500 ha in 2006 (Barcenas Ortega & Aguirre Paleo, 2005; COMA, 2007). In 2005, Michaocan produced over 84% of all avocados grown in Mexico and over 40% of those grown worldwide (APEAM, 2005).

Since 1914 and prior to 1997, Mexican avocados had been banned from the United States due to the presence of the avocado seed borer (*Conotrachelus perseae* Barber) in native avocados varieties. Although avocado growers in Mexico pushed for the lifting of trade bans with passage of the North American Free Trade Agreement (NAFTA) in 1994, California growers successfully lobbied for the continuation of the phytosanitary ban (Stanford, 2005). Beginning in the early 1990s, an network of producer and packing organizations, government agencies, and research institutions successfully argued that avocado exports should be allowed into the United States through an expensive inspection and eradication program under the oversight of the USDA (Stanford, 2002). In 1997 exports to the United States were first allowed to 19 northeastern states in four winter months, and from 1991 to 1998, total export volume grew from 13,000 tons to 47,000 tons (Barcenas Ortega & Aguirre Paleo, 2005). The ban was gradually lifted, and in November of 2004, access was expanded to year-round access to 47 states. Mexican avocados were finally allowed into California, Hawaii, and Florida in 2007 (APEAM, 2004). This parallels growth in exports: In 1997, produce from only 1500 ha was exported, or roughly 2% of the total (APEAM, 2005). In 2005, produce from 32,500 ha was exported, or about 28% of total production, and roughly 62% of this went to the United States (APEAM, 2006).

Policy changes: the Reform of Article 27 and the 1992 Forestry Law

We suggest that two policy changes seemingly unrelated to avocado production – the Reform of Article 27 of the Mexican Constitution (the 1992 Reform) and 1992 Forestry Law – debilitated local governance structures in some communities and led to forest cover change prior to the intent to establish avocado orchards in former forests. These policies were part of the same suite of policies that promoted free markets and deregulation. The 1992 Reform allowed the titling and sale of commonly owned land under certain conditions. The process involves the intervention of a government program (Program for the Certification of Ejido Rights – PROCEDE) in which communities can opt to have communal lands measured for individualization. Certificates are then issued for individual parcels, which can be converted to private property upon approval of a two-thirds majority of the communal assembly (Government of Mexico, 1992a). While many assumed that the Reform would end communal tenure in Mexico (Bray, 1996; Goldring, 1996; Harvey, 1996; Stephen, 1998), the effect on forests should have been minimal since, as a protection against

Table 1
Characteristics of case study communities, Michoacan, Mexico.[a]

	Active forestry program	Annual permitted volume (m^3)[b]	Total surface area (ha)[c]	1990 Forested surface area (ha)[d]	Total population[e]	Distance to paved road[c]	Topographic roughness[f]
Las Lomas	Yes	970	1116	319	794	0.1	1.015
San Juan	Yes	2100	971	286	748	1	1.027
El Cajoncito	No	0	946	441	537	4	1.030
Las Palmas[g]	No	0	3329	1598	710	7	1.033

[a] Community names have been changed to pseudonyms.
[b] Data obtained from the Secretariat of the Environment (SEMARNAT) in each state.
[c] Calculated using GIS shapefiles of community outlines and roads.
[d] Calculated using Landsat TM images, see methodology below.
[e] Data obtained from 2005 Population Count (National Institute of Statistics, Geography and Information – INEGI).
[f] This is a measure of rugosity created using SRTM digital elevation models and the ArcView plugin Benthic Terrain Modeler. Rugosity, as defined here, is the mean of each cell's ratio between the surface area and planar area, averaged over the community. Values from 1 to 5 are given to each cell, from 1 = flat to 5 = steep. For more information see (http://www.csc.noaa.gov/products/btm/).
[g] During fieldwork, we discovered that four individuals (of 32 voting members) have a forest management plan on forest that was extracted from common use in the early 1990s. Since this plan is not managed at a community level and applies to less than 10% of the community's former forest area, this community was classified as without a community forestry management plan.

deforestation, the 1992 Reform stated that common forests could not be divided. Although division of common lands has occurred (Haenn, 2006; Muñoz-Piña, de Janvry, & Sadoulet, 2003; Nuitjen, 2003; Zepeda, 2000) and forest loss has accompanied individualization in certain cases (Barsimantov, Racelis, Barnes, & DiGiano, 2010), the system of communal land tenure in Mexico remains relatively intact. Fewer than 10% of *ejidos* have converted to private property nationwide (Procuraduría Agrariac, 2007).

A central goal of the 1992 Forestry Law was simplifying the regulatory process in an attempt to improve efficiency in the timber industry. Prior to 1992, log trucks were required to obtain and carry papers that certified the legality of transported timber. These papers stated the origin, destination, and quantity of timber to be transported within a certain timeframe. While the acquisition of this paperwork was time consuming and therefore a disincentive for forest management, it provided a mechanism by which illegal logging could be monitored. The Forestry Law of 1992 replaced this documentation with the stamp of a special hammer that was used by foresters to mark the ends of logs, signifying the legality of timber. Widespread abuse of the hammer, along with hammer forgeries, was common immediately following the law and led to an high level of illegal logging activity, according to multiple interviewees. Due to this, paper documentation was reinstated several years later. We explore how this opportunity for illegal logging, combined with the 1992 Reform, led to the collapse of local governance in certain communities and subsequent deforestation.

Research design and methodology

Fieldwork was conducted from January to June, 2006 in four *ejidos* (hereafter communities) in the municipality of Ario de Rosales in the state of Michoacan, Mexico. Ario de Rosales is the fourth largest of twelve avocado producing municipalities in the state, with 8000 ha of production in 2006, while other municipalities ranged from 1120 to 16,598 ha. Of Ario's total surface area, 11.5% is devoted to avocado production, sixth among the twelve municipalities, which range from 1% to 39.8% (COMA, 2007). In this respect, Ario is indicative of Michoacan's avocado growing region. In addition, road density in Ario de Rosales (4.88 m/ha) is slightly higher than the average of these municipalities (2.57), range on road density (4.88 m/ha, range of 1.35–5.73 m/ha), as is the percent of land in common property tenure (58.9%, average of 45.5%, range of 31.6–73.8%).[1]

With the help of a local NGO and government contacts at Secretariat for the Environment and Natural Resources (SEMARNAT), two communities with active community-level forest management programs (forestry communities) and two without active management programs (non-forestry communities) were selected.[2] Forestry communities were selected from the eight communities in the municipality with permits based on the existence of avocado production and their population size. All communities were selected to control for exogenous factors that could influence resource management outcomes and confound experimental design. Values for population size, forest area, topography, and distance to population centers are all as similar as possible, especially given the highly variable context of Mexico's communities (Table 1). Controlling for forest type and spatial location was also important in order to reduce the potential for confounding factors, such as timber value and local market conditions, to influence results. Therefore, all case study communities are accessed from the same paved road, each community has at least one boundary adjacent to another community, and all community boundaries are within a few kilometers of one another. In sum, the goal was to select communities that are similar on a number of demographic and geographic factors to allow a meaningful comparison of forestry and non-forestry communities, as opposed to attempting to select a representative sample, which would be impossible in this small sample (Fig. 1).

In each community, a household survey was applied in a roughly 20% random sample of households, resulting in 122 surveys. This ranged from 20 to 40 surveys in the four communities, which ranged from 70 to 190 households. Response rates were between 85% and 100%. Questions were developed with the aid of a local NGO and were pre-tested in eight households in the first community. Surveys were administered orally by two research assistants from Mexican universities, and in each community a local resident was hired to locate selected houses and introduce survey administrators to heads of households. Surveys required between 40 min and 1 h and response rates were between 90% and 100% in each community. Survey questions pertained to the entire household as well as specifically to the head of the household, and were organized into five sections: (1) household demographics, (2) employment and income sources, (3) agricultural production, (4) community participation, and (5) use of commonly owned natural

[1] Data was compiled from GIS layers from the National Agrarian Registry and the National Institute of Geography and Information (INEGI).

[2] Existence of forestry permits was confirmed during compilation of a forestry reports database from all communities from 1993 to 2004 in Michoacan, compiled by the authors.

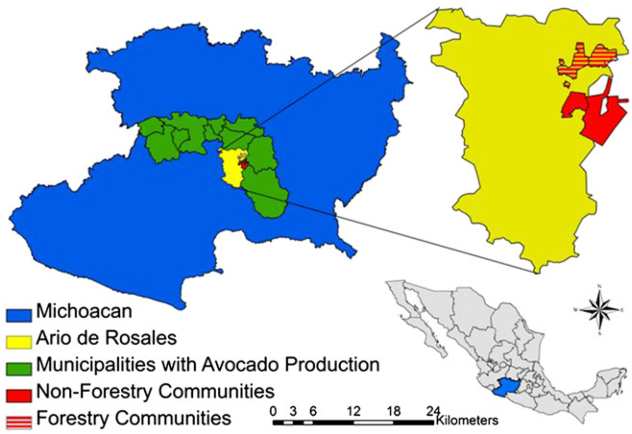

Fig. 1. Location of study region and case study communities

resources. Data were entered into an Excel spreadsheet, and analysis was conducted with the SAS statistical package.

In each community between 8 and 12 open-ended interviews were conducted with local authorities, locals with knowledge of forest use and management, and older community members with knowledge of community history. In addition, a total of 24 interviews were conducted with external actors involved in community forestry and avocado production throughout the state, including government officials (10 interviews), NGO staff (7), private foresters (6), and timber companies (1). In community interviews, questions included forest use history, communal governance, employment patterns, infrastructure and social services, use of income from timber harvests, opinions of external non-government actors, capacity building for forest management, and participation in development projects. Questions for external actor interviews pertained to individuals' knowledge of case study communities, interactions in general with forest communities, the forestry sector in the state, avocado production, and illegal logging activities. This interview data was used to help inform the analysis and give context to results. Interviews were recorded on a digital voice recorder, except for two respondents that asked not to be recorded, and recordings were analyzed qualitatively.

Finally, a forest cover change analysis using Landsat TM and ETM satellite images was conducted to determine the extent of forest cover change in case study communities and in the eleven municipalities that comprise the majority of Michoacan's avocado production region.[3] Forest cover was calculated for 1990, 1996, 2002, and 2006.[4] Image years were selected to measure forest cover change in three time periods: when trade rules prevented avocado exports and during the policy changes mentioned above (1990 and 1996), during rapid expansion of the avocado industry (1996–2000), and in the more recent period of orchard expansion (2000–2006).[5] By isolating the period before expansion of avocado exports, we hoped to determine how policies other than changes in avocado trade rules affected deforestation in Michoacan.

Post-classification techniques and the ENVI software package were used to determine forest cover change. ERDAS Imagine software was used to conduct some preprocessing functions.[6] Land cover classifications were conducted using a maximum likelihood supervised classification tool using three vegetation classes in Michoacan (forest, non-forest, and orchards) to take special attention in distinguishing orchards from forests. However, orchards of under three years of age were found to be indistinguishable from agricultural fields. Therefore the orchard class and the non-forest class were combined once the analysis was complete to make a single non-forest class. Categories of water and volcanic rock were also used to exclude these areas from analysis.

It is important to note the criteria used for classifying forest and non-forest areas. After illegal logging occurs, forests are degraded to the point that many ecosystem services are effectively lost and natural recovery of the forest is severely constrained, as evidenced by logged forests that have not shown marked recovery in over 20 years. Land cover change has not occurred in these areas, but, as discussed later, areas that are denuded of all valuable timber become easy to convert to avocado orchards. Creating an additional 'degraded forest' category would have added a difficult layer of complexity, so we chose to classify degraded forests as non-forest. These degraded forests were identifiable in the field by their characteristic dense shrub cover, lack of conifers, and minimal canopy cover. Ground control points were taken to train ENVI software in the supervised classification, in the same manner used to conduct classifications of other land cover types. We found the inclusion of degraded forests into the non-forest class especially useful because it allowed us to determine the moment, in many cases, in which forest cover change was initiated through degradation. We therefore refer to this analysis as forest cover change, rather than land use change.

Post-classification techniques were used to compare forest cover in the four images to produce a final calculation of forest cover change. To test accuracy of classifications, 350 GPS groundtruthing points were collected in the field to evaluate classification of the 2006 image, and aerial photographs from 1995 were used to locate additional control points and evaluate the 1996 classification. Overall accuracy was between 96.5% and 98.0%, and the kappa coefficient was between 0.86 and 0.93 for all classifications.

Results and discussion

Forest cover change at the regional level

Results of the forest cover change analysis in 10 municipalities that produce avocados[7] show that over 33.1% of forest cover, or 48,600 ha of 146,700 ha, has been lost between 1990 and 2006 in elevations above 1200 m (Table 2). This represents a 2.5% annual rate of change, much higher than the 1% rate of change for highland

[3] For the purposes of this analysis, we define the avocado production region in a slightly smaller elevation zone (1200–2500 m above sea level, as compared to 1050–2600 m) due to the fact that production in the highest and lowest elevations is difficult and less than 0.2% of orchards are found below 1200 and above 2500 m.

[4] All images were row 28, path 47. Image dates: 3/16/1990, 4/1/1996, 3/9/2002, 4/5/2006.

[5] Due to a failure of the Scan Line Corrector (SLC) in the Landsat 7 satellite in 2003, all images taken after 2003 have gaps of striping across the image, covering roughly 10% of the image. To fill these gaps, three images, taken on similar dates either in the same year or in adjacent years were selected, which the USGS used to produce a gap-filled image. While this interpolation process clearly distorts actual spectral values, valid land cover classification can still be performed, and the use of images for gap-filling from similar months and adjacent years makes it likely that error from the SLC image is minimal (Tappen & Kushing, 2004).

[6] The 1990 image was geometrically rectified to control points obtained from 1995 orthorectified aerial photos, and the rest of the Landsat images were geometrically rectified to the corrected 1990 images, with a root mean square error of the rectification process was less than 0.7 pixels for all images. All images were obtained with radiometric correction already performed. Orthorectification to correct for terrain variation was conducted the 1990 Michoacan image using Shuttle Radar Topographic Mission (SRTM) digital elevation models and the orthorectification tool in the ERDAS Imagine software package. The other three images were obtained with orthorectification already performed. Cloud cover in all images except the 2006 image was 0%. Minimal cloud cover (<3%) was found in the 2006 image.

[7] These are 10 of the 12 municipalities produce over 95% of avocados grown in Michoacan (APEAM 2006; COMA 2007). One municipality fell outside the set of satellite images and therefore was not included.

forests across the country (Velazquez et al., 2002). In elevations between 1200 and 2500 m above sea level, the zone suitable for avocado production, 39.5% of forest has been lost, corresponding to an annual deforestation rate of 3.1%. In elevations above 2500 m, only 13% of forest has been lost, corresponding to a 0.9% rate of deforestation.

These results might suggest that deforestation for avocado production results from simple utility maximizing by farmers in the region. While this explanation may be correct in general, it does not explain why some communities choose to deforest while others with similar geographic characteristics do not. In other words, it ignores local governance. In addition, this explanation does not explain the role of policy changes in catalyzing land cover change well before the rapid increase in avocado production. As shown in Table 2, deforestation rates before rapid growth in avocado production were the same or higher as afterward. We can assume that deforestation in these years was unrelated to avocado production since avocados production was not yet rapidly increasing, which is corroborated by case study data. Rather, we assert below that it was catalyzed by the policy changes described above.

Land cover change in case study communities

Of the four case study communities, two have an active community forestry program and two do not. All four communities are relatively small, with between 32 and 82 member households, with one community possessing a considerably larger surface area. From results of the land cover change analysis in these four communities (Table 3), and it is clear that deforestation has varied considerably between the two pairs of communities (Figs. 2 and 3).

In the two non-forestry communities, over 85% of forest was lost between 1990 and 2006. Most of this forest area, according to community members, is legally designated as commonly owned but has been sold illegally to outsiders by individual community members. In the two forestry communities, the extent of forest loss has been much less, and only small patches of land have been sold to outsiders. According to forest cover change results, the majority of deforestation occurred before the expansion of avocado production, suggesting that other factors catalyzed deforestation.

It is important to first exclude physio-geographic factors that might explain deforestation processes. Higher road density and flatter topography have often been found to be related to increased deforestation (Chomitz & Gray, 1996; Freitas, Hawbaker, & Metzger, 2010; Kaimowitz & Angelsen, 1998; Nelson & Hellerstein, 1997). On the other hand, Cropper and Griffiths (1994) show that these variables can increase deforestation in some cases but not others, and historical or policy factors may play a role. Visual interpretation of imagery and digital elevation models suggests that deforested areas in the two non-forestry communities were those with the steepest topography, while forested areas in flatter areas in the other two communities were not deforested. However, in this study, greater access does not lead to greater deforestation; the two non-forestry communities are actually more topographically rough than the other two communities (Table 1). In addition, ease in road access did not increase likelihood of deforestation, as is often suggested in the literature. Communities with low deforestation have better road access than the two with high deforestation, principally because they are not as steep. This suggests that non-physio-geographic factors played an important role in driving land cover change.

Table 2
Forest cover change in the avocado region of Michoacan.

	Percent change in forest cover (%)			
	1990–1996	1996–2002	2002–2006	1990–2006
Ario	−27.4	0.1	−22.4	−43.6
Nuevo Parangaricutiro	−15.6	−13.4	−8.3	−33.0
Periban	−9.2	−24.3	−16.1	−42.3
Salvador Escalante	−21.6	11.9	−10.6	−21.6
Tacambaro	−8.2	−14.7	−4.1	−25.0
Tancitaro	−10.5	−10.9	−10.4	−28.5
Tingambato	−4.6	−27.0	−4.2	−33.3
Turicato	−36.8	−29.0	−28.1	−67.7
Uruapan	−18.7	−16.2	−7.4	−36.9
Ziracuaretiro	−16.1	−33.5	−23.1	−57.1
Total	−13.8	−13.1	−10.7	−33.1

Non-forestry communities

Both non-forestry communities actually had forest management activities prior to 1990. However, this was before community forestry became widespread in Mexico, and in both communities participation by locals was minimal. Private foresters and local timber companies conducted all activities related to timber harvesting and communities were severely under-compensated for timber. Productive activities of locals in communal forest consisted of collection of tree resin and firewood harvesting. Each community member possessed individual usufruct rights to an area of forest, termed *cuarteles*, for the extraction of resin. These use rights, however, did not include rights to timber or land, evidenced by the fact that the size of *cuarteles* was determined based on the amount of resin potentially available rather than on surface area. In addition, *cuarteles* were only transferable to other member or non-member residents as an entire membership package; sale to outsiders or in individual parcels was not allowed. Community members could not recall the exact year in which their forest management plans were discontinued, and these data were not available from the Ministry of the Environment.

In 1992, both communities described visits by people from outside the community who told residents that, as a result of the 1992 Reform, communal lands were no longer government property and could be divided into individual parcels. While the 1992 Reform did end ultimate government ownership of communal lands, it did not allow immediate division of common lands. Interviewees either couldn't remember or were unsure whether these visitors were government officials. These visitors did not initiate the official process of certification of communal lands under the PROCEDE program, which only occurred several years later. In this official process, rules stating that forested lands cannot be divided are explained and usually enforced.

Following this visit, both communities decided that individual members henceforth had rights to harvest timber in *cuarteles*. In addition, the communal assembly in both communities began to meet less frequently and with fewer members attending. Previously, interviewees recalled monthly meetings with high levels of participation.

In the same year, the Forestry Law of 1992 made the transport of timber less cumbersome by ending the requirements for written documentation. According to interview respondents, this change combines with their misinterpretation of the 1992 Reform, initiated a wave of illegal logging in these communities and in others in the region. Using replications of the special hammer used to legalize transport under the Forestry Law of 1992, community members had little difficulty in illegally harvesting and transporting timber to saw mills. Local informants and government functionaries reported that, between 1992 and 1995, at times between 30 and 40 logging trucks brought timber out of these two communities on a daily basis. In a few years, the majority of timber had been

Table 3
Land cover change in case study communities.[a]

		Forest area 1990 (ha)	1990–1996	1996–2002	2002–2006	Overall (1990–2006)
Forestry communities	Las Lomas	319				
	Hectares of change		−41	+11	−29	−91
	Percent change		−12.9%	4.0%	−10.0%	−18.5%
	Deforestation rate		−2.3%	0.6%	−2.6%	−1.3%
	San Juan	286				
	Hectares of change		−5	+11	−26	−21
	Percent change		−1.7%	3.9%	−8.9%	−7.3%
	Deforestation rate		−0.3%	0.6%	−2.3%	−0.5%
Non-forestry communities	El Cajoncito	441				
	Hectares of change		−338	−24	−20	−381
	Percent change		−76.6%	−23.3%	−25.3%	−86.4%
	Deforestation rate		−21.5%	−4.3%	−7.0%	−11.7%
	Las Palmas	1598				
	Hectares of change		−1030	−415	−32	−1477
	Percent change		−64.5%	−73.1%	−20.9%	−92.4%
	Deforestation rate		−15.8%	−19.6%	−5.7%	−14.9%

[a] Annual rate of deforestation calculated using the following formula: $((A_2/A_1)\hat{}(1/(t_1 - t_2))) - 1$, see Puyravaud (2003).

harvested. Payment for timber was extremely low; one interviewee estimated that members sold timber for roughly the 2006 equivalent of 30 pesos ($2.70) a cubic meter. The 2006 value of timber fluctuated around 700 pesos ($63.6) per cubic meter.

Local informants and external actors reported that the intention of illegal logging in the years immediately after 1992 was not eventual sale of land or establishment of avocado orchards. “They didn’t cut timber with that mentality [to sell land], it wasn’t until later that they sold [land].” This coincides both with results of the forest cover change analysis described above: from 1990 to 1996, before rapid expansion of orchards, annual rates of forest cover change in the non-forestry communities were −15.8% and −21.5%, while between 1996 and 2000 they were −4.3% and −19.6%, and between 2000 and 2006 they decreased to −5.7% and −6.9%. This suggests that the impetus for deforestation was not selling land and planting orchards.

This also coincides with interviewees reports that only several years after forests had been illegally logged did outsiders from larger population centers buy land with the intention of planting avocados. According to a community member from Las Palmas, “Before they planted avocados, about 15 years before, they went finishing off the timber, and it was a very difficult thing because the people didn’t stop, and if someone said something they got mad… and it was better not to get into problems [with them].” As communal forests no longer had timber value, members extended their usufruct rights to individual ownership of land. “It was like the timber, people started selling and slowly the majority decided to sell their land.” In fact, it may have been difficult to sell land with standing pine trees since new owners would not want to be responsible for illegal logging. In an example of this phenomenon, the *cuartel* of one community member burned in a forest fire several years prior to the rush of land sales. Because his land had

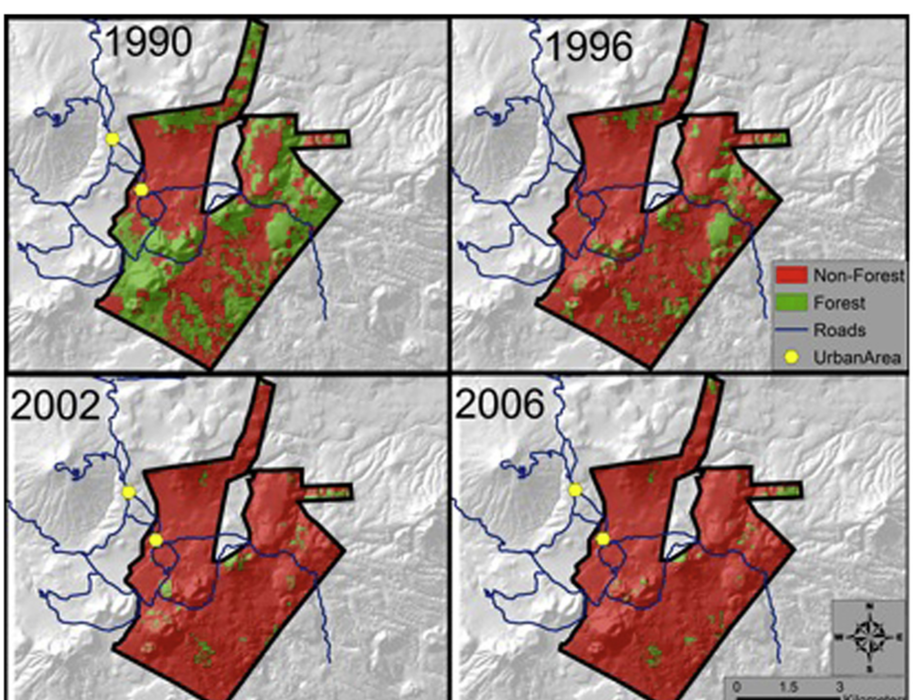

Fig. 2. Las Palmas, non-forestry community, avocado region, Michoacan. Forest cover change 1990–2006.

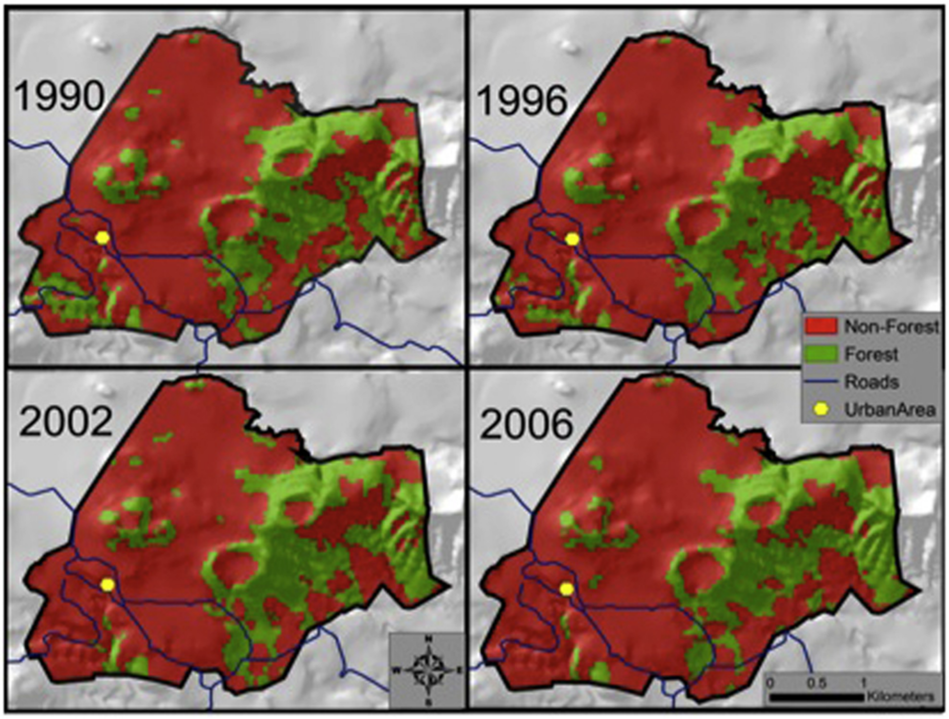

Fig. 3. San Juan, forestry community, avocado region, Michoacan. Forest cover change 1990–2006.

dense pine regrowth at the time of land sales, he did not sell his land. In these cases, illegal logging may have been a necessary precursor to illegal land sales and conversion to orchards.

According to interviewees, members in both communities have sold between 50% and 75% of all land in their community, corresponding to a much higher percentage of all common forest land. Most sold land at the 2006 US equivalent of between $487 and $974 per hectare, and the 2006 price of land without a planted avocado orchard was roughly $10,000 per hectare. All sales were illegal because (1) forested land cannot be sold under the 1992 Reform and (2) the official certification and titling process had not been conducted. Currently, nearly all orchards in areas forested prior to 1992 belong to outsiders, while community members have begun planting orchards in agricultural fields they still own. In many cases, members or their children have become day laborers on land they formerly owned. As one community member put it, "If our grandparents knew that we sold with the land they fought for [in the Mexican Revolution], they would roll over in their graves." At the time of fieldwork, assemblies in each community met as little as once a year, usually to elect new local authorities or for visits from government officials: "It's been more than four months since we met [for a community assembly]… but before we would meet every week to talk about community issues and about government programs, and about health and those types of things."

Table 4
Results of stepwise analysis to determine potential household characteristics for inclusion in discriminant function analysis.

Variable	Partial R-square	p value
Age of head of household	Not entered	>0.15
Education level of head of household	0.0988	0.0232
Hectares of land owned	Not entered	>0.15
Hectares of avocados planted 2006	Not entered	>0.15
Hectares of corn planted 2006	Not entered	>0.15
Percent of corn sold	0.0960	0.0240
Currently planting less corn than five years ago	Not entered	>0.15
% of food from subsistence	Not entered	>0.15
% Domestic use timber from communal forest	Not entered	>0.15
Use gas or firewood to cook?	0.3370	<0.0001
Purchase or collect firewood?	Not entered	>0.15
Weekly hours collecting firewood	0.1423	0.0632
Own refrigerator	Not entered	>0.15
Anyone in household living outside the municipality?	Not entered	>0.15
Agriculture is primary occupation	0.0904	0.0272
Confidence in local governance and participation	Not entered	>0.15
Strength of community governance changed in past 10 years?	0.0824	0.0391
Total land sold over past 10 years	0.0762	0.0456

Forestry communities

The two forestry communities show a very different history of forest use. In 1990 neither community had forest management plans and timber was harvested principally for domestic consumption with small quantities sold illegally by individuals. Usufruct rights to resin were distributed in a similar fashion to the other two communities. Local informants reported no effects of the 1992 Reform or the Forestry Law of 1992 on quantities of timber extracted, privatization of communal land, or timber rights. Frequency of and participation in assemblies has stayed about the same since 1990, with meetings occurring between every month to every three

Table 5
Test classification of samples: percent of samples classified into forestry types.

Forestry type	Non-forestry	Forestry	% Error[a]	# of Samples
Non-forestry	77.4	22.6	22.6	31
Forestry	18.2	81.8	18.2	22

[a] Total error = 20.5%.

Table 6
Means, standard errors, coefficients and p values for household characteristics used in discriminant function analysis, by existence of forestry program.

	Means and std. errors (in parens)				DFA coefficients		p Value
	Non-forestry communities		Forestry communities		Non-forestry	Forestry	
Cooking fuel range: 1 = only gas to 5 = only firewood	3.60	(0.066)	2.67	(0.106)	12.17	9.13	<0.0001
Education level of head of household[a]	1.66	(0.117)	2.39	(0.171)	4.78	5.70	0.0031
Strength of community governance changed in past 10 years? [b]	1.88	(0.092)	1.50	(0.090)	4.57	4.73	0.0460
Weekly hours collecting firewood	2.19	(0.120)	1.51	(0.152)	0.85	0.20	0.0194
Land sold over past 10 years (ha)[c]	1.48	(0.318)	0.47	(0.139)	0.02	−0.30	0.0225
Percent of corn sold	0.15	(0.037)	0.23	(0.043)	−2.46	1.36	0.1820
Agriculture is primary occupation	0.85	(0.045)	0.67	(0.063)	9.33	7.65	0.1328

[a] Highest level of education obtained: 1 = none, 2 = did not complete primary school, 3 = completed primary school, 4 = completed middle school, 5 = completed high school, 6 = completed post-high school education.
[b] Respondents were asked whether the assembly was functioning the same or better as 10 years ago (1), a little worse (2), or much worse (3).
[c] Land sales in non-forestry communities are probably grossly underreported. Many respondents did not include illegal sales of common forest held in usufruct use.

months and the majority of members attending. In 1997 in one community, and in 2002 in the other, forest management plans were initiated. In both communities, some members advocated for the division of common forest or independently began to illegally deforesting adjacent to agricultural areas. However, because the majority of the community wanted to maintain commonly owned forests, and since communal governance structures were functioning, common forests were maintained. According to a community member in one of the non-forestry communities, forests in Las Lomas were preserved because, "there is communication between them, and here there isn't." San Juan also initiated a communal avocado orchard and profits are used for community projects. Recently this income has been used to pave the steep road that enters the community that often become impassable in the rainy season. In Las Lomas, a community land use plan was completed with the help of a local NGO, and one of the principal results has been limiting pressure on forest resources through more active local governance.

Comparison of individual characteristics of households in case study communities

Which household characteristics are most important to distinguish case study communities with and without forestry programs? To begin to answer this question, we use discriminant function analysis in the SAS statistical package. Discriminant function analysis is a statistical tool used to determine which linear combinations of variables discriminate between groups. A statistically significant variable suggests that the variable is important in discriminating between the groups. The procedure begins by splitting records randomly into a 'training' group and a 'test' group and conducting a stepwise analysis of the 'training' group using all variables considered potential discriminators. This analysis determines which may contribute most to the discrimination. In this forward stepwise analysis, we used $p \leq 0.15$ to enter the function and $p \leq 0.1$ to be retained in the final function. Using significant variables from the stepwise analysis, we ran the discriminant function analysis, training the function with the 'training' group and testing the classification with the 'test' group. Because sample sizes were not equivalent in each community, we used the 'priors proportional' statement in SAS.

For the initial stepwise analysis, we used all available survey variables describing respondent characteristics that may influence interest, ability, or need to participate in a community forestry program, and results of this initial procedure produced a subset of variables. Of eighteen candidate characteristics, seven were retained in the final discriminant function, based on the stepwise selection (Table 4), including using gas versus firewood, education level, changes in strength of community governance, weekly hours collecting firewood, and total land sold in the last 10 years.

Using the 'test' group to see how well the discrimination described groups showed that the two pairs of communities are significantly different (Wilkes Lambda = 0.4193, $p < 0.0001$). The confusion matrix, which shows the percent of test samples that were correctly classified, showed 20.5% overall error, a robust discrimination (Table 5). For ease of interpretation, mean values, standard errors, coefficients, and p values for each group are shown in Table 6.

Non-forestry communities have lower education levels and have sold more land than forestry communities. They also are more reliant on firewood than forestry communities and spend more time per week collecting firewood. This implies that they may have lower incomes and that firewood is more difficult to find in these communities. While firewood dependence may imply that communities have greater interest in protecting access to those resources, the need for short-term timber income may outweigh this factor, especially when accompanied by a breakdown of governance. Finally, they more often report that local governance has weakened over the past 10 years than forestry communities. Percent of corn sold and occupation type were not significant in the discriminant function analysis.

Conclusions

The sharp contrast in rates of forest cover change between the two pairs of communities and subsequent qualitative analysis of local governance leads us to certain key conclusions. First, it is clear that the forestry communities had lower deforestation, while non-forestry communities have deforested extensively. Second, forestry communities have functioning local governance structures that were in existence even before forest management was initiated, whereas local governance in non-forestry communities is nearly non-functioning. Third, local governance in non-forestry communities suffered a collapse in the early 1990s. According to interview respondents both within and outside the community, this was primarily initiated by policy changes in 1992. Forest cover change data also supports this conclusion, since high rates of deforestation occurred in that time period and well before the rapid expansion of avocado orchards. Therefore, it was the breakdown of local governance and the potential to sell illegal lumber that initiated deforestation, rather than the expansion of avocado production. These results indicate that the resilience of local governance to policy changes may be a determinant of a community's ability to manage natural resources.

Based on our results, we suggest two potential explanations why some communities are more resilient to policy shocks than others. The first set of explanations relies on household survey results: Higher education levels and less dependence on firewood suggest that forestry communities are in better socio-economic condition than non-forestry communities and therefore may have less immediate need to deforest. In addition, case study communities that have maintained forest cover have stronger local governance institutions, while non-forestry communities reported a recent decline in the strength of the assembly. Fewer land sales suggest that the community is more physically intact, can more adequately enforce rules, and chooses to maintain the common property regime. While these results are robust in both a quantitative and qualitative analysis, to generalize these conclusions a larger sample size would be necessary.

Our second set of explanations is based on qualitative data and proposes that marked differences in forest management history could have affected the events that took place in the early 1990s. The two non-forestry communities actually had forest management plans prior to 1990, and thus had an understanding of the value of timber through their experiences. Since they had little control over and received little benefit from forest management, the policy changes of 1992 might have given them the opportunity to finally take advantage of their resources, leading to rapid extraction. On the other hand, the two forestry communities did not have systematic experience of economic value derived from timber harvests prior to 1992. For this reason, the policy changes of 1992 may not have created the same response of exploitation. The opportunity for greater participation and fairness in timber sales when these communities initiated their forestry programs several years later may have been important in maintaining forest cover.

We conclude by noting that if deforestation was facilitated by policy changes in land tenure, forestry, and trade, there is no doubt that the path to reducing deforestation rates will require integration, participation, and co-responsibility of these three sectors, particularly with respect to strengthening local governance structures. Multiple programs implemented in recent years in Mexico are attempting to improve environmental management by strengthening community governance, including the PROCYMAF (Program for Communities and Forest Management) and COINBIO (Indigenous and Community Biodiversity Project), yet their ultimate success depends on supportive policy in other sectors. Nested governance structures are an important mechanism for natural resource management, and Mexican policy changes should take advantage of existing governance structures to promote forest stewardship.

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