GLOBALIZED AGRICULTURE AS A DRIVING FORCE OF CHANGE TO MAYA COMMUNITY-MANAGED LANDSCAPES ACROSS YUCATÁN, MÉXICO

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Indigenous community land tenure systems in many locations worldwide are shifting toward individually parcelized and privatized systems. Among the drivers of this shifting land tenure, are distant political-economic forces and commodity markets, from local to global. Accompanying the observed land tenure changes are shifts in livelihoods, away from subsistence-based, and toward market-oriented activities. These changes can ultimately impact land use and land cover patterns. I investigated a global-to-local casual pathway, from agriculture, livestock and forestry production for distant markets, extending through shifting land tenure and livelihoods, to impacts on land use and land cover within ejidos (a type of community landholding) across Yucatán, México where Maya people are the primary land stewards.

My research questions are: 1) what underlying and broad-scale social processes influence changes to ejido land tenure and livelihoods, and 2) in what way do the changes to ejido land tenure and livelihoods influence land use and land cover? To investigate these questions, first I use descriptive statistics to initially assess the shift in ejido land tenure, from community to individually parcelized systems, and the shift in a principal subsistence livelihood and land use activity, from maize cultivation to cattle rearing. Next, I use ordinary least squares regression, mapped variables, and

variographic analyses to assess spatial patterns and correlations. I further explored relationships among variables using spatially-explicit simultaneous autoregressive models. Finally, I use remotely sensed satellite images to map and analyze changes to land use and land cover patterns across the state, and particularly among ejidos (pre- and post- parcelization).

I show that commodity production for distant markets is strongly related to parcelized ejido lands. Moreover, I show that changes to land use and land cover patterns among ejidos are associated with changes to ejido land tenure. Specifically, parcelized ejido lands are often deforested. Conversely, I show that community-managed ejidos comprise a larger percentage of conservation lands or lands undergoing forest regeneration, and therefore are much more likely to be densely forested. In all, I conclude that land privatization can threaten the conservation potential of community-managed forests and landscapes across the state of Yucatán.

BIOGRAPHICAL SKETCH

Ted Lawrence holds several graduate degrees from the University at Albany, State University of New York. Specifically, he holds an M.S. from the Department of Biological Science, M.A. from the Department of Anthropology, M.A. from the Department of Economics, and an M.A. from Rockefeller College of Public Affairs and Policy. He also holds a B.A. in Political Science from St. John Fisher College and an A.A. in Interdisciplinary Studies from Sage College of Albany.

DEDICATION

I dedicate my dissertation to everyone that helped me make it happen. Specifically, Dr. Sarah Taylor, Department of Anthropology, California State University, Dominguez Hills; the ejido communities of X-kumil and Dzalbay, as well as other nearby ejido communities; research assistants; Drs. Richard Stedman and Stephen Morreale (my special committee co-chairs); special committee members Drs. James Lassoie, Wendy Wolford, Fouad Makki; Faculty in the Department of Natural Resource and other Departments across Cornell University; Alejandro Cabrera Valenzuela (a field colleague); Cornell University graduate students; and mom, for all of her support through the years.

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CHAPTER 1

INTRODUCTION

Landscape change is ubiquitous across the globe (Verburg et al., 2013). Landscape change influences social and ecological conditions at the local level, while also being a pervasive factor of global change and transformation in social-ecological systems on a planetary scale (Verburg et al., 2015). As a result, landscape change is increasingly recognized as an important factor in, and indicator of, local to global change (Nagendra et al., 2004; Verburg et al., 2013).

Landscapes are where human and natural forces interact (Lassoie & Sherman, 2010). As complex social-ecological systems, landscapes also are where social institutions interrelate with the biophysical environment (Fischer, 2018). Much of a landscape's social-ecological structure and function is defined by spatial relationships and interactions among social institutions and the biophysical environment (Cumming, 2011), which links social-ecological systems across multiple spatial and temporal scales. Thus, examining spatial relationships and interactions on a landscape scale can help researchers and practitioners understand and devise ways to cope with widespread change (Harden et al., 2013).

Despite the importance of spatial relationships and interactions associated with landscape change, few studies link social institutions to the biophysical environment using spatially explicit approaches (Stanfield et al., 2002). The lack of such studies is partly because mechanisms underlying landscape change often originate at different spatial scales, which can make them difficult to examine (Bechtold et al., 2013). Disentangling the complex web of interactions between multi-scale social processes and ecological patterns is conceptually and methodologically challenging (Nagendra et al., 2004). Nevertheless, investigating the spatial relationships and interactions on a landscape scale is one of the most important research areas in global change science (Wu & Hobbs, 2002; Verburg et al., 2015).

Examining changes to land use and land cover is recognized as an effective way to spatially link multi-scale social processes to ecological change (Nagendra et al., 2004). Indeed, land use is a critical link between underlying social forces and causal mechanisms that drive changes to the biophysical environment (Geist & Lambin, 2002). However, numerous factors, including a complex set of social, cultural, political, and economic institutions, as well as technological variables, can influence land use (Kolb et al., 2013).

A particularly important influence on land use and landscape patterns, is land tenure (Holland et al., 2014). As a social institution, land tenure determines the relationships between people and land, which involve organizations, rules, rights, and restrictions that control the allocation and use of land (Cumming & Barnes, 2007). Furthermore, land tenure mediates spatial relationships and interactions between social processes and land use (Barnes, 2009). However, land tenure is intertwined with many other factors shaping land use. For example, changes to land tenure regimes can be related to changes in livelihood and land use activities, such as land privatization and market-oriented agriculture development. In all, changes in land tenure have important implications for social-ecological systems on multiple spatial and temporal scales (Cumming & Barnes, 2007).

Few studies examine relationships between 1) gradual changes to land tenure and livelihoods, and 2) land use and land cover change (Borras Jr. & Franco, 2011), especially using spatially explicit methods (Hersperger & Burgi, 2009). For example, much of the recent literature on land tenure and landscape change has compared deforestation rates inside and outside protected areas. Other studies have focused on land use outcomes related to tenure security *versus* insecurity (Robinson et al., 2014), or as an outcome related to land grabbing, where foreign investors or transnational corporations buy land to extract resources for markets (Borras Jr. & Franco, 2011). Such research traditionally involves local place-based studies (Verburg et al., 2015; van Vliet et al., 2016), focusing on proximate causes of landscape change (Meyfroidt et al., 2013). Indeed, place-based social and environmental factors, such as soil quality, climate, proximity to urban areas and markets, and human population growth do mediate the causal pathways that lead to landscape change (Wassenaar et al., 2007). However, scientists rarely conduct studies on broader regional scales, because the methods for conducting them are not well established (Rudel, 2007; Verburg et al., 2015). While understandable, the lack of landscape and regional-scale studies examining the spatial relationships and interactions between land tenure, institutional factors (e.g., markets), and land use and land cover belies the importance of the influences of multiple scales on landscape change.

Community-managed landscapes are important to landscape conservation on regional scales. Community-managed landscapes involve large land areas that are managed collectively and where land managers hold similar land and natural resource management goals (Ojha et al., 2016). Furthermore, community-managed landscapes involve socio-cultural institutions related to land tenure, livelihoods, and land use (Agrawal & Gibson, 1999). However, community-managed landscapes are much more complex, in that broader-scale social and environmental factors substantively influence land management practices (Stone & Nyaupane, 2013). Therefore, community-managed landscapes should be envisioned as involving interactions among actors within and between spatial scales and levels of political-economic organization (Ojha et al., 2016).

In this dissertation, I examine inter-relationships among broad-scale changes to land tenure, livelihoods, land use, and land cover within ejidos, which are a predominant form of landholding in the Yucatán region of México (Ellis et al., 2015). Yucatán is more broadly representative, in that more than 50% of all México's land is primarily governed under the ejido system. Ejidos are a form of community-based land tenure, created through Article 27 of México's constitution in 1917, which originally excluded individual ownership and commercial interests from holding or administering rural properties (Barnes, 2009). Moreover, ejidos were intended to primarily support subsistence-based agriculture. Throughout the 20th Century, ejidos grew to over 30,000 across México, and substantially contributed to social-ecological systems at the landscape scale (Barnes, 2009).

In 1992, Article 27 of México's constitution was altered to allow for individualized land tenure in ejidos. At the same time, México started experiencing rapid and substantive changes in regional land use and land cover (Mas et al., 2004; García-Frapolli et al., 2007). As a result, México's federal government has attempted to attenuate landscape change (CONAFOR, 2016), through policies that integrate approaches to conservation and development on landscape scales (García-Frapolli et al., 2007). However, government policies often fail to consider ejidos, and their local natural resource management institutions, especially ones with indigenous populations (García-Frapolli et al., 2008). This neglect is partly because the government policy-makers often disregard traditional rural livelihoods (Smardon & Faust, 2006), and the policy-makers expect to transform local subsistence activities and natural resource management into market-oriented approaches (West & Brockington, 2006).

In México's effort to attenuate landscape change, the Yucatán peninsula, a global biodiversity hotspot (Vázquez-Domínguez & Arita, 2010), was recently identified by the federal government as a high priority region (CONAFOR, 2016). Although, ejidos occupy over half the land in the state (RAN, 2017), since the change to Article 27, ejidos have been shifting away from community management, and toward individualized and private property. Currently, in the State of Yucatán approximately one-third of all ejido lands are individually parcelized (RAN, 2019). Simultaneously, the State of Yucatán, comprising approximately 5 million hectares, has in recent decades experienced over 80% forest loss (Ellis et al., 2017), contributing to heightened concerns.

For my dissertation, my objective is to investigate landscape change in ejidos across the State of Yucatán. My research questions are *1) what underlying and broad-scale social processes influence changes to ejido land tenure, away from community management, and toward individualized systems, and 2) in what way do the changes to ejido land tenure influence land use and land cover?* Included in these analyses are spatially explicit methods that involve mapping key variables, cartographic analysis, and variographic analysis to determine the presence of spatial relationships; spatial regression models to help determine causality in observed spatial relationships; and land use and land cover modeling using geographic information techniques to examine the association between land tenure change and changes in land cover over time, and specifically before and after the change to Article 27. The development of this dissertation is also based on fieldwork and community-engagement that contributed to my understanding of why ejidos choose to parcelize and how this is related to engagement in commodity markets. Although findings from the fieldwork and community engagement are not explicitly included, such work did help me to better understand the human actors and motivations in my spatially-oriented research.

In Chapter 2, I examine and explain a global-to-local casual pathway that stems from processes of globalized agriculture and manifests in changes to indigenous community-managed landscapes. The global-to-local casual pathway involves a nested hierarchy of political-economic processes, specifically involving land and natural resource privatization, commodification, and acquisition. At the local landscape level, I focus on changes to land tenure, livelihoods, land use, and land cover. The dominant changes to land tenure involve a shift away from community, and toward individual ownership and management. Concurrently, market-oriented agriculture livelihoods substantially increase, particularly in the form of cattle rearing. Subsequently, land use shifts away from small-scale extensive, and toward large-scale intensive crop cultivation; away from diverse crop cultivation and toward monocropping; and away from cropping, toward livestock farming. Ultimately, there are shifts in land cover, away from diverse agro-forested landscapes, and toward homogeneous deforested lands.

I illustrate the above relationships using ejidos in Yucatán, México as an exploratory example. I use descriptive statistics to initially assess the shift in ejido land tenure, from community to individually parcelized systems, and the shift in a principal subsistence livelihood and land use activity, from maize cultivation to cattle rearing. Also, I highlight a key finding, that individually parceled areas within ejidos are more deforested than community-managed areas. In all, I recommend that landscape conservation scientists should more fully consider impacts stemming from globalized agriculture, and I call for the advancement of more extensive studies and analyses, both in breadth and in depth.

In Chapter 3, I formally investigate the spatial relationships associated with the global-to-local pathway, from agriculture, livestock, and forestry production for distant markets, extending through shifting land tenure and livelihoods, and to impacts on forest cover within ejidos across

Yucatán, México. To reveal this pathway, I conducted exploratory data analysis using ordinary least squares regression, mapped variables, and variographic analyses to assess spatial patterns and correlations within the State. I further explored relationships among variables using spatially explicit simultaneous autoregressive models. My spatial analyses revealed that commodity production for distant markets is strongly related to parcelized ejido lands, which in turn are often deforested. Conversely, community-managed lands, which traditionally have involved subsistence-based agroforestry, are much more likely to be densely forested. Overall, I conclude that recent deforestation of ejido lands across the State is, at least partly, the result of shifting land tenure and livelihoods due to the increasing presence of commodity markets. Moreover, I conclude that community-managed lands and associated subsistence livelihoods can attenuate deforestation and potentially advance forest and biodiversity conservation efforts across México and elsewhere.

In Chapter 4, I explicitly analyze change over time, by examining the shift in ejido land tenure and concomitant changes to land use and land cover in all ejidos across the State of Yucatán, prior to and following the commencement of ejido land parcelization. In these analysis, I examine how land use and land cover changes within ejidos between approximately 1986 and 2016; and how land use and land cover differs between individually parcelized and common use (community-managed) ejido lands in 2016. These analyses include the use of remotely sensed satellite imagery to map and analyze land use and land cover change across the State, specifically within ejidos. I show that land use and land cover change in ejidos over a 30-year span is associated with changes to ejido land tenure. In particular, I demonstrate that individually parcelized ejidos exhibit a much larger increase in agricultural land use than community-managed ejidos. I also show that community-managed ejidos comprise a larger percentage of lands, either dedicated to conservation, or undergoing forest regeneration. In all, I conclude that land privatization can threaten the conservation potential of community-managed forests and landscapes in Yucatán and beyond.

In Chapter 5, I provide recommendations designed to help better understand and mitigate landscape change in ejidos and elsewhere. Specifically, I promote the need for evidence-based conservation and meta-analyses of land tenure change and its relationship to land use and land cover change. I also argue for landscape conservation approaches that account for the complex relationships and interactions between social process and ecological patterns. Additionally, I argue for the conservation value of community-managed landscapes globally, and the conservation value of secondary forests as part of rotational land use strategies in community-managed landscapes. In conclusion, I argue for landscape approaches on scales that matter, and especially on regional scales.

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CHAPTER 2

RETHINKING LANDSCAPE CONSERVATION: LINKING GLOBALIZED AGRICULTURE TO CHANGES TO INDIGENOUS COMMUNITY-MANAGED LANDSCAPES

1. Introduction

Community-managed landscapes have valuable conservation potential (Harvey et al., 2008). For example, community-managed forests across the tropics have showed lower and less-variable annual deforestation rates than protected forests (Porter-Bolland et al., 2012). In particular, indigenous community management has slowed deforestation and land degradation (Blackman et al., 2017; Ceddia et al., 2015). Although landscape conservation depends on the social, political, and economic context (Baynes et al., 2015), often community-managed landscapes sustain biodiversity at levels comparable to old-growth forests and pristine reserves (Jose, 2012). As a result, community-managed landscapes are becoming a global trend (Baynes et al., 2015), and offer potential management options that conservationists have recently acknowledged (Sistla et al., 2016; Vallejo-Ramos et al., 2016).

Land tenure systems are important to landscape conservation. As informal and formal resource management institutions, land tenure systems determine the relationships among people and their land (Barnes, 2009; Spalding, 2017), and are intricately tied to culture (Berkes, 2012). For indigenous societies, land tenure often follows cultural norms and values based on land use over many generations. Hence, livelihoods involve detailed knowledge about local ecological conditions, plants, animals, and interconnecting ecological processes that culminate in complex systems for categorizing ecological characteristics and patterns (Altieri, 2004; Kassam, 2009). Consequently, indigenous land and resource management can be quite sophisticated and adaptive (Berkes, 2009), often involving low-intensity inputs with little mechanization, multiple and intermingled use, and rotational strategies (Robinson, 2018). In these cases, traditional knowledge and practices can result in extensive ecological gradients, diverse patches and high-quality habitat, ecosystems, and landscapes with a wide array of species and considerable biodiversity (Fischer et al., 2012; Ribeiro Palacios et al., 2013).

Despite the importance of such landscapes to conservation, globalized agriculture – integration of local-to-national agriculture markets into the global market economy via the reduction of international trade barriers and subsequent expansion of trade – is driving changes to indigenous community-managed landscapes. Specifically, globalized agriculture is shifting: 1) land tenure away from community and towards individual ownership and management; and 2) livelihoods away from subsistence, and towards market-oriented activities. In turn, land use and land cover are changing. Moreover, the changes to indigenous community-managed landscapes can lead to broader landscape impacts and more extensive consequences for global biodiversity (Jose, 2012).

In rural agrarian-based tropical countries, the changes stemming from globalized agriculture can be particularly acute and widespread (Laurance et al., 2014), making indigenous landscapes increasingly fragile and vulnerable (Harvey et al., 2008; Rudel et al., 2009). For example, agricultural expansion and exports are considered a primary driver of tropical deforestation (Chowdhury, 2010; DeFries et al., 2010; Laurance et al., 2014). Such patterns are troubling because many of these same countries harbor extensive global biodiversity and diverse indigenous cultures (Ribeiro Palacios et al., 2013).

Despite their potential importance, it is rare that political-economic processes related to globalized agriculture, such as international trade, are implicated as a key driver of landscape change (Pace & Gephart, 2017). In particular, the influence of globalized agriculture on changes to indigenous community-managed landscapes is seldom acknowledged and is afforded minimal consideration in regional or international conservation planning (Treweek et al., 2006). For example, the Convention on Biological Diversity addresses issues concerning local development and poverty reduction (SCBD, 2010). However, these and similar efforts fall short of addressing broader political-economic forces, such as global agricultural commodity markets as underlying drivers of change to indigenous landscapes (DeFries et al., 2010; Meyfroidt et al., 2013, 2014; Pace & Gephart, 2017). Rather, land privatization and its integration into the global agriculture and food economy often is seen as a key strategy toward improving food security, reducing poverty, identifying the capacity for growth and promoting natural resource management (Spalding, 2017). Similarly, the International Union for the Conservation of Nature emphasizes how traditional knowledge and practices can contribute to conservation (SCBD, 2014), but discussions about how globalized agriculture affects such knowledge and practices are often lacking.

Globalized agriculture as a key driver of landscape change is seldom discussed, partly because systematic explanations and empirical evidence are lacking (Carrasco et al., 2017; Jepsen et al., 2015; Liu et al., 2015a; Plieninger et al., 2016; Spalding, 2017). Consequently, dominant global-to-local casual pathways that impact landscape patterns remain poorly understood (Garrett et al., 2013; Meyfroidt et al., 2014; Pereira et al., 2016; Riekkinen et al., 2016; Taylor et al., 2016; Yu et al., 2014). Distant political-economic driving forces of landscape change have been studied for decades (Blaikie & Brookfield, 1987; Bürgi et al., 2005; Hersperger & Burgi, 2010) using household surveys (Hersperger et al., 2010) or remote sensing and census data (Castella & Verburg, 2007). However, these approaches often focus on land use and land cover patterns (Chowdhury, 2006), rather than examining underlying *processes* that drive these changes (Hersperger & Burgi, 2009). Moreover, rarely integrated with land use and land cover change analyses is agrarian change – the shift in rural agrarian land tenure and livelihoods, from non-capitalist to capitalist relations due to broader-scale political-economic forces (Akram-Lodhi & Kay, 2010a,b). Nevertheless, the need for such synthesis is increasingly acknowledged (Borras Jr. & Franco, 2012; Borras Jr. et al., 2011; Holland et al., 2014; Lambin et al., 2003; Robbins et al., 2015; Robinson, 2014; Wittman et al., 2017). Overall, impacts to indigenous community-managed landscapes that stem from globalized agriculture are likely to increase. This topic deserves greater attention (Pace & Gephart, 2017).

The objective of the study in this chapter is to describe and explain a global-to-local casual pathway that stems from processes of globalized agriculture and drives changes to indigenous community-managed landscapes. The global-to-local casual pathway involves a nested hierarchy of the political-economic forces: land and natural resource privatization, commodification, and acquisition. At the landscape level, this chapter focuses on connections between globalized agriculture and shifting land tenure, livelihoods, land use, and land cover. The approach in this chapter can contribute to more contextually and historically place-based hypotheses and explanations, better data collection instruments, more robust models and empirical analyses and ultimately guide more effective conservation policy, planning, and action (Hersperger et al., 2010; Ostrom et al., 2009; Verburg, 2014). To illustrate the approach, this chapter focuses on Yucatán, México using ejidos, a type of community-managed lands, as an exploratory example. This chapter uses descriptive statistics to highlight the effects of parcelization on deforestation, the shift in ejido land tenure, from community to individually parcelized systems, and the shift in a principal subsistence livelihood and land use activity, from maize cultivation to cattle rearing.

2. *Global-to-local casual pathways*

2.1 A nested hierarchy of political-economic processes

Investigating globalized agriculture and its influence on indigenous community-managed landscapes involves analyzing a nested hierarchy of the political-economic forces at work. This nested hierarchy approach entails political-economic actors on a global scale, such as transnational corporations and international banks, interacting with political-economic actors on smaller spatial scales, such as national governments and local businesses. In particular, this approach emphasizes: 1) shifts in political-economic activity to the global scale; 2) shifts in the distribution of power to the global scale; and 3) cause-effect mechanisms whereby political-economic processes at the global scale affect political-economic processes on smaller spatial scales. In all, the nested hierarchy approach helps to separate and clarify the political-economic processes embedded at varying spatial scales that create a top-down influence on indigenous community-managed landscapes.

The nested hierarchy approach is particularly important because agriculture markets have changed over the last few decades. Prior to the 1980s, agriculture trade involved an increase in the *distance* of exchange beyond national borders. Accordingly, the processes scaled up an agricultural economy, from the local to the regional, to the national, to the global, in a linear way (Bridge, 2002). Although economic activity extended beyond national borders it was regulated from within nations. Consequently, the world's agriculture markets were subservient to national interests, which guided public policies that influenced nationally based markets (Rodrik, 2011). In this context, an indigenous community-managed landscape may have been involved in agriculture production for export, but the cross-scale power distribution remained largely within the nation of residence.

More recently, agriculture trade has involved a nested hierarchy of political-economic forces (Borras Jr, 2009). Additionally, the influence over agriculture markets is now centralized in global institutions that operate outside national boundaries (Griffin, 2003). As a result, national interests have become subservient to the global agricultural market economy, while transnational corporations, investors, and banks influence globally-based markets (Rodrik, 2011). This is largely because present-day economic globalization has fundamentally transformed the scales over which agriculture's political-economic activity historically has been organized (Bridge, 2002). Accordingly, agricultural market activity and its management have shifted to larger scales. The scale transformations create and reinforce nested hierarchical organizational structures with a more complex web of relations, involving more actors and linkages from the global to the local scale (Brenner, 2001). In this context, the power distribution has shifted to the global scale, which can increasingly marginalize indigenous community-managed landscapes at the local level, further accelerating the shift.

Despite the change to the agricultural economy's structure, globalization-based studies more recently favor operational approaches that emphasize *distance* between key actors and sites (Mackinnon, 2011). Telecoupling, the socioeconomic and environmental interactions between two or more places over *distances* (Liu et al., 2013, 2015a,b; Moser & Hart, 2015; Seto et al., 2012; Yu et al., 2014), is an example of a recently developing approach to investigate sustainability in a globalized world. For example, studies on telecoupling have mainly focused on linkages related to specific land uses, sectors, or other natural resources, such as soybean and beef production for international trade (Friis & Nielsen, 2017). Such a framework can contribute to understanding landscape change, particularly with regard to land and natural resource supply and demand between distant locations (Munroe et al., 2014). However, telecoupling and similar approaches lack the operationalization of the local in relation to larger spatial scales, including the global scale.

2.2 Political-economic processes related to globalized agriculture

The agricultural economy's globalization in recent years involves unprecedented increases in land and natural resource privatization, commodification, and acquisition (Clapp, 2015). These processes are linked to political-economic forces, involving widespread state reform of property rights, resource access, local-to-global commodity-chain corporatization, and the global agro-industry's financialization (Bernstein, 2008). These changes have contributed to the central role the agro-industrial food system now plays in the global market economy (McMichael, 2009); namely acquiring large tracts of agricultural land around the world (Sonnenfeld, 2008). These processes and the interactions between the associated political-economic forces form a global-to-local pathway that profoundly changes indigenous community-managed landscapes by initiating a gradual process of change that is more insidious than foreign investors merely buying up land, as is the case with land grabbing (Borras Jr & Franco, 2012).

Land and natural resource privatization undermines indigenous community-managed landscapes. This often is because the market economy places greater importance on the market value of land and its resources over its social and cultural worth. However, in indigenous landscapes the relationship between people and land is intricately tied to its social and cultural importance (Berkes, 2012). In contrast, governments strongly influenced by economic globalization emphasize the market value of land and resources over its social and cultural value. Although transnational corporations and investors lead investments in land at the global scale (Borras Jr et al., 2012), often national governments play a key role in land privatization that undermine indigenous land tenure systems. For example, in 2001, Panama established the

National Land Administration Program to provide free land titles to the rural population and then in 2010 created the National Land Administration Authority to regulate and streamline all processes related to land privatization (Spalding, 2017). These and similar programs throughout Latin America seek to regulate private property and to facilitate creating a market for land, often neglecting traditional indigenous land tenure systems and their associated conservation potential (Barnes, 2003).

Following privatization, land and resource commodification for global agricultural markets can further weaken indigenous community-managed landscapes. Cultural norms and values in indigenous community-managed landscapes often involve non-capitalist relations to land that ultimately define the potential land uses for subsistence and petty trade. However, increased markets for land and resources can lead to a more economically efficient land system that will, in turn, facilitate increased foreign investment (Spalding, 2017) and may ultimately displace traditional land use practices. For example, prior to the 1980s local state-controlled agricultural commodity chains operated in many rural agrarian-based tropical countries, which covered much of the world's agricultural areas (McMichael, 2009). Trade in these countries also remained under substantial state control, including high tariffs on imported agricultural inputs restrained food exports, and state subsidies supporting subsistence agriculture. But, widespread trade liberalization initiated in the 1980s and subsequent international development agencies' actions, such as the World Trade Organization's Agreement on Agriculture (Blandford, 2015), led to the state controlled agriculture and food systems being reorganized into a small number of transnational corporate-owned entities (McMichael, 2012). Government agricultural subsidies were restructured to encourage market participation, sizably reduced or eliminated altogether, resulting in foreign investors obtaining greater access to land and resources. However, the local food system's reorganization, from state to market control, can strongly influence community land tenure systems as local livelihoods are more tightly linked to broader markets.

Land acquisition also can have considerable social and ecological impacts on indigenous community-managed landscapes (Borras Jr & Franco, 2012). In rural agrarian-based tropical countries, communities often are displaced from their land due to land acquisitions intended for agricultural and forestry production, as well as energy and mining (Borras Jr, 2009). As a result, land use and land cover also is altered. With transnational corporations and investors now playing a key role in organizing production, including the land and resources utilized for production, the acquisition by these actors of large tracts of land has increased dramatically over the last decade (Clapp, 2015). Such land acquisition is a consequence of the gradual process of land privatization and commodification. Therefore, land acquisition should be analyzed in the context of this process of change rather than solely as foreigners buying land. Land acquisition is nothing new, but the character, scale, pace, and key drivers of the recent wave of land acquisition is historically distinct and closely linked to major shifts in agricultural production (Margulis et al., 2013) and overall agricultural exports into the global market economy are rapidly increasing, 60% between 2000 and 2012 (Carrasco et al., 2017). Land acquisitions thus undercut community land tenure systems as well as impacts associated with livelihoods, land use, and land cover.

Land and natural resource privatization, commodification, and acquisition reinforce authority at broader scales, disempower local actors and undermine resource management (Adger et al., 2006). For example, global corporations and financial actors play an increasingly active role in food retailing and processing, commodity trading, setting prices, agricultural risk's distribution and agricultural input's provisioning, and agricultural lands' ownership and control (Isakson, 2014). As land and resources become more concentrated in a small number of global capital intensive agro-industries and foreign investors, indigenous community-managed landscapes shrink and local markets for small-scale producers are eliminated (Moore, 2010). As a result, new differentials in bargaining power emerge that favor transnational agro-food corporations, and global food retailers and supermarkets, such as Walmart (McMichael, 2012). Moreover, global food retailers have emerged as the most powerful actors within the agro-food system (Isakson, 2014), and never before have the commoditized exchange and the power of large-scale food retailers been so great (McMichael, 2009). In all, land and resource privatization, commodification, and acquisition lead to broader shifts in food supply where widespread state reform, trade liberalization, corporatization, and financialization are rapidly reorganizing agro-industry and precipitating a decline in the relative power of nations and particularly of local indigenous community-managed landscapes (Margulis & Porter, 2013).

Although political-economic processes related to globalized agriculture can be distant and diffuse, these processes initiate a series of top-down changes in rural agrarian-based tropical countries. Indigenous community-managed landscapes become embedded within more complex global-to-local interactions through market and urban expansion within a region (Wittman et al., 2017). Such global-to-local linkages and interactions represent a dominant casual pathway, which changes these landscapes (Robbins et al., 2015), by replacing or rearranging local political-economic factors and shifting the political-economic and environmental relationships from the local to global scale (Meyfroidt et al., 2013). Figure 2.1 illustrates how political-economic processes of globalized agriculture alter how people relate to vital resources, to each other, and to the broader political economy.

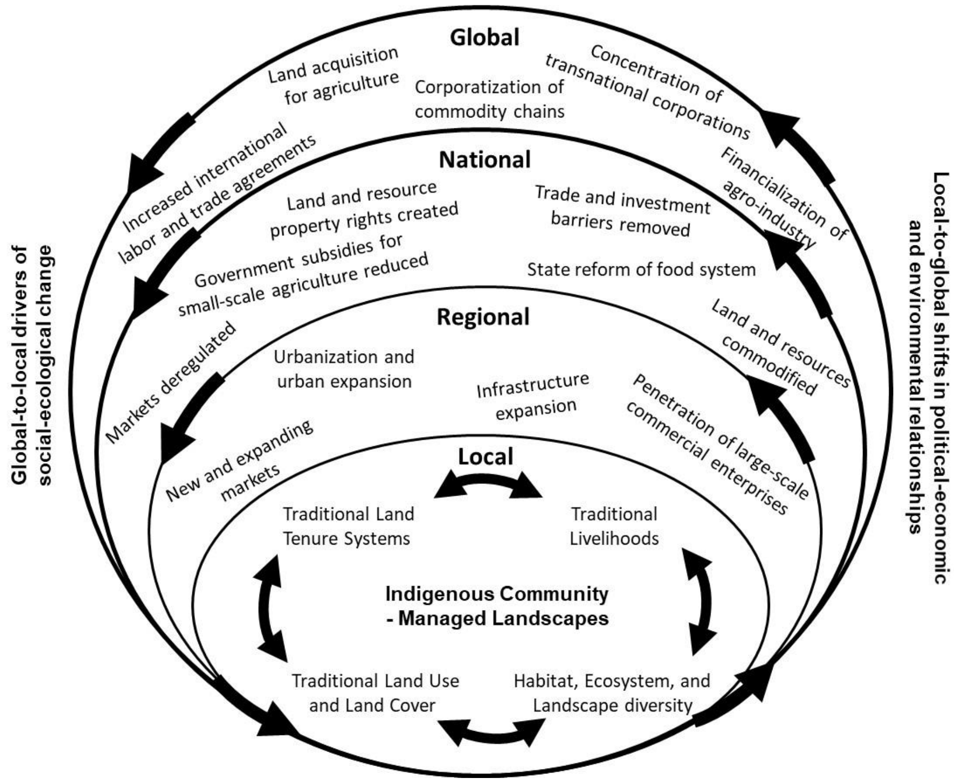

Figure 2.1 A nested hierarchy of political-economic processes of globalized agriculture. Indigenous community-managed landscapes are embedded in a multi-scale process of change where political-economic and environmental relationships shift from the local to the global, and broader scale factors drive changes to local social-ecological systems. The changes to indigenous community-managed landscapes involve the complex interaction of changes to traditional land tenure, livelihoods, land use, and land cover that can impact broader landscape and biodiversity patterns.

2.3 Changes to indigenous community-managed landscapes

Based on the above, rural agrarian-based tropical countries are seeing traditional land tenure systems moving away from community, and toward individually managed, privatized systems. A shift from community to individual management often involves land parceling, exclusive access, private ownership, and ownership loss as outside investors purchase land and resources (Barnes, 2009; Oliveira & Hecht, 2016). Some of these changes, such as privatization, displace landless and rural poor who are driven toward marginal landscapes and frontiers, or urban slums (Hecht, 2010; Robson & Berkes, 2011). Regardless of the particulars, shifting land tenure regimes are a powerful driving force of change (Robinson et al., 2014).

Accompanying shifting land tenure are changes to livelihoods, away from subsistence, and toward market-oriented activities. Changes to livelihoods generally involve declines and losses of traditional knowledge and practices as people increasingly rely on broader regional-to-global markets (Butler et al., 2014; Sreeja et al., 2015). For example, a shift away from traditional livelihoods can involve an increase in wage-earning and market-oriented activities, further resulting in declining subsistence activities and, ultimately, the loss of associated knowledge (Hecht, 2010). Subsequently, migration toward urban centers further exacerbate livelihood change (de Janvry et al., 2015).

Following the changes to land tenure and livelihoods are changes to land use, away from small-scale extensive, and toward large-scale intensive crop cultivation; away from diverse crop cultivation, and toward monocropping; and away from crop toward livestock farming practices (Lambin & Meyfroidt, 2011). These changes to land use are because land management strategies and adaptive capacities also are constrained and altered, and resources become restricted, thus intensifying land use (Turner, 2010). In turn, forest–agriculture cycles and rotational and intermingled land use become more uniform and homogenized (Barsimantov et al., 2010). Commonly, traditional land use patterns are modified and new cultivars, new domestic animal breeds, and new technologies are adopted, bringing about further modifications to the landscape. Associated with many of these changes are higher nutrient inputs and pesticide application, and increased mechanization (Robinson, 2018). The changes to traditional land use patterns can further lead to the penetration of large-scale commercial enterprises into indigenous landscapes, including industrial agriculture, forestry, and ranching.

Accompanying these types of changes to land use are changes to land cover, away from diverse agro-forested and toward homogeneous deforested lands. As indigenous landscapes become fragmented, primary habitat and ecosystems are reduced and isolated with fewer resources available to maintain viable populations of many species (Fischer et al., 2012). Soil also degrades as forested areas become sparse and agriculture intensifies. Ultimately, the land cover transforms almost entirely into a single type of land use that severely restricts landscape composition, configuration, and structural connectivity. In turn, landscape functioning and diversity diminishes. As a result, reductions in landscape connectivity and lack of patches large enough to support viable populations lead to substantial declines in local biodiversity (Vallejo-Ramos et al., 2016).

Overall, the changes to indigenous lands can produce broader-scale landscape fragmentation and homogenization. Such changes can ultimately impact, and extensively alter, global biodiversity patterns, as landscape heterogeneity is often critical to broader biodiversity patterns (Vallejo-Ramos et al., 2016). Thus, beginning at a global level, as shown in Figure 1, this chapter traces a causal pathway through the combined changes in traditional livelihoods and land use accompanying shifting land tenure, illustrating a top-down sequence that impacts a much broader landscape (Ogden et al., 2013). Exemplified in Figure 2.2 is the process of change, away from indigenous community-managed landscapes as a local rural political economy transitions to a global urban political economy.

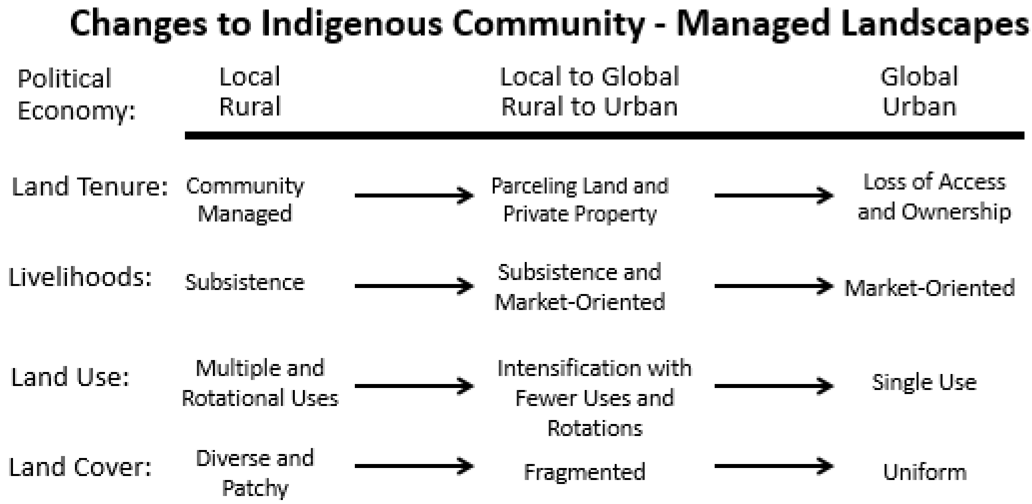

Figure 2.2 The process of change that indigenous community-managed landscapes undergo due to globalized agriculture. Traditional land tenure, livelihoods, and land use and land cover shift along a spectrum as a society transitions from a local rural, to a global urban political economy.

3. Globalized agriculture and Yucatán, México: An exploratory example

3.1 Globalized agriculture and México

Many processes associated with globalized agriculture are exerting themselves through shifting land tenure in México's ejidos, which are a type of community landholding that the federal government created during the early 1900s through Article 27 of México's constitution. The creation of ejidos was intended to support small-scale subsistence agriculture and to redress long-standing land and natural resource inequality (Perramond, 2008; Barnes, 2009). Following the logic described above, this chapter initially assesses changes to México with a focus on its ejido land tenure system as an exploratory example of the influence of globalized agriculture on indigenous community-managed landscapes. This chapter uses descriptive statistics to illustrate 1) the influence of globalized agriculture on changes to indigenous (Maya) ejido landscapes in the State of Yucatán, through land tenure shifting from community, to individual management; 2) the associated change in traditional livelihoods away from subsistence agriculture; and 3) how these changes impact forest cover, and ultimately landscape patterns and biodiversity.

In México, approximately 30,000 ejidos comprise 52% of all land and 80% of forestlands, and involve over 60 indigenous groups as land stewards (INEGI, 2016). In all, thousands of México's indigenous communities possess legally recognized land rights in the form of ejidos (Smith et al., 2009). Such landholdings are considered social property, intended to be managed at the community level (Barnes, 2009). Because of their ubiquity, ejidos drive local political-economic and environmental relationships and power distribution (Perramond, 2008). Thus, the ejido system influences the rural sector's social-ecological complexity, and contributes to the conservation of cultural and natural heritages. Ejidos are therefore a prime example of community-managed landscapes that support extensive biodiversity, intertwined with subsistence-based livelihoods and long-standing indigenous cultural beliefs and land use practices. As such, the ejido system has played a critical role in defining the indigenous peoples' relationships with each other and their land and natural resources. All told, ejidos have influenced and shaped México's social, economic, and ecological landscape for much of the 20th Century (Loewe & Taylor, 2008).

During the 1980s and 1990s, the World Bank and International Monetary Fund influenced México's political-economic system to shift from a government-led and locally focused economy toward a free market and globalized economy. Specifically, policies known as structural adjustments were initiated. These policies sought to reduce the state's role in the economy, reduce its expenditures on social services, including agricultural subsidies, and expand trade liberalization, resource privatization, and market deregulation (Edelman & Haugerud, 2005). Following this shift in the mid-1980s, México's government began to withdraw from its role in the country's agricultural sector, and in 1986, entered into the General Agreement on Tariffs and Trade (Carte et al., 2010). Around the same time, federal agrarian policies and laws that supported ejidos were altered in favor of more globally integrated market-oriented approaches to agriculture (McAfee & Shapiro, 2010).

Multiple changes to México's constitution were initiated in 1992, specifically Article 27, which originally established the ejido system. These changes allowed ejido lands to be sold as private property (Perramond, 2008). In addition, the creation of new ejido landholdings ended; land parceling and legal certification began through Programa de Certificación de Derechos Ejidales y Titulación de Solares: PROCEDE (Program of Certification of Ejidal Rights and Titling of Parcels); restrictions on ejido lands being rented, sold, bought, or leased were eliminated; and a series of policies were initiated to pave the way toward land privatization and the eventual displacement of the ejido system (Loewe & Taylor, 2008; Smith et al., 2009). In 1994 México joined the North American Free Trade Agreement, furthering private investment in México and integrating its markets into the global economy. The changes were further supported in 1995 through the World Trade Organization's establishment and its Agreement on Agriculture (Blandford, 2015), which provided a framework for long-term agriculture trade reform and domestic policies, leading to the state controlled agriculture and food systems' reorganization into a small number of transnational corporate owned entities (McMichael, 2012). Accordingly, México removed high tariffs and ended import restrictions, thereby allowing increased trade and investment in agriculture and forestry. Therefore, land privatization, along with repeal of government subsidies, encouraged international private investment in large-scale commercial agriculture, rather than state investments in small-scale subsistence agriculture that can be traced down to the local level (Carte et al., 2010).

Overall, the changes to México's political economy were based in global political-economic forces that sought to restructure México's national economy, redistribute power and open the door to foreign ownership of assets. For example, shares in México’s food retailing by global supermarkets rose from approximately 5 to 10% in 1990, to 50 to 60% by the early 2000s (McMichael, 2017). Much of these chronicled changes due to an expanded global influence in México also have manifested and are evident in ejidos across the State of Yucatán.

3.2 Changes to ejido land tenure in Yucatán

Approximately 700 ejido lands, primarily under the stewardship of indigenous (Maya) communities, occupy over 2.5 million hectares in the State of Yucatán, or nearly 60% of all land in the state (RAN, 2017). Consequently, shifting land tenure has affected both the ejido system’s social-ecological complexity, and the overall landscape composition. Currently, about two-thirds of the state’s ejidos remain mostly community-managed, while the remainder have shifted toward parcelization and individual-based land management/ownership (Figure 2.3). The progression toward privatization is a gradual change, however. In some ejidos that are in the process of parcelization and where there is a shift toward individual management, some tracts of land may be retained for common use. In such cases, land use management decisions for common use areas remain at the community level. Even when ejidos are fully parcelized and distributed among individuals, the community’s ejido assembly retains some governing responsibilities. In Yucatán, 64% of all ejidos are completely common use, or contain less than 20% parceled land, and land use decisions remain mostly at the community level. At the other extreme, 5% of all ejidos contain 80% or more parceled land, and management decisions are mostly individual, with a lesser degree of community governance (Figure 2.4). The shifts in tenure arrangements within Yucatán have all occurred in recent years, and are part of a larger complex of social and environmental changes within the region.

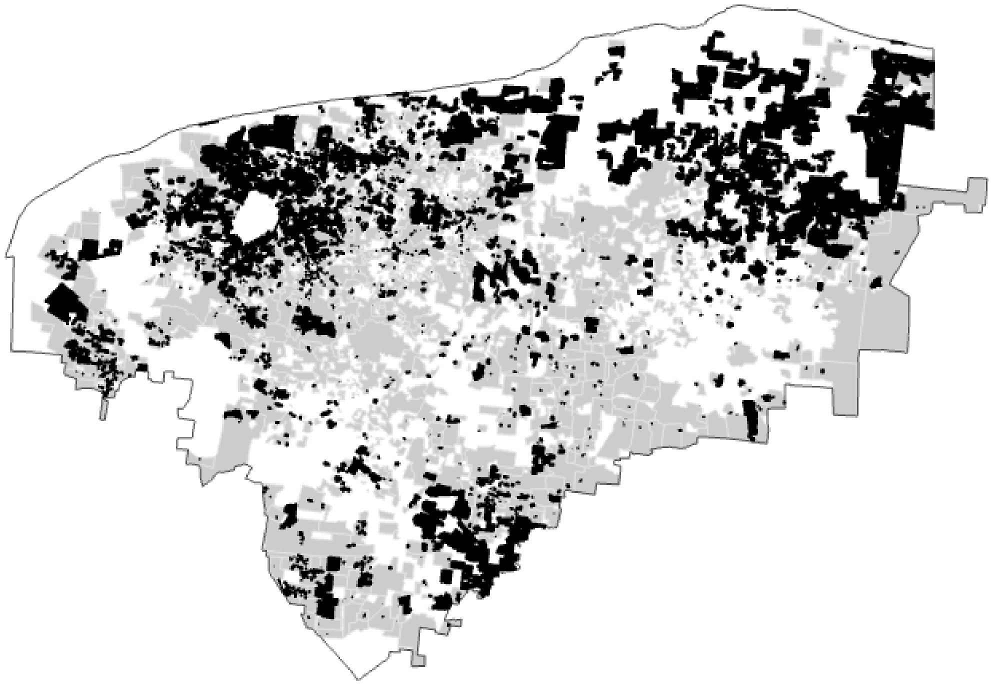

Figure 2.3 Ejidos across the State of Yucatán. Parceled ejido areas are shown as black polygons; community-managed or common use ejido areas are shown as grey polygons. The remaining white areas represent land outside of ejidos, which include private and government-owned land. The ejido polygons and data on parceled and common use areas were obtained from México's Registro Agrario Nacional, March 2017.

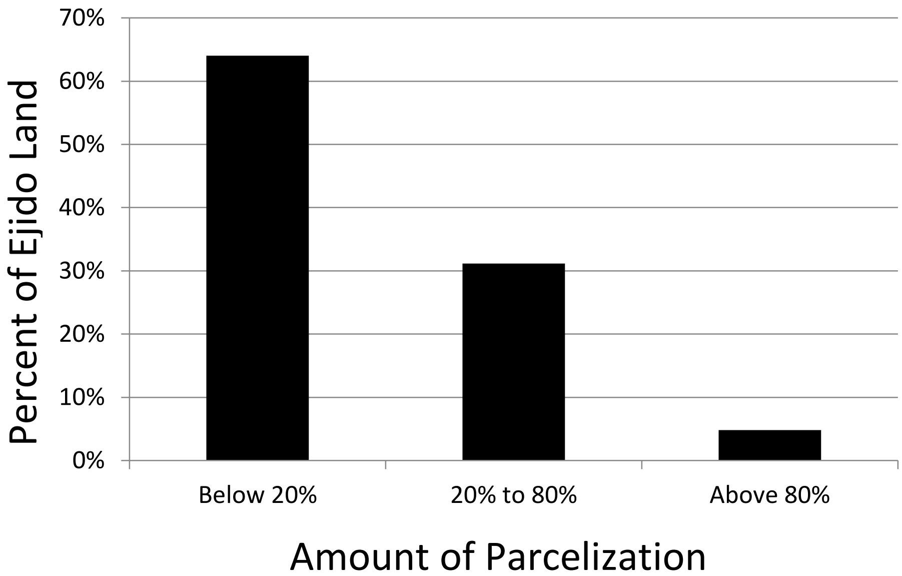

Figure 2.4 The distribution and degree of parcelization with ejido lands across the State of Yucatán. Sixty-four percent of all ejidos contain from 0-20% parceled land; 31% contain 20-80% parceled land; and 5% of ejidos are more than 80% parcelized. Ejido parcelization data were obtained from México's Registro Agrario Nacional, March 2017.

3.3 Changes to traditional Maya livelihoods in Yucatán

Concurrent with shifts in México's ejido land tenure are changes to livelihoods in México that are, at least partly, due to new corporate commodity chains. Prior to the mid-1980s México's food production was subsidized and a state-led governance structure (*parastatals*) managed the food commodity chains that were regionalized within national borders (Galvan-Miyoshi et al., 2015). At this time, only a few regional supermarkets existed in México and accounted for less than 20% of all food sales, while small-scale grocers and municipal markets serviced most of the population (Biles et al., 2007). Overall, México's food production system was largely locally-based, while the federal government exercised control over land distribution, prices, agricultural extension services, and food supply patterns. Such polices supported the ejido land tenure system across México. Following important changes to federal agrarian laws between 1986 and 1994, price controls were abandoned and the parastatal system was eliminated (Galvan-Miyoshi et al., 2015). As a result, the commodity chain governance shifted from *parastatals* and small retailers, to large foreign transnational corporations, bringing about rapid expansion in large-scale and capital-intensive production systems (Biles et al., 2007).

Currently, in the State of Yucatán, as land tenure shifts toward individual management, Maya livelihoods are transitioning away from subsistence agroforestry that primarily involves growing maize, toward market-oriented farming production of new crops and livestock. Since the change to Article 27, traditional crop growing activities have largely decreased in highly parcelized ejidos across the State of Yucatán, but have increased in ejidos with little to moderate parcelization (Figure 2.5). The decrease in traditional crop growing activities is at least partly due to a reconfiguration of maize and cattle commodity chains for distant markets (Appendini, 2014; Galvan-Miyoshi et al., 2015). For example, in 1991, only 64 of the roughly 700 ejidos in the state had cattle rearing as a principal livelihood activity, whereas in 2007, there was nearly a ninefold increase, with 567 ejidos engaged in cattle rearing as a principal livelihood activity (INEGI, 1994, 2007). Parcelized ejido lands are primarily clustered in Yucatán's cattle producing region around the City of Tizimín and the metropolitan region surrounding the City of Merida, the State's main export hub. A similar smaller cluster of parcelized ejido lands is in Yucatán's southern fruit producing region, primarily around the Town of Peto (Figure 2.6). Overall, with reductions in government subsidies supporting traditional subsistence agriculture, along with the expansion of corporate commodity chains across the state, the Maya people in the state increasingly participate in market-oriented, rather than traditional subsistence, livelihood activities.

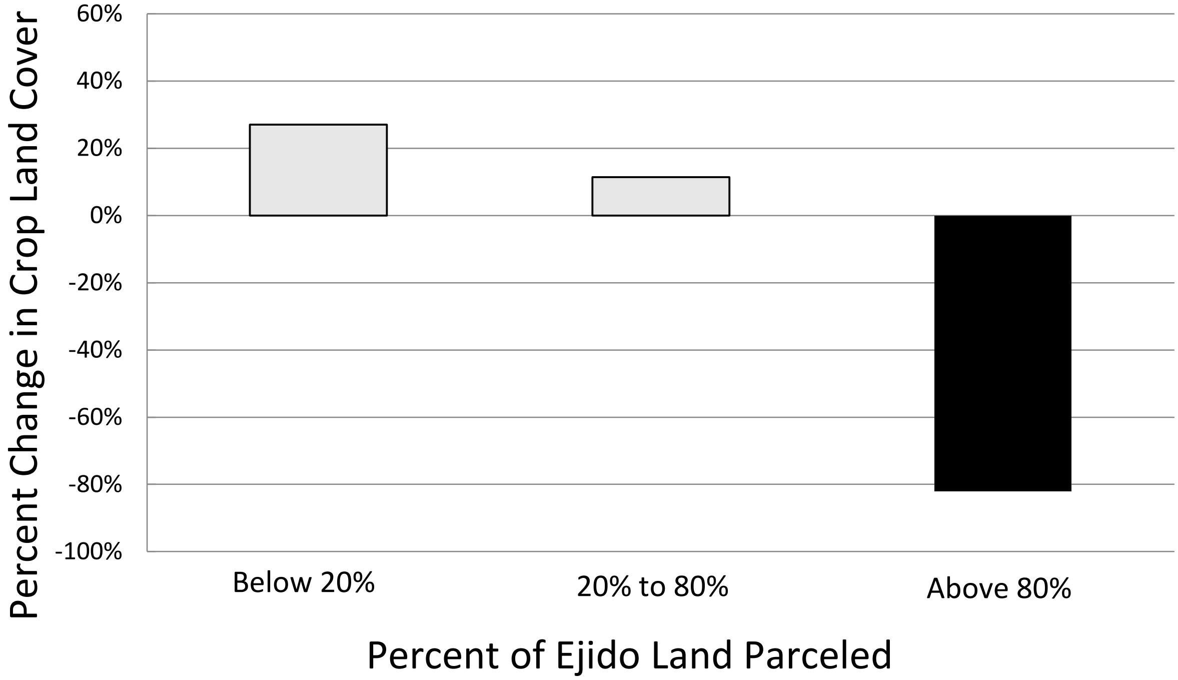

Figure 2.5 Change in agricultural cropland cover across all Yucatán ejidos between 1991 and 2007**.** During that period, the total amount of cropland increased 25% in ejidos containing from 0-20% parceled land, and 11% in ejidos containing from 20-80% parceled land. In contrast, for ejido land that was more than 80% parcelized, cropland decreased by more than 82%. Data obtained from México's Instituto Nacional de Estadística y Geografía, ejidal census, 2007.

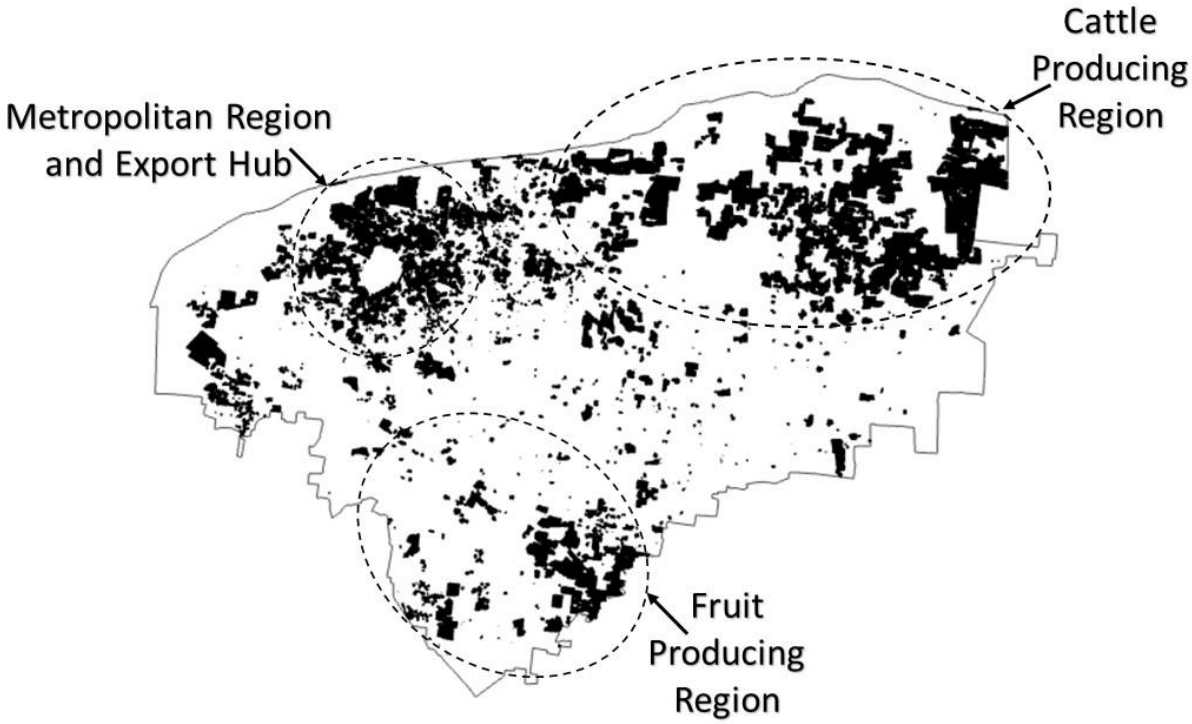

Figure 2.6 Parcelized ejido lands. Parcelization is primarily clustered in Yucatán's cattle producing region around the City of Tizimín and metropolitan region around the City of Merida, the state's main export hub. A smaller cluster of parcelized ejido lands is in Yucatán's southern fruit producing region, primarily around the Town of Peto. Ejido parcelization data were obtained from México's Registro Agrario Nacional, March 2017.

3.4 Ejido forest cover in Yucatán

Following ejido land parcelization and changes to livelihoods, there has been a decrease in traditional land uses involving small-scale crop cultivation, grasslands, and multiple tracts of forests and other varying successional habitats. Across México, both forest resources and available arable land are becoming increasingly limited as large-scale supermarkets and commercial agriculture and forestry industries penetrate into different regions (de Janvry et al., 2015). Government programs further exacerbate this problem. For example, Programa de Apoyos Directos al Campo or PROCAMPO (Program of Direct Payments to the Countryside) and Alianza para el Campo (Alliance for the Countryside) have been associated with increased levels of deforestation in México (Ellis et al., 2015), including the ejido landscapes of Yucatán. These government programs are intended to increase agriculture investment, increase productivity and intensification in ejidos and facilitate the integration of México's agricultural sector into the global market economy (Schmook & Vance, 2009). Additionally, the government of México has simultaneously reduced support for community forest management and has shifted forest management and production back toward industry. This shift was codified in the 1992 Forest Law (Ellis et al., 2015). As a result of these and México's efforts to embrace and encourage global economic forces, Yucatán ejidos are being increasingly integrated into the global agriculture market economy in ways reflected in Figure 2.1.

In the State of Yucatán, shifts in land tenure and changes to traditional Maya livelihoods and land uses have been strongly associated with diminishing forest cover. For example, parcelized ejido lands in the Yucatán peninsula have more land in use and higher deforestation rates than common-use ejido lands (DiGiano et al., 2013). Taking advantage of satellite imagery, the forest cover was calculated (from the GLAD, 2010, and Hansen et al., 2013 dataset) in the State of Yucatán during the year 2000, seven years after the constitutional reforms that initiated ejido parcelization, and again in 2010, shortly following the conclusion of the 1st stage of parcelization through PROCEDE (Figure 2.7). By the year 2000, 24% of parceled areas was devoid of forest cover, while within common-use (i.e., community-managed) areas, only 6% of the land was devoid of forest. On the other end of the forest cover continuum, more than 60% of the common-use land contained 80-100% forest cover, compared to only 37% of parceled areas with such high proportions of forest cover. By 2010, the complete absence of forest cover in parceled areas increased to 34%, while dense forest cover decreased to 27%. Deforested ejido lands are primarily located in the northern region of the State where parcelized ejido lands and agricultural commodity production are clustered (Figure 2.8).

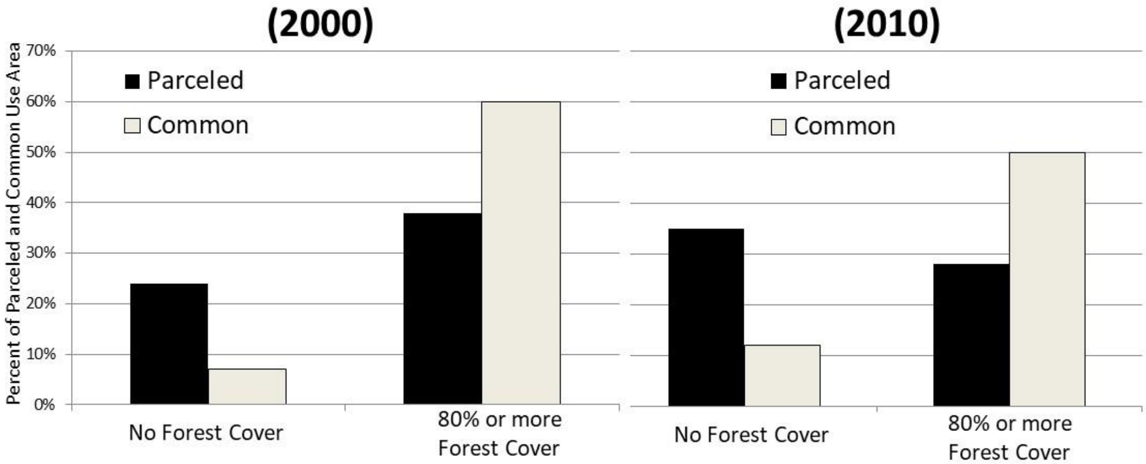

Figure 2.7 Amount of forest cover relative to the percent of ejido land that is parceled or common use (i.e., community-managed) in year 2000 and 2010 for the State of Yucatán. For year 2000, within parceled land, more than 24% of the area had no forest cover, whereas only 6% of common use areas had no forest cover. In addition, only 37% of parceled areas have 80% or more forest cover, whereas 60% of common use areas have 80% or more of forest cover. In year 2010, the amount of parceled land devoid of forest cover increased to 34%, and land with 80% or more forest cover decreased by 10%. Dense forest cover also decreased by 10% in common use areas, but the amount of land with no forest cover only increased by 5%. Forest cover data were obtained from Global Forest Change Data (Hansen et al., 2013).

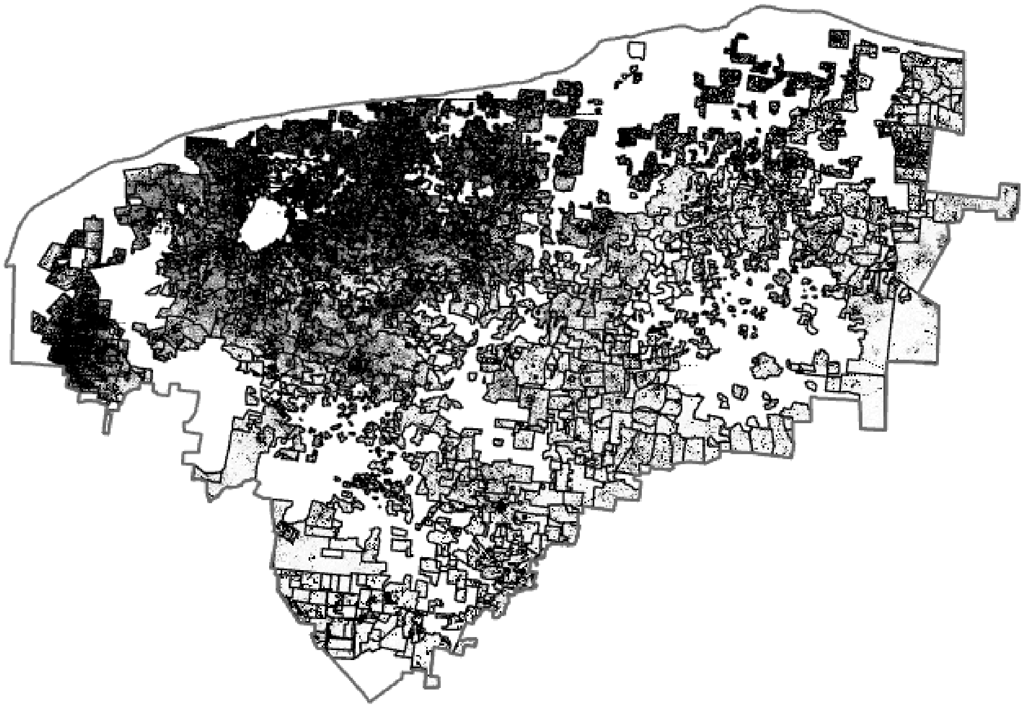

Figure 2.8 Yucatán's ejido tree cover in the year 2010. Darkened areas in ejidos represent deforested lands. Forest cover outside of ejidos are not shown here. Forest cover data were obtained from Global Forest Change Data (Hansen et al., 2013).

With international trade barriers now mostly removed, large agro-businesses continue to penetrate and acquire parcelized ejido lands, contributing to regional changes in land use and forest conversion. As agro-businesses have displaced traditional subsistence farming, agriculture in Yucatán has become more market-oriented, land cover even more fragmented, and patches of land that previously harbored high biodiversity levels have become more isolated, degraded, or diminished. Such observed patterns of forest loss and landscape fragmentation are likely to increase with further penetration of broader regional and global agricultural commodity chains that incentivize shifts toward different and more homogenous crops, switches from farming to cattle rearing, and changes in land use practices toward less sustainable forestry. In all, due to many forces and processes that originate from the outside world and beyond the influence of local control, ejido land cover, Maya livelihoods, land use practices, and land tenure systems in Yucatán are shifting away from traditional norms in many of the ways outlined in Figure 2.2.

4. Rethinking landscape conservation

In considering academic and policy recommendations, it is worth noting that conservation efforts in Yucatán have mostly focused on local manifestations of broader political-economic factors, rather than distant driving forces of changing landscapes. For example, the México REDD + Alliance and the Tropical Research Center of Veracruz University, recently conducted an exhaustive literature review on determinants of deforestation and land degradation across the Yucatán peninsula (Ellis et al., 2015). The review concluded that few studies have analyzed the underlying causes of change, including economic factors such as market growth, investment, and demands, or institutional factors such as government policies. Rather, attention has focused on local small-scale agricultural practices, which are often indicted as having the greatest overall impact on environmental change. The report from the study also suggests that the Méxican government considers traditional subsistence agroforestry as ecologically destructive. This is in contrast with many studies elsewhere, that emphasize the impact of government-initiated agricultural development projects, which tend to foster increased modern agricultural inputs, pasture development for livestock, and commercial logging operations that are the major causes of destruction of large tracts of forests across Yucatán (Chowdhury, 2010).

Conservation focused on local manifestations, rather than distant driving forces of changing landscapes across Yucatán is a problem because the peninsula, a global biodiversity hotspot (Vázquez-Domínguez & Arita, 2010), was recently identified by the federal government as a high priority region to address landscape change (CONAFOR, 2016). Therefore, increased efforts to better understand the structure and scale of political-economic and environmental relationships are needed. Such efforts should include more extensive and collaborative studies and analyses of global-to-local processes of change, along with causal pathways resulting in changes to livelihoods, landscapes, and biodiversity patterns. Long-term studies, such as the Global Land Project (Verburg et al., 2015), and the Land-Cover and Land-Use Change in the Southern Yucatán Peninsular Region Project (Turner et al., 2016), as well as other more recent efforts, have contributed greatly to understanding how distant political-economic driving forces impact local landscapes. But, much work remains, particularly with respect to drivers of land tenure change and how, through this important factor, globalized agriculture impacts indigenous community-managed landscapes.

Analyses moving forward should focus on broader scale political-economic forces underlying globalized agriculture. This chapter's contribution places emphasis on globalized agriculture as a driving force of change to indigenous community-managed landscapes, through the important mechanism of shifting land tenure and the concurrent transformation of livelihoods and land use and land cover. Such an expanded focus can serve as a foundation and aid the important task of landscape planning and conservation.

Promoting community sovereignty over land can empower and strengthen communities to adapt and be resilient to distant political-economic driving forces. The degree to which indigenous peoples and peasants are able to exert effective control over their livelihoods and landscapes is a significant consideration for landscape conservation (Sarkar & Montoya, 2011); their resource and property rights are increasingly relevant to landscape conservation (Blackman et al., 2017). Since the 1990s, numerous policy-oriented institutions, such as United Nations Educational, Scientific and Cultural Organization, Convention on Biological Diversity, World Wildlife Fund, and International Union for the Conservation of Nature (IUCN) all have commissioned studies and published articles on links between conservation and indigenous landscapes (Berkes, 2009). Yet, little is known about how indigenous community-managed landscapes, along with associated livelihoods and land uses, may be leveraged to enhance landscape conservation and inform policy (Sarkar & Montoya, 2011). One possible institution that may be used to facilitate conservation within indigenous community-managed landscapes is the Indigenous Peoples' and Community Conserved Areas, an organization promoted by IUCN. To further such a task, increased efforts are needed for intergenerational community landscape planning and institutional development over the long-term that can build greater capacity for adaptive governance. Regardless of the institutional processes, it will be particularly important to retain traditional land tenure systems and to build capacity within indigenous community-managed landscapes to adapt to distant political-economic driving forces of change.

5. Conclusion

Globalized agriculture is one of the greatest challenges confronting landscape conservation today. In the midst of this new globalized era, indigenous community-managed landscapes also face new and greater challenges. In México, the shift in ejido land tenure toward formal land parceling, individual management, and ultimately private property, threatens the vast conservation potential across the country's extensive ejido system. More broadly, similar indigenous community-managed landscapes throughout the tropics also are vulnerable to shifting land tenure. Such impacts can be compounding across a broader landscape and can culminate in widespread biodiversity loss with global consequences. Already, high rates of land conversion represent a great threat to global biodiversity (Fischer et al., 2006). Additionally, over half a billion people in developing countries currently depend on community-managed forests (Baynes et al., 2015) and access to land is one of the most contested issues facing indigenous groups worldwide.

Conservation efforts will be better served if we understand and engage the entire process of change that indigenous community-managed landscapes experience due to globalized agriculture. Indigenous community-managed landscapes alone cannot conserve biodiversity, but they can serve as highly effective conduits for biodiversity conservation (Robson & Berkes, 2011). Moreover, multiple factors influence the conservation potential of these landscapes. However, political-economic processes of globalized agriculture can be a major impediment to long-term diversity and healthy functioning of these landscapes.

Conservationists should develop new and additional ways for indigenous community-managed landscapes to increase resilience and adapt. As social and ecological change accelerate, more attention should be given to the need for a more far-reaching vision of landscape conservation. For conservation to alleviate the massive and compounding effects of changes to indigenous community-managed landscapes now underway, conservationists must rethink landscape conservation. Overall, landscape conservation scientists are urged to more fully consider: 1) impacts stemming from globalized agriculture and dominant global-to-local casual pathways that extend through community-managed landscapes; and 2) advancing the breadth and depth of more extensive studies and analyses. Such efforts can improve decision-making and planning in landscape conservation more broadly and can better protect biodiversity at all levels.

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CHAPTER 3

DISTANT POLITICAL-ECONOMIC FORCES AND GLOBAL-TO-LOCAL PATHWAY TO IMPACTS ON FORESTS OF EJIDO LANDSCAPES ACROSS YUCATÁN, MÉXICO

1. *Introduction*

Indigenous community-managed land tenure systems in many locations worldwide are shifting towards individualized and privatized systems (Kelly et al., 2010; Grimm & Lesorogol, 2012; Loehr, 2012). Accompanying shifts in land tenure are changes in livelihoods, away from subsistence-based, and toward market-oriented activities (Pereira et al., 2016). Distant political-economic driving forces, including commodity markets for agriculture, livestock and timber, are larger factors affecting this shift in land tenure and livelihoods (Shriar, 2014).

The link between commodity markets, land tenure and livelihoods is conspicuous in tropical dry forest biomes or regions that have pronounced seasonality in rainfall distribution (Miles et al., 2006), which produce much of the world's commodity products, such as fruit and beef (Portillo-Quitero & Sánchez-Azofeifa, 2010). Dry tropical forests, which comprise 42% of all tropical land areas (Daniels et al., 2008), also support a large proportion of global biodiversity and represent one of the world's most threatened biomes (Stoner & Sánchez-Azofeifa, 2009; Portillo-Quitero & Sánchez-Azofeifa, 2010).

In many parts of the tropics, such as southern México, dry tropical forest land is managed by indigenous communities. Such indigenous community-managed land tenure, especially in concert with traditional livelihood systems, can be valuable for conservation (Harvey et al., 2008; Ceddie et al., 2015), in some cases comparable to the value of old-growth forests and pristine reserves (Jose, 2012; Sistla et al., 2016; Vallejo-Ramos et al., 2016; Blackman et al., 2017). For example, community-managed landscapes and forests have exhibited lower and less variable annual deforestation rates than protected areas (Porter-Bolland et al., 2012). Conversely, individually titled and private property can lead to capital accumulation and market access in ways that result in land use and land cover change, and specifically deforestation (Liscow, 2013; Holland et al., 2017). Thus, as communities in dry tropical regions become increasingly integrated into global commodity markets, and land tenure and livelihood systems shift to individualized and privatized systems, the spatial organization of land use and land cover changes in ways that can ultimately impact biodiversity and conservation potential (Hecht, 2010; Turner, 2010; Lambin & Meyfroidt, 2011; Oliviera & Hecht, 2016).

Many socioeconomic and environmental factors can drive land use and land cover change, including deforestation. However, broad-scale political-economic forces primarily drive proximate causes of land use and land cover change (Geist and Lambin, 2002). Moreover, land tenure and agricultural commodity production for distant markets are widely recognized as key drivers of land use and land cover change (Rudel et al., 2005; DeFries et al., 2010; Robinson et al., 2014). Despite this recognition, the cross-scale interaction between these and other important drivers of landscape change form complex and coupled social and ecological systems that, as a whole, are challenging to conceptually map and spatially model (Rindfuss et al., 2004).

Global-to-local causal pathways and distant driving forces that impact landscape and biodiversity patterns remain poorly understood and are seldom documented (Jepsen et al., 2015; Plieninger et al., 2016; Spalding, 2017). Accordingly, empirical studies often focus on landscape patterns (Chowdhury, 2006), rather than examining underlying processes that contribute to these patterns (Hersperger & Burgi, 2009). For example, spatially explicit statistical methods are rarely used, despite their potential to capture and connect broad-scale complex processes and reveal linkages and causal pathways to landscape impacts (Chowdhury, 2006). Nevertheless, increasingly recognized is the need for empirical studies that explain global-to-local pathways, from distant political-economic driving forces, extending through rural agrarian shifting land tenure and livelihoods, and ultimately to changes in land use and land cover (Borras Jr. et al., 2011; Borras Jr. & Franco, 2012; Holland et al., 2014; Robinson, 2014; Robbins et al., 2015).

Yucatán, México is an exemplary location to investigate such global-to-local pathways that may impact rural agrarian land tenure and livelihoods within an indigenous community-managed landscape. The State of Yucatán is embedded in a dry tropical forest region with diverse vegetation and a species-rich landscape (Porter-Bolland et al., 2015). The state also is part of the Mesoamerican Biological Corridor, a global biodiversity hotspot with unique and diverse indigenous cultural heritages.

For nearly a century, indigenous Maya communities have managed much of the state's forests and biodiversity under México's ejido land tenure system. Ejidos are a type of community landholding that the federal government created during the early 1900s, through Article 27 of México's constitution to support small-scale subsistence agro-forestry and to redress long-standing land and natural resource inequality (Perramond, 2008; Barnes, 2009). Ejido-managed lands often have high levels of biodiversity, especially in the State of Yucatán, due to a mosaic of multiple-use forests and small-scale subsistence agriculture (Robson & Berkes, 2010). Although it is hardly the case that every ejido is sustainable, ejidos overall can play an important role in conservation efforts. Indeed, multiple studies across México, and specifically in the Yucatán peninsula, have shown that ejidos can contribute to landscape conservation (Barsimantov & Kendall, 2012; DiGiano et al., 2013; Ellis et al., 2017a). In particular, community forest management for timber extraction has played a pivotal role in maintaining forest cover and biodiversity conservation (Ortega-Huerta & Kae Kral, 2007; Ellis et al., 2015a). Ultimately, ejidos as a common resource institution have become a foundation for subsistence livelihoods across México, and a model of sustainable community-forest landscape management (Bray et al., 2003; Berkes, 2009).

Despite the subsistence livelihood and conservation value of ejidos, Article 27 was significantly altered in 1992 as part of México's push for market liberalization and increased integration into the global economy. Specifically, the creation of new ejidos was discontinued; land parceling and legal certification began; and restrictions were eliminated, allowing ejido lands to be rented, sold, bought or leased (Perramond, 2008; Smith et al., 2009), with the exception of forested ejido lands (Barsimantov et al., 2010). Overall, the changes to Article 27, specifically the provisions that ejido common use lands could be divided and managed among individual farmers of the ejido, enabled and promoted a shift in land tenure strategies, away from community-managed, and toward individually-managed lands.

Exacerbating the change to ejido regulations, México's agricultural food system, which conspicuously supported the ejido land tenure system (Galvan-Miyoshi et al., 2015), also was restructured in the mid- to late 1980s. Prior to the 1980s, México's agricultural food system was based on a state-led governance structure involving locally-based and small-scale municipal markets, while the federal government exercised control over food prices and agricultural extension services. But, with changes to agrarian policies in the late 1980s, the governance of the agricultural food system has shifted towards dominance by large foreign transnational corporations, bringing about rapid expansion in large-scale and capital-intensive production systems (Biles et al., 2007), and resulting in a fivefold increase in agricultural exports between 1990 and 2010 (UNCTAD, 2013). Concurrently, agriculture development of crop and pasture lands drives land use and land cover change, contributing to deforestation across the Yucatán peninsula (Ellis et al., 2017a,b).

In the face of all of the changes to México's ejido land tenure and agricultural food systems, as well as potential associated impacts to forest and biodiversity patterns, the Yucatán peninsula is an ideal place to study cross-scale linkages. Consequently, we set out to explore the global-to-local pathway from these distant political-economic forces and commodity markets to attendant shifts in ejido land tenure and livelihoods, and the associated effects on land use and land cover in Yucatán. Our objective for this article was to examine – in a spatially explicit way – (a) the relationship between commodity production for distant markets and effects on ejido land tenure and (b) subsequent and possibly consequent patterns of forest cover in the State of Yucatán. In our analysis, we considered the influence of commodity markets to be reflected in the total area of agriculture, pasture and forestry lands cultivated for markets (commodity production) within municipalities (administrative division of a state within which ejido lands are located), and total area of common use (community-managed) ejido lands that shifted to legally parcelized (individually-managed) ejido lands. We compared the difference in forest cover between parcelized and common use ejido lands, using two categories: deforested lands (0% tree cover), *versus* densely forested lands (≥80% tree cover). Using these measures and spatially explicit analyses, our research questions were:

(1) what is the relationship between municipality-level commodity production and the extent of individually managed ejido lands?

(2) what is the relationship between individually managed versus community-managed ejido lands and forest cover?

2. *Materials and Methods*

2.1 Study Area: Yucatán, México

Our study area, the State of Yucatán, México, lies between 19.6° and 21.6° north latitude and 87.3° and 90.4° west longitude. With a land area of 43,577 km², the state is divided among 106 municipalities and represents approximately 30% of the Yucatán Peninsula (INEGI, 2016; Islebe et al., 2015). The City of Mérida and Port of Progreso, in the northwestern region are the only large metropolitan areas in the state. A few small cities and numerous smaller towns and rural villages are dispersed throughout the remainder of the state. Indigenous Maya people make up roughly 65% of state's total population, and are especially common in rural areas and more remote areas in the state's southern region (INEGI, 2016). There are approximately 700 ejidos in the State of Yucatán, comprising approximately 56% of all land and 64% of all forested lands in the state. With ejidos occupying over 2.5 million ha across the state, most ejidos comprise roughly 1 thousand ha, but can be as large as approximately 39 thousand ha.

Most ejidos in the state are under the primary stewardship of Maya people (INEGI, 2016; Trench et al., 2017), and these communities have historically engaged in traditional land use and subsistence agroforestry livelihoods (Sánchez-Sánchez et al., 2015). Specifically, most ejido land use are milpa systems (Graefe, 2003), which has existed in the peninsula for over three millennia (Parsons et al., 2009), and employ a complex and rotational (slash-and-burn) and mixed agriculture-forest system that primarily involves growing maize, squash, beans, tomatoes, jalapeños and other supplementary vegetables (Sánchez-Sánchez et al., 2015). Milpa products are primarily for home consumption (Parsons et al., 2011), and are not usually sold in markets (Diemont et al., 2011). Moreover, since milpa is a rotational system, any forest clearing that occurs is merely temporary. Traditional milpa system management generally involves: 1) manual tree removal and a controlled burn on 2–4 ha of land per ejidatario (ejido farmer) and their household; 2) after 2–4 years of harvesting, the milpa is left fallow and new milpa is cleared; 3) shrub land grows for 5 years before nurse trees are planted to encourage regeneration of the forest; 4) as a new forest stand matures beyond 10 years, bee colonies are reintroduced to aid in pollination; 5) after regenerating for 30 years, a stand is structurally considered a mature forest. Overall, traditional milpa farming involves small-scale rotational system with active restoration that mitigates deforestation. In the milpa system, soil erosion and deforestation tend to be less severe than in permanent and more intensive agricultural systems (Pérez-García & del Castillo, 2016). However, present day milpas often vary from traditional systems to include modern practices, such as using herbicide and pesticides. In addition, fallow periods often are shortened, along with the entire rotation cycle, which can even be reduced to less than 15 years.

Following the national trend, traditional livelihoods and land uses in the State of Yucatán, and the region more broadly, are shifting away from traditional practices and toward market-oriented activities (Chowdhury, 2010; Radel et al., 2010). For example, between 1991 and 2007 pasture land for commodity production increased 36% across the state and there was a sixfold increase in agricultural exports (INEGI, 1994; 2007a). At the same time, since the changes in Article 27, more than 500 ejidos across the state have formally apportioned and legally designated at least some of their lands as parcels among individual ejido farmers (INEGI, 2016). Specifically, 680,675 ha of all ejido land in the state are individually parceled. However, formal parcelization is a gradual process through PROCEDE (Programa de Certificación de Derechos Ejidales y Titulación de Solares), and community governance still exists over all ejido lands, but to a much lesser extent in individually parcelized areas *(*Barnes, 2009). Additionally, ejidos may informally parcel their lands regardless of PROCEDE, which is not uncommon in anticipation of formal parcelization. Overall, as agricultural land use increases, particularly in parceled areas with less land available for cultivation, fallow periods shorten, negatively affecting crop yields and, in turn, further spurring demand for forest conversion (Parsons et al., 2009) and shorter rotations.

2.2 Data Description

Our calculations of the amount of parcelized ejido lands (ha) and common use ejido lands (ha) were derived from the Censo Agropecuario 2007: IX Censo Ejidal del estado de Yucatán (INEGI, 2007b). For our analysis, the amount of parcelized and common use ejido lands was aggregated within the municipality in which they are located. Commodity production land (ha) was measured at the municipality level using the total surface area of the units of production for agriculture, pasture and forests; the data are from the Censo Agropecuario 2007: Agrícola, Ganadero y Forestal (INEGI, 2007c) for the 106 municipalities in the State of Yucatán. Among other factors, the municipality-wide commodity production represents the agro-economic system within which ejidos are embedded. Within commodity production land, agriculture lands are defined as largely comprising crops, pasture lands primarily involve livestock rearing, and forestry lands are natural forests comprising timber harvested for commodity markets. Although forestry comprises a small amount of commodity production in the state, we included forestry lands in the model to provide a comprehensive picture of all major land uses associated with livelihoods within ejido lands. The 2007 census data were particularly important to our analysis, because these data were gathered at the conclusion of the 1st stage of the land parcelization process in México, which was administered through Programa de Certificación de Derechos Ejidales y Titulación de Solares (PROCEDE) from 1993, to December 2006.

To analyze forest cover in ejidos across the state, we used tree cover data for circa 2010 from Global 2010 Tree Cover (GLAD, 2010), which is based on the Global Forest Change Data (Hansen et al., 2013). A tree in this dataset was defined as any vegetation taller than 5 m in height. Tree cover in this dataset was based on median per pixel estimates of 2008 to 2012 percent maximum (peak of growing season) tree canopy cover derived from cloud-free annual growing season composite Landsat 7 ETM+ data (GLAD, 2010). Thus, the 2010 tree cover dataset provided a good approximation of overall forest cover following the conclusion of PROCEDE in December 2006 and was contemporaneous with the Censo Agropecuario 2007.

The forest cover data were spatially referenced with ejido boundaries, and boundaries of parcelized and common use areas for all ejidos of the State of Yucatán that were derived from México's Registro Agrario Nacional, March 2017. To correspond to the census data, ejido forest cover data also were aggregated at the municipality level. Ultimately, the data from the municipality of Tizimín were omitted from the final statistical analyses, because the municipality's large size relative to the other 105 municipalities disproportionately influenced and exaggerated the results. The four municipalities comprising the metropolitan region were also excluded, because we were focused on differences in rural land tenure, livelihoods, land use and forest cover.

2.3 Data Analysis, Model Evaluation and Selection

We analyzed the data via a combination of non-spatial and spatial analyses using R (R Core Team, 2013). In an early exploratory phase, we used ordinary least squares regression to identify a subset of variables. After examining general patterns in the data, we determined that many of the variables were potentially spatially correlated. Using ArcGIS (version 10.6), we first mapped and examined this subset of variables with respect to the spatial arrangement of municipality-level commodity production, parcelized and common use ejido lands, and ejido forest cover.

We then formally investigated and quantified spatial correlation of and between selected key variables using variographic analysis, which decomposes the spatial variability of observed variables among distance classes. In this process, first, we examined the spatial autocorrelation of commodity production. Next, we examined spatial correlation: a) between commodity production and ejido land tenure, and b) between ejido land tenure and forest cover. For the variographic analyses we fitted the data using spherical and exponential models and used a distance of 100 km, which was deemed conservative, based on the maximum distance of 288 km for the State of Yucatán (Journel & Huijbregts, 1978; Crawley, 2013).

After confirming spatial correlation among variables, we specified four sets of simultaneous autoregressive (SAR) models, a statistical method that augments linear regression models with an additional term to account for the spatial correlation structure in a dataset (Kissling & Carl, 2008). To include the spatial correlation structure of our dataset into the SAR models, we defined neighbors among the municipalities based on shared borders, and created a spatially weighted matrix. Using shared borders to define neighbors, rather than including municipalities beyond those with shared borders, allowed us to account for spatial correlation if it diminished over an increasing distance. We weighted each municipality's neighbor equally, such that the weights of all neighbors of a municipality sum to one. Equation 1 shows the general SAR model in matrix form that includes the spatial structure of our dataset.

Eqn 3.1. $Y = X\beta + \lambda Wu + e$

where

λWu = the spatial structure (λW) in the spatially dependent error term (u)

λ = the spatial autoregression coefficient

W = the spatial weights matrix

β = a vector representing the slopes associated with the explanatory

variable(s) in the original predictor matrix X

e = the (spatially) independent errors

Our first SAR analyses involved two models that we constructed to test whether commodity production (as a composite variable that combined the measurements of agriculture, pasture, and forestry lands cultivated for market into one variable) was more likely related to: 1) parcelized ejido lands, or 2) common use ejido lands. The second set of SAR analyses involved four separate models to test whether parcelized ejido lands were more likely to be related to the cultivation for market of 1) agriculture lands; 2) pasture lands; 3) forestry lands; or 4) all three individual commodity production variables tested together. A third and fourth set of SAR analyses each involved two models to test the response variables of deforested ejido lands and densely forested ejido lands against the independent variables of parcelized and common use ejido lands. We evaluated and compared the SAR models relative to each other using the Akaike information criterion (AIC).

3. RESULTS

Our non-spatial exploratory analysis revealed that commodity production for distant markets, parcelized ejidos, and deforested ejido lands are all strongly interconnected through a series of complex pathways that can lead to broader landscape impacts. Specifically, the plotted data and trend lines of land tenure indicated that the amount of parcelized ejido lands in municipalities, in general, was strongly and positively related to the amount of agriculture, livestock and forestry lands cultivated for markets. The relationship between commodity production and degree of parcelization was illustrated well by first combining all three of these market-based land use categories into a single composite value of commodity production and then plotting this variable against the total area of parcelized land (Figure 1a). In comparison, the amount of common use ejido lands was much more weakly related to commodity production (Figure 1b). The positive, but weak relationship suggests that the expansion of market-oriented activities and land use decisions was not strictly tied to ejido land tenure arrangement. The degree to which ejido lands were parcelized also was positively related to the amount of deforested ejido lands (Figure 1c). Although the plotted data and trend line show a wide variation in levels of deforestation across parcelized ejido lands, the amount of parcelized ejido lands was more strongly related to lack of forest cover than was the amount of common use ejido lands (Figure 1d).

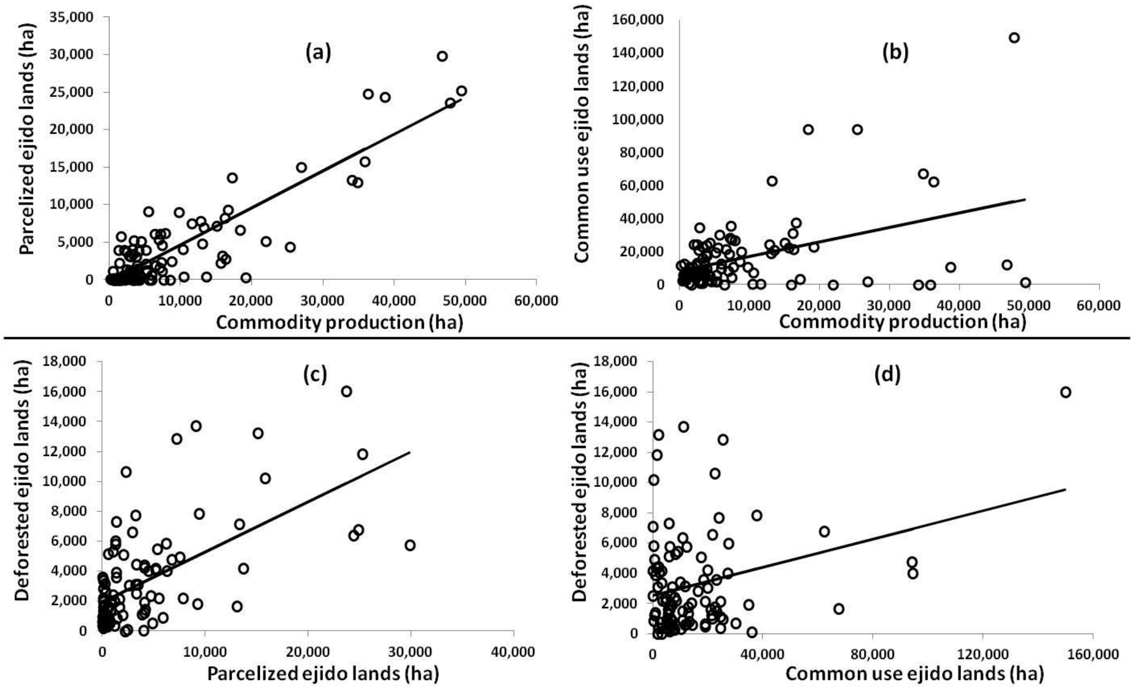

Figure 3.1 Parcelized ejido lands (a) were more strongly related to municipality commodity production than were common use ejido lands (b). Deforested ejido lands (c) were more strongly related to parcelized ejido lands, rather than were common use ejido lands (d).

These exploratory data, although informative of general relationships, did not account for the evident geographic clustering and spatial correlation within and between commodity production, parcelization, and deforestation (Figure 2). The largest commodity-producing municipalities appeared mostly clustered in the northeastern corner of the state around the City of Tizimín, in the most southern region around the Town of Peto and, to a lesser degree, in the northwestern region around the City of Mérida. Indeed, our variographic analyses revealed that municipality-level commodity production was spatially autocorrelated, and this influence extended over a distance of 195 km (Figure 2a).

Also associated with commodity production was the nature of the land tenure system. Specifically, we found strong spatial correlation between commodity production and parcelization. The heavily parcelized ejidos throughout the State of Yucatán were mostly clustered in the northeastern corner of the state around the City of Tizimín, and in the northwestern region around the City of Mérida (Figure 2b). Ejido lands that were 25% or more parcelized typically clustered around market areas and primary transportation routes between the urban areas of Tizimín, Mérida, and Peto. Accordingly, variographic analysis revealed that parcelization was spatially correlated with commodity production, and this extended over a distance of 91 km.

Similarly, we observed a clustering of deforested ejido lands that was spatially correlated with the degree of ejido land parcelization. Deforested ejido lands were primarily distributed along the northern region of the state and were spatially correlated with parcelized ejido lands over a distance of 17 km (Figure 2c). In contrast, the most densely forested ejido lands were located in the southeastern region of the state, where the milpa system dominates the land use, and ejidos are mostly community-managed. Overall, our variographic analyses emphasized the direct linkages between municipal-level commodity production and degree of ejido land parcelization, which in turn were linked to deforested ejido lands.

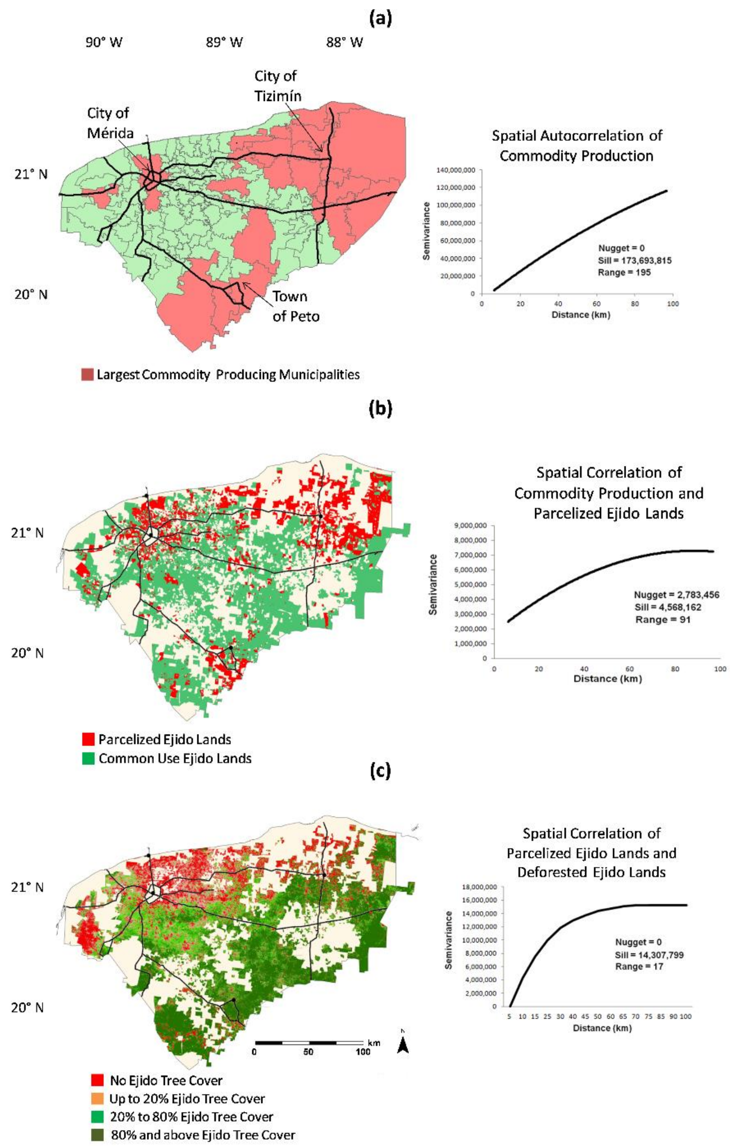

Figure 3.2 Commodity production and forest cover within ejido lands were clustered and spatially correlated with the ejido land tenure system across the State of Yucatán. (a) Municipality commodity production was clustered in the northeastern and southern regions of the state, while exhibiting spatial autocorrelation over a distance of 195 km. (b) Parcelized ejido land tenure was clustered in the northeastern, northwestern and southern regions of the state and was spatially correlated with commodity production over a distance of 91 km. (c) Deforested ejido lands were clustered in the northeastern and northwestern region of the state and were spatially correlated with parcelized ejido lands over a distance of 17 km. Data sources: INEGI, 2007a,b, and Hansen et al., 2013.

The simultaneous autoregressive models, which accounted for spatial correlation, confirmed that lands cultivated for commodity markets, parcelized ejido lands and deforested ejido lands all were interconnected through a complex pathway (Table 1). Although both land tenure strategies are related to commodity production, the AIC values of our SAR models revealed that parcelized ejido lands were more likely to be cultivated for commodity markets (AIC = 2079, P= 0.0001) than common use ejido lands (ΔAIC = +111, P=0.0001). Moreover, parcelized ejido lands were more likely to involve multiple types of commodity production, as indicated by the composite commodity production variable (AIC=1999, P=0.0245), relative to the single categories of land use for commodity markets: agriculture (ΔAIC = +14, P=0.0006), pasture (ΔAIC = +53, P=0.0172) and forestry (ΔAIC = +77, P=0.0109). Agriculture lands were most likely to be cultivated for commodity markets, followed by pasture lands, and then by forestry lands. Despite the small amount of forestry lands in the state relative to other types of commodity production, forestry lands were statistically significant. In addition, deforested ejido lands were more likely to be parcelized (AIC = 2030, P=0.0002) than managed within a common use system (ΔAIC = +8, P=0.0001). Common use ejido lands were also much more likely to be densely forested (80% or more tree cover) than parcelized lands (AIC = 2210, P=0.0001), (ΔAIC = +136, P=0.05).

Table 3.1 Spatial Simultaneous Autoregressive (SAR) Model Results.

Variables Response Explanatory	Coefficient Estimate	Standard Error	Autoregressive Coefficient (Lambda)	*P*-value	AIC and Δ AIC
Commodity Production (composite variable)					
Parcelized Lands	1.44	0.08	0.51	0.0001	**2079**
Common Use Lands	0.19	0.03	0.68	0.0001	+ 111
Parcelized Lands					
Agriculture, Pasture and Forestry Lands	--	--	0.34	0.0245	**1999**
Agriculture Lands	0.81	0.06	0.43	0.0006	+ 14
Pasture Lands	0.29	0.03	0.37	0.0172	+ 53
Forestry Lands	4.52	0.66	0.39	0.0109	+ 77
Deforested Lands (0% Tree Cover)					
Parcelized Lands	0.41	0.07	0.42	0.0002	**2030**
Common Use Lands	0.10	0.02	0.54	0.0001	+ 8
Densely Forested Lands (≥ 80% Tree Cover)					
Common Use Lands	0.75	0.04	0.46	0.0001	**2210**
Parcelized Lands	1.34	0.29	0.24	0.05	+ 136

4. Discussion

The changes to México's ejido land tenure and agricultural food systems, in the 1980s and 90s, were intended to replace the traditional community-managed and subsistence-based agro-forestry system with a market efficient and modern agricultural land system (Herrera Rodríguez, 2012). In turn, this new system was envisioned as attracting higher levels of foreign investment, particularly in large-scale agriculture (Spalding, 2017). Government programs, such as PROCAMPO (Program of Direct Payments to the Countryside) and Alianza para el Campo (Alliance for the Countryside) have since promoted this goal through encouraging market-oriented agriculture and pasture land use, and particularly in ejidos (Daniels et al., 2008). Such changes to land tenure and land use have been reported to reshape the State of Yucatán's landscape (DiGiano et al., 2013; Ellis et al., 2017b). However, few studies establish causal links between agricultural commodity production for distant markets, and local land use and land cover change at the local level (Meyfroidt et al., 2013). Moreover, the role of shifting land tenure as a driver of deforestation, and particularly in the Yucatán, rarely has been empirically assessed (Ellis et al., 2017c).

In the State of Yucatán, what began as an engagement with commodity production, especially in previously more isolated regions, appears to have manifested as the disruption and alteration of Maya ejido land tenure strategies, combined with a shift in livelihoods away from subsistence, and toward market-oriented activities (Rudel et al., 2009). Much of Yucatán commodity-producing activities, however, supply distant markets. For example, habanero chilis are largely produced for the rest of México and, in recent decades, for export to the United States and Japan (Biles et al., 2007). Similarly, much of the beef produced in the State of Yucatán is sent to other regions of México. Recently, much of the deforestation there, as well as elsewhere across the Yucatán peninsula, has involved conversion to pasture lands (Díaz-Gallegos et al., 2010; Ellis et al., 2017a,b). Overall, we see a web of connections that have contributed to an accelerated transition along a pathway, from commodity production for distant markets, through shifting ejido land tenure, and extending to deforested ejido lands.

The observed connections between 1) commodity production at the municipal level, and 2) ejido land tenure and forest cover, are strongly expressed and sharply revealed through a spatially explicit lens. In particular, ejido land tenure and modes of production appear to follow the municipality's agro-economic system, in which ejidos are embedded (Barsimantov et al., 2012). The cultivation of lands for distant markets and parcelized ejido lands were both largely clustered in rural regions with small cities serving as hubs for commodity production. We acknowledge that the apparent clusters also relate to historical land use regions in the state. For example, the northwest region around the state's capital (City of Mérida) and near the port of Progresso was the earliest and most rapidly developed region, the northeast region is historically considered a cattle rearing region, the southern region a fruit producing region, and the central region, with the least amount of commodity production, is traditionally a milpa region (Biles et al., 2007). The differences in land use in these regions are in part, likely linked to soil characteristics and ease of conversion to agriculture or pasture. For example, forests in more level, drier terrain, and higher-fertility areas are more likely to be cleared (Wyman et al., 2007). In addition, the southern (fruit producing) region has a more nutrient rich soil, compared to the northeast (cattle rearing) region. Indeed, biophysical characteristics can influence the nature and the use of the land. However, the observed clustering pattern seems to manifest beyond these local-level geographies. Rather than isolated patches, clusters of the largest commodity-producing municipalities and higher degrees of parcelization of ejido lands often coincide and are often contiguous, indicating an increased likelihood of co-occurrence among neighboring communities. Contiguous clusters appear to concentrate as well along main transportation routes with direct access to regional and global markets. In this way, global market penetration into a region bears a resemblance to an initial inoculation point, followed by a contagion spreading along specific pathways. As a result, isolated ejidos that lack direct access to commodity markets are less likely to alter traditional land tenure regimes and livelihood practices, and in turn, can experience less land use and land cover change.

Understanding the drivers of landscape change can help to identify more sustainable land uses (Meyfroidt et al., 2018) and to develop sustainable transformations through stakeholder engagement and land governance (Verburg et al., 2015). This is particularly important as global and regional political economies increasingly influence local land tenure, livelihoods, land use and land cover (Magliocca et al., 2015). Moreover, changes to landscapes reach far beyond the local level and are pervasive factors in global environmental change (Verburg et al., 2013). Thus, understanding the global-to-local causal pathways to landscape change is fundamental to understanding global environmental change (Turner II et al., 2008).

Perhaps the most important aspect of our analyses is the evidence for the conservation potential of community-managed ejido lands across the State of Yucatán to help mitigate land use and land cover change. The community-managed ejidos were observed to be minimally engaged in commodity production and much more likely to be densely forested. In addition to other factors, this land use pattern likely results from long-standing livelihood strategies, customary practices, and institutions that reduce vulnerability from external pressures and exclude outsiders from using land and resources (Hayes, 2007; DiGiano et al., 2013; Buntaine et al., 2015; Delgado-Serrano et al., 2017). For example, the milpa is more than a rotational agro-forestry system to ejidatarios. Milpa farming also is a socio-cultural institution governing livelihood and land use strategies in ejidos that reinforce land stewardship and can enable social and ecological resilience (Colfer et al., 2015). Milpa plays a key role in the peoples' identity and connects them to a wider society that involves cultural legacy, traditional knowledge and livelihood practices, and adherence to a particular way of life (de Frece & Poole, 2008). In turn, milpa is considered resilient, sustainable, and an outstanding shifting cultivation system in Mesoamerican tropical areas, particularly in the context of recent global land use change (Bermeo et al., 2014; Pérez-García & del Castillo, 2016). However, milpa sustainability likely varies due to local social and environmental conditions. Milpa farming also does not lend itself to land parceling, because milpa is relocated to potentially better land every two to four years (Anderson, 2005). Therefore, sharing land and resources for mutual benefit in ejidos can empower community members through expanded access to land for milpa farming and provide more alternatives in response to external shocks that might otherwise lead to livelihood hardships (Robinson et al., 2014). As a result, community-managed ejidos across Yucatán have the potential to better integrate forest use, rural development and biological conservation than other land tenure systems (Robson & Klooster, 2019), and have recently gained attention for their relevance to conservation and development issues, such as food security (Bermeo et al., 2014).

Although the Maya are the primary land stewards in ejidos across the state (Trench et al., 2017), data on the distribution of the Maya population across ejidos was unavailable. However, most community-managed ejidos are located in the state's central region in municipalities that are largely comprised of Maya populations compared to municipalities across the northern region. Additionally, ejidos in the central region tend to be more socially isolated compared to other regions. The Maya people are fiercely protective of their independence and their land, hold strong communal values, and often are suspicious of the government trying to parcel their land and selling the land to outsiders (Anderson, 2005). The traditional relationship between the Maya people and land, similar to other indigenous groups (Berkes, 2012), is intricately tied to its social and cultural importance, rather than solely its market value (Anderson, 2005). In turn, the socio-cultural organizational and institutional structures of community land tenure and milpa farming regulate land use in ways that promote stewardship and equitable distribution of resources (Barnes, 2009). In all, ejidatarios in the state, and elsewhere in México, often resist changes to their way of life and their traditional milpa production, including market and financial incentives (de Frece & Poole, 2008). Thus, community-managed ejido land tenure often involves non-capitalist relations to land and resources based on low-intensity agricultural systems, with a greater representation of native ecosystems, such as tree-dominated agroforestry systems, that lead to lower and less variable annual deforestation rates than experienced among individually parcelized ejidos (Porter-Bolland et al., 2012).

The positive influence of community-managed ejido land tenure on biodiversity and conservation is not specific to the State of Yucatán (Ortega-Huerta and Kae Kral, 2007; Barsimantov et al., 2011; Barsimantov & Kenndall, 2012; DiGiano et al., 2013; Ellis et al., 2015; 2017c). Indigenous community-managed land tenure systems elsewhere have been reported to have a similar positive impact on conservation (Harvey et al., 2008; Robinson et al., 2014; Buntaine et al., 2015; Ceddie et al., 2015; Blackman et al., 2017). However, we do not expect community management to mitigate land use and land cover change everywhere, nor to be a one-size-fits-all solution to deforestation. For example, community-managed land has performed with more mixed effects in some places in Africa compared to Latin America (Robinson et al., 2014). Moreover, the local context is an important factor that can affect the success of community management, such as roads and access to markets, market value of resources, and infrastructure development, as well as socio-economic, environmental and biophysical factors. Regardless, we believe that community-managed lands can strengthen communities to adapt and to be resilient to the impact of distant political-economic driving forces of landscape change (Hayes, 2007).

Little is known however, about how community-managed lands, along with associated livelihoods and land uses, may be precisely leveraged to enhance conservation (Sarkar & Montoya, 2011).

Increased efforts are needed to better understand and enlist community-managed lands into conservation efforts more broadly. In particular, cross-site and cross-cultural international conservation research of community-managed lands could prove useful. One possible institution that may be used to facilitate community-managed conservation is the Indigenous Peoples' and Community Conserved Areas (ICCA), an organization promoted by the International Union for Conservation of Nature.

Community-oriented landscape conservation approaches have been widely embraced more recently (Sistla et al., 2016; Vallejo-Ramos et al., 2016) and many international conservation initiatives now focus on multifunctional landscapes and not solely on protected areas (Robson & Berkes, 2010; Sayer et al., 2013). As a result, community-managed forest landscapes are becoming a global trend (Baynes et al., 2015). Although often neglected or not recognized in official conservation systems in the past, community-managed lands can be an invaluable conservation tool, not only for conserving forests and landscape biodiversity across the State of Yucatán, but more broadly, across multiple spatial scales, and with substantial contribution to national and international conservation objectives.

5. Conclusion

The shift in ejido land tenure toward formal land parcelization, individual management, and ultimately private property, undermines the vast conservation potential of the extensive ejido system across México. Traditional ejido landscapes alone cannot conserve forests and biodiversity throughout México, but they can be invaluable to its long-term success. More broadly, similar community-managed traditional landscapes across the tropics and elsewhere also are vulnerable to shifting land tenure due to distant political-economic forces. Subsequent impacts can be compounding across a broader landscape and can culminate in widespread biodiversity loss with global consequences. If conservation is to stave off global biodiversity loss, it should better understand and engage larger processes of change based in distant political-economic driving forces and global-to-local pathways that ultimately impact landscapes, biodiversity and conservation.

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CHAPTER 4

PRIVATIZATION PERIL TO COMMUNITY-MANAGED LANDSCAPES AND IMPACTS ON LAND USE AND LAND COVER

1. Introduction

Community-managed forests and landscapes are common across the globe (Baynes et al., 2015). Currently, about one-third of the world's forests are community-managed (FAO, 2016). In particular, tropical forests are predominantly (up to 90% in some regions) community-managed and collectively owned (Alexiades et al., 2013). Across the neotropics, communities control and manage vast forest areas (Cronkleton et al., 2011). For example, forests in México, Columbia, and Bolivia are largely (50% or more) community-managed (Pelletier et al., 2016).

Community-managed landscapes make substantial contributions to global biodiversity conservation (Gabay and Alam, 2017; Sistla et al., 2016, Vallejo-Ramos et al., 2016). Indeed, community-managed forests and landscapes can sustain biodiversity at levels comparable to old-growth forests and pristine reserves (Jose, 2012). For example, a meta-analysis of published case studies showed that as a whole, community-managed forests exhibited lower and less variable annual deforestation rates than protected areas (Porter-Bolland et al., 2012). Granting formal land titles to local communities can help slow rates of global deforestation and land degradation (Blackman et al., 2017; Ceddia et al., 2015). The broader conservation implications of community-level management are especially important in the neotropics, which contain approximately one quarter of the world's tropical forests and contribute substantially to global biodiversity (Delgado-Serrano et al., 2017).

Given the prominence and importance to conservation, it is concerning that community-managed forests and landscapes are shifting, away from community management, and toward individualized and privatized systems. For example, land privatization is a favored development strategy in African countries, such as Kenya, Somalia, and Uganda (Cronkleton et al., 2011). In tropical developing countries, shifting land tenure is due mainly to land privatization that is promoted through individual land parceling and titling. Multiple Latin American governments have initiated land parceling and titling, such as has been promoted in México starting in 1992 (Perramond, 2008) and Panama, starting in 2001 (Spalding, 2017). Such shifting land tenure affects land use and land cover, which, in turn, can impact landscape and biodiversity patterns.

It is essential to analyze land tenure change to understand associated changes in land use and land cover (Nagendra et al., 2008). As informal and formal resource management institutions, land tenure arrangements determine the relationships among people and their land (Barnes, 2009; Spalding, 2017). However, these relationships can differ sharply in community-managed lands compared to individualized and private property (Gabay & Alam, 2017). Specifically, community land tenure systems tend to emphasize stewardship (Berkes, 2009), whereas individual private property focuses more on access and control. Beyond land parceling and titling impacts to community socioeconomic characteristics, much remains to be learned about how the transition from communal to individual land tenure can impact land cover composition and structural connectivity (Grimm & Lesorogol, 2012).

México is an ideal location to analyze shifting land tenure and associated impacts on land use and land cover. Within México, an exemplary model of community-managed landscapes are ejidos (Bray, 2003), a type of community landholding that the federal government created in the early 1900s for subsistence-based agriculture (Barnes, 2009; Perramond, 2008). Approximately 30,000 ejidos comprise 52% of all land and roughly 80% of forestlands across México (INEGI, 2016). These ejidos account for nearly 3 million *ejidatarios* (ejido farmers) that depend on the land for their livelihoods (RAN, 2019). Thus, not only do ejidos strongly influence México's social-ecological complexity, but they contribute substantially to global biodiversity conservation.

With changes to México's constitution that were initiated in 1992, México's ejidos began shifting away from community management, and toward individually parcelized land tenure (Smith et al., 2009). This is due specifically to changes in Article 27, which originally established the ejido system, and now allows ejido lands to be formally divided among individual ejidatarios and legally rented, leased, or sold (Perramond, 2008). Ultimately, the changes to Article 27, with subsequent land parceling and legal certification through Programa de Certificación de Derechos Ejidales y Titulación de Solares or PROCEDE (Program of Certification of Ejidal Rights and Titling of Parcels) have paved the way toward land privatization and the eventual displacement of ejidos (Smith et al., 2009). Such major changes in ejido land tenure arrangements can lead directly to broad-scale impacts to landscapes and biodiversity.

México is one of the most biologically rich and megadiverse countries in the world (Ellis & Porter-Bolland, 2008, Garcia-Frapolli et al., 2009). A primary contributor to México's megadiversity is the country's southeastern tropical region (Díaz-Gallegos et al., 2010), however, this region recently has experienced more than 80% forest loss (Challenger & Soberón, 2008; Ellis et al., 2017). In particular, México's Yucatán peninsula has been heavily deforested and much of the forest loss has been attributed to crop and pasture land expansion for agriculture markets (Ellis et al., 2015; 2017). As a result, the Mexican government recently identified the Yucatán peninsula as a high priority region to address landscape change, deforestation and biodiversity loss (CONAFOR, 2016).

With market-driven agriculture development, the parceling of ejido land may exacerbate land use and land cover change. As a result, biodiversity across the Yucatán peninsula can be considerably impacted and can increasingly jeopardize the peninsula's contribution to global biodiversity. However, few studies have examined land use and land cover change across the Yucatán peninsula (Ellis et al., 2015), and there are only rare analyses of shifting ejido land tenure and associated land use and land cover (DiGiano et al., 2013). Moreover, land use and land cover analyses have been limited to short time periods (Ellis et al., 2017), such as using Global Forest Change data 2001-2013 (Hansen et al., 2013), or have been limited to a few specific ejidos (DiGiano et al., 2013).

The objective of this chapter is to examine the shift in ejido land tenure and reveal connections to changes to land use and land cover in the more than 700 ejidos across the State of Yucatán prior to, and following the changes to Article 27 of México's constitution. The research questions are: 1) *how do land use and land cover patterns change with increasing parceling of ejido lands, between approximately 1986 and 2016*, and 2) *how do land use and land cover patterns differ between individually parcelized and common use (community-managed) ejido lands in circa 2016?* To investigate these questions, this chapter maps and analyzes land use and land cover change across the State and in ejidos (pre- and post- parcelization) using remotely sensed satellite imagery. In particular, this chapter examines the following land use and land cover classes: 1) Bare or Sparse Vegetation, 2) Crop or Pasture 3) Shrub to Early Forest, 4) Mid-Growth Forest, and 5) Mature Forest. Ultimately, this chapter shows that land use and land cover change in ejidos is associated with changes to ejido land tenure. Specifically, this chapter demonstrates that individually parcelized ejidos exhibit a much larger increase in agriculture (crop or pasture) land use than community-managed ejidos. This chapter also shows that community-managed landscapes comprise a larger percentage of conserved lands and lands undergoing forest regeneration.

2. *Methods*

2.1 Study Area

The study area, the State of Yucatán, México between 19.6° and 21.6° north latitude and 87.3° and 90.4° west longitude, is embedded in a dry tropical forest region with diverse vegetation and a species-rich landscape (Porter-Bolland et al., 2015). Currently, 710 ejidos are managed by 101,382 ejidatarios and occupy more than 2.5 million hectares, making up over 50% of the entire State of Yucatán (RAN 2017, 2019), as shown in Figure 4.1. Since the constitutional changes to Article 27, ejido lands in the state have been divided between individually parceled areas and common use areas with settlements or residential areas comprising the remaining lands. Currently, within ejido lands the individually parceled areas total 680,633 hectares, while the common use areas total 1,774,698 hectares. Although all ejidos are community-managed, individual ejidos can range from consisting entirely of common use lands, to almost completely individually parcelized lands. Within the more parcelized ejidos there is a lesser degree of community governance, and land management is mostly at the individual level, especially within individual parcels. Ejido lands can also be sold as private property, but in such cases the land is no longer considered or legally recognized as ejido land.

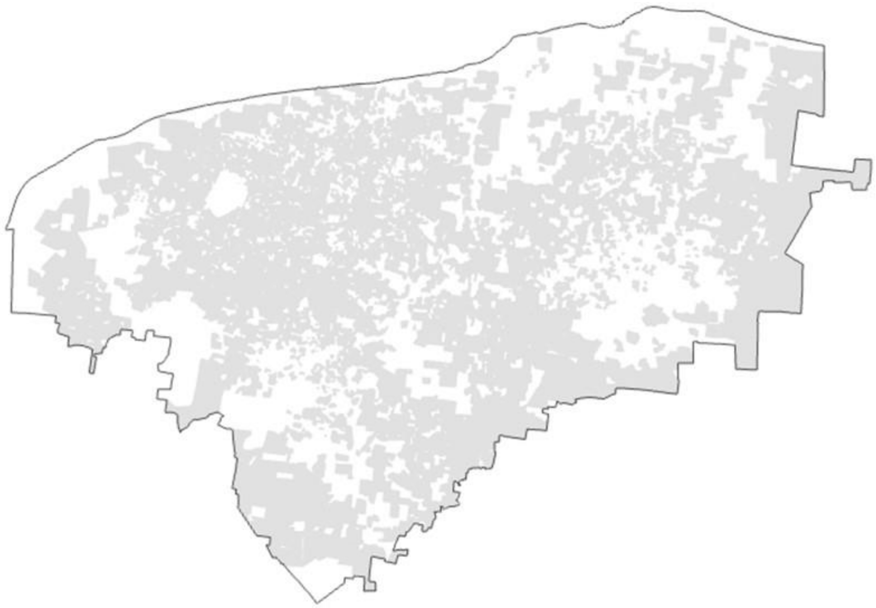

Figure 4.1 Ejidos across the State of Yucatán, México. Ejido lands are shown as grey areas. Source: México's Registro Agrario Nacional, March 2017.

Most ejidos in the State are characterized as milpa systems (Graefe, 2003), which are a complex and rotational (slash-and-burn) and mixed agriculture-forest system that primarily involves growing maize, squash and beans (Sánchez-Sánchez et al., 2015). In milpa systems, burning takes place at the dry season's end in March or April and sowing starts during the transition to the rainy season in May or June (Graefe, 2003). The farmers also have detailed knowledge about the regeneration process, which they use to manage and maintain forested areas over the long-term. As a result, the Yucatán region has exhibited a highly complex and patchy landscape for many generations.

Despite the milpa system's contribution to landscape complexity and heterogeneity, the traditional, or what use to be considered traditional, farming practices are shifting to more market-oriented and productive systems involving new crop cultivation and cattle rearing. On a broader landscape level, increasingly more forestlands have been converted into extensive cattle ranches and citrus plantations (Graefe, 2003). For example, in 1991 less than 10% of ejidos in

Yucatán were engaged in cattle rearing, whereas by 2007, approximately 80% were so engaged. In all, ejidos across Yucatán are gradually shifting toward an individually based and parcelized land tenure system, while livelihood and land use activities are moving away from traditional farming practices.

2.2 Data Collection

Data collected for the study area included: 1) land cover satellite images accounting for the entire extent of the state; 2) surveyed and geo-referenced boundaries of all ejido lands (n=710); 3) surveyed and geo-referenced boundaries of all ejido common use areas (n=1,623); 4) surveyed and geo-referenced boundaries of all ejido parceled areas (n=1,608); and 5) current number of all ejidatarios in each ejido (RAN, 2017).

Satellite images were obtained through USGS EarthExplorer. Images for analysis were selected for minimal cloud cover and occurring within the growing season, from March through May. Two discrete sets of imagery were chosen to represent time periods before and after the constitutional change to Article 27. The earlier satellite data were obtained from Landsat5 imagery between 1984 and 1988, and the later satellite data were from Landsat8 imagery between 2014 and 2018. All images were obtained from Landsat Level 1 collection, which is an archive of consistent data quality to support time series analyses (EarthExplorer, 2018). Within Level 1, the images were obtained from Tier 1, which meets formal geometric and radiometric quality criteria. All images had a processing level of L1T/L1TP, the highest quality Level-1 products suitable for pixel-level time series analysis.

The surveyed and geo-referenced ejido, common use, and parceled boundaries were obtained from México's National Agrarian Registry, 2017. The current numbers of ejidatarios in each ejido were obtained, from National Agrarian Registry in January 2019, to examine land use per ejidatario in community-managed and individualized ejidos following the changes to Article 27.

2.3 Processing Land Cover Images, Creating NDVI Images and Defining LULC

Image processing was performed using Google Earth Engine (Gorelick et al., 2017) with the goal of creating pre- and post- ejido parcelization land cover images and conducting an NDVI-based land use and land cover classification for both pre- and post- images. Normalized Difference Vegetation Index (NDVI) is a dimensionless index that describes the difference between visible and near-infrared spectral reflectance (ratio of the intensity of reflected radiation to that of incident radiation) of vegetation cover (Pettorelli, 2013). NDVI values range between -1 to +1, high NDVI values indicating dense vegetation and low NDVI values indicating sparse vegetation. NDVI was used as a measure of vegetation density on the ground, to conduct land use and land cover classification, and to detect changes in land use and land cover over time, as exemplified in numerous previous studies (Lu et al., 2004).

First, the median pixel value of each pixel in each band (a single layer of an image created using a specific range of wavelengths) was calculated for the 1984-1988 image series and separately for the 2014-2018 image series. From these pixel-level calculations, a pre-parcelization (circa 1986) and a post-parcelization (circa 2016) land cover image free of clouds was created. Next, five land use and land cover classes were defined: 1) Bare or Sparse Vegetation, 2) Crop or Pasture 3) Shrub to Early Forest, 4) Mid-Growth Forest, and 5) Mature Forest. Land use and land cover classes were based on previous definitions (FAO, 2016), and on my own field observations of the different classes in 2014, 2015, and 2016.

Using the pre- and post-parcelization land cover images, NDVI was calculated using Equation 4.1 and 4.2, and a pre-parcelization and a post-parcelization NDVI image was created. Based on the post-parcelization NDVI image, NDVI intervals (i.e., representative of pixel values) were created for each land use and land cover class by comparing the post-parcelization NDVI image to the post-parcelization land cover image and inspecting the NDVI values for each class. To improve the effectiveness of the intervals we simultaneously compared the post-parcelization NDVI image to high resolution imagery in Google Earth (Yucatán, 2015). Ultimately, an NDVI interval was constructed for each land use and land cover class using a stepwise process starting with Bare or Sparse Vegetation. Bare or sparsely vegetative surfaces are assumed to have an NDVI close to 0 with an estimated mean NDVI of approximately 0.10 (Montandom & Small, 2008) and a maximum NDVI of roughly 0.20 (Pettorelli, 2013). At the other end of the spectrum, the highest NDVI values correspond to highly dense and mature forests. Table 4.1 shows the land use and land cover definitions and the associated NDVI profiles.

Eqn. 4.1 Pre-parcelization Normalized Difference Vegetation Index (NDVI)

$$NDVI = \frac{NIR - Red}{NIR + Red} = \frac{Band\ 4 - Band\ 3}{Band\ 4 + Band\ 3}$$

Eqn. 4.2 Post-parcelization Normalized Difference Vegetation Index (NDVI)

$$NDVI = \frac{NIR - Red}{NIR + Red} = \frac{Band\ 5 - Band\ 4}{Band\ 5 + Band\ 4}$$

Table 4.1 Land use and land cover definitions and NDVI profiles

Land Use & Land Cover	Definitions	NDVI Profiles
Bare or Sparse Vegetation:	Land area with approximately 20% or less vegetation cover and mostly comprised of soil, sand or rocks. Vegetation, if present, is widely spaced and scrubby.	0 < Bare or Sparse Vegetation < 0.20
Crop & Pasture:	Land used primarily for food and fiber production. Cropland is a distinctive two-dimensional geometric field relative to surrounding area with vegetation cover that is continously scrubby across most of the field. Pastures have natural vegetation that is predominantly grasses, grasslike plants, or forbs.	0.20 < Crop & Pasture < 0.25
Shrub to Early Forest:	Former crop or pasture lands where vegetation has grown in a mostly continuous and dense mixture of herbaceous, shrub, brush, and trees across most of the area in transition back to forest. Early forest has sparse canopy or crown cover.	0.25 < Shrub to Early Forest < 0.30
Mid-Growth Forests:	Land area of more than 0.5 ha with continuous and moderate to dense tree canopy cover and the absence of other predominant land uses.	0.30 < Mid-Growth Forests < 0.40
Mature Forests:	Land area of more than 0.5 ha with continuous and highly dense tree canopy cover and the absence of other predominant land uses.	0.40 < Mature Forests

2.4 Creating a Land Use and Land Cover Maps

Using the defined classes, a supervised classification across the entire State of Yucatán was performed to create pre- and post-parcelization land use and land cover maps. To initially train the classification algorithm, a minimum of 100 different sites were selected for each class that were pure representatives of each land use and land cover class (Richards, 2013). Each training site polygon had a minimum size of roughly 90 square meters. Additionally, 100 training sites were created for water, which had a negative NDVI value. Although there are no substantial inland bodies of surface water in the state, there are inlets along the northern coast.

To create the pre- and post-parcelization land use and land cover maps, first spectral signatures (the variation of reflectance of vegetation with respect to wavelengths) were assigned from the post-parcelization NDVI image to the training site polygons using ArcGIS Pro (ESRI, 2015). Next, a supervised classification was conducted on the pre- and post- NDVI images, which used the training data's spectral signatures to group the cells of the images into the predefined land use and land cover classes (Chuvieco, 2016), using the maximum likelihood algorithm (Sisodia et al., 2014). The maximum likelihood algorithm in ArcGIS Pro computes a set of probabilities for each cell and the relative likelihood that the cell belongs to each land use and land cover class, as shown in Equation 4.3 (Richards, 2013).

Equation 4.3 Maximum Likelihood

$$p(x) = \sum_{i=1}^{m} p(x|w_i)\, p(x|w_i)$$

where

$p\ (x\ |w_i)$ are the set of class conditional probabilities

$p\ (w_i)$ is the probability that cells from class w_i appear anywhere in the image.

2.5 Accuracy Assessment

Once the classification process was complete, an accuracy assessment was conducted to measure agreement between the pre- and post-parcelization land use and land cover classified maps and the pre- and post-parcelization NDVI images (Olofsson et al., 2013), using ArcGIS Pro (ESRI, 2015). For the accuracy assessment, an equalized stratified random sample of points was conducted, which randomly distributed 100 points within each of the five land cover classes of the newly classified maps (Foody, 2009). All randomly sampled points were generated from outside the training data areas. To validate each randomly selected sample, the NDVI value of the cell was on the reference map and compared to the value to the predetermined NDVI class intervals.

To quantify accuracy, error matrices of the land use and land cover classes were computed from the classified maps and the NDVI images as reference maps (Olofsson et al., 2014). The error matrix's main diagonal indicates correct classifications, whereas the off-diagonal elements show underestimation of a particular class or omission error and overestimation of a particular class (commission error; Chuvieco, 2016). The rows in the error matrix rows represent the land use and land cover classes shown in the classified map and the columns represent the land use and land cover class data obtained from the NDVI images (Olofsson et al., 2013). In all, the error matrix reflects the agreements and disagreements between the classified maps and NDVI images (Chuvieco, 2016).

Included with the error matrix are three distinct metrics of accuracy. Producer's accuracy is the actual proportion of the area made up of a particular class that is also designated as that class by the classification process (Equation 4.4). User accuracy is the proportion of the area designated as a particular class relative to the actual total area of that class (Equation 4.5).

Overall accuracy is the proportion of the area that is designated by the classification process correctly (Equation 4.6). Also, a kappa index of agreement was calculated, which is an overall measure of accuracy that adjusts for random effects, as shown in Equation 4.7 (Olofsson et al., 2013). Finally, to assess overall accuracy we used the generally accepted threshold of 85%, which is standard for image classifications (Foody, 2002).

Equation 4.4 Producer's accuracy (PA_i)

$$PA_i = \frac{X_{ii}}{X_{+i}}$$

where

x_{ii} is the diagonal of each column of the error matrix

x_{+i} represents the total of column i.

Equation 4.5 User's accuracy (UA_i)

$$UA_i = \frac{X_{ii}}{X_{i+}}$$

where

x_{ii} is the diagonal of each row of the error matrix

x_{i+} represents the total of row i.

Equation 4.6 Overall accuracy (OA)

$$OA = \frac{\sum_{i=1,n} x_{ii}}{\sum_{i=1,n} \sum_{j=1,n} x_{ij}}$$

where

x_{ii} is the diagonal of each column of the error matrix

x_{ij} is a cell in the error matrix.

Equation 4.7 Kappa Statistic (k)

$$k = \frac{n\sum_{i = 1,n} X_{ii} - \sum_{i = i,n} X_{i+} X_{+i}}{n^2 - \sum_{i=i,n} X_{i+}X_{+i}}$$

where

n is the sample size

X_{ii} indicates the observed agreement

$X_{i+}X_{+i}$ is the product of the total row and column that estimates the expected agreement for each category i.

2.6 Estimating areas of land use and land cover change

Using the results from the classified maps, the different land use and land cover class areas were tabulated for each ejido's total land area, common use land areas, and parceled land areas both pre- and post-parcelization. Next, the statewide percentage changes were calculated in each class for: 1) Non-ejido areas; 2) Ejidos; 3) Least-parcelized Ejidos (20% or less parcelized); and 4) Highly Parcelized Ejidos (80% or more parcelized). Finally, the percent change in land conserved or regenerating and land use were calculated for these categories. Conserved lands are defined according to ejidatarios as land that will not be used for agriculture or pastures for a minimum of approximately 25 years, which was based on over 100 transect walks with ejidatarios in 2013 through 2016. Regenerating lands are defined as areas that are transitioning or have transitioned to forest (Shrub to Early Forest, Mid-Growth Forest, Mature Forest). Land use is defined in this study as involving the combination of land with bare or sparse vegetation and crop or pasture. Finally, the average agriculture or pasture land use per ejidatario, average total lands conserved or regenerating per ejidatario, and average total available land per ejidatario was calculated.

3. Results

3.1 Shifting land tenure in Yucatán

Since 1992, approximately 665 (94%) of all ejidos in the State of Yucatán have undergone some amount of parcelization, with an average of 36% of the total land parcelized within those ejidos. As of 2017, parcelized land made up 27% of all ejido lands in the State. The parcelized ejidos tend to be clustered in 1) the northeast around the City of Tizimín, 2) the northwest around the City of Mérida, and 3) the southeast around the Town of Peto (Figure 4.2). Of the 710 ejidos, 187 ejidos are highly parcelized, exceeding a total of 80% parcelization. These highly parcelized ejidos comprise 477,096 parceled hectares (nearly 20% of the total area of all ejido lands), which are under the individual management of 18,652 ejidatarios. At the other end of the spectrum, 396 ejidos are least parcelized, containing less than 20% parcelized land area. These least-parcelized ejidos comprise 1,583,251 common use hectares (63% of all ejido lands) that are collectively managed by 53,587 ejidatarios. Together, these two categories, the highly parcelized and least-parcelized ejidos, account for over 80% of all ejido lands in the state.

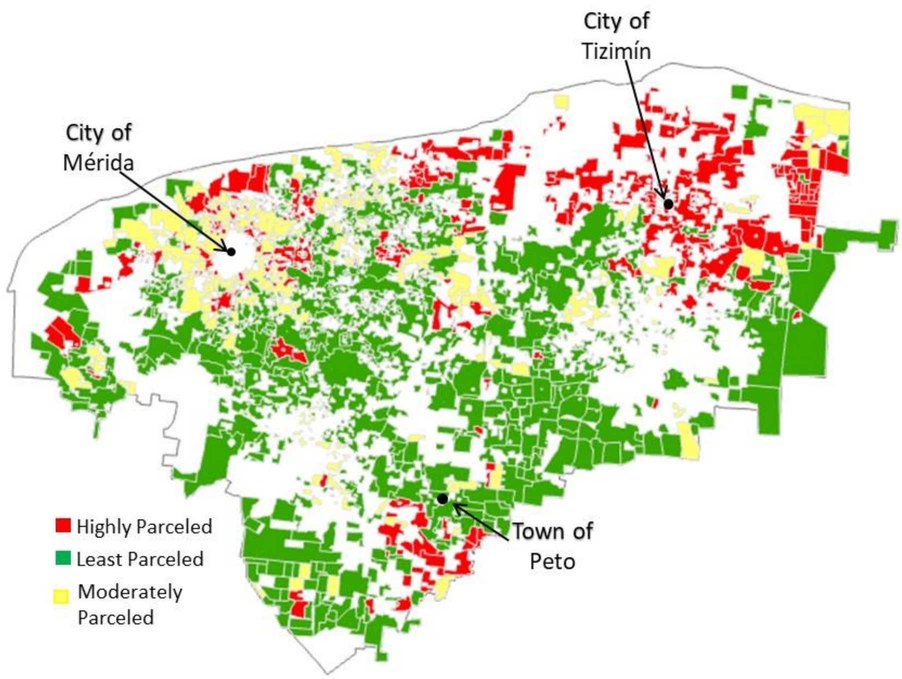

Figure 4.2 Yucatán Ejidos. Highly parcelized ejidos (80% or more parceled), least-parcelized ejidos (20% or less parceled), and moderately parcelized ejidos (greater than 20% and less than 80% parceled).

3.2 Statewide land use and land cover change

Landscape changes are apparent in the statewide classified maps, showing a significant decline in Mature Forests (Figure 4.3). This is consistent with Ellis et al. (2015) that found deforestation in the state is primarily along the eastern boarder extending from north to south. There also was a noticeable decline in Bare or Sparse Vegetation across the State. Overall, it appears that land use and land cover is converging toward mostly agriculture or pasture, shrub to early forest, and mid-growth forest.

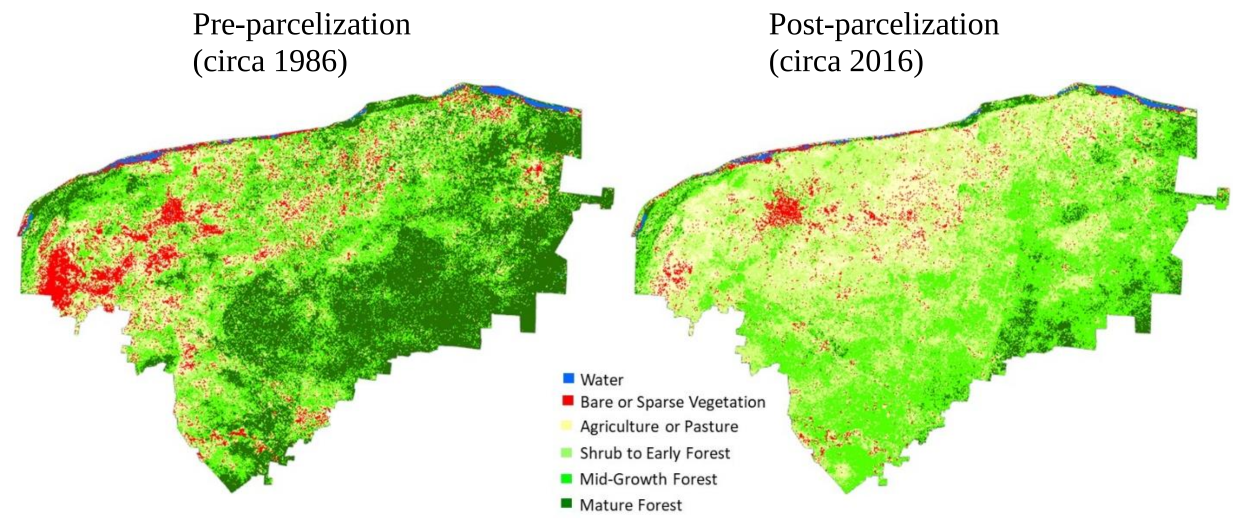

Figure 4.3 Classified land use and land cover images of pre-parcelization (circa 1986) and post-parcelization (circa 2016).

3.3 Land use and land cover change across land tenure types

There were declines (roughly -50% to -65%) in Bare or Sparse Vegetation lands across all categories: Non-ejido areas, Least-parcelized Ejidos and Highly Parcelized Ejidos. Similarly, Mature Forests declined roughly the same (-85%) across all categories, which is consistent with similar studies that found more than 80% forest loss in the region (Ellis et al., 2015). Most notable was the 127% increase, or 4.2% average annual increase, in Crop or Pasture lands of Highly Parcelized Ejidos. Meanwhile, the same land use increased 62% and 65%, or roughly a 2% average annual increase, across Non-ejido and Least-parcelized Ejido lands, respectively (Table 4.2). Highly Parcelized Ejidos exhibited the lowest growth in Shrub to Early Forests and a decline in Mid-Growth Forests. In contrast, all other categories exhibited larger increases in Shrub to Early Forests and increases in Mid-Growth Forests. Least-parcelized Ejidos exhibited the largest increases in Shrub to Early Forests (137%) and Mid-Growth Forests (28%).

Table 4.2 Amount and percent change in land use and land cover

Land Use & Land Cover	Bare or Sparse Vegetation	Crop or Pasture	Shrub to Early Forest	Mid-Growth Forest	Mature Forest
Statewide excl. Ejidos					
1986 (ha)	202,244	289,769	444,581	771,718	791,592
2016 (ha)	105,120	470,737	895,858	927,648	119,103
% change	-48%	62%	102%	20%	-85%
Ejidos					
1986 (ha)	203,024	243,812	427,064	791,214	853,040
2016 (ha)	80,803	442,030	958,151	910,855	126,314
% change	-60%	81%	124%	15%	-85%
Least Parceled Ejidos (20% or less parcelized)					
1986 (ha)	122,624	151,323	263,439	507,339	613,708
2016 (ha)	42,505	249,445	624,418	651,432	90,632
% change	-65%	65%	137%	28%	-85%
Highly Parceled Ejidos (80% or more parcelized)					
1986 (ha)	40,885	52,604	94,037	167,934	149,680
2016 (ha)	17,491	119,599	183,204	163,726	21,122
% change	-57%	127%	95%	-3%	-86%

Overall, 9% or 45,463 hectares of land that was determined to be conserved or regenerating (Shrub to Early Forest, Mid-Growth Forest, and Mature Forest combined) shifted to Bare or Sparse Vegetation and Crop or Pasture lands in Highly Parcelized Ejidos. At the other end of the spectrum, in the Least-parcelized Ejidos only 1% or 16,588 hectares of land designated as conserved or regenerating shifted to "Bare or Sparse Vegetation and Crop or Pasture combined" (Table 4.3). Ultimately, ejidatarios in Highly Parcelized Ejidos use an average of roughly two hectares more of Crop or Pasture lands than ejidatarios in Least-parcelized Ejidos and on average have less land available to ejidatarios for farming (Table 4.4). In addition, ejidatarios in Least-parcelized Ejidos conserve an average of five more hectares than ejidatarios in Highly Parcelized Ejidos.

Table 4.3 Proportion of land use and land conserved or regenerating.

	Land Conserved or Regenerating	Land Use		Land Conserved or Regenerating	Land Use
Statewide excl. Ejidos			Ejidos		
1986	80%	20%	1986	82%	18%
2016	77%	23%	2016	79%	21%
Change	-3%	3%	Change	-3%	3%
Least Parceled Ejidos (20% or less)			Highly Parceled Ejidos (80% or more)		
1986	83%	17%	1986	82%	18%
2016	82%	18%	2016	73%	27%
Change	-1%	1%	Change	-9%	9%

Table 4.4 Land use, conserved lands, and available land per ejidatario.

2016	Average Crop or Pasture Land Use per Ejidatario (ha)	Average Total Conserved Lands per Ejidatario (ha)	Average Total Available Land per Ejidatario (ha)
All Ejidos	5.6	21	26
Least Parcelized	5.4	25	30
Highly Parcelized	7.4	20	26

The accuracy assessment to measure the degree of agreement between the classified land cover results and the NDVI images yielded an estimated overall accuracy of 93%, with a Kappa statistic of 0.91 for the 1986 classification (Table 4.5), and an estimated overall accuracy of 94%, with a Kappa statistic of 0.93 for the 2016 classification (Table 4.6). The error mostly reflects uncertainty about land cover that were located on the edges between classes, and in particular between Shrub to Early Forest and Mid-Growth Forest, as shown in the error matrices.

Table 4.5 Error matrix for the 1986 classified map

Classified Map	Reference Map						
	Bare or Sparse Vegetation	Agriculture or Pasture	Shrub to Early Forest	Mid-Growth Forest	Mature Forest	Total	User accuracy
Bare or Sparse Vegetation	93	7	0	0	0	100	93%
Agriculture or Pasture	0	96	4	0	0	100	96%
Shrub to Early Forest	0	2	80	18	0	100	80%
Mid-Growth Forest	0	0	0	95	5	100	95%
Mature Forest	0	0	0	0	100	100	100%
Total	93	105	84	113	105	N = 500	
Producer accuracy	100%	91%	95%	84%	95%		

Overall accuracy = 92.8%; Kappa = 0.91

Table 4.6 Error matrix for the 2016 classified map

Classified Map	Reference Map						
	Bare or Sparse Vegetation	Agriculture or Pasture	Shrub to Early Forest	Mid-Growth Forest	Mature Forest	Total	User accuracy
Bare or Sparse Vegetation	94	6	0	0	0	100	94%
Agriculture or Pasture	0	96	4	0	0	100	96%
Shrub to Early Forest	0	2	85	13	0	100	85%
Mid-Growth Forest	0	0	0	98	2	100	98%
Mature Forest	0	0	0	1	99	100	99%
Total	94	104	89	112	101	N = 500	
Producer accuracy	100%	92%	96%	88%	98%		

Overall accuracy = 94.4%; Kappa = 0.93

4. Discussion

In the State of Yucatán, ejidos that are managed primarily at the community level exhibit valuable conservation potential over time. The least-parcelized ejidos showed relatively low levels of expansion of agriculture or pasture and the largest increases in land that was being conserved or regenerating. Similar studies support these findings more broadly across the Yucatán peninsula *(*DiGiano et al., 2013). Because lands that are designated as conserved or regenerating are largely secondary forests, these ecosystems have multiple positive impacts on the local and global environment and provide important ecosystem services, such as carbon sequestration, habitat for endangered species, and support forest-based livelihoods (Nagendra et al. 2008). These community-managed landscape have helped slow environmental change across the Yucatán, which is consistent with community management stewardship trends globally (Blackman et al., 2017; Ceddia et al., 2015*)*.

Despite the positive conservation outcomes, least-parcelized ejidos still showed declines in mature forests that likely stem from widespread anthropogenic pressures. Across the state, loss of forest in ejidos and non-ejido land, between roughly 1986 and 2016, is consistent with broader regional deforestation estimates (Challenger & Soberón, 2008; Ellis et al., 2017). As deforestation continues to threaten biodiversity and livelihoods, secondary forest regeneration is increasingly important to conservation in the region and beyond (Hartter et al., 2008).

As long as land privatization threatens community-managed ejido landscapes, forest and landscape conservation across the state and the peninsula will be exacerbated. This study's most prominent finding is that the largest increase in agriculture and pasture lands was on individually parcelized ejido lands. The difference was conspicuous; the percent increase in agriculture and pasture lands on highly parcelized ejidos was roughly twice that of least-parcelized ejidos and other land tenure types outside the ejidos. In addition, individually parcelized ejidos tended to have a higher deforestation rate when accounting for changes in both mid-growth and mature forests. Ultimately, highly parcelized ejidos had a much higher proportion Bare or Sparse and Crop or Pasture lands than conserved lands, compared to least-parcelized ejidos, a phenomenon that also is occurring elsewhere across the peninsula (DiGiano et al., 2013).

The link between parcelized lands, agriculture expansion, and deforestation form an important pathway from broader political-economic forces to social-ecological change across ejido landscapes. The federal government intended for parcelization to incentive ejidatarios to expand their agriculture and pasture lands and to increasingly engage in market-oriented livelihood activities (Grimm & Lesorogol, 2012). To that end, agriculture extension programs, such as PROCAMPO and PRONASOL that promote market-oriented agriculture encourage the increase in ejido agriculture and pasture land use, and particularly in highly parcelized ejidos (Daniels et al., 2008). This likely has led to over one-third more area being used by ejidatarios in highly parcelized ejidos on average than ejidatarios in least-parcelized ejidos. Overall, the combination of land privatization and agricultural expansion exacerbates the impacts to forests, can accelerate land use and land cover change, and is a major threat to conservation in the State of Yucatán and beyond.

Landscape change is pervasive across the Yucatán peninsula region (Urquiza-Haas et al., 2007). The critical link between forest cover and communal land tenure in the region underscores the importance of analyzing land use and land cover change in a shifting land tenure context. (Daniels et al., 2008). However, when analyzing land use and land cover patterns, it is important to consider that conservation is embedded within particular social–political contexts (Gavin et al., 2015). Forests also are embedded within larger-level socio-economic and political systems, which can influence biodiversity conservation. Specifically, land privatization and commodification put enormous pressures on forested landscapes. Thus, more detailed examinations of land cover change across different tenure regimes and rule systems are needed (Nagendra et al., 2008). Such studies can significantly advance knowledge about how shifting land tenure can drive landscape change and deforestation from a local to a global scale.

5. Conclusion

Land use and land cover change is a key process of global environmental change (Meyfroidt et al., 2018; Verburg et al., 2015). Individualized and privatized land tenure systems can amplify the negative impacts of rapid changes. Conversely, community-managed forests and landscapes are increasingly acknowledged as a potential mechanism for conservation. However, land privatization threatens the conservation potential of community-managed landscapes, and may further catalyze environmental change at all scales. For conservation to persevere, we must better understand shifting land tenure, its relationship to agriculture markets and its impacts on deforestation. This task is as urgent as it is complex.

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Yucatán. 20*35’59.30” N and 88*53’19.71” W. Google Earth. December 13, 2015. November 15, 2018.

CHAPTER 5

RECOMMENDATIONS FOR LANDSCAPE CONSERVATION SCIENTISTS

Landscape changes across the State of Yucatán, México are linked to inter-relationships among broad-scale changes to land tenure, livelihoods, land use and land cover within ejidos. I investigated these inter-relationships and subsequent landscape change in ejidos across the State using a spatial-temporal approach. Included in these analyses were spatially-explicit methods that involved mapping key variables, cartographic analysis, and variographic analysis to determine the presence of spatial relationships; spatial regression models to help determine causality in observed spatial relationships; and land use and land cover modeling using geographic information techniques to examine impacts of land tenure change on land cover over time, and specifically before and after the change to Article 27. As a result, my dissertation provides empirical evidence of landscape change in ejidos across the State of Yucatán due to broader-scale political-economic factors.

Landscape changes across the Yucatán region, and elsewhere in México, are likely to continue and to result in important and far-reaching social and ecological impacts. As an example, agricultural commodity production has substantially increased, particularly in highly parcelized ejidos. This increase indicates a shift away from traditional livelihood practices and is likely a substantial driver of deforestation across the State of Yucatán. The observed changes in Yucatán are illustrative of change in other tropical landscapes. Moreover, many of the mechanisms and the complex and sometimes mutually reinforcing nature of the inter-relationships among many drivers of change global impacts to local landscapes will likely intensify. Therefore, based on findings presented in my current study, I offer a few modest recommendations to landscape conservationists that may help mitigate undesired impacts of global-to-local changes. The recommendations are based on two important outcomes of this study: 1) the substantial influence of globalized agriculture on shifting land tenure and landscape change, and 2) the conservation value and vast potential of community-managed landscapes.

Conservationists should pursue ways to reduce the influence of broad-scale socioeconomic factors, such as globalized agriculture markets on changes to land tenure, and subsequent transformations of land use and land cover. One approach is to disincentivize abandoning community management. To that end, conservationists should work closely with governments to design more policies and programs that prioritize community land and natural resource management, and pathways to legally establish and recognize community-managed landscapes. Community conservation is acknowledged internationally as the oldest form of land and natural resource management, but it often has had limited official recognition (Martin et al., 2011). This may be changing. For example, the State of Oaxaca, México has gained recognition as a leader in declaring indigenous and mestizo certified community reserves (Bray et al., 2008). Moreover, community-managed reserves are legally recognized in México's general environmental law (Martin et al., 2011). Such community-conserved areas are also gaining recognition and support through the International Union for Conservation of Nature: Indigenous and Community Conserved Areas (Berkes, 2009). Despite these documented conservation successes, many more community-conserved areas are needed throughout the world. The success stories, such as in Oaxaca, can serve as examples for the implementation of community management elsewhere. Overall, such a conservation agenda can bring attention to land and natural resource stewardship at community levels, rather than policies and programs that integrate land and natural resources into markets through individualized and private property.

Conservation studies that examine tropical rural landscape change in indigenous community-managed landscapes are lacking (Chazdon et al., 2009). Many studies examine landscape change in and around biosphere reserves and protected areas (Ellis & Porter-Bolland, 2008), but the amount of protected areas are limited and, all-told, they comprise a small percentage of total area across the globe. For example, more than 90% of tropical forests are outside protected areas (Chazdon et al., 2009). Therefore, more studies are needed in tropical rural landscapes that local people actively manage or modify to better understand the effects of land tenure change on landscape structure and dynamics.

Because of the importance of long-term landscape change in the tropics, it is particularly important to address the above gap in the literature. Landscape conservation cannot be based solely on recent conditions (Crumley et al., 2017). This is especially true for tropical dry regions, which have experienced excessive resource extraction (Stoner & Sánchez-Azofeifa, 2009), and have come to include some of the most threatened biomes (Portillo-Quintero & Sánchez-Azofeifa, 2010). Long-term research should include social, political, economic, and institutional organization, as well as land tenure, of local resource users and land managers with the goal of understanding how these local factors interact with factors at regional, national, and global scales (Chazdon et al., 2009). Such information can provide a stronger basis to develop conservation policy and planning at multiple scales.

An important finding in Chapter 4 was that community-managed ejidos conserve substantially more secondary forests than highly parcelized ejidos. This phenomenon was linked to levels of agriculture land use and consequently, as Chapter 3 suggests, the degree of engagement with broader scale agricultural commodity markets. Because of global trends, much more conservation is needed in landscapes that comprise tropical secondary forests. Across the tropics, mature and old growth forests are rapidly disappearing, similar to the patterns observed in Yucatán. Although protecting the remaining old growth forests is a high priority, restoring and conserving secondary forest are equally important (Herrera-Montes & Brokaw, 2010). Secondary forests also have great conservation value. For example, secondary forests can enhance vegetation structure up to 77% and biodiversity up to 84%, compared to degraded ecosystems (Crouzeilles et al., 2016). Notably, multifunctional community-managed landscapes often comprise secondary forests that play an important role in conserving biodiversity (Jose, 2012), a pattern that was evident in my study in Yucatán. Therefore, community-managed landscapes can be a valuable approach to conserving secondary forests. However, long-term patterns of tropical secondary forest remain poorly understood (Chazdon et al., 2009), because most studies and management are directed at early restoration and conservation stages (Herrera-Montes & Brokaw, 2010). Moreover, most secondary forest restoration and conservation efforts are implemented at local, rather than landscape scales (Crouzeilles et al., 2016).

In all, conservation scientists and practitioners urgently need to undertake research and action to cope with distant political-economic forces that can drive, or accelerate tropical landscape change. A primary challenge to such a task is the complex array of linkages between landscape change and broader-scale socioeconomic factors, especially globalized agriculture. However, land tenure can be an important factor in mediating the influence of broader-scale factors on landscape change, and therefore its consideration should play a more prominent role when designing conservation strategies. It is my overall assessment that conservation strategies that involve community management can be an effective approach to mitigating landscape change, potentially culminating in positive outcomes, extending from local to global scales.

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