Firewood Extraction as a Catalyst of Pine-Oak Forest Degradation

in the Highlands of Chiapas, Mexico

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Abstract

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I examined the impact of firewood extraction on the degradation of an oak-pine forest in the highlands of Chiapas, Mexico. The study site, Lázaro Cárdenas, is a 1702 ha community-managed forest (i.e. *ejido*) supporting 1177 indigenous Tzotzil people. The *ejido* owns and actively manages the land including: *milpa* agriculture, grazing livestock, collecting non-timber forest products for ceremonial and medicinal uses, extracting pine lumber, and collecting firewood for cooking and heating. I collected forest vegetation data at 24 plots in the *ejido* spanning a range of degradation. I also used semi-structured interviews of 16 households to assess firewood use and perceptions of forest change. Firewood extraction causes forest degradation with heavily used sites showing lower biomass of oaks, lower forest cover, lower species diversity, and higher pine establishment than in sites where firewood is not extracted. Interviews documented people's preference for burning oak, and interviewees noted a decline and access to oak for firewood. The average firewood use calculated from interviews is 2.45 kg person^{-1} day^{-1}, while calculations from direct measurement of woodpiles suggests an average of 10.5 kg person^{-1} day^{-1}; a total of 831 MgC is removed each year. The results suggest that preferential selection of oak for firewood over pine is an early cause of induced pine dominance, *pinarización*, in the Chiapas highlands.

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Preface

This thesis is organized in two parts. In Chapter 1 I describe the dynamics of forest community change as related to firewood extraction in a 1702 hectare community-managed forest in Chiapas, Mexico. In Chapter 2 I document forest degradation from the perspective of the residents of that community, and identify firewood extraction and consumption methods to improve firewood resources and regional biodiversity conservation. This thesis approaches the community forest of Lázaro Cárdenas as a coupled human and natural system. I collected forest vegetation data and observed and conducted interviews with the people of the community. Each chapter has its own introduction and conclusions. Together they propose that firewood extraction may contribute significantly to ecosystem change in the highlands of Chiapas, from a traditionally pine-oak forest to one dominated by pine (*pinarización*).

Chapter I. Forest Community Changes Resulting From Firewood Harvest in the Highlands of Chiapas, Mexico

1. Introduction

Between one-third and one-half of people worldwide – particularly in developing countries – rely on wood and other biomass fuels for energy (Bailis et al. 2012). In Mexico, 25% of people (25 million) use firewood as a main source of cooking fuel (Riojas-Rodríguez et al. 2001). Firewood harvest has decreased in importance as a major driver of deforestation at a worldwide scale (Arnold et al. 2003). However, one of its most common consequences is forest degradation: a reduction in the forest's overall biomass and species richness and in the presence of key species (Toledo-Aceves et al. 2011). How many trees are removed, over what time period, and the harvest techniques employed influence the potential for firewood harvest to instigate forest community change. Firewood removals impact the forest's ability to maintain or recover biologically and humanly valuable function, including the future provision of firewood.

In the highlands of Mexico's Chiapas state, firewood extraction ranks with subsistence agriculture, small-scale forestry and livestock grazing as a major driver of forest degradation (Quintana-Ascencio et al. 2004). The highlands' historical pine-oak forest (Miranda and Hernández X. 1963, Breedlove 1981) is highly degraded and dominated by secondary vegetation (Ochoa-Gaona et al. 2004) after losing around 50% forest cover in the period 1975-2000 (Cayuela et al. 2006). The selective felling method employed in that region for firewood extraction may be expected to lead to homogenization of the forest community: harvesting the best individuals of preferred firewood genera, *Quercus* and *Pinus*, decreases the contrast between patches and the traditional ecosystem functions of the remaining forest (Ochoa-Gaona et al. 2004). This standardization of tree species and forest structures is reinforced by the forest's regeneration regime. Because pine species are more tolerant of the increased light and temperature environment created by gaps, pine may increase its dominance of the system over time (González-Espinosa et al. 1991).

This study aims to shed light on the dynamics of forest community change as related to firewood extraction. In Mexico, 80% of forests are managed by indigenous and agrarian communities (*ejidos)* (Klooster 1999). Technically these forests have been community-managed since the 1930s, but communities have had effective control over their resources only since the late 1970s (Johnson and Nelson 2004, Mathews 2008). *Ejidos* share resources communally among members, and forest products compose an important part of many *edjio* members' livelihoods (Bray et al. 2003). This study is located in a firewood-dependent *ejido* in the highlands of Chiapas where residents suspect that their forest is "running out" and that there will not be firewood available for future generations. Community members acknowledge that overharvest may be a cause of decreasing firewood availability – an understanding that is not unique in firewood-dependent communities (Thomas et al. 2011). My objectives were 1) to determine if firewood extraction is causing a transition of the pine-oak forest to a pine-dominated, less diverse forest community; and, 2) to determine how permanent that change might be. I tested the hypothesis that the tree species and structures in the community's forest differ by intensity of firewood harvest. Understanding the role that firewood plays with respect to changes in the forest community is the first step toward enhancing the forest's function, both in the interest of livelihood provision and biodiversity conservation – particularly as part of an effort to maintain the Mesoamerican pine-oak forest (Alliance for the Conservation of Mesoamerican Pine-Oak Forests 2007).

2. Methods

2.1 Study area

The study site, Lázaro Cárdenas (Figure 1), is a 1702 ha *ejido* in the Chiapas municipality Huixtán. The *ejido* is owned and managed communally by a population of 1177 indigenous Tzotzil people living in 214 households (INEGI 2011). Residents rely exclusively on communal forest resources for timber, firewood and non-timber forest products. Unlike many *ejidos* in the highlands, Lázaro Cárdenas is largely isolated with respect to its natural resources. Besides purchasing very little energy from outside the community, residents do not sell firewood resources outside of the community or permit outsiders to harvest on their land. *Ejido* members expect that their descendants will depend on firewood as a primary energy source.

Beck et al. (2001) and Thomas et al. (2009) found that distance from settlement and diversity of plant species were correlated for Bolivian firewood-dependent communities. Based on community members' input, we assumed that in Lázaro Cárdenas, firewood harvest intensity would depend on road access and slope of terrain in addition to distance from the *ejido*'s three areas of residential concentration. Data sampling was organized into four zones defined by our predictions of the effect of roads and accessibility on the quantity of firewood that can be harvested and removed at one time in different areas of the *ejido*'s forest (see Figure 2 for photographic depictions of differences between the zones).

> **Zone A**: Accessible to and frequented by trucks; intensive grazing with sporadic presence of corn/bean cultivation
> **Zone B**: Accessible to trucks but roads seasonal and utilized with less frequency than those of zone A
> **Zone C**: Inaccessible to trucks; firewood can be cut here and rolled or carried out
> **Zone D**: Inaccessible for firewood collection due to lack of road, steep slope and distance from residences

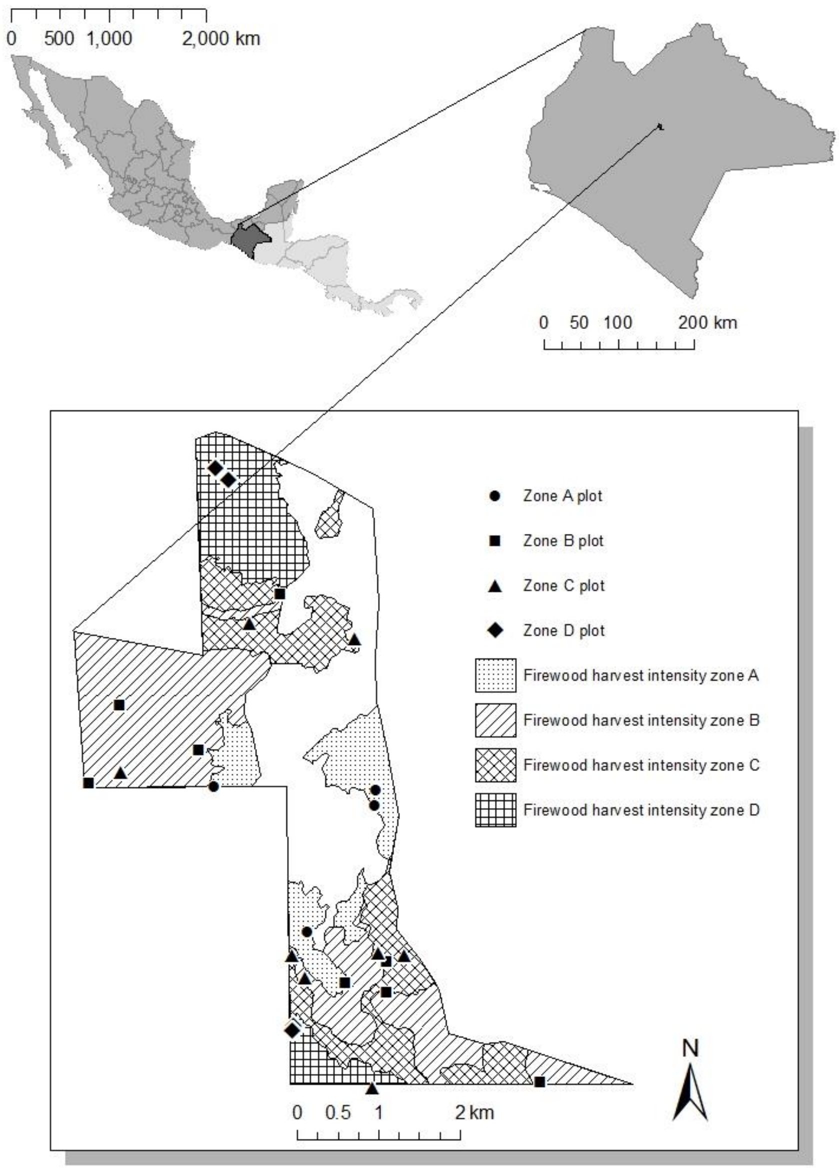

Figure 1. Locations of e*jido* Lázaro Cárdenas, zones of firewood harvest intensity, and data collection plots. The nonforest area of the *ejido* is 506 ha, and the areas of each zone of firewood harvest intensity are as follow: A – 146 ha, B – 517 ha, C – 305 ha, and D – 226 ha. All data collection plots are passed through by residents on foot and plots are all grazed to some extent by: goats, sheep, pigs or horses. Plots were assigned to a zone at data collection following *ejido* members' suggestion and observation of the immediate area. Upon completion of fieldwork, zones were drawn for the whole *ejido* in ESRI's ArcMap 10 based on first-hand knowledge, forest classifications (Centro de Planeación e Información para la Conservación de ProNatura Sur A.C. 2011), satellite imagery, and elevation data. All data were analyzed based on each plot's original assigned zone; contradictions between plot and polygon identifiers occur where plots are more similar to the forest type indicated by the polygon than the zone with which they were originally identified or where plots represent microsites within a zone of firewood harvest intensity.

Figure 2. Images of forest in each firewood harvest intensity zone. Clockwise from top left: zones A, B, C, and D.

In April through June of 2012, 24 0.01 ha circular plots were established in the forested areas of Lázaro Cárdenas. Data were collected at 4 plots in each of Zones A (highest human impact) and D (least human impact), and 8 plots each in Zones B and C, in order to describe greater differences in those intermediate zones. Plots are located in the elevation range 2280 to 2618 m a.s.l. Average annual precipitation in the *ejido* is 1186mm, with a distinct wet season from March through November (Servicio Meterological Nacional n.d.), as is common for the Mexican mesophyll mountain forest (Rzedowski 1983). Average annual temperature is 13.9° C (Servicio Meterological Nacional n.d.). Plots were haphazardly located within forest stands considered by community members to be characteristic of each zone of firewood harvest intensity. All sampling sites were reached on foot in the company of community "directors" who had authority to sample on *ejido* land.

Plots were identified by 2-letter codes, indicating zone (A, B, C or D) and within-zone data collection order (1-4 or 1-8). In each plot except for A1, B1, and B2, all trees ≥ 3cm dbh (diameter at breast height, 1.4m above ground level) were measured for diameter to the nearest 1 cm and identified to species. In plots A1, B1 and B3, the minimum dbh measured was 5cm. (Those three were the first plots measured and they demonstrated that stems 3-5cm dbh compose an important part of the forest community, so I adjusted the data collection protocol accordingly.) Heights of 3 trees representing the upper canopy and 3 representing the lower canopy were measured. Cores were extracted from three *Pinus* individuals in each plot with increment borers at a cross slope position to reduce potential of encountering compression wood. All stems of tree species < 3cm dbh (seedlings and saplings) and stumps were identified to species and counted. Optical assessments of ground cover were conducted by quarter-plot and then averaged to generate one value per plot. The same procedure was followed using a spherical densiometer to quantify plot canopy cover.

Slope was recorded from top to bottom of each plot with a Suunto PM5/360PC Clinometer. Plot center points were permanently marked with a 1 meter piece of rebar, and their altitude and position were recorded with a Garmin eTrex 10 Worldwide Handheld GPS Navigator.

2.2 Analysis

Individual tree biomass was calculated with equations suited to the species classes and region. For *Pinus* species, we used the equation described by Mendoza-Ponce and Galicia (2010) and developed by Ayala-Lopez et al. (2001) for the same and similar *Pinus* species in the central Mexican plateau: $Y = 0.084(\text{dbh})^{2.475}$. Návar (2009)'s *Quercus* species equation for total aboveground biomass, developed for northwestern Mexico, was used for *Quercus* species in this study: $Y = 0.089(\text{dbh})^{2.5226}$. (Návar's equation for *Quercus* was used here in place of that of Ayala-López (2001) because the latter requires tree heights, which were not available for all individuals. It was considered that extrapolation of heights based on a regression equation created from the measured heights of 4.5% of total oak individuals would add uncertainty.)

Návar's equation for total aboveground biomass of tropical dry forests was used for all other genera. That equation, $Y = 0.37(\text{dbh})^{1.96}$, calculates considerably lower biomass for these other genera than do the equations for *Pinus* or *Quercus* species.

Differences in the distribution of the following data sets across zones of firewood harvest intensity were assessed using the Kruskal-Wallis one-way analysis of variance for nonparametric data, Mann-Whitney two-way post-hoc tests and box plots in IBM SPSS Statistics 19 (IBM Corp. 2010):

- Elevation
- Canopy cover
- Biomass (MgC ha^{-1})
- Seedlings/saplings: number of trees in the plot with dbh <3 cm
- All trees: number of all trees with dbh ≥3 cm
- Small trees: number of trees 3-19 cm dbh
- Medium trees: number of trees 20-49cm dbh
- Large trees: number of trees <50 cm dbh
- Stumps

Differences in regeneration across elevation and canopy cover classes were analyzed in SPSS using Kruskal-Wallis and Mann-Whitney tests. We used PC ORD (McCune and Mefford 2011) to explore similarities and differences between plots by tree species and to assess the relationship of species groupings with environmental variables. We conducted cluster analyses and nonmetric multidimensional scaling ordinations to examine percent basal area of all trees with dbh ≥3 cm as well as number of stems by size category.

For all the analyses in PC ORD, the main matrix consisted of rows with plot data and columns with species data. To examine relationships between sites with respect to tree composition by basal area, main matrix cells were populated with the total basal area of each species in a plot. In the second matrix, rows represented plot data while columns were environmental variables (elevation class, aspect class, slope location, canopy cover), harvest class and zone. The same second matrix was used in every analysis. To examine relationships between sites with respect to species richness and frequency, main matrix cells were populated with the number of individuals of each species in a plot. Such matrices were created for all trees in the plot with dbh <3 cm (seedlings/saplings), all trees with dbh ≥3 cm, 3-19 cm dbh (small), 20-49cm dbh (medium) and <50 cm dbh (large). Finally, data on the number of pine <3 cm dbh populated a main matrix used specifically to explore the relationship of pine regeneration with canopy cover and elevation. Sorenson (Bray-Curtis) distance measures and Ward's group linkage method were used in all cluster analyses and Sorenson (Bray-Curtis) distance measures were used for ordinations.

3. Results

3.1 Tree species and species class

Given its elevation and location, one might expect the forest of Lázaro Cárdenas to be evergreen cloud forest; however, years of human impact have resulted in structures more similar to Breedlove's (1981) description of montane rain forest. Both categories belong to Rzedowski's (1983) description of a "*bosque mesófilo de montaña*," a mesophyll mountain forest. The forest has 1-3 layers of canopy with a dense, shrubby understory. Epiphytic ferns, orchids, and bromeliads are abundant in the most conserved areas of the forest. The tallest canopy measured in Lázaro Cárdenas was 37m high (*Pinus tecunumanii* dominated the tallest canopies), with mean diameter of trees ≥30cm dbh equal to 23m (median 22m).

Forty-four species were identified in data collection plots, with a range of 1-15 species per plot. González-Espinoza et al. (2009) found that 40-50 tree species per hectare are not uncommon in well-conserved fragments of mesophyll mountain forest in the highlands of Chiapas. Species commonly used for firewood in Lázaro Cárdenas are listed in Table 1 (for a full species list, see Appendix 1).

Tree species were grouped according to indigenous significance as pine, oak and other species, the latter of which are all hardwoods [these groups are the same as those used by González-Espinosa et al. (2009) in describing species richness and anthropogenic disturbance in the highlands]. *Ejido* members recognize various benefits of individual species, but for use as firewood they are most interested in the advantages of each genus. *Quercus* species are most preferred, because they burn long and hot. According to one *ejido* member, the *Quercus crispipilis* Trel. "lasts longest in the fire. It is split more rapidly, as well." *Pinus* species are preferred "only for helping [to start] the fire." They are also harvested for firewood when *Quercus* are not conveniently located. "Now the pine is closer," one resident reported; "there are more pines now," said another. Other species are typically not used as firewood.

Table 1. Species commonly used for firewood in the study site in alphabetical order (residents did not consistently prefer a certain species within either genera). Four species of *Pinus* are present in the *ejido*, one (*Pinus ayacahuite* var. *ayacahuite* C. Ehrenb. Ex Schltdl.) is protected from harvest. Common names are in Spanish or Tzotzil.

Scientific name	Common name(s)
Pinus montezumae Lamb.	Bochto, ocote
Pinus pseudostrobus var. *apulcensis* (Lindl.) Shaw	Saquil toh, ocote
Pinus tecunumanii F. Schwerdtf. Ex. Eguiluz & J.P. Perry	Sahalsach toh, ocote
Quercus crassifolia Humb. & Bonpl.	Bochje, tulan
Quercus crispipilis Trel.	Chiquinib
Quercus laurina Bonpl.	Saquil chiquinib
Quercus peduncularis Nee	Tulan, bochje
Quercus rugosa Nee	Bochje

Table 2. Differences in the distribution of environmental characteristics, tree biomass and number of stems per stem size class between zones of firewood harvest intensity. Results with statistical significance greater than α = .05 are listed in bold; marginally significant results (significant at α = .10) are italicized. See Appendix 2 for full biomass and stem size class distribution test results.

Distribution	**Kruskal-Wallis p-values BETWEEN ZONES**	**Mann-Whitney U p-values**					
		A:B	**A:C**	**A:D**	**B:C**	**B:D**	**C:D**
Elevation (m a.s.l.)	**.014**	**.017 A<B**	**.027 A<C**	**.021 A<D**	.793	*.061 B<D*	*.062 C<D*
Percent canopy cover	**.042**	.865	.126	**.020 A<D**	.529	**.027 B<D**	**.027 C<D**
Species richness (# of species per plot)	*.087*	.145	*.074 A<C*	**.020 A<D**	.293	.125	.799
Total biomass (MgC/ha)	**.043**	.610	.865	**.021 A<D**	.674	**.042 B<D**	**.007 C<D**
Oak biomass (MgC/ha)	**.024**	.349	**.042 A<C**	**.021 A<D**	.529	**.027 B<D**	**.027 C<D**
Other biomass (MgC/ha)	**.026**	.481	.124	**.020 A<D**	.561	**.040 B<D**	**.007 C<D**
Medium-sized oaks (# of oak stems 20-49 cm dbh)	**.013**	.289	*.059 A<C*	**.038 A<D**	*.056 B<C*	**.010 B<D**	.103
Medium-sized other species (# of other species stems 20-49 cm dbh)	**.026**	.294	.105	**.014 A<D**	.396	**.018 B<D**	*.097 C<D*
Pine regeneration (number of pine stems <3 cm dbh)	**.046**	.497	.393	**.018 A>D**	.155	**.024 B>D**	*.064 C>D*

3.2 Tree community variation among zones

Tree community composition and the distribution of tree biomass differ across the zones of firewood harvest intensity (Table 2). Differences in species composition between zones were observed by species class – pine, oak and other species. Plots in Zones A, B and C contain less total biomass than does Zone D, the area of the *ejido* least impacted by firewood harvest. The distribution of pine biomass is not different between zones. However, there is less biomass of both oak and other species in Zones A, B and C than in Zone D. Zone A, the most impacted area of the *ejido*, also has less oak biomass than Zone C. Zone C is areas beyond roads with high slope, where firewood extraction must take place by hand.

The difference in biomass between zones in part reflects differences in the distribution of medium-sized (dbh 20-49) individuals of oak and other non-pine species. Medium-sized stems of oaks and other species are both less frequent in Zones A and B than in zone D. Zone C has marginally more medium-sized oaks than either A or B. Zone D has marginally more medium-sized stems of other species than does Zone C.

Nonmetric multidimensional scaling ordination of plot tree composition by basal area demonstrates that harvest intensity is not completely aligned with tree species composition. Group 1 in Figure 3 is comprised of sites that are entirely or almost entirely *Pinus montezumae* by basal area. *P. montezumae* is found commonly but not exclusively in lower elevation areas of the *ejido* – it also makes up 22% of basal area in the D site closest to group 1 (situated at 2618 m a.s.l.) and 14% of basal area in the nearest C site (2308 m a.s.l.). This group seems to be defined more by use patterns than by environmental characteristics. Despite two sites in group 1 having been identified as B plots at the time of data collection, their accessibility to the population and the constant presence of humans and grazing animals in the sites makes them more typical of Zone A. Sites in group

1 are all relatively open (average 53% canopy cover) pine forest with pine and oak regeneration and heavy pine needle litter.

If it were the case that firewood extraction intensity was the only factor defining tree species community, one would expect to see the plots grouped exactly by zone in Figure 3. However, group 2 in Figure 3 comprises 10 plots from every zone in which *Pinus tecunumanii* makes up ≥28% of basal area. Given the relatively low presence of *P. tecunumanii* by basal area (≤3%) in all other sites, it is likely that presence of *P. tecunumanii* outweighs management effects as a unifying characteristic of this group. These sites differ by elevation and aspect. Both *P. montezumae* and *P. tecunumanii* grow commonly at all elevations in the *ejido* and on all slopes (Ramírez-Marcial et al. 2010); however, the range of slopes represented in group 2 plots (15-40°) is greater than the range of group 1 (0-20°).Sites outside of groups 1 and 2 are distinguished by their greater diversity of species. In most of these sites, a large proportion of basal area is taken up by species other than pine or oak.

3.3 Environmental characteristics affecting plots across management zones

The different zones of firewood impact are associated with different elevations. Centers of population are in lower elevation areas of the *ejido*, so Zone A, the most accessible area, has lower elevation than all other zones (Table 2 and Table 3). One of the limiting factors of firewood harvest in Zones C and D is that, compared to population centers, those zones are either on steep slopes or flatter areas above these steep slopes that are inaccessible by road; Zone C plots have highest average slope, and Zone D plots have the highest average elevation (Table 3).

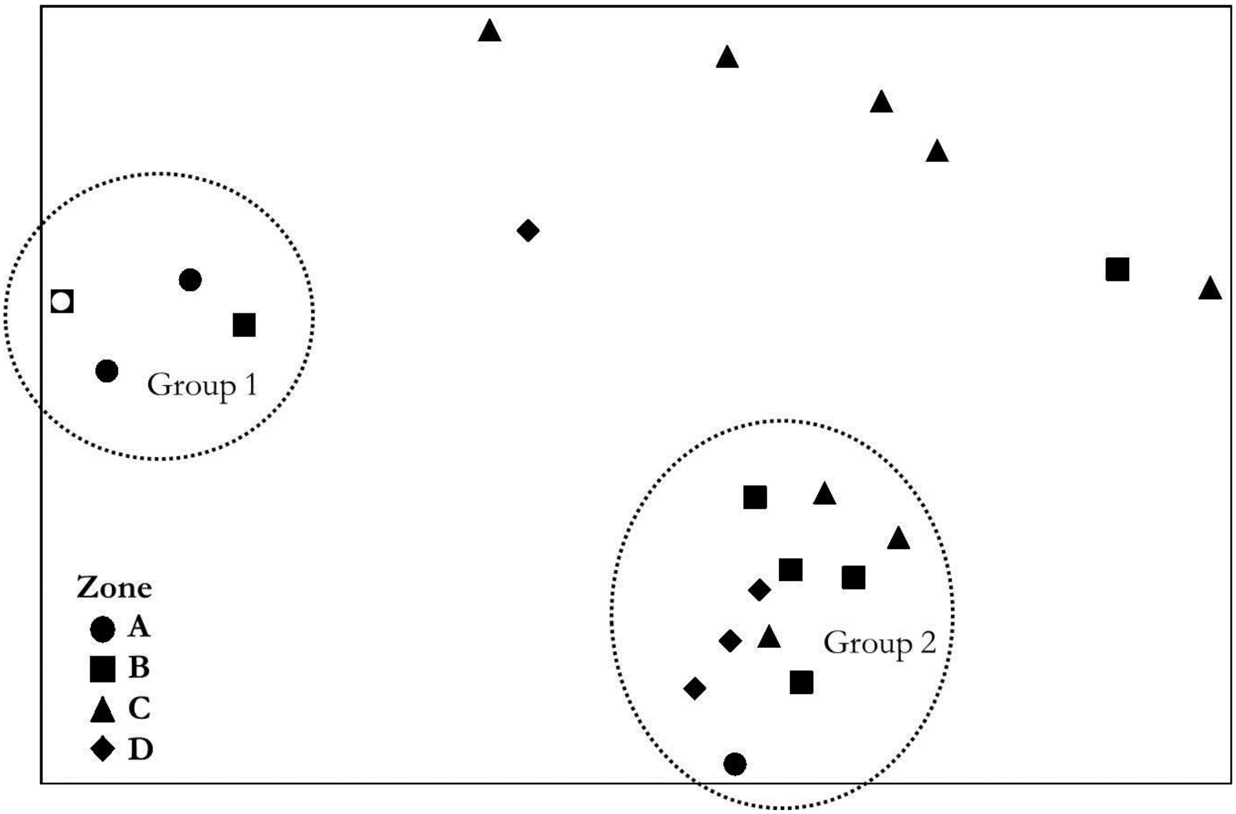

Figure 3. Ordination of basal area composition in data collection plots. ◘ Indicates a direct overlap between 1 Zone A and 2 Zone B plots.

Table 3. Environmental characteristics of zones of firewood harvest intensity, calculated as average of all sample data in each zone.

Zone	**Elevation range** (m a.s.l.)	**Average slope** (◦)	**Average canopy cover** (%)
A	2280-2320	18	61
B	2336-2501	19	64
C	2308-2449	34	69
D	2348-2618	30	85

Canopy cover is a management-influenced site characteristic. Average canopy cover increases with decreasing zone accessibility (Table 3), and Zone D has significantly more cover than Zone A (Table 2). Species richness varies with marginal significance by zone; Zones C and D each demonstrate greater richness than Zone A (Table 2). In particular, other species richness increases considerably in sites with >60% canopy cover (Figure 4).

Throughout the *ejido*, microsites create conditions that are more favorable to certain tree species. For example, Indicator Species Analysis demonstrates a relationship between *Quercus laurina* and Zone D (Table 4). Because Zone D has higher elevation and greater canopy cover than other zones, however, it is difficult to say that *Q. laurina* is associated with that zone because it is where least firewood harvest occurs. It is possible to refer more directly to that species' established association with high elevation and dense canopy cover (Eduardo Martínez Ovando, personal communication, 26 April 2012; Figueroa-Rangel and Olvera-Vargas 2000, Valencia A. 2004). *Quercus crispipilis* and *Buddleja cordata* are indicators of Zone C, possibly in relation to steeper slopes or lower intensity harvesting.

The presence of stumps of different species classes at different data collection sites also demonstrates the compounding effects of site environmental and management characteristics (Figure 5). Stump data suggest that few oaks have been harvested recently in Zone A, but this information must be interpreted together with the knowledge that oaks currently make up <5% of basal area in 3 out of 4 Zone A sites. This is likely due to a combination of environmental and human impact factors. Oaks stumps were observed in each of the other zones.

3.4 Regeneration

Though there is no difference in the distribution of the number of stems of oak or other species <3cm dbh (seedlings and saplings) by zone, there is a difference in the distribution of pine seedlings by zone (Table 2): there are more pine seedlings and saplings in Zones A and B (and with marginal significance in Zone C) than there are in Zone D. The number of pine seedlings and saplings decreases with increasing canopy cover, with the most individuals populating the 45-59% cover class. The maximum number of pine seedlings are found in plots with <65% cover, while plots with the most oak seedlings have between 55-75% cover and the plots with most other species seedlings have over 75% cover (Figure 6). Elevation influences which species regenerate at each site. Ordination of tree species for all stems <3cm dbh by plot (Appendix 4) shows strong grouping by elevation class.

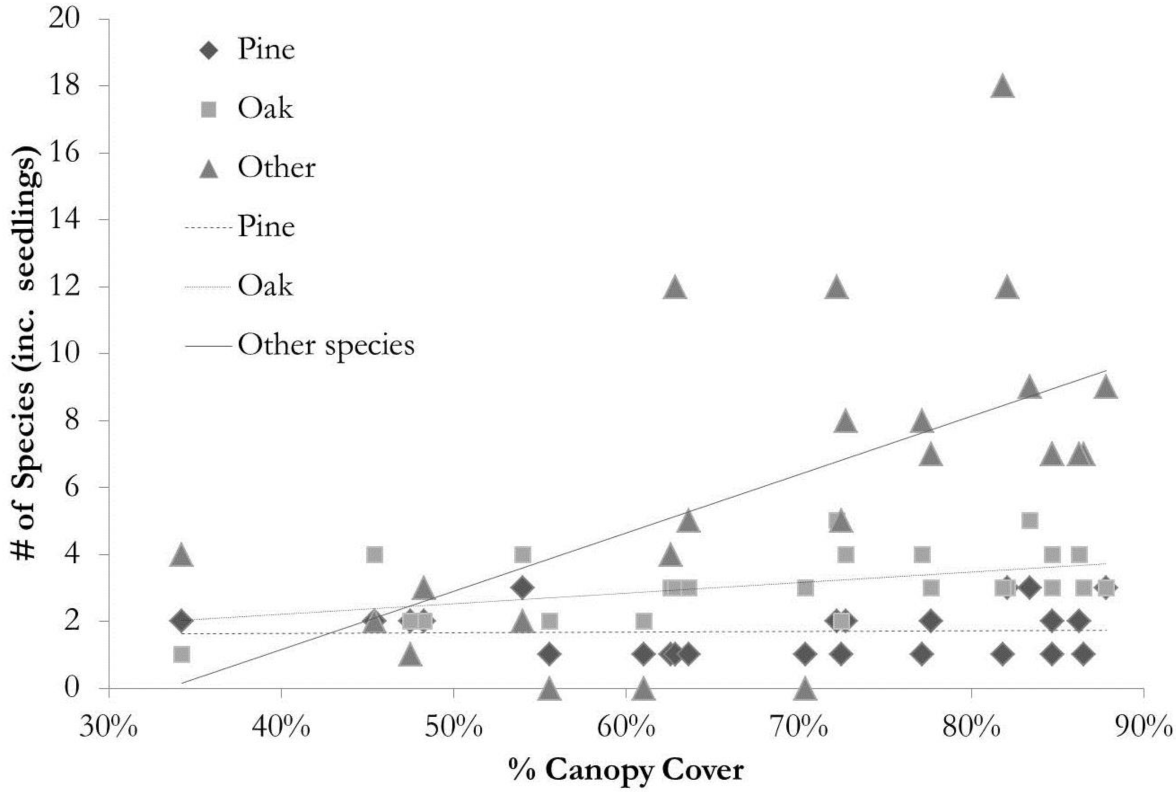

Figure 4. Species richness by canopy cover

Table 4. Maximum observed indicator values assessed for all trees ≥3cm dbh by basal area, all trees ≥3cm dbh by number of stems, and for stems of all sizes. P = proportion of randomized trials with indicator value equal to or exceeding the observed indicator value. List includes all species with p ≤ .10. See Appendix 3 for full indicator species analysis results.

	Species	Observed Indicator Value (IV)	Zone with Maximum Observed IV	P
PERCENT BASAL AREA stems ≥3cm dbh	*Quercus laurina* Bonpl.	85.1	D	0.00
	Quercus crispipilis Trel.	64.8	C	0.00
	Pinus montezumae Lamb.	46.4	A	0.06
NUMBER OF STEMS ≥3cm dbh	*Quercus laurina* Bonpl.	61.0	D	0.01
	Quercus crispipilis Trel.	54.1	C	0.01
	Buddleja cordata Kunth	45.6	C	0.10
	Pinus montezumae Lamb.	44.6	A	0.10
NUMBER OF STEMS TOTAL	*Quercus laurina* Bonpl.	70.9	D	0.00
	Buddleja cordata Kunth	45.6	C	0.10

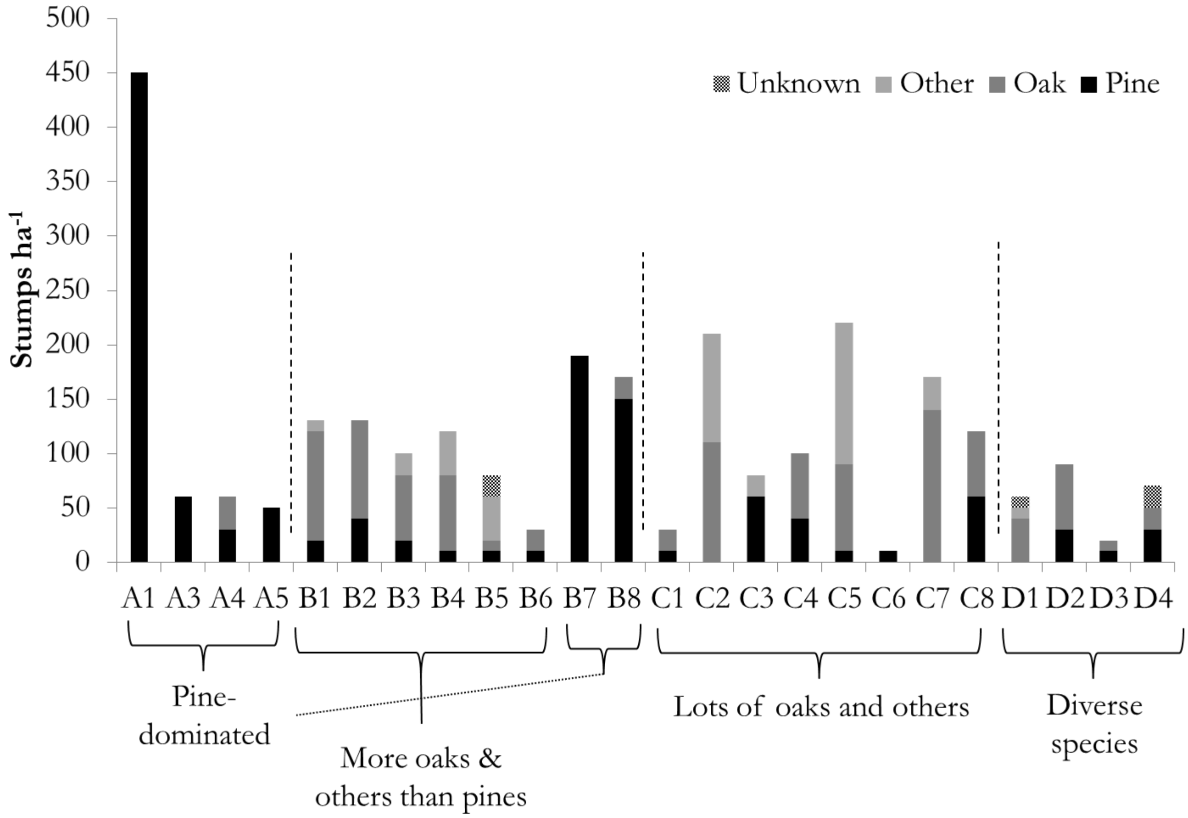

Figure 5. Stumps per hectare counted in each data collection plot. Dashed vertical lines delineate zones.

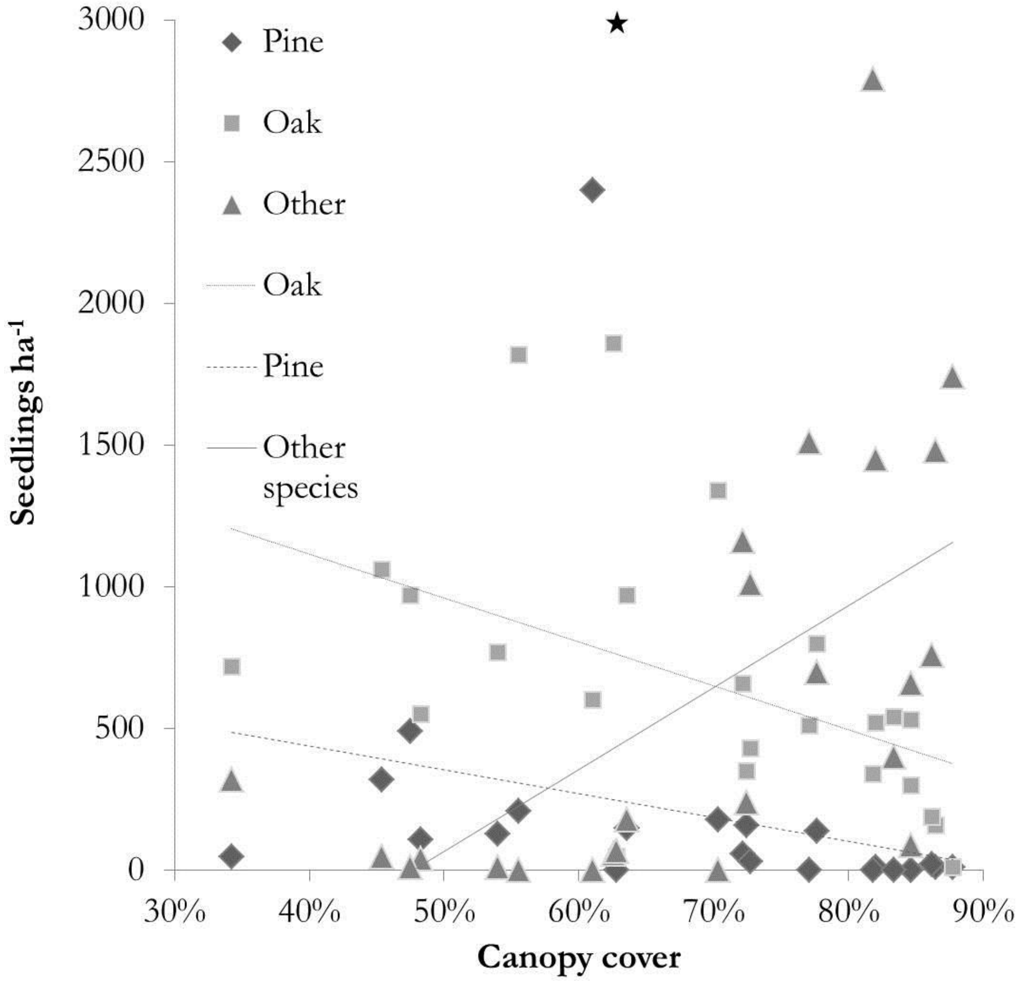

Figure 6. Regeneration by species class compared with canopy cover. Average canopy cover in plots sampled in Zones A, B, C and D is 61%, 64%, 69% and 85%, respectively. ⋆ Indicates a plot off the chart with 11600 pine seedlings ha^{-1}.

4. Discussion

4.1 Characteristics of firewood extraction zones

Zone A has the most open canopy, a high proportion of pine biomass and considerable seedlings and saplings in each of the species classes, particularly oak seedlings. This is the zone most impacted by humans, but not necessarily where the most firewood is extracted. The preferred firewood species are not big enough in most of Zone A to merit their harvest. Community mores limit *ejido* members from cutting trees in direct view of residential areas, so it is likely that any pine cut in this zone are for timber production, which has a perceived higher economic incentive than firewood. In this zone, community members cut down oak seedlings to prevent competition with pines.

Traditional forest management in the Chiapas highlands is a shifting cultivation *milpa* system: corn, beans, squash and other vegetables are grown on a slash and burn cycle. The land is left to rest 3-15 years in between vegetable production, and firewood can be harvested from trees that come back during the rest period (Wagner 1962, Roncal-Garcia et al. 2008). *Milpas* are traditionally concentrated around population centers, in and around the area classified in this study as Zone A. In Lázaro Cárdenas, as in other *ejidos* in the Chiapas highlands, Zone A *milpas* transitioned to non-forest use or were abandoned and allowed to return to forest as people established more residential and commercial infrastructure in the center of the *ejido* (Ochoa-Gaona and González-Espinosa 2000). Scattered *milpas* still exist in other zones of the *ejido*. Sun-tolerant pines colonized abandoned *milpas* more quickly than shade-tolerant oaks, and people prevent oak growth by cutting down seedlings. The impact of constant human and animal presence in these forest stands keeps down the understory, inhibiting the growth of shade-creating canopy layers and further impeding oak or other species regeneration. One plot sampled in Zone A exemplifies an early stage of the transition from *milpa* to open pine forest: that site has significant oak presence including coppiced oak trees with approximately two year-old growth that indicate that it *milpa* was until recently.

Zone B has characteristics of both Zones A and C. There was only one statistically significant difference between Zones B and C across all distributions tested (number of oaks 20-49cm dbh, B<C with p = .056). The presence of roads in Zone B does not seem to facilitate much more firewood gathering there than in the zone just beyond the road. While some people in the *ejido* harvest firewood by hiring a chainsaw and truck in roaded areas, others cut trees down with an axe in any forested area and and carry out the wood. Because trucks can only be used in the dry months, the volume of mechanically removed oak does not cause changes in the forest community in Zone B that are significantly different than the impact of year-round removal of slightly smaller trees by hand in Zone C.

Zone C has more oak biomass than Zone A, reflecting the difference in the amount of time since people first harvested oaks in Zone A as opposed to Zone C. Some extraction of oaks in Zone C is ongoing, evidenced by the fact that Zone C has fewer oaks than Zone D. The incidence of oak stumps in Zone C plots that do not have pine stumps indicates not only that there have been entries for firewood harvest but that people are willing to harvest firewood where the forest has not been opened for timber (pine) harvest by the establishment of a road. Oak harvest can be the initial step in the degradation process. Elsewhere in Chiapas, Miranda (1952, in Rzedowski 1983) found that *Carpinus caroliniana*, a marginally significant indicator of this zone (p = 0.13 by basal area, 0.19 by number of stems – see Appendix 3), established after primary forest clearing. *C. caroliniana*'s presence in Zone C is also suggestive of the higher species richness and greater dominance of understory trees and shrubs under closed *Pinus*-*Quercus* or *Quercus*-dominated canopies, such as those of Zones C and D, than in more simplified *Pinus*-dominated stands (Quintana-Ascencio et al. 2004).

An oak, *Quercus crispipilis*, is one of the species identified in Lázaro Cárdenas classified as vulnerable on the IUCN Red List of threatened species (IUCN 2012; for a full list of *ejido* species' Red List status, see Appendix 1). *Q. crispipilis* is a strong indicator of Zone C (see Appendix 3), and its survival in the *ejido* should be monitored if roads are built into that area or it is otherwise accessed more frequently for firewood harvest. All critically endangered, endangered and other vulnerable species recorded in Lázaro Cárdenas were all hardwoods that are most abundant in Zones C and D and out-competed by pines in Zone B and/or selected against by humans in Zone A.

Zone D has the most biomass of all zones; this zone is distinct from other areas of the *ejido* in its retention of oak and other non-pine species biomass. Zone D has more medium-sized stems of oak and other non-pine species than Zones A or B, indicating that *ejido* residents are taking advantage of the "low-hanging fruit": trees that are of a useful size for firewood are being harvested where it is most convenient. The presence of stumps is evidence that Zone D experiences some harvest. Community members suggest that it is harvested by people from neighboring *ejidos*, who can access Zone D forest via roads, though they are not permitted to go in Lázaro Cárdenas' forest. Alternatively, harvest in Zone D may represent cutting by community members that the *ejido* is unaware of or reluctant to admit to outsiders because of the value that they assign to well-conserved forest.

4.2 The degradation process

Current firewood harvest practices may be one of the first steps in the forest degradation process leading to increased pine dominance of the pine-oak forest in the highlands of Chiapas (González-Espinosa et al. 1991, 2001). Firewood harvest targets oaks and creates gaps or partial canopy clearings in the forest that favor the regeneration of pine (Quintana-Ascencio et al. 2004), which is then protected by Lázaro Cárdenas residents who value it for timber. Stump and current tree data indicate that oaks have not been a major component of the Zone A system in the *ejido* for quite some time. This was likely initiated by the firewood harvest-pine transition process and exacerbated as a result of increasing *ejido* population and intensification of land use in that most accessible areas of the *ejido* (Ochoa-Gaona and González-Espinosa 2000, INEGI 2011). Selection harvest of the best oaks will continue in the future as areas of the *ejido* are opened by road establishment (Zone B-type forest). People collect firewood by hand throughout the *ejido* regardless of road access, but the more ground the roads cover the easier it is for residents to remove more firewood, even beyond the roaded area. The diversity of species and the oak and other hardwood indicator species of Zones C and D support the idea that the firewood harvest-pine transition process has not affected those zones to the extent that it has the areas of the *ejido* with roads, Zones A and B. However, it may be expected that in a few years, as oaks are eliminated in Zones A and B, community members' demand for firewood will be higher, which may result in increased extraction in Zones C and D.

4.3 Restoration

Members of Lázaro Cárdenas became aware of changes in their forest community while natural regeneration of robust pine-oak forest is still possible. Species that often establish in the mesophyll mountain forest, such as *Cornus disciflora* and *Carpinus caroliniana* (Rzedowski 1983) or *Pinus* *oocarpa*, which often replaces *Pinus tecunumanii* (Conifer Specialist Group 1998 2012), are not yet indicators of any zone, as might occur in the case of a long-lasting transition of the forest community. An important feature of degradation events is whether their structural legacies conserve or eliminate sources of regeneration (Griscom and Ashton 2011). Firewood harvest is an acute driver of degradation. In Lázaro Cárdenas, we find no evidence that firewood harvest or other activities impacting the forest have yet eliminated the seed sources of the key species of the most recent dominant forest community. Despite the considerable disturbances from firewood harvest evidenced in the different zones of the *ejido's* forest, each zone has an abundance of regeneration in all species classes. As long as they are not eliminated by humans, shade-tolerant oak seedlings (González-Espinosa et al. 1991) will continue to survive in the area of the *ejido* with most canopy cover – Zone D. Regeneration of oak and other non-pine species in Zone A indicates that even in that most-impacted zone of the *ejido* non-pine species are not entirely gone from the system even as community members attempt to control their numbers by cutting them down.

Modifications of *ejido* residents' behavior with respect to firewood extraction and their priorities for forest management would result in restoration of large areas of forest. Key elements of such behavior changes are 1) to create shade, enabling oak seedlings to compete with pine seedlings; 2) to stop the thinning of oak seedlings and protect a number of individuals in anticipation of their release upon harvest of mature pine trees; and, 3) to implement browse control to facilitate natural regeneration. In order to ensure that future generation can be independent with respect to firewood resources, the community should develop an oak management plan. Harvesting oaks should be off-limits in Zone D. In other parts of the *ejido*, a minimum and maximum diameter should be established below and beyond which oaks cannot be harvested – ensuring a renewable firewood supply by protecting young trees and legacy trees. The board of directors should assign a "forest vigilance” committee that has responsibility for ensuring that the *ejido*’s resources are not compromised by incursions by outsiders. This could be accomplished through meetings with neighbor *ejidos* regarding rules and more frequent monitoring of all parts of the forest, particularly those parts on the border where people do not have cause to be often.

Traditional *milpa* agriculture with sufficiently long rotation periods can be a sustainable method for highlands *ejido* members to meet both food and fuel needs (Diemont et al. 2011, Dalle et al. 2011).

In order to supplement natural regeneration and/or maximize the production of firewood resources close to the population, the *ejido* might establish oak greenhouses, plantations and/or coppice plots. Further research should explore the potential volume and number of coppice “rotations” with the desired species in such a system. These firewood-focused investments might be supported by the proceeds of *ejido* timber sales (examples of community investment in non-timber forest resources in other parts of Mexico include those cited by Bray et al. 2003).

5. Conclusions

In the community of Lázaro Cárdenas, firewood harvest preferences and abilities are in large part responsible for increasing pine dominance in the traditional pine-oak evergreen cloud forest ecosystem. The degradation of the pine-oak forest to secondary forest in transition zones between pine-oak and pine forest has reduced the resources available to community members. Future studies might use Thomas et al.’s (2011) methodology to determine individual species’ “extraction impact value” as a way of further engaging the *ejido* in management and understanding the value of some of the non-oak hardwoods. Restoration techniques should aim to reestablish a high diversity of species throughout the *ejido*, but particularly in the areas beyond where roads currently reach.

Community-managed forests, particularly in Mexico, have proved effective at maintaining forest if forest resources are managed for the benefit of the community (Klooster 1999, Bray et al. 2008, Porter-Bolland et al. 2012). I am not the first to suggest that Lázaro Cárdenas and other *ejidos* that value their forest resources take steps to actively manage their forest. Many highlands *ejidos* already dedicate more land than Lázaro Cárdenas does to permanent agriculture or to livestock grazing, and as a result have fewer forest resources to use and maintain. They risk becoming less invested in maintaining their forest and more invested in generating cash to buy in fuel resources from outside the *ejido*, potentially triggering a different scale of forest impacts. The scale of this study is small, but it suggests that the diversity and structure of major forest change is underway even in areas of the Chiapas highlands that retain substantial forest cover. *Ejido* members and conservationists who wish to realize the full ecosystem potential of the pine-oak forest of the Chiapas highlands must recognize the land owners' needs. These needs are primarily recognized to be the income earned from timber sales, but resource management planning should not take that value into account. *Ejidos* that want to conserve their pine-oak forest for future generations should build their capacity to manage for multiple products and values, including firewood.

Chapter II: Firewood Use in a Community-Managed Forest in the Chiapas Highlands

1. Introduction

The contemporary pine-oak forest of Mexico, Guatemala, El Salvador, Honduras and Nicaragua comprises 2.67 million hectares, only 26% of the total area that it once occupied in that region (Alliance for the Conservation of Mesoamerican Pine-Oak Forests 2007). It is reduced in extent and degraded as a result of subsistence agriculture, small-scale forestry, livestock grazing and firewood gathering (González-Espinosa et al. 1991). The northernmost extent of the Mesoamerican pine-oak forest, which is also the farthest north wintering ground of the endangered golden-cheeked warbler *(Dendroica chrysoparia)* (Rappole et al. 1999), is located in the highlands of Mexico's Chiapas state.

The highlands forest is important to the Chiapas community of Lázaro Cárdenas because it supplies its 1122 indigenous Tzotzil (Maya) residents with wood fuel for cooking. Lázaro Cárdenas is an *ejido*, one of the indigenous and agrarian communities that manage a total of 80% of Mexican forests (Klooster 1999). *Ejido* members manage natural resources collectively, through an assembly of all registered members and an elected community board (Antinori and Rausser 2007). In addition to firewood, Lázaro Cárdenas residents use their forest as a source of timber (for members' construction projects and for sale outside of the *ejido*) and ceremonial plants. However, Lázaro Cárdenas residents sense that their forest is changing directly as a result of firewood extraction. In particular, they find it harder now than it was earlier in their lifetimes to find *Quercus* species, trees that are only harvested for firewood. *Quercus* are a representative species of the region's traditional pine-oak forest (Miranda 1952, Breedlove 1981, Rzedowski 1983). As *Quercus* disappear, the forest transitions into a pine-dominated community (González-Espinosa et al. 1991, 2001, 2006, 2009, Galindo-Jaimes et al. 2002, García-Barrios et al. 2009). Research by the Alliance for the Conservation of Mesoamerican Pine-Oak Forests (Corral et al. 2010) supports the fact that forest change is occurring in Chiapas: that organization's work shows that the historical boundaries of the pine-oak forest are more extensive in the highlands than the area currently occupied by pine-oak ecosystems.

Due to Lázaro Cárdenas' desire for forest resource independence now and in the future, understanding forest degradation and the potential for forest restoration in that community is an urgent need. If unchecked, degradation due to firewood extraction in Lázaro Cárdenas may impact the composition of the forest community in such a way that residents will have to adapt their uses of the forest, using less-preferable species for firewood, timber or traditional ceremonial uses. Forest devaluation due to excessive firewood extraction could lead to an intentional or unintentional shift in use of forest to land for agriculture, grazing or development. Both of these potential effects have consequences for the ecology of the Chiapas highlands and the species that the region can support.

1.2 Firewood use by communities in Mexico

The average fuelwood (firewood and charcoal) consumed per year in Chiapas is over 12,000 tons (Masera et al. 2006); and the Tzotzil area of the highlands is considered to be one of Mexico's 16 "hotspots" of firewood use impact (Ghilardi et al. 2007). Ghilardi points out that due to the high variability of firewood use and impact even in regions of cultural and economic similarities (e.g. Quiroz-Carrana and Orellana 2010), it is important to study this subject at small spatial scales.

Case studies of *ejidos* in Chiapas and other highly firewood-dependent regions of Mexico (Michoacán, Tabasco, Yucatán) have focused on understanding the amount of firewood used, firewood use's effect on the climate (Ochoa-Gaona et al. 2011, Bailis et al. 2012) and the impact of new cookstove technologies (particularly the health and fuel use changes associated with their uptake). More than 70% of fuelwood used in Mexico is obtained by and for its users, while 30% is purchased (Arias et al. 2010). *Ejido* case studies find that firewood is principally used for domestic consumption (Ochoa-Gaona et al. 2011), but Lázaro Cárdenas is still somewhat exceptional in that it does not buy or sell firewood outside of the *ejido*. There is no legal obligation to report the amount of firewood harvested for that purpose (Arias et al. 2010). Case studies' and models' quantification of firewood consumption per person range from 2.1 kg/person/day in the Yucatán – a warmer climate than the highlands of Chiapas (Quiroz-Carrana and Orellana 2010), to 3.0 kg/person/day for temperate Mexican forests (Ghilardi et al. 2007), to as much as 16.9 kg/person/day in the rainy season in Chiapas (Suárez 2009). Most assessments of firewood use in the highlands of Chiapas are between 2-6 kg/person/day (Calderón 2001, Riojas-Rodríguez et al. 2001, Escobar-Ocampo et al. 2009, Burgos Lugo 2010, Ramírez-López et al. 2012). These studies serve as the basis of methodologies for community needs assessments such as that of Holz and Ramírez-Marcial (2011). The case studies also demonstrate that traditional open fires continue to be used when "firewood-saving" stoves are available and in use (Troncoso et al. 2007, Escobar-Ocampo et al. 2009); Ramírez-López et al. (2012) found no significant differences between firewood use in households that use firewood-saving stoves in combination with traditional stoves and those that only use traditional stoves. Despite their widely varying designs, most firewood-saving stoves that function correctly contain particulate matter from cooking fires better than traditional stoves (Riojas-Rodríguez et al. 2001). This has been found to have a positive effect on health of cooks and household members who spend time in the kitchen building (Sandoval et al. 1993, Troncoso et al. 2007, Burgos Lugo et al. 2009, Riddervold et al. 2012).

Firewood is a renewable resource and potential environmentally sustainable energy source for communities such as Lázaro Cárdenas. However, several challenges act as barriers to enhancing the production potential of Mexican wood fuels (Arias et al. 2010):

1) Existing selective cutting practices without thinning or other maintenance efforts directed at enhancing oak stocks;
2) Underdeveloped/informal market;
3) Government agencies/regulations' preference for low-intensity management strategies; and,
4) Low *ejido* capacity for intensive management and/or access to markets.

Mexico's ejidos

During his 1934-40 presidency, President Lázaro Cárdenas oversaw transfer of much of Mexico's forest to communal land management (Klooster 1999, Mathews 2008). It wasn't until the late 1980s that a grassroots movement and forest service officials supportive of indigenous people's rights claimed power for communities, claiming that indigenous people would be "ecologically sensitive guardians of nature" (Johnson and Nelson 2004, Bray et al. 2006, Mathews 2008). *Ejidos* are required to have a government-approved timber management plan. Nationally, however, fewer than a quarter of such plans are active due to high preparation costs (White and Martin 2002).

While many studies have analyzed the strengths and challenges of forest management by *ejidos* (among others Klooster 1999, Asbjornsen and Ashton 2002, Bray et al. 2003), such work are typically focuses on community forestry enterprises that manage for commercial timber as a first priority. Firewood, non-commercial timber (for local construction) and non-timber forest products are more often integrated into commercial timber management plans to support the community and ensure that timber values are maintained, rather than prioritized on their own rights. My work suggests that for communities such as Lázaro Cárdenas, where timber management is not well-understood by the majority of *ejido* members, firewood management might be the place to start a forest management plan.

1.3 Induced pine forests

Quintana-Ascencio et al. (2004) found that wood removed to be used as fuel has a structural impact on the ecology of the region that makes it at least in some part responsible for *pinarización*: induced pine dominance of stands that were formerly pine-oak forest. To what degree fuelwood removals are responsible for inducing change in biomass and vegetation community composition is unknown. Oak harvested for firewood are usually logged before they get too big to remove easily from the forest, which is often before they reach reproductive maturity (González-Espinosa et al. 1991, 2001, 2006, 2009, Ramírez-Marcial et al. 2001, García-Barrios and González-Espinosa 2004). For the most part, pines are left to grow to merchantable timber size (>20cm or >35cm dbh), beyond reproductive maturity (Ramírez-Marcial et al. 2001, García-Barrios and González-Espinosa 2004, González-Espinosa et al. 2006). Ramírez-Marcial et al. (2001) and Galindo-Jaimes et al. (2002) suggest that there is a threshold value for stand basal area of *Pinus* spp. beyond which the basal area of *Quercus* spp. drastically decreases, and further that induced pine forests typically are species-poor and structurally simpler than the pine-oak forest they replace. Induced pine dominance is increasingly common in the Chiapas highlands and its resource-supply and ecological consequences should be considered in *ejido*s' land management strategies.

1.4 Potential for regeneration

According to González-Espinosa et al. (1991), local extinction of many mesic species is not a guaranteed result of the increased occurrence of dry pine forests. Oak species are more shade-tolerant than pine species, and therefore could flourish under pine-dominated canopies until the pines are harvested or until the oaks join them in the upper canopy (Galindo-Jaimes et al. 2002). Conversely, other broad-leaved species might not establish as well in the interior conditions of a pine stand as they would in a more varied pine-oak forest (Ramírez-Marcial et al. 2001, Galindo-Jaimes et al. 2002).

For much of the highlands, it is unclear if changing firewood harvest practices alone, or even completely excluding human and animal presence from an induced pine forest, would facilitate the growth of a more diverse oak-dominated community or if those pine forests would persist (Galindo-Jaimes et al. 2002, González-Espinosa et al. 2009). It is important for communities that wish to restore native forest types for resource and ecological purposes to refer to locally developed information on the propagation and plantation of native plants and restoration of forests in general, particularly that with a firewood-focus (e.g. Holz and Ramírez-Marcial 2011).

1.5 Study purpose

The connection between an *ejido*'s firewood requirements and the effects of firewood harvest on forest communities has not previously been detailed in a case study. This study's goals are 1) to document forest degradation due to firewood harvest in a Chiapas *ejido* from the perspective of its residents; and, 2) to identify practical ways of enhancing forest management to benefit future generations in the *ejido* and regional biodiversity conservation. Non-governmental organizations and government agencies need criteria for the types and amount of support they provide to forestdependent Chiapas communities. This study provides an example of management practices (or lack thereof) that make an *ejido* a priority for, and well suited to, intervention. This study focuses on communities that, through firewood extraction, are the primary perpetrators of forest degradation. It proposes strategies by which those communities might attempt to ensure their resource needs are met while enhancing the ecological complexity of the vegetative community, thereby supporting native fauna communities and maintaining environmental processes.

In order to understand firewood harvest-induced forest degradation, I estimate firewood use, assess the impact of that use on the existing forest, and examine existing and potential management and restoration strategies. Participant observation forms the basis of the study. Semi-structured interviews provide the bulk of my data on firewood harvest and use practices within the *ejido*. I conducted statistical analysis of data obtained in direct measurement of the *ejido*'s forest in order to understand the composition of the current forest community and capture existing impacts of firewood harvest. I use the case of Lázaro Cárdenas to draw direct connections between firewood use and forest community change. Finally, I offer some suggestions for community management grounded in ensuring firewood supply but appropriate to maintaining functioning pine-oak forest ecology.

2. Methods

2.1 Learning about local perceptions of the forest

I followed the approach of Weiss (1995) in conducting semi-structured interviews in order to learn about people's perceptions about their forest and firewood use. A preliminary interview guide was developed based on the *ejido*'s perceived challenges and other firewood use studies (Burgos Lugo et al. 2009, Burgos Lugo 2010, Quiroz-Carrana and Orellana 2010, Holz and Ramírez-Marcial

2011). The interview guide was revised based on testing some of the original questions in conversation with community directors familiar with the project to check for cultural appropriateness and information learned about the *ejido* during the exploratory phase of research.

Interviewees were selected by walking through the *ejido* following irregular paths, without previous knowledge of the households, and randomly selecting doors to approach. At each house, I requested an interview with the male head of household, if present, and the woman of the house. It is a formality that outsiders will speak with the head of household, but these are also men who are or have been responsible for providing firewood for their families. The women in the household are those who "consume" the firewood by using it in cooking and other applications. The presence of two directors assured potential interviewees that it was all right to talk with the outside researcher. Three interviews were conducted in each of the smaller population centers, and 10 interviews were in households within the largest neighborhood.

I started the interview by picking up on the subject where the directors left off in their introductions, which was not always the same – sometimes regarding forest conservation, other times firewood use, other times that week's festival day. Some interviews took the form of a conversation between interviewer and subject, flowing from topic to topic. In others I simply asked a set of questions and received yes or no answers. The interviews began outside, in the household's common space. I asked people about the forest itself, how they interacted with the forest, their use of firewood, and the community's management of firewood (see Appendix 5 for the full interview guide). In each interview, I asked to measure the volume of firewood kept at the house and, if possible, what amount they used during one day. I also examined subjects' cooking, living and other areas to see if there were other uses of firewood that did not come to the interviewee's mind, or mine.

Interviews were conducted in Tzotzil with Spanish translation, or completely in Spanish. Audio of each interview was recorded and the interviews were transcribed in Spanish within a day of recording. The interview transcripts were translated from Spanish to English. The Spanish- and English-language transcripts were classified with short phrases (codes) using ATLAS.ti 6 and 7. A list of codes was created deductively prior to the coding exercise, based on expectations generated from literature and past experience. The coding structure developed inductively, as themes emerged that were pertinent to my research questions.

Per person firewood use was calculated based on information obtained from willing households and averaged to estimate average firewood use. I measured the volume of household firewood reserves and converted it to weight by assuming that firewood reserves were composed of 50% *Pinus* and 50% *Quercus* and applying a wood density factor, 0.594, which is the average of wood density factors two *Pinus* and *Quercus* wood density factors. I used Gonzalez Zarte's (2008) calculation of median *Pinus maximinoi* density at dbh as an estimate for *Pinus* wood density. The *Quercus* factor is an average of Gonzalez Zarte's Quercus spp. calculation and the average of Ramírez-Marcial's (unpublished) factors for *Quercus crispipilis*, *Q. crassifolia*, *Q. rugosa* and *Q. laurina* – all species encountered in Lázaro Cárdenas.

2.2 Assessing current forest composition

During the same time period as interviews were conducted, forest measurement data were collected from 24 0.01 ha circular plots haphazardly located in the forested areas of Lázaro Cárdenas (Figure 1). Plots are located in the elevation range 2280 to 2618 m a.s.l. All sampling sites were reached on foot in the company of community directors. All of the sites were grazed to some extent by: goats, sheep, pigs or horses. In each plot except for A1, B1, and B2, all trees ≥ 3cm dbh (diameter at breast height, 1.4m above ground level) were measured for diameter to the nearest 1 cm and identified to species. (In plots A1, B1 and B3, the minimum dbh for this measurement was 5cm. Those three were the first plots measured; experiences in those plots demonstrated the need to adjust data collection protocol to capture stems 3-5cm dbh that composed an important part of the forest community.) Heights of 3 trees representing the upper canopy and 3 representing the lower canopy were measured. Cores were extracted from three *Pinus* individuals in each plot with increment borers at a cross slope position to reduce potential of encountering compression wood. All stems of tree species < 3cm dbh (seedlings and saplings) and stumps were identified to species and counted.

Individual tree biomass was calculated with equations suited to the species classes and region. For *Pinus* species, I used the equation described by Mendoza-Ponce and Galicia (2010) and developed by Ayala-Lopez et al. (2001) for the same and similar *Pinus* species in the central Mexican plateau: $Y = 0.084(\text{dbh})^{2.475}$. Návar (2009)'s *Quercus* species equation for total aboveground biomass, developed for northwestern Mexico, was used for *Quercus* species in this study: $Y = 0.089(\text{dbh})^{2.5226}$. Návar's equation for *Quercus* was used here in place of that of Ayala-López (2001) because the latter requires tree heights, which were not available for all individuals. It was considered that extrapolation of heights based on a regression equation created from the measured heights of 4.5% of total oak individuals would add uncertainty. Návar's equation for total aboveground biomass of tropical dry forests was used for all other genera. That equation, $Y = 0.37(\text{dbh})^{1.96}$, calculates considerably lower biomass for these other genera than do the equations for *Pinus* or *Quercus* species.

Data collection plots were identified with 4 zones defined based on the quantity of firewood that could be harvested and removed at one time in that area of the forest. 4 plots were located in each of Zones A (highest human impact) and D (least human impact), and 8 plots each in Zones B and C, in order to describe greater differences in those intermediate zones, where the most firewood is extracted. Zones were drawn in ArcMap 10 based on first-hand knowledge, forest classifications, satellite imagery, and elevation data (Centro de Planeación e Información para la Conservación de ProNatura Sur A.C. 2011). For each zone, biomass per hectare (total and by species class) was calculated by averaging the biomass of the plots in that zone.

Table 5. Forest uses in *ejido* Lázaro Cárdenas in order of perceived importance as described by *ejido* members.

Activity	Desired tree species	Proponent	Permission to harvest	Limitations
Construction timber harvest	*Pinus ayacahuite* *P. montezumae* *P. tecunumanii* *P. pseudostrobus*	*Ejido* members	Permission from the *ejido* board to harvest specific trees identified by the "applicant"	• Must use the whole tree – do not leave limbs • Report to the *ejido* board when harvest is complete • Permitted harvest: ~5 trees per household per 5 years • Harvest of *P. ayacahuite* not permitted
Firewood	*Quercus laurina,* *Q. crispiplis* *Q. peduncularis* *Q. rugosa* *Pinus montezumae* *P. tecunumanii* *P. pseudostrobus*	*Ejido* members	No permission required	• No formal restriction, but the norm is not to cut more than three truckloads per family at one time
Plants and saplings for use as decorations	A variety of *Orchidaceae* species *Chamaedorea ibarrae* *Myrsine juergensenii*	*Ejido* members, principally board members in preparation for holidays	No permission required	No restrictions

3. Results

3.1 Perceived value of Lázaro Cárdenas' forest

Table 5 describes the four major uses identified in this study for Lázaro Cárdenas' forest products. Like many *ejidos*, Lázaro Cárdenas manages its forest for timber production. A group of *ejido* members manage a sawmill and furniture factory in the center of the *ejido* and are granted responsibility for all commercial timber harvest. Residents described several medicinal uses for forest plants, but in most cases they could not be precise about these plants' identification, preparation, treatment ability or effectiveness. For example, when asked if there were plants in the forest that the community members use, one respondent said "Yes, there are plants. We don't know their names. [We use them for] decorations, medicine, a little bit of everything." Another said,

> *There are flowers that we hang [points to lilies around the yard], for the house. I don't know the names. There are some medicinals…. For coughs, we cut the leaves of certain bromeliads and cook it in a tea.*

Some years ago, but within current members' lifetimes, the *ejido* operated a nursery that grew *Juniperus gamboana* Martinez to plant along the *ejido*'s river. The nursery lost funding and is now defunct.

Firewood for cooking and heating

Table 6 presents the ways that I observed that firewood used 15 Lázaro Cárdenas households.

The traditional stove of the Chiapas highlands, the *fogón*, consists of a raised concrete platform that supports an open fire. Flat, circular *comales* are typically propped directly over the fire for grilling tortillas. In recent years, the Secretary of Social Development (SEDESOL) has given many community members "firewood-saving" or "ecological" stoves. In Lázaro Cárdenas those stoves contain the cooking fire inside brick walls and transport its smoke via a pipe that goes through the kitchen's roof. Wood-fueled stoves, especially open fires, have a secondary purpose: 8 of 16 interviewees talked about the importance of the warmth provided to family members by the kitchen fire, particularly in the rainy season. When asked if she used more heat in the summer (the rainy season) than in the winter, a subject responded

> *Yes, yes to heat. Because we have animals, sometimes we go out into the mountain, sometimes we come back wet and put on more wood to warm us up.*

Another said that they used a traditional fireplace to warm themselves, not only during the afternoon but "all year round. It is always cold during the afternoon." Some residents prefer the traditional fire over the firewood-saving stove for warming. In a household that had both types of stoves, a man admitted that though it makes more smoke, his family uses the traditional stove because it "warms more rapidly. This for me doesn't warm the house well. We use it to keep us warm." Another interviewee with both a firewood-saving stove and a traditional stove indicated that they use the traditional stove to keep warm, "nothing more." She said,

> *Nothing more than I'm going to make a little [fire] here. I have my little kids that come here to warm themselves up. When they feel cold, we make a little fire here in the morning. Not in the afternoon.*

Some use portable braziers for the same purpose: "This is to go into the room [outside of the kitchen building]. If you are cold, you use it, if you are not cold, you don't use it," said one woman.

Firewood is also used to heat saunas, a type of bath becoming less common among residents of the *ejido:* one respondent indicated that they only use the sauna about three times a week, but that it was more before. At another house the interview subject, a woman, laughingly told me it was only used by old men.

Propane-fueled stoves are used in some homes in Lázaro Cárdenas, but the quality of the *ejido's* roads makes it difficult to transport propane tanks to most parts of the community. Both interviewees who relied almost exclusively on gas lived on paved roads where trucks passed frequently. One knew about, a propane storage facility two kilometers down the road, and said that his propane was delivered. In contrast, in a household where there were two gas stoves going unused (the family cooked with a traditional stove), I was told "you can't get gas, you have to go get it. Here they don't sell it, let's say, very nearby. You have to go and ask for it." Perhaps there was a wealth differential between the two households that made the two kilometers seem greater or more burdensome to the second subject than the first.

Another barrier to using gas is the necessity of cash to pay for the propane. In the household where there were two unused gas stoves, the cost of propane is considered to be prohibitive:

> *Let's put it this way, like we use it, it doesn't last, unless we specifically try not to use very much gas we go through a lot. So it's better that we cook with wood.*

Wood is considered to be a free resource, though one interviewee had priced it out and determined that by the time he paid everyone involved in the harvest, using propane was less expensive than using wood.

Residents prefer tortillas – a staple food – cooked on *comales* or firewood-saving stoves to those cooked over gas heat. I asked the owner of a gas stove if they ever made tortillas on the gas stove, and her response was definite:

> *No. I can't. They're poorly made there; one can't make them. The traditional stove is quicker for food than the gas stove. If the food is already prepared, you can heat the food quicker on the gas stove than in the traditional stove.*

Table 6. Use of firewood in 15 Lázaro Cárdenas households. Three of these households also use firewood to heat saunas, two use firewood in braziers for heat, and one had an outdoor fireplace.

Traditional stove only	Firewood-saving stove only	Traditional & firewood-saving stoves	Traditional & gas stoves	Traditional, gas & firewood-saving stoves
6	1	4	3	1

3.2 Formal and informal community forest management

I observed that forest management efforts by the *ejido* and individuals consist of official rules set up by the board of directors and mores enforced through social pressure. Unlike many *ejido* boards, that of Lázaro Cárdenas does not have a forest management sub-committee. My research assistants, all directors, said that they walk the forest together once or twice a year to check and make sure that nothing is going on that is not permitted, and that no one ever tries to rob wood from the *ejido*. However, in several instances I saw trees that elders of the *ejido* presumed to be "illegally" felled due to their locations near the *ejido*'s borders. These areas were only easily accessible from neighboring *ejidos*. As I was told by the research assistants, neighboring *ejidos* collaborate on forest management by maintaining fire breaks along *ejido* borders. I observed that these fire breaks do create a distinct border for the *ejido*. Despite these activities and the directors' confidence in their own knowledge of the forest community, on more than one occasion during data collection my research assistants found themselves in areas of the forest where they had never been before.

Timber Perhaps because timber harvest is a method of bringing cash money into the *ejido*, the timber trees – pines – are protected by *ejido* members. In pine-dominated stands, men use machetes to hack down oak and other hardwood saplings. I observed my research assistants unconsciously taking part in this activity. When asked about it, they said that they were "cleaning" around established pine trees in an effort to help them grow. They associate the benefits of such "cleaning" primarily with increased water available to the pine individuals.

Supporting the growth of healthy, merchantable pine seems to be a collectively-felt responsibility, not one limited to those directly responsible for harvest. The directors of the community board informed me that the group responsible for the sawmill/furniture factory is charged with cutting trees approved by an outside forester. This group pays the *ejido* for harvest rights, but no interviewee could explain how the compensation worked. I asked an interview subject if he received benefits from the revenues earned by the sawmill, and he responded “they are going to pay. I don’t know how much they’ll pay.” One explanation for this lack of knowledge is that it was feigned: the interviewee was reluctant to share that information with an outsider.

Timber harvest is a major justification for road-building in Lázaro Cárdenas. Evidence of recent years’ harvest was confined to Zone B, the roaded area outside of the main areas of residential concentration. Some pine-dominated Zone A forests were observed to be nearing harvestable size; it is likely that these forests are at least in a second rotation.

It was well known among interviewees that harvest of one particular species of pine, *Pinus ayacahuite* (pinabete), is prohibited except by special permission. When asked if different types of pine existed in the community, one male resident responded “there are two classes. The other [the one that is not standard pine] is finer – pinabete, it is called.” When the subject was asked if he was allowed to cut the pinabete, his wife jumped in with an emphatic “no!” Residents described not having been able to cut *P. ayacahuite* during their lifetimes because it is rare and the best quality for timber:

> *It’s that first they’re for us, and there aren’t many. That’s why they’re being preserved and you can’t fell them. First-class wood. There aren’t many on the hill.*

The *ejido*’s board suggested that every once in a while it permits harvest of a *P. ayacahuite* tree, for example, to construct a door for a village school.

Construction timber Cement blocks are an increasingly common construction material now that many members of Lázaro Cárdenas earn cash money working outside the *ejido*. Explaining a decline in his income from chainsaw work inside the *ejido*, one subject said the following:

> *[Before,] there wasn't pay to build a house out of cinder blocks. And we'd do it more from wood. But right now the people are changing materials. Now we work more than before outside of the* ejido.

However, timber from the forest is still a low-cost alternative: the cost is only that of the chainsaw operator and any required transportation.

The process for cutting construction timber does not start in the forest. Asked how rules were made for harvesting timber for construction, one subject's reply highlights the adjudicating power of the board of directors and especially its commissioner:

> *It is the commissioner of the ejido. Or rather, these norms are in agreement with the general assembly, of all the* ejido *members. This is the agreement: that when an* ejido *member needs wood for the construction of their house, they go to the commissioner of the* ejido *and ask permission. The agreement appears in front of the general assembly*[1]*. It has always been like this.*

When asked whether the rules change, the same respondent continued.

[1] It is likely that the subject misspoke and intended to say board of directors. The assembly involves all registered members of the *ejido* and does not meet frequently enough to judge every request for construction harvests.

Yes, they change. Rules change. Before, when the trees were big, there were two trees per person. Now that there are not anymore, that they are very slim, now there are three per person.

Residents also explained that the rules had changed during their lifetimes to require removal of all parts of the tree – branches as well as trunk – in an effort to better use the felled wood. After wood is harvested and cut into boards, it may be left in the woods to dry before it is transported to its final destination. During data collection, I passed a few such displays in locations where the directors were unaware what people had been authorized to harvest. The directors noted that they would report their findings to others on the board. The final step in securing timber for construction is to report back to the board that you have harvested and removed your wood.

Decorative and medicinal plants Residents spoke of no formal management for harvest of these products. *Ejido* directors bear responsibility for collecting the bromeliads and saplings that are used to decorate the church and other important sites for holidays, I was told by my research assistants. They work together and maintain that they visit different areas of the *ejido* not only to find the best supply of these plants but also to give a rest to recently-harvested areas.

Firewood Unlike timber, firewood harvest is not regulated by the board of directors. Most residents described amounts of wood removed from the forest in terms of loads of a truck with $7m^3$ bed capacity. When pushed, one interviewee described how he understood the mores regulating firewood removal. First I asked if one needed to have permission to harvest firewood, then I urged him to consider how many truckloads one could harvest in a given year.

For firewood, no [you don't need to ask permission to harvest]. This has another "law." For firewood it depends how you use it as well. You can load 2 or 3 trucks a year. Well, no. Now *you couldn't [take 5 trucks]. Only 2 or 3 trucks. Because, well, it has a limit too…. Until now, we haven't seen [anyone] take 5 trucks. Two to three only.*

I also asked about harvesting on behalf of your neighbor ("Well, you can't") and selling firewood outside of the *ejido* ("That you couldn't do. It is prohibited."). Few *ejido* members purchase fuel-wood from outside; only one interviewee said that her household purchased charcoal occasionally. This household was located nearby to a store in a neighbor *ejido* that often had charcoal for sale. When I asked about charcoal-making, this interviewee denied that Lázaro Cárdenas residents have knowledge of charcoal-making: "Here, no! We don't know how to make it, I think! [laughing]."

In addition to volume, the defining factors of firewood harvest are location, cutting method, transport, and seasonality. The forest closest to the centers of residential concentration is protected. One resident explained that he went to the woods to the south of his house for firewood "because close to here you can't cut them [trees] down anymore. You have to look for something further away, because that's what the authorities say. Because here you can't cut trees any closer; they want to you to do it farther away and that's how it is." Like this interviewee, most residents harvest firewood from the area of the *ejido*'s forest that is nearest to their residence but outside the immediate center. "Since we're from here," one resident said, "we go around here, and the people from there [other residential centers] stay there." Harvesters' choice of pine or oak and of tree size is influenced primarily by how they plan to cut and remove the wood. The majority of interviewees described looking for a place where they could take two or three good sized trees (approximate diameters of both 40cm and 80cm diameters were suggested as ideal sizes), preferably oak. If the head of the household that will use the wood does not own a chainsaw, he or she hires someone to cut the trees down and pays that person by the tank of chainsaw fuel. Then a truck is hired and members of the household go with the truck to retrieve the wood, bring it back to the house and stack it. In situations like this, people must harvest within a reasonable distance of accessible roads – limiting harvest to the dry season, December through February, and whatever other times roads are passable.

A portion of people, represented by two of the three interviewees from the *ejido*'s northern center of residential concentration, cut their firewood exclusively by hand, using an axe, and carry it out of the forest. More people live in closer proximity to dense forest in the northern part of the *ejido* as compared to the central and southern *ejido*. Roads in this area are less well built and the people are poorer. People who harvest firewood using chainsaws and trucks also harvest and transport "by hand" to supplement their major loads, especially if they begin to run low during the rainy season. One interviewee described how the whole family helps to procure firewood, often as they are out grazing the animals:

> *I go with my wife, my son. My daughter. The whole family goes to bring a little bit. Sometimes, if there's money, I pay a person with a chainsaw. If there's not, well, then there's no money. Cut, split, carry....*

The trees cut in this situation are smaller, but may come from areas of higher oak concentration as the harvesters are not limited by roads for transportation. Carrying wood from the most remote parts of the *ejido*'s forest is unreasonable, and for that reason the forest on top of many of the steep hills of the *ejido* remains reasonably protected. One hill has the additional protection of being considered a sacred place. This hill, near the northern *ejido* border, is understood to have Maya history and it is where the Festival of the Crosses is celebrated every May with a ceremony and permanent cross markers.

Harvest dynamics affect the proportion of oak and pine used as firewood more than preference for specific species between these two genera. When prompted, interviewees identified some species within each genus, but maintained that the genus characteristics were more important than those of individual species. All households where firewood was observed had reserves of both pine and oak. Interviewees explained that they look for pine because “there isn’t oak” and “oak is very scarce; it’s more isolated and because we’re in the rainy season, the car can’t access it” and “the oak is farther away and the ones that people use the most are here, [closer to households].”

3.3 How much firewood the community uses

Most households estimated that they used 1 truckload of wood a year, the equivalent of 1.9 cords (6.9 m^3) of wood. Representatives of households that harvest firewood by hand on an as-needed basis could not estimate how much wood they used in a year. Of the households for which I were able to calculate firewood use per person per day, the estimated use is 2.45 kg $person^{-1}$ day^{-1} (Table 7). This is on the low end of that which has been found by previous studies in Chiapas. Direct volume measurements – of woodpiles and units of daily use – resulted in an average 10.5 kg $person^{-1}$ day^{-1} use that is on the high end of figures in existing literature. The average of all estimations in our study generates an annual firewood use of 1.4819 Mg $person^{-1}$ $year^{-1}$. Estimation of firewood use is challenging in the absence of a precise measurement system such as twice-daily weight measurements.

3.4 Current forest composition

The estimation of this study that people use 1.4819 Mg $person^{-1}$ $year^{-1}$ is equivalent to approximately 0.74095 MgC $person^{-1}$ $year^{-1}$ which means that a total of 831 MgC $year^{-1}$ is removed from the *ejido*’s forest. I wanted to understand if the way that this amount of biomass is removed from the forest could be related to elimination of meaningful presence of oak species in Lázaro Cárdenas. Results indicate that the *ejido*'s tree community varies with respect to firewood harvest intensity both in distribution of biomass and species composition. Considering the indigenously important categories of pine, oak and other species (all hardwoods), I found that there is more of both oak and other hardwood biomass in Zone D, the areas of least firewood harvest intensity, than in all other zones (Figure 7 and Figure 8). Zone D makes up 19% of the *ejido*'s forested area, but it accounts for 36% of its biomass. Zone B has the most pine biomass (50%), Zone D has the most oak (43%) and other hardwood (45%) biomass. Though Zone A is accessible, it has few oaks, and firewood is largely harvested in Zones B and C. In Zone B, firewood is accessible to trucks in the dry season. Zone C is inaccessible to trucks due to slope or distance from population centers; firewood cut here must be rolled to a road or carried out by hand. Zone D has highest biomass per hectare and is least used for firewood extraction due to its distance from population centers, high elevation, lack of access via roads and, in some areas, sacred site designation.

Table 7. Firewood use by household. Annual use was calculated based on the number of trucks harvested and typical truck bed size. Daily use was calculated by measuring the volume of wood in an armload and multiplying by number of armloads used per day. All figures were annualized and converted from volume to weight. Two different measurements, represented by I(1) and I(2), were taken at household I.

Household	Kg $person^{-1}$ day^{-1}	Data source
A	1.1	Estimated annual use
B	1.3	Estimated annual use
C	1.6	Estimated annual use
D	2.3	Estimated annual use
E	2.8	Estimated annual use
F	3.3	Estimated annual use
G	3.5	Estimated annual use
H	3.7	Estimated annual use
I(1)	10.1	Estimated daily use
I(2)	10.9	Wood pile volume measurement

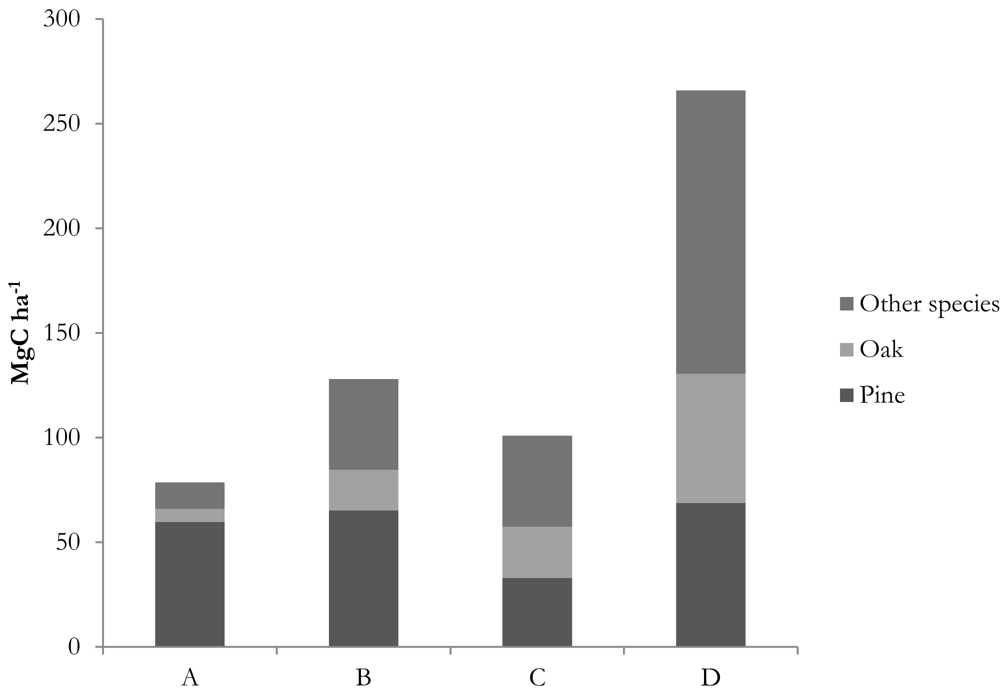

Figure 7. Distribution of biomass per hectare by zone of firewood harvest intensity.

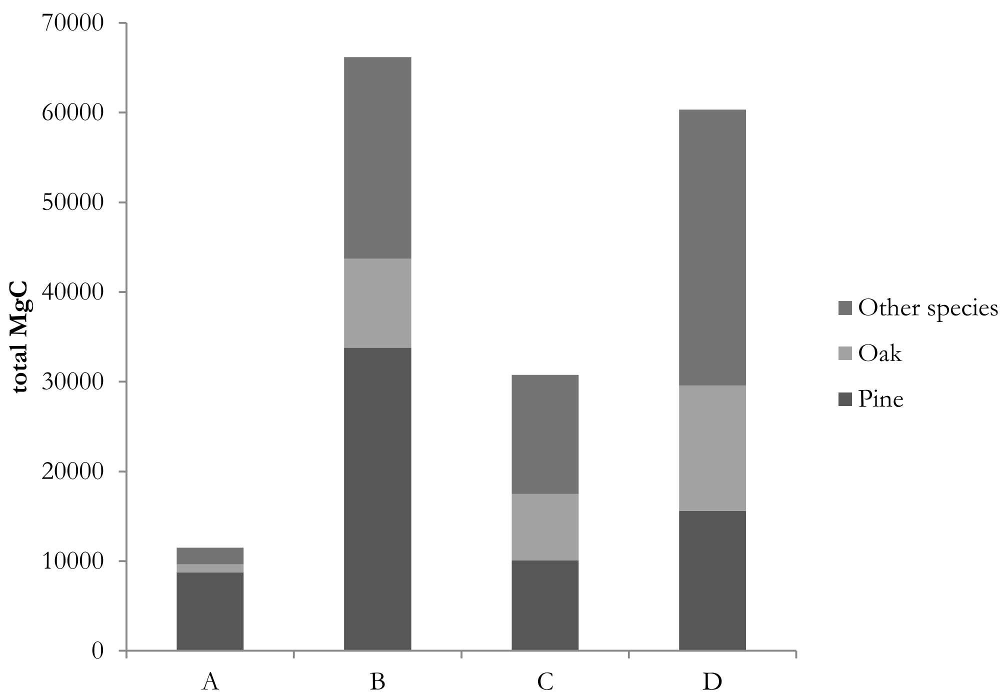

Figure 8. Actual biomass in each of the zones of firewood harvest intensity in Lázaro Cárdenas (per hectare values multiplied by area occupied).

Table 8. Interviewees' responses regarding their perceptions of forest change.

	Agree	Disagree	Don't know
The forest has changed in my lifetime	10	2	
The forest will change in the future	7	2	4

3.5 Observed changes in the *ejido*'s forest

Residents of Lázaro Cárdenas are in their forest area often. Even when their primary purpose is not forest products harvest, they pass through the forest on their way to farming plots and in order to graze animals. Many interviewees confidently assessed whether or not the *ejido* forest is changing (Table 8).

The majority of interviewees told me that the forest is "running out". When asked to describe changes in the forest during their lifetimes, some residents described a reduction in the density of the forest. When asked how the forest has changed during his life, one subject responded as follows:

> *Well, it's changed a little. Before it was denser; now it's getting thinner. Because we're using it. Because we have more people, we're using more trees, more wood to cook. And this is changing little by little.*

Others predicted reduction in the number of big trees in the forest:

> *It is already coming to an end. Even though we continue conserving it, the forest is going to end. Because we are 500 members. If 50% cut their wood by truckloads, 250 families, that would be 500 trips a year. [Accompanying directors: (exclamation of surprise).] So it is a lot*

and throughout time if the ejido continues growing the forest is not going to increase—it is going to cease.

Before there were big trees, over there behind these houses [points to an area still within the center of Chilil, the main neighborhood of the three in Lázaro Cárdenas], there were trees like this size [makes a circle with his arms indicating a tree of ~80cm diameter]. But little by little they are ceasing. Here we are in the hills. The hill ends here; people have to ascend to the top. I do not know how they do it, but they have to ascend to cut.

Through a translator, another subject conveyed the same idea more simply: "in the past there were big trees but now we are already running out of forest."

People also suggested that the extent of the forest area had been reduced within their lifetimes:

It has changed now. Because before there was still a lot, well, [of] the forest. Trees. Before The area of the forest was a lot bigger still. Well, now it is changing. It is changing. Well… we'll see if the government will help us a bit, if they give us a stove. If they help us a bit. Because the trees, well, they're running out. Now they're going to run out.

While some said that they have to go further now to collect firewood, others maintained that the forest is the same now as it has been during their lifetimes and that they can collect firewood in the same places they always have. Independently, two respondents explained that the forest is always changing; that *ejido* members harvest firewood in different places each time in order to allow the forest to recuperate. The respondents that noted the continually changing nature of the forest agreed that the forest was not recovering as it had in the past, though they disagreed on the cause: one suggested that this was due to increasing temperatures, the other increasing heat.

As can be seen in their descriptions of forest change, many participants attributed forest change to their own firewood use. They expressed the high value of firewood in their everyday lives and their desire to maintain the resource. As one interviewee said, “The truth is that we use trees, we always collect firewood.” “We don’t want to run out [of forest], but firewood is needed. If the trees fall, they should plant two,” one subject said. Interviewees’ understanding that firewood was the main subject of the interview may have influenced this result.

4. Discussion

4.1 Impact of firewood harvest on the forest community

The estimated total 831 MgC year^{-1} removed from the *ejido*'s forest per year is equivalent to the biomass of approximately 10 hectares of Zone B forest. The current forest has been shaped by years of use by *ejido* members. Over time, oak has largely been removed from areas closest to human populations. Oak's share of stand basal area has largely been replaced by pine, which is more successful than oak in gaps and under lower canopy cover (González-Espinosa et al. 2001, Quintana-Ascencio et al. 2004). The areas closest to centers of residential concentration do not experience much firewood harvest, because of the directors' protection and because of their lack of oak. A good deal of harvest takes place in the area with passable roads outside the *ejido* center. There are proportionally fewer oaks in this zone than in areas beyond roads, so people select pine instead of oak in order to harvest at scale with chainsaws and trucks. This pattern exacerbates pine dominance of the system. People's habit of "cleaning" hardwood seedlings and saplings from the forests that they pass through most frequently – those closest to their residences and within the roaded area – further enhances pine's prominence in terms of basal area and canopy composition. The largest proportion of hardwood biomass in the *ejido*'s forest (26%) is located in Zone D, the most remote, conserved areas. Despite having a lower proportion of hardwoods than Zone D, the extensive Zone B (roaded area outside main residential areas) forests contain 19% of total hardwood biomass in Lázaro Cárdenas. The proportions do matter: if oak trees are a smaller component of the forest in areas where people harvest more firewood, the larger the areas of firewood harvest grow, the less significant oak will become as part of the pine-oak forest of Lázaro Cárdenas. This will make it harder for people to find their preferred firewood species and have negative impacts on the ecological integrity of that forest type in the highlands.

4.2 Impact of existing forest management on the forest community

Though members of Lázaro Cárdenas sense an increasing shortage of oak in the *ejido*, their leadership does not have a clear understanding of the extent of its forest resources or their use. If direct measurements of firewood reserves and daily use units are more reliable than extrapolations of estimates based on annual use, then results indicate that households use nearly three times more firewood than they realize. The reason for this is likely that they underestimate the amount of firewood harvested by hand that supplements the truckloads that form the basis of annual wood use. Mores limiting the number of truckloads of firewood permitted $year^{-1}$ $household^{-1}$ are quite prevalent, but do not take into account supplemental wood harvesting. This suggests that the *ejido* would benefit from better understanding actual firewood used per household or per person, which might be achieved through direct measurement. Lázaro Cárdenas would also potentially benefit from an *ejido*-wide conversation about more formal forest management that would take into account firewood needs as well as timber harvest for commercial and domestic needs and non-timber forest products, and be shared with all community members.

Trends in* ejido *life The recent increase in number of households in Lázaro Cárdenas is an important development despite the *ejido*'s lack of population increase (INEGI 2011). Households with more people typically use less firewood per capita than households with fewer people (Ramírez-López et al. 2012). More people work outside of the *ejido* than have previously, either in nearby Huixtán or San Cristobal de las Casas, or as far as Chiapas' capital, Tuxtla Gutierrez. Work outside the *ejido* generates cash that can be used to purchase substitutes for forest products, including cement block for home construction and propane for gas stoves. Furthermore, the activities necessary to earn cash limit the amount of time residents can spend in and around the *ejido*'s forest. Having cash in hand empowers some *ejido* members to pay others to maintain their agricultural crops.

4.3 Management reforms to ensure stability of the pine oak forest

Each of the three categories of trees – pine, oak and other hardwoods – is present in each zone of firewood harvest intensity within Lázaro Cárdenas. Even in the areas that are already dominated by pines and have very little hardwood presence in the canopy, regeneration is possible and probable if the *ejido* takes actions to reform forest management. Figure 9 illustrates the potential pathway of such a progression.

Excluding human interventions and animal grazing from Zone B or even Zone C and D forest is not a realistic option for the residents of Lázaro Cárdenas. A more pragmatic balance of resource utilization and forest ecosystem maintenance would be for the *ejido* might develop strategies to enhance the supply of firewood and ecological robustness of Zone B forest, advance Zone C forest toward maturity and to conserve Zone D forest. The induced pine forest of Zone A could potentially be restored to a more robust pine-oak forest over time (Galindo-Jaimes et al. 2002), but focusing on Zones B-D is advisable given the *ejido*'s resource limitations.

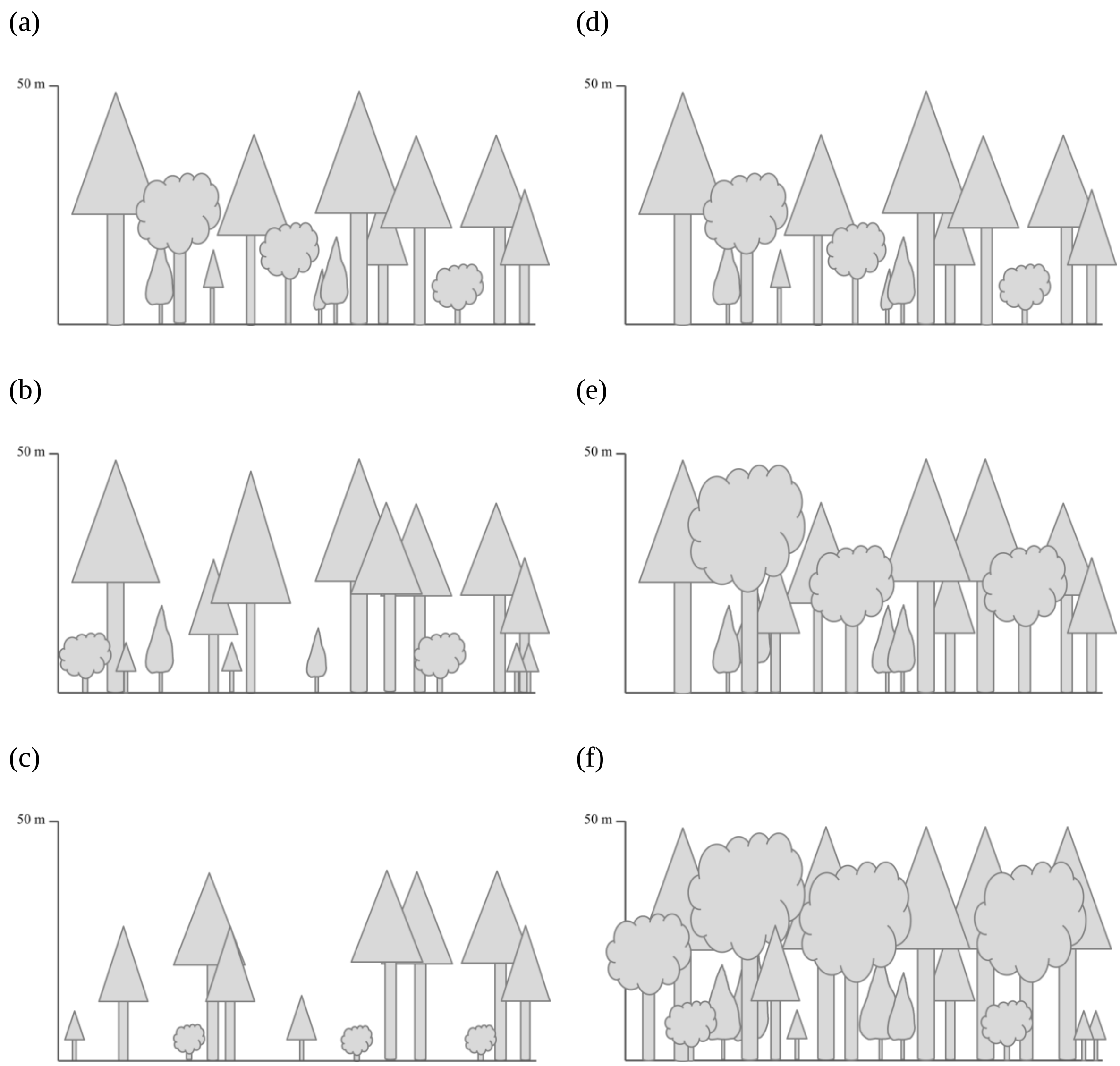

Figure 9. Development pathways of a Zone B-type forest stand. Trees with triangular crowns represent pines, round-crowned trees represent oaks, and teardrop-shaped crowns represent other hardwood species. (a) and (d) Current Zone B forest. (b) Zone B forest after 10 years with no action – pines dominate the canopy, though hardwood saplings and suppressed trees can still establish. (c) Zone B forest after 20 years with no action – large pines have been harvested and intermediate pines released; the stand is similar to the present Zone A forest. Oak seedlings still germinate, but they are cut down before they get to sapling size. (e) Zone B forest after 10 years of exclusion of human interventions (oak suppression and harvesting) and grazing – intermediate oaks reach the upper canopy and understory trees (other hardwoods) flourish in the variable light regime. The stand looks similar to a current Zone C forest. (f) Zone B forest 20 years after exclusion – a fully mixed pine-oak canopy and well-developed intermediate layer with substantial regeneration.

4.4 Limitations

There are some limitations to consider when interpreting the results of this study. I was only able to participate in community life through data collection approximately six hours a day, four to five days a week, for three months. I speak Spanish as a second language and I do not speak Tzotzil. Furthermore, I had very little background in the community's culture and values. My outsider status resulted in lack of trust between me and the community members, as well as lack of clarity in some conversations and lack of understanding in others. Further uses of the forest, for example, might be discovered through more in-depth interviews with the elders of the *ejido* or more time spent in the *ejido*.

The community has a strong desire to better understand their situation with respect to firewood provision and use and the board of directors' support for the study. I constantly reconfirmed their involvement in the study, as did ProNatura Sur, a local non-governmental organization, and the four directors who participated in the study on a daily basis. The directors with whom I engaged were from the central neighborhood of the *ejido*, and it became apparent as I traveled in the two other neighborhoods that those directors did not reach out to make the others aware of the study and encourage them to participate.

The presence of directors serving as research assistants and translators reassured potential subjects that participation in the study had been officially approved. Only one household's members re-fused to be interviewed when the study was explained by the directors, and more might have re-fused had I not have been accompanied by these figures of power. Some subjects deferred to the directors when asked to describe rules of the *ejido* and all likely felt some pressure to provide "correct" answers during the interview as a result of the directors' presence. When these directors were called upon to act as interpreters, I had no way of telling if they provided a direct translation or not. More often than not, I suspect that they summarized the interviewees' responses.

Though the directors acknowledged that a female translator would be an asset to me in speaking with female interview subjects, one was never available. Female subjects generally only spoke when permitted to do so by their male head of household, or when they could be interviewed alone.

I regret my inability to obtain information about Lázaro Cárdenas' commercial timber harvest plan, as timber harvest influences firewood harvest through road-building and forest community composition through its preference for pine species.

5. Conclusion

This study illustrates how firewood harvested and used by residents of Lázaro Cárdenas in their *ejido* affects the composition of the forest community. Firewood harvest, which is increasing as the population divides itself into more households, has led to the removal of oak species from the forests nearest the *ejido*'s population centers outward toward the *ejido* borders, advancing first near to roads and next up hillsides. The removal of oak trees and suppression of oak seedlings and saplings has induced pine forest where there was once pine-oak forest.

Because residents of Lázaro Cárdenas have little exchange with outsiders for cooking and heating fuel, they are slightly unique in the realm of community-managed forests. This *ejido*'s "self-containment" provides a useful case for examining the impacts of long-term, limited-management firewood harvest. Several characteristics make Lázaro Cárdenas a good candidate for support from non-governmental organizations and government agencies interested in forest conservation. First, the *ejido* has a high proportion of forested land. Unlike neighbor *ejido*s, in Lázaro Cárdenas cattle do not compose a major component of resident's livelihoods. As a result, large portions of forest that might otherwise have been converted to pasture have remained forested. Second, the "contained" nature of fuel resources reduces the number of factors affecting firewood demands that might be managed. Third, *ejido* members are concerned about their diminishing firewood supply – they are motivated to engage in firewood demand reduction and/or supply development. Fourth, the pine-oak forest that does or could exist in the *ejido* is ecologically important and of interest to international organizations, such as the Alliance for the Conservation of the Mesoamerican Pine-Oak Forest, that may lend support to conservation efforts.

Challenges in improving forest management Lázaro Cárdenas include the limited capacity of the board of directors for forest management (the board is composed of volunteers and does not include any members with forestry training), the high perceived value of commercial timber harvest in contrast to the rarely-quantified value of firewood provision, and the little-understood rate and impact of "invasions" by people entering Lázaro Cárdenas' forest from other *ejido*s.

Following the work of Cortina (2006), Cayuela et al. (2006) and others, future work that looks more broadly throughout the Chiapas highlands at the role of firewood removal as a *primary* driver of forest degradation would be useful. Though firewood removals have an important impact on forest community change in Lázaro Cárdenas, that *ejido*'s fuel use characteristics and "self-containment" may inflate firewood's impact beyond that which it has in other highlands forests.

Because knowledge, time and resources are important issues for the *ejido* to face in managing its forest resources, practical, easily-shared strategies for selecting firewood for harvest are crucial to maintaining and enhancing the forest's resources.

Points for Further Research

This is a small study that could potentially contribute to several areas of further research. First, historical ecosystem change. Induction of pine forest in the highlands of Chiapas is now oriented at maximizing value for timber harvest. However, this study shows that firewood extraction can be a catalyst in those parts of the highlands that still have remnants of the pine-oak ecosystem. Could removal of oaks for firewood have played a more significant role in past conversion?

Second, studies of the effectiveness of *ejido* management should not only consider the timber revenue stream and conservation of forest ecosystems, but also placing full value on all of the non-timber forest products, including but not limited to firewood, that are used by the community. Is it better for communities to have cash or natural resources? Which do they prefer?

Third, the potential of coppice and *milpa* systems should be reviewed. Would these systems suffice to meet a community such as Lázaro Cárdenas' demand for firewood? On what rotation period would they need, and what portion land would the *ejido* need to dedicate to meet the community's firewood needs?

Fourth, from a practical perspective, the capacity of *ejido* boards in the highlands of Chiapas must be improved with respect to natural resource management. Nongovernmental organizations and universities such as ProNatura Sur and El Colegio de la Frontera Sur are taking the lead in this area.

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Appendix 1. Tree species documented in data collection

* Red List status indicates a species' risk of extinction, as determined by the IUCN Categories and Criteria (IUCN 2012). Status indicators are as follow (in order of extinction risk, highest to lowest): CR – critically endangered; EN – endangered; VU – vulnerable; NT – near threatened; and, LR – least concern. Only one of the vulnerable species recorded in Lázaro Cárdenas is a pine – *Pinus ayachuite* – and its harvest by individuals of the *ejido* is prohibited by the community's directors.

Family	**Genus and Species**	**Tzotzil**	**Spanish**	**Red List status***
Adoxaceae	*Viburnum elatum* Benth	ich akt mut		VU
Adoxaceae	*Viburnum jucundum Morton* ssp. *Jucundum*			EN
Adoxaceae	*Viburnum obtusatum* D. Gibson			CR
Adoxaceae	*Viburnum* aff.			
Aquifoli-aceae	*Ilex vomitoria*			
Araliaceae	*Oreopanax xalapensis* (Kunth) Decne. & Planch.	(ich ak mut)		NT

Betulaceae	*Alnus acuminata* ssp. Arguta (Schlecht.) Furlow	nok (nahk')	LR
Betulaceae	*Carpinus caroliniana* Walter	tzu tuk te	NT
Betulaceae	*Ostrya virginiana* var. *guatemalensis* (H.J.P. Winkl.) J.F. Macbr., *synonym of* Ostrya virginiana *(Mill.) K.Koch.*	ut ut te	
Boragina-ceae	*Tournefortia acutiflora* M. & G.	(k'ewex wamal - tetzal)	
Cannabaceae	*Trema micrantha* (L.) Blume	chishte	
Compositae	*Baccharis vaccinioides* Kunth	meste'	
Compositae	*Roldana acutangula* (Bertol.) Funston H. Rob. & Bretell [formerly *Senecio acutangulus* (Bertol.) Hemsl.]	tutu mixik'	
Compositae	*Verbesina* aff. *perymenioides Sch. Bip. ex Klatt*		
Compositae	*Verbesina* aff. *perymenioides Sch. Bip. ex Klatt*		
Compositae	*Verbesina perymenioides* Sch. Bip. ex Klatt		

Compositae	*Vernonia patens* Kunth	(t'zim)	hierba del burro	
Compositae				
Cornaceae	*Cornus disciflora* DC	ma oak		VU
Cornaceae	*Cornus excelsa* Kunth	is bon		
Cupres-saceae	*Juniperus gamboana* Martinez	nikulpat	cipres rojo	VU
Ericaceae	*Arbutus xalapensis* Kunth	on te'		LR
Fagaceae	*Quercus crassifolia* Humb. & Bonpl.	bochje, tulan	roble	
Fagaceae	*Quercus crispipilis* Trel.	chiquinib		VU
Fagaceae	*Quercus laurina* Bonpl.	saquil chiquinib	encino	
Fagaceae	*Quercus peduncularis* Nee	tulan, bochje		
Fagaceae	*Quercus rugosa* Nee	bochje	roble	

Garryacae	*Garrya laurifolia* Hartw. ex Benth. subsp. *Quichensis* (Donn.Sm.) Dahling	ich akt mut		VU
Lauraceae	*Litsea glaucescens* H.B.K.	tz uuch		
Lauraceae	*Olmediela blechleriana*		aguacate del monte	
Leguminosae	*Acacia pennatula* (Schltdl. & Cham) Benth	sachim, guash		
Malvaceae	*Chiranthodendron pentadactylon* Larreat.	selupat (sahalpat), sajalal		VU
Myricaceae	*Morella ceifera* (L.) Small	ich atk mut (cera-te)	(satín)	
Myrsinaceae	*Myrsine juergensenii* (Mez) Ricketson & Pipoly	tilil (Tzeltal)	naranjillo	NT
Onagraceae	*Fuchsia paniculata* Lindl.	atzamnichin		
Pinaceae	*Pinus ayacahuite* var. *ayacahuite* C. Ehrenb. Ex Schltdl.	pinabete	pino blanco, ocote	VU

Pinaceae	*Pinus montezumae* Lamb.	bochto	ocote rojo, pino	LR
Pinaceae	*Pinus pseudostrobus* var. *apulcensis* (Lindl.) Shaw, *Pinus oxa-cana* Lindl.	saquil-saschto	ocote	LR
Pinaceae	*Pinus tecunumanii* F. Schwerdtf. Ex Eguiluz & J.P. Perry	salalchacto	ocote, pino	NT
Rosaceae	*Crataegus pubescens* (C. Presl.) C. Presl.		manzanita, manzanilla	
Rosaceae	*Holodiscus argenteus* (L. f.) Maxim.	ich akt mut		
Rosaceae	*Prunus serotina*	chishte		
Rubiaceae	*Randia aculeata*			
Scrophulari-aceae	*Buddleja cordata* Kunth	selupat, nikulpat, sasalte		EN
Symploca-ceae	*Symplocos breedlovei* Lundell	cocoshte		EN

Theaceae	*Cleyera theoides* (Sw.) Choisy	chayil momol/pom momol

Appendix 2. Relationships between biomass, regeneration and stump presence by zone

	Kruskal-Wallis p-values	**Mann-Whitney U p-values**					
Distribution	BETWEEN ZONES	A:B	A:C	A:D	B:C	B:D	C:D
Elevation (m a.s.l.)	.014	.017 A<B	.027 A<C	.021 A<D	.793	*.061* *B<D*	*.062* *C<D*
Percent canopy cover	.042	.865	.126	.020 A<D	.529	.027 B<D	.027 C<D
Species richness (# of species per plot)	*.087*	.145	*.074* *A<C*	.020 A<D	.293	.125	.799
Pine species richness	.399						
Oak species richness	.123						
Other species richness	.133						
Total biomass (MgC/ha)	.043	.610	.865	.021 A<D	.674	.042 B<D	.007 C<D
Pine biomass (MgC/ha)	.308						

Oak biomass (MgC/ha)	.024	.349	.042 A<C	.021 A<D	.529	.027 B<D	.027 C<D
Other biomass (MgC/ha)	.026	.481	.124	.020 A<D	.561	.040 B<D	.007 C<D
# Total stems ≥ 3 cm dbh	.171						
# Pine stems ≥ 3 cm dbh	.143						
# Oak stems ≥ 3 cm dbh	.320						
# Other stems ≥ 3 cm dbh	.260						
# Total stems <3 cm dbh	.211						
# Pine stems <3 cm dbh	.046	.497	.393	.018 A>D	.155	.024 B>D	*.064* *C>D*
# Oak stems <3 cm dbh	.199						
# Other stems <3 cm dbh	.298						

# Total stems 3-19 cm dbh	.110						
# Pine stems 3-19 cm dbh	.549						
# Oak stems 3-19 cm dbh	.410						
# Other stems 3-19 cm dbh	.286						
# Total stems 20-49 cm dbh	.430						
# Pine stems stems 20-49 cm dbh	.332						
# Oak stems 20-49 cm dbh	.013	.289	*.059* *A<C*	.038 A<D	*.056* *B<C*	.010 B<D	.103
# Other stems 20-49 cm dbh	.026	.294	.105	.014 A<D	.396	.018 B<D	*.097* *C<D*
# Total stems <50 cm dbh	.076						
# Pine stems <50 cm dbh	.061						

# Oak stems <50 cm dbh	.107
# Other stems <50 cm dbh	.572

Appendix 3. Indicator Species Analysis

Trees >3cm dbh only. P = proportion of randomized trials with indicator value equal to or exceeding the observed indicator value. Indicator values significant at α = .05 are in bold; values significant at α = .10 are in italics.

				IV From Randomized Zones		
	Species	**Zone with Maximum Observed IV**	**Observed Indicator Value (IV)**	**Mean**	**Standard Deviation**	**P**
PERCENT BASAL AREA (stems ≥3cm)	***Quercus laurina***	**85.1**	**D**	**25.5**	**11.32**	**0.00**
	Quercus crispipilis Trel.	**64.8**	**C**	**33.2**	**9.19**	**0.00**
	Pinus montezumae Lamb.	*46.4*	*A*	*27.3*	*10.41*	*0.06*
	Quercus rugosa Nee	41.4	D	32.6	11.19	0.19
	Quercus peduncularis Nee	38.9	D	34.5	10.62	0.29
	Buddleja cordata Kunth	35.7	C	23.3	11.79	0.17
	Quercus crassifolia Humb. & Bonpl.	34.0	B	25.9	12.17	0.23
	Carpinus caroliniana Walter	33.9	C	23.7	12.21	0.13
	Pinus pseudostrobus var. *apulcensis* (Lindl.) Shaw	31.7	C	30.2	12.29	0.36

Pinus tecunumanii F. Schwerdtf. Ex Eguiluz & J.P. Perry	29.5	D	30.0	8.52	0.45
Myrsine juergensenii (Mez) Ricketson & Pipoly	25.9	B	25.7	11.96	0.41
Cornus excelsa Kunth	25.0	C	17.7	9.10	0.24
Verbesina perymenioides Sch. Bip. ex Klatt	25.0	C	17.0	9.53	0.25
Ostrya virginiana var. *guatemalensis* (H.J.P. Winkl.) J.F. Macbr.	25.0	D	16.7	5.92	0.34
Symplocos breedlovei Lundell	21.8	C	30.2	12.37	0.72
Arbutus xalapensis Kunth	21.1	D	21.5	11.20	0.46
Viburnum jucundum Morton ssp. Jucundum	14.3	C	19.8	10.74	0.61
Baccharis vaccinioides Kunth	12.5	A	17.7	10.14	0.88
Cornus disciflora DC	12.5	C	16.7	5.89	1.00
Crataegus pubescens (C. Presl.) C. Presl.	12.5	C	16.7	5.89	1.00

	Fuchsia paniculata Lindl.	12.5	C	16.8	5.93	1.00
	Ilex vomitoria	12.5	C	16.7	5.89	1.00
	Tournefortia acutiflora M. & G.	12.5	C	16.8	5.93	1.00
	Trema micrantha (L.) Blume	12.5	B	16.8	5.93	1.00
	Verbesina aff. *perymeni-oides* Sch. Bip. ex Klatt	12.5	C	16.7	5.89	1.00
	Acacia pennatula (Schltdl. & Cham) Benth	11.8	D	22.9	11.22	0.89
	Pinus ayacahuite var. *ayacahuite* C. Ehrenb. Ex Schltdl.	7.6	C	20.3	10.87	1.00
NUMBER OF STEMS (≥3cm)	*Quercus laurina*	*61.0*	*D*	*29.1*	*10.65*	*0.01*
	***Quercus crispipilis* Trel.**	**54.1**	**C**	**33.0**	**7.31**	**0.01**
	Buddleja cordata Kunth	*45.6*	*C*	*28.9*	*12.26*	*0.10*
	Pinus montezumae Lamb.	*44.6*	*A*	*28.8*	*11.35*	*0.10*
	Myrsine juergensenii (Mez) Ricketson & Pipoly	39.7	D	32.4	11.87	0.25

Quercus crassifolia Humb. & Bonpl.	39.4	B	26.3	12.65	0.12
Carpinus caroliniana Walter	39.4	C	28.2	13.43	0.19
Pinus pseudostrobus var. *apulcensis* (Lindl.) Shaw	38.8	C	32.6	12.53	0.25
Quercus peduncularis Nee	30.2	D	37.0	11.15	0.68
Quercus rugosa Nee	29.6	D	31.0	9.37	0.49
Viburnum jucundum Morton ssp. Jucundum	29.5	C	27.5	11.48	0.33
Pinus tecunumanii F. Schwerdtf. Ex Eguiluz & J.P. Perry	29.2	D	30.8	9.39	0.50
Symplocos breedlovei Lundell	28.6	C	29.5	10.20	0.46
Verbesina perymenioides Sch. Bip. ex Klatt	25.0	C	17.2	8.85	0.24
Cornus excelsa Kunth	25.0	C	18.3	9.20	0.24
Acacia pennatula (Schltdl. & Cham) Benth	25.0	C	17.7	9.47	0.25

Cleyera theoides (Sw.) Choisy	25.0	D	16.7	5.90	0.33
Viburnum spp.	25.0	D	16.7	5.90	0.33
Ostrya virginiana var. *guatemalensis* (H.J.P. Winkl.) J.F. Macbr.	25.0	D	16.7	5.91	0.34
Baccharis vaccinioides Kunth	25.0	C	24.8	12.53	0.38
Crataegus pubescens (C. Presl.) C. Presl.	21.9	C	26.7	12.56	0.55
Alnus acuminata ssp. *Arguta* (Schlecht.) Furlow	20.8	D	24.8	10.39	0.60
Pinus ayacahuite var. *ayacahuite* C. Ehrenb. Ex Schltdl.	18.8	D	22.1	11.69	0.59
Arbutus xalapensis Kunth	16.7	C	25.9	10.48	0.88
Unknown (various	15.0	C	18.8	10.27	0.63
Trema micrantha (L.) Blume	12.5	D	17.7	9.33	0.77
Chiranthodendron pentadactylon Larreat.	12.5	C	16.6	5.88	1.00
Cornus disciflora DC	12.5	C	16.6	5.88	1.00

Fuchsia paniculata Lindl.	12.5	C	16.6	5.87	1.00
Fuchsia aff. *paniculata* Lindl.	12.5	B	16.6	5.88	1.00
Ilex vomitoria	12.5	C	16.6	5.88	1.00
Morella ceifera (L.) Small	12.5	B	16.6	5.88	1.00
Olmediela blechleriana	12.5	C	16.6	5.87	1.00
Roldana acutangula (Bertol.) Funston H. Rob. & Bretell	12.5	C	16.6	5.88	1.00
Tournefortia acutiflora M. & G.	12.5	C	16.6	5.87	1.00
Vernonia patens Kunth	12.5	B	16.6	5.88	1.00
Verbesina aff. *perymeni-oides* Sch. Bip. ex Klatt	12.5	C	16.6	5.88	1.00
Viburnum elatum Benth	12.5	C	16.6	5.87	1.00
Litsea glaucescens H.B.K.	10.0	C	18.4	11.68	0.82
Viburnum obtusatum D. Gibson	10.0	A	17.6	10.02	1.00

	Oreopanax xalapensis (Kunth) Decne. & Planch.	8.3	B	17.5	9.12	1.00
NUMBER OF STEMS (total)	***Quercus laurina***	**70.9**	**D**	**28.6**	**10.21**	**0.00**
	Quercus rugosa Nee	49.1	A	35.9	9.37	0.11
	unknown (various)	47.2	C	32.2	14.36	0.23
	Buddleja cordata Kunth	*45.6*	*C*	*28.9*	*12.21*	*0.10*
	Litsea glaucescens H.B.K.	41.1	D	29.3	12.58	0.15
	Pinus montezumae Lamb.	40.7	A	29.3	11.11	0.15
	Pinus pseudostrobus var. *apulcensis* (Lindl.) Shaw	39.6	C	33.7	13.31	0.26
	Quercus crassifolia Humb. & Bonpl.	39.3	B	27.2	12.65	0.15
	Myrsine juergensenii (Mez) Ricketson & Pipoly	39.0	D	29.8	10.14	0.17
	Carpinus caroliniana Walter	38.4	C	29.3	13.14	0.18
	Quercus crispipilis Trel.	34.5	C	33.7	5.83	0.41
	Verbesina perymenioides Sch. Bip. ex Klatt	32.9	C	20.7	11.06	0.18

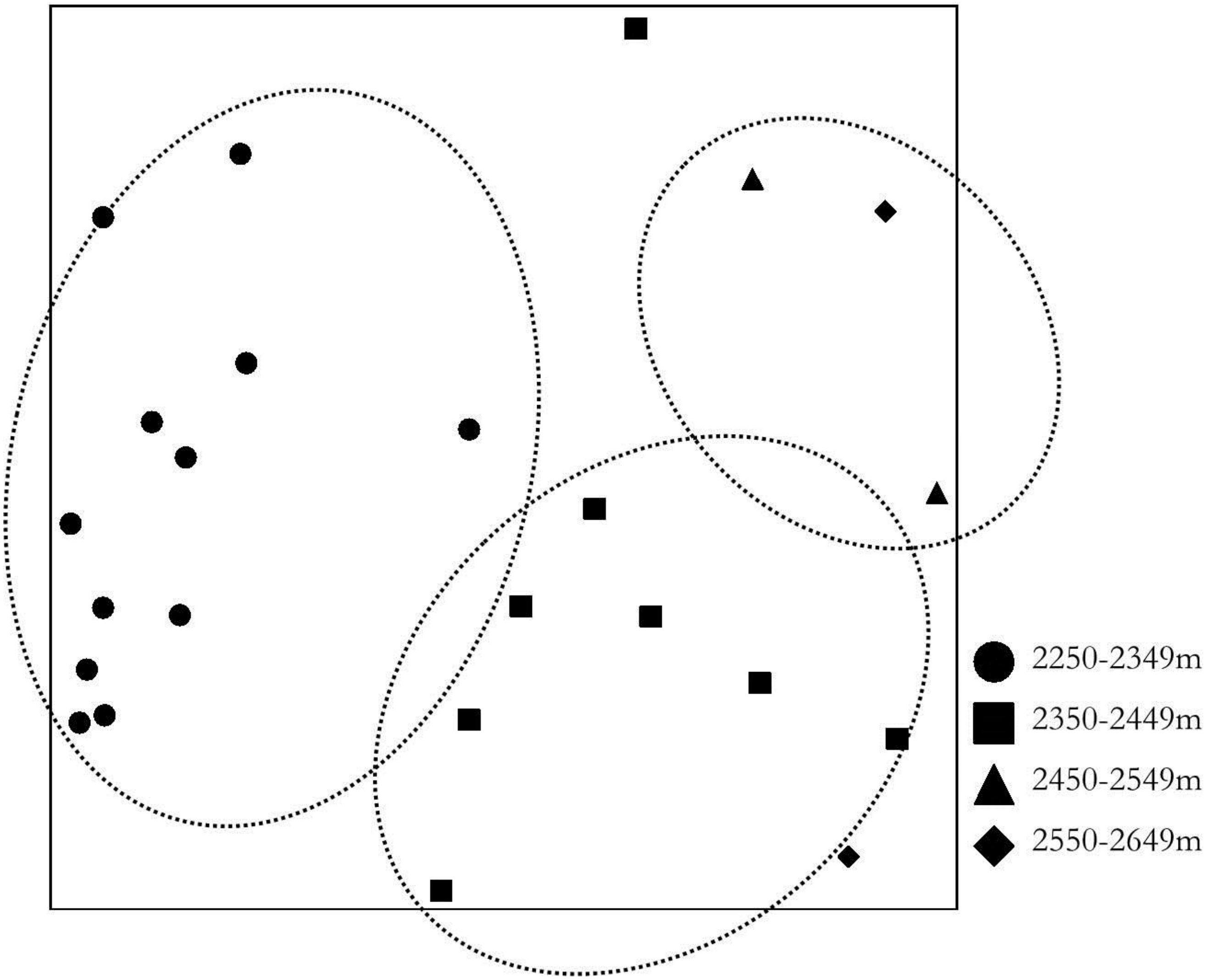
Pinus tecunumanii F. Schwerdtf. Ex Eguiluz & J.P. Perry	32.0	B	30.8	8.52	0.36
Symplocos breedlovei Lundell	31.2	C	30.5	9.02	0.39
Cornus excelsa Kunth	30.5	C	22.2	11.29	0.21
Quercus peduncularis Nee	28.4	C	38.8	11.30	0.80
Baccharis vaccinioides Kunth	25.3	C	26.8	12.04	0.47
Acacia pennatula (Schltdl. & Cham) Benth	25.0	C	19.1	9.18	0.24
Cleyera theoides (Sw.) Choisy	25.0	D	16.6	5.86	0.33
Viburnum spp.	25.0	D	16.6	5.86	0.33
Ostrya virginiana var. *guatemalensis* (H.J.P. Winkl.) J.F. Macbr.	25.0	D	16.7	5.91	0.34
Oreopanax xalapensis (Kunth) Decne. & Planch.	24.1	C	22.9	10.82	0.52

Viburnum obtusatum D. Gibson	22.0	A	21.8	11.12	0.53
Viburnum jucundum Morton ssp. Jucundum	21.9	C	27.7	11.58	0.65
Alnus acuminata ssp. *Arguta* (Schlecht.) Furlow	20.8	B	27.0	10.20	0.66
Crataegus pubescens (C. Presl.) C. Presl.	20.7	A	28.9	12.61	0.69
Olmediela blechleriana	20.0	D	17.6	9.02	0.48
Arbutus xalapensis Kunth	20.0	A	29.4	10.02	0.84
Pinus ayacahuite var. *ayacahuite* C. Ehrenb. Ex Schltdl.	19.1	D	21.9	11.24	0.59
Fuchsia paniculata Lindl.	15.6	D	17.3	9.40	0.71
Trema micrantha (L.) Blume	12.5	D	17.8	9.27	0.78
Chiranthodendron pentadactylon Larreat.	12.5	C	16.6	5.87	1.00
Cornus disciflora DC	12.5	C	16.6	5.87	1.00
Fuchsia aff. *paniculata* Lindl.	12.5	B	16.6	5.86	1.00

Garrya laurifolia Hartw. ex Benth. subsp. *Quichensis (*Donn.Sm.) Dahling	12.5	C	16.6	5.88	1.00
Ilex vomitoria	12.5	C	16.6	5.87	1.00
Morella ceifera (L.) Small	12.5	B	16.6	5.86	1.00
Roldana acutangula (Bertol.) Funston H. Rob. & Bretell	12.5	C	16.6	5.87	1.00
Tournefortia acutiflora M. & G.	12.5	C	16.5	5.85	1.00
Vernonia patens Kunth	12.5	B	16.6	5.86	1.00
Verbesina aff. *perymeni-oides* Sch. Bip. ex Klatt	12.5	C	16.6	5.87	1.00
Viburnum elatum Benth	12.5	C	16.8	5.94	1.00
Prunus serotina	11.1	A	19.2	10.76	0.80

Appendix 4. Relationships among regeneration communities

NMDS ordination of number of stems <3cm dbh shows noteworthy grouping by elevation. Outlying plots mainly differed from their elevation class by number of seedlings (one outlier has distinctly fewer seedlings than any other plot) and distinct species (one outlier is the only plot to have either *Pinus ayacahuite* or *Olmediela blechleriana* stems < 3cm dbh).



Appendix 5. Interview guide

Interview Guide: Women and Men in Household[2]

1. OPENING

- Tell me something you like about your life here in Chilil

[2] For men alone, ask questions about cooking but adapt since they're not likely to be the ones doing the actual cooking.

- Do you think that the forest in Chilil has changed? (Changes in where trees are, what kinds of trees, etc.)
- How do you see the forest in 10 years? 50 years?

2. GENERAL FOREST

- Can you explain to me why people in this barrio go to the forest? (Timber, firewood, edible plants, ceremonial plants, medicinal plants….)
- Where do you think they go? When?

3. THE EJIDO AND THE FOREST

- Do you think that people can do whatever they want in the forest? Of whom do you have to ask permission for…?
- Are there things that people are not allowed with respect to the forest? (If I were a member of the *ejido*, is there anything I could do that would merit a fine? Who makes the rules?)
- Do you think that there are there areas of the forest that you can't go to? Can you explain that to me?
- How long ago do you think the rules/norms were started?
- Does anyone from outside the *ejido* go into the forest?

4. FUELWOOD

- Do you feel prepared for the rainy season in terms of how much fuelwood you have?
- How many people will this firewood serve?
- How long do you think the fuelwood that you have will last?
- What do you think you will when it runs out? (Where might you get gas, charcoal? How much does it cost?)

- Could I see your fuelwood pile, to see how much wood it is that you're dealing with? I can't picture it.
- Where did this come from?
- How do you choose what wood to cut? Does it have to be a certain species or a certain size?
- How did it get here?
- Who brought it? *Why did that person care to help you out?*
- How much did it cost?
- Do you share with anyone or sell this firewood? *Why do you care to help people out?*

5. COOKING

- Can you tell me about how you cook food normally?
- How do you like the stove that you have? Do you consider the amount of wood that is used by this stove to be about the same as that of other stoves? How much wood do you think it uses every day?
- Who cuts the wood to get it ready for the stove? Why do you think that person does it?
- How much of other fuels do you use every day?
- Think about other seasons – are you using different fuels in the fall than you do now? In the winter?

6. PERSONAL INFORMATION

Name, age, how many people eating in the house, role in household

7. SUMMARY & FINAL THOUGHTS

Interview guide: chainsaw operator

Same as guide for women & men in their houses, but inserting the following section second – immediately following the opening. Cut sections of the men & women interview that are least relevant to keep the interview to around an hour long.

CHAINSAW

- Can you tell me why you bought the chainsaw in the first place?
- When did you get it?
- What kinds of things do you use it for?
- How are you paid for jobs – by the day? By the tree?
- Walk me through what happens when someone asks you to do a job – how does it go?
- Which kinds of people work with you when you’re using the chainsaw?
- How many days a month do you work with the chainsaw? Does this vary before the rains, during, after…?
- What kinds of places have you been working lately? Have you always worked in those places?