Land Use Change and Adaptation to Climate Variability and Change in the Mayan Forest and the Americas' Internationally Adjoining Protected Areas

by

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List of Abbreviations

A&C – Administrative and Commercial

CBD – Convention on Biological Diversity

CBR – Calakmul Biosphere Reserve

CFD – Causes of Forest Decline

CMDRS – Municipal Council for Rural Sustainable Development

CRASX - Regional Council for Agriculture, Silviculture, Livestock, and Services of Xpujil

CRIPX - Regional Indigenous and Popular Council of Xpujil

CVC – Climate Variability and Change

IAPA – Internationally Adjoining Protected Area

IFRI – International Forestry Resources and Institutions

IUCN- International Union for Conservation of Nature

MBR – Mayan Biosphere Reserve

MF – Mayan Forest

NGO – Non-Governmental Organization

PA – Protected Area

SES – Social-Ecological Systems

TBPA – Transboundary Protected Area

UNEP – United Nations Environmental Programme

WCPA – World Commission on Protected Areas

Abstract

The growing evidence of the negative impacts of climate change on livelihoods suggests that the implementation of household based adaptation strategies is likely to grow dramatically in the next few decades. Household adaptation could become a critical factor in environmental change, as its effects span over time and across social and ecological systems. Without understanding of the likely effects of adaptation on environmental change, efforts to foster adaptation can produce unintended outcomes. This dissertation assesses how household-based adaptation strategies, together with a range of other factors such as institutions, governance, and socioeconomic conditions, influence land use change, as a specific form of environmental change. These strategies include storage, diversification, exchange and pooling and have been used, through history, by different societies to adapt to climatic, economic, or political changes. To answer its research questions, this dissertation draws inferences from a large-N case study in the Mayan Forest and a comparative analysis of internationally adjoining protected areas across the Americas.

The causes of land use change have been extensively studied; nonetheless, scholars have not yet systematically addressed land use change within the context of adaptation to climate variability and change. This dissertation makes a contribution to the scholarship on climate adaptation and land change by examining the influence of adaptation as a potentially major driving factor of land use change. It finds that adaptation exercises a critical influence on land use change in the Mayan Forest, as well as in the protected areas throughout the Americas. The results from the Mayan Forest case study show that the influence of adaptation on land use change depends on the socioeconomic and institutional context within which they occur. The comparative analysis across protected areas supports these findings suggesting that adaptation mediates the influence of social, economic, institutional, and governance factors. The effects of adaptation on land use change, in magnitude and direction, depend on the specific adaptation strategy households follow. In the context of the Mayan Forest, land use change is likely to increase when people rely on government aid or follow storage as adaptation strategy. In contrast, land use change decreases if people choose to exchange, diversify, or pool to adapt. Across the Americas diversification and migration are associated with lower land use change, but no evidence was found to suggest a significant relationship between other forms of adaptation and land use change in the cases examined. These results can yield useful lessons for donors and policymakers to develop new approaches to support adaptation strategies considering explicitly the effects of adaptation on environmental change.

Chapter 1

Introduction

The growing evidence of the negative impacts of climate change on livelihoods suggests that the implementation of household based adaptation strategies is likely to grow dramatically in the next few decades. The importance of adaptation however, goes beyond its objective to minimize and take advantage of the effects of climate variability and change on livelihoods. Household adaptation could become a critical factor in environmental change, as its effects span over time and across social and ecological systems. Without understanding of the likely effects of adaptation on environmental change, efforts to foster it can produce unintended outcomes. This dissertation examines the role of adaptation in influencing land use change—here defined as a specific form of environmental change.

A range of environmental change outcomes could be expected depending on the adaptation strategies households choose to take advantage of the opportunities or to minimize the effects of climate variability and change. For instance, forms of adaptation that worsen natural resources conditions may lead to the reduction of ecosystems' capacity to produce environmental services[1], likely resulting in negative

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[1] E.g. regulation of climate, protection against natural disasters, soil conservation, supply of forest products used as inputs or final good. For a comprehensive review of ecosystems services, see Capistrano (2005).

consequences for livelihoods prospects. Likewise, forms of adaptation involving land cover conversion can lead to biodiversity loss, siltation, and soil degradation, may contribute to alterations in biochemical cycles, or may reinforce climate change by increasing CO2 levels in the atmosphere (Dale, 1997; FAO et al., 2008; Gutman et al., 2004; Houghton and Skole, 1990; Kaimowitz and Angelsen, 1998; Locatelli et al., 2010; Vitousek et al., 1997). In these situations, adaptation would address immediate social needs at the expense of the environment, representing a win-lose situation in the short run. Given its effects over natural resources and livelihoods prospects, adaptation could also lead to lose-lose situations in which the ecological and the social components of the system lose over time.

Household-based adaptation is subject to households' access to natural resources and the condition of the resources (Adger, 1999; Adger, 2006; Seymour, 2011). Thus, in the long run, if adaptation erodes ecosystems' capacity to produce environmental goods and services, adaptation could also affect the adaptive capacity and livelihoods alternatives for those who are not only climate, but also natural resources dependent, leading to a lose-lose situation (Adger et al., 2002; Batterbury and Forsyth, 1999; Fabricius et al., 2007; Foley et al., 2007; Folke et al., 2005; Gunderson and Holling, 2002; Orlove, 2005; Robson and Berkes, 2010; Rodriguez et al., 2006). Alternatively, adaptation strategies that for instance support ecosystems' capacity to deliver environmental goods and services represent an opportunity to address environmental changes and for conservation of natural resources in the context of protected areas.

The sheer scale of expected adaptation in the coming years and its potential impacts on social-ecological systems make the study of the relationship between adaptation and environmental change extremely important. However, little attention has been paid to analyzing this dimension of adaptation. The extensive scholarship on adaptation has largely focused on adaptation as an outcome, not as a causal factor (Adger, 2000; Adger, 2003; Baas and Ramasamy, 2008; Eakin, 2005; Lemos et al., 2007). The importance of natural resources for adaptation and adaptive capacity, meanwhile, is widely recognized; it constitutes the basis of Ecosystem-based Adaptation, EbA (IUCN, 2010; Locatelli et al., 2010; UNEP and CBD, 2003). Nevertheless, scholars have not yet systematically analyzed the feedbacks between adaptation and natural resources by studying the environmental impacts of households' adaptation.

This dissertation argues adaptation is a critical causal factor of environmental change and proposes to contribute to the existing scholarship by examining and addressing adaptation as a factor influencing land use change. In addition, by examining the relationship between adaptation and land use change, the dissertation contributes to the literature on land use change. The causes of land use change have been extensively studied; nonetheless, scholars have not yet systematically addressed land use change within the context of adaptation to climate variability and change.

Adaptation can take multiple forms and be implemented by diverse actors (Burton, 1996; Smithers and Smit, 1997). This dissertation focuses on households' adaptation strategies in the form of migration, storage, diversification, exchange and pooling. The selection of these strategies is based on its historic use by different societies to adapt to climatic, economic, or political changes. The common use of these strategies is related to their ability to spread the risks to livelihoods across space, time, assets, and community members (Agrawal, 2008; Eakin, 2005; Halstead and O'Shea, 1989). The focus is on households' adaptation strategies because households are direct agents of environmental change.

Advancing our understanding of environmental change requires effort to harness complexity, integrating knowledge from different scholarships into an analytical framework, and analyzing a range of variables and their interactions (Adger and Luttrell, 2000; Clark, 2009; Folke et al., 2002; Howden et al., 2007; Ostrom, 2007). Hence, together with adaptation, the dissertation examines how several other factors influence land use change. Specifically the dissertation assesses how households' adaptation strategies, together with institutions, governance, and socioeconomic conditions, influence land use change in and around protected areas. To answer the research question, this dissertation carries out two separate but related studies. First, it focuses on household adaptation strategies in the Mayan Forest shared by Mexico and Guatemala. Second, it examines adaptation and land use change across 55 internationally adjoining protected areas (IAPAs) across the Americas[2].

The Mayan Forest straddles the international border between Mexico and Guatemala and constitutes the second largest forest in the Americas, holding great international importance due to its biological diversity. It is integrated by two biosphere reserves, Calakmul on the Mexican side, and the Mayan on the Guatemalan. Each Reserve represents the largest remaining primary forests in Mexico and Guatemala. At the same time these Reserves are home for vulnerable populations, whose livelihoods

[2] Internationally adjoining protected areas refers to neighboring protected areas located by international borders. When these are managed cooperatively, they form transboundary protected areas (TBPAs) (Sandwith et al., 2001). The 55 internationally adjoining protected areas studied in the dissertation integrate 25 potential TBPAs, representing 86% of a total of 29 TBPAs in the studied region.

strongly rely on seasonal agriculture and natural resources, which may get seriously affected by climate change.

The case study focuses on the Mayan Forest for multiple reasons. It constitutes the second largest forest in the Americas (2,823,185 hectares), holding great international importance due to its biological diversity. The Mayan Forest is the starting point of the Mesoamerican Biological Corridor, straddling the international border between Mexico and Guatemala. The Calakmul and the Mayan biosphere reserves represent the largest remaining primary forests in Mexico and Guatemala.

These two biosphere reserves are home to vulnerable populations, whose livelihoods rely on seasonal agriculture and have already been affected by CVC for the last five to ten years. This story is likely common among the tropical forests of the world. The study of what agricultural communities in the Mayan Forest are already doing to adapt and how it affects land use change is thus expected to produce insights in tropical forests beyond Central America. The challenge of adapting livelihoods production to CVC without hindering ecosystems' capacity to provide environmental goods and services is particularly critical for communities within or around protected areas in tropical forests, due to their rich biological diversity. The impact of adaptation in such cases would go beyond local livelihoods and adaptive capacity prospects; it would reach global scale.

Internationally adjoining protected areas are important subjects of study for multiple reasons. IAPAs produce and maintain environmental goods and services supporting the livelihood of millions of people, the economies of nation states and international peace among neighboring countries (van der Linde Harry, 2001; Zbicz, 1999). When grouped, internationally adjoining protected areas are distinctive because they protect ecosystems that straddle international borders, supporting the maintenance of ecosystem functionality and enhancing social-ecological resilience. Groups of IAPAs can constitute transboundary protected areas, whose number around the world has increased 34% from 2005 to 2007 (IUCN and WCPA, 2010; Nigel et al., 2010). The Convention on Biological Diversity has proposed the creation transboundary protected areas as a climate change response strategy. Transboundary protected areas can facilitate flora and fauna adaptation to climate change, buffer climate change effects on ecosystems, in addition of helping people to cope with the effects of climate change (Heller and Zavaleta, 2009; Sandwith et al., 2001; UNEP and CBD, 2003). Finally, overall, the dissertation focuses on protected areas given that these are the last frontiers where land use change replaces the natural land cover with human uses such as cropland, rangeland, infrastructure, or urbanization.

The empirical evidence from this research shows that adaptation does exercise a critical influence on land use change. The results from the Mayan Forest case study show that the influence of adaptation on land use change depends on the socioeconomic and institutional context within which they occur. The comparative analysis across protected areas supports these findings suggesting that adaptation mediates the influence of social, economic, institutional, and governance factors.

A major point of interest of this study is the differentiation of the effects that diverse forms of adaptation can have on land use change. The findings from the case study and IAPAs analyses agree on the potential of diversification and migration to reduce land use change. However, only the comparative analysis across protected areas found both types of adaptation statistically significant to explain land use change. In the context of the Mayan Forest, there is not enough evidence to suggest that migration is causal factor of land use change. On the other hand, there is strong evidence for the Mayan Forest to suggest that land use change is likely to decrease when adaptation takes the form of exchange and pooling and to increase when adaptation is related to storage and government aid. Across the Americas, storage, exchange and pooling were not significant to explain land use change. These results shed light on the differentiated implications of different types of adaptation on land use change.

The findings of both analyses also suggest that governance is a critical factor to explain land use change. If community members in and around protected areas participate in decision-making processes concerning natural resources or community affairs, land use change is likely to decrease. In the Mayan Forest and across the Americas the results indicate that land use change is likely to increase when the distance from the communities to the market and administrative center decreases. Whereas participation and distance have been widely argued to be critical for natural resources conditions in the literature focusing on land use change, common pool resources and environmental governance, this study further advances our understanding of their role to explain land use change by analyzing them in the context of adaptation to CVC (Agarwal, 2001; Agrawal and Chhatre, 2006; Agrawal and Yadama, 1997; Rudel and Horowitz, 1993).

The dissertation findings showing that 1) adaptation is an influential factor of land use change and 2) adaptation can be a factor to foster or to tame land use change calls conservation and adaptation practitioners to work together. The integration of policies on climate change and conservation would allow taking advantage of the opportunity that adaptation brings to meet social and ecological goals simultaneously or to prevent further environmental change led by land use change. The findings also call for the academic and policy agendas to expand its scope. In addition to advance our understanding of how can we adapt, we need to investigate how the way we are adapting affects livelihoods and adaptation prospects, the resilience of the ecosystem to cope with climate change, the sustainability of communities, public health, and land productivity, for example.

The dissertation is divided in five chapters. Following this introduction, chapter 2 presents an overview of common methods used in the literature to examine the drivers of land use change, as well as the data collection methods for the case study and the analysis across protected areas. Chapter 3 defines the dissertation analytical framework, the variables analyzed, and the hypotheses tested in the two analyses. Chapter 4 provides the results and discussion. Finally, chapter 5 offers conclusions integrating the findings for the two analyses.

Chapter 2

Methods

2.1 Methods overview

2.1.1 Large-N Cross-National Analyses

In general large-N analyses across sites provide a powerful basis for making causal inferences. The strength of this type of analysis comes from the opportunities provided by the large number of observations. Specifically in the field of land use change, large-N analysis can be very useful for three key reasons:

First, the number of factors likely influencing land use change and the number of interactions occurring between such factors is larger than our ability to assess them without using statistical tools. Case studies are very useful to unveil those factors effectively. Alternatively, large-n analyses helps to learn if the relationship between land use change and the unveiled factor is statistically significant. If significant, how important is the factor to explain land use change? How important is the factor in relation to other causal factors? (Agrawal and Chhatre, 2006). Assessments are critical to target (human, financial, policy and even research) resources effectively. *Second*, delving into the complexity of land use change requires more than in depth knowledge of the social-ecological systems where it occurs. It requires the simultaneous examination of a range of causal factors, for which large-N analyses are designed. *Third*, a general understanding of the drivers of land use change requires the systematic analysis of rival explanations of land use change for the identification of broad patterns across sites (e.g. nations, protected areas, or tropical forests) (Agrawal and Chhatre, 2007). Through the use of statistical tools the large-N cross-national studies can advance important insights to the understanding of land use change.

The analytical potential, as well as the main flaws of large-N cross-national land use change analyses are associated to the data they need to use statistical tools. In general, in the land use change research field, large-N research has been done at the national level due to the availability of statistical data. However, comparative research of land use change across nations still faces significant challenges, both in terms of availability of data and the quality of the available data.

Large-N cross-national analyses have the technical power to assess a range of rival hypotheses, yet they tend to miss a comprehensive assessment of causal factors due to missing data on critical explanatory variables. For example, there are no national or even local statistical datasets of institutions and governance mechanisms. Variables reflecting these two key drivers of land use change are difficult to quantify. Even if these variables were operationalized and measured, it is unlikely there would be a consensus on how to do it. Furthermore, assuming such agreement could be reached, it would be difficult and costly to operationalize such variables for a number of sites large enough to analyze them statistically. Therefore, for different reasons, just like case studies, large-N cross national analyses can lead to the overestimation of some factors, generating misleading conclusions. Critics of cross-national comparisons claim that the use of this methodological strategy can lead to unreliable inferences and simplistic explanations of a very complex problem (Geist and Lambin, 2001).

The quality of the available data also represents a major problem for cross-national analyses. The methods used to produce national statistics can be many times unreliable and inconsistent across countries. Regardless of the quality, cross-national analyses inferential power is weakened by the aggregated nature of its data. For land use change, having disaggregated data is key, given that land use change occurs at the individual or community level. Furthermore, the methods used to aggregate the data could also be questionable and the use of homogeneous methods to aggregate the data across countries is unlikely (Lambin et al., 2001; Rindfuss et al., 2007). The use of aggregated data hinders the possibility of cross-national analyses to capture the diversity within the studied cases and increases the possibility of meaningless conclusions. Cross-national analyses findings may also be incompatible with those produced with micro- or meso-scale data sets due to the use of aggregated data (Rindfuss et al., 2004).

2.1.2 Case Studies

Case studies are an alternative the literature has extensively used to examine the causes of land use change, arguing the methodology provides opportunities to measure causal variables in a disaggregated, representative and more accurately way than cross-national studies. By establishing chronologies associated to the causal factors, and unveiling possible interactions between causal variables and feedbacks between dependent and independent variables case studies shed light on causal mechanisms (Lieberman, 2003). In-depth knowledge case studies have the potential to show more complex sets of relationships than those large-N cross-national analyses alone can assess.

However, drawing general conclusions from case studies is flawed by the application of their findings only to specific circumstances, and inattention to rival explanations (Achen and Snidal, 1989; King et al., 1994; Lambin et al., 2001). Moreover, case studies cannot assess the magnitude and relative importance of causal factors, potentially leading to biased conclusions based on the impressions of the researcher (Agrawal and Chhatre, 2006).

2.1.3 Comparative Case Studies

Comparative case studies are a methodological approach used by land use change literature to address the data and generalizability challenges associated to cross-national analysis and case studies. There are two major strategies to develop comparisons across case studies: 1) compare cases identified from a pool of pier reviewed papers (Geist and Lambin, 2002; McConnell and Keys, 2005) and 2) compare standardized case studies developed using common protocols (Chhatre and Agrawal, 2008).

Following the strategy 1, the method is only partially successful addressing the generalizability and data challenges it aims to address. Comparisons tend to be made across cases sharing a range of characteristics with the objective of ruling out the variance between cases is explained by factors not considered in the analysis (Lieberman, 2003). Therefore, the gain in terms of generalizability by comparing case studies is limited and restricted only to cases with similar conditions, for example to tropical forests, or coastal zones. Nonetheless, the method is a useful resource to advance the understanding of land use change in larger geographical contexts (Rindfuss et al., 2007).

On the other hand, while the compared cases bring with them in-depth knowledge of causal factors and mechanisms, the method following strategy 1 also faces data problems. Although the scale of the data problem is not as large as in cross-national analyses, unless the comparison uses cases developed based on a common protocol, the comparison is likely to rely on data with different degrees of reliability and variables conceptualized and measured in different ways (Rindfuss et al., 2004).

When following strategy 2, the data problem is addressed. Such is the case of comparative research based on cases developed using the International Forestry Resources and Institutions (IFRI) research tools. IFRI cases are particularly powerful to account for theoretically critical variables, such as governance and institutions, which are also variables out of the reach of large-N comparisons across countries.

2.1.4 Models

Besides these two approaches, modeling has been a very important analytical tool used by the land use change literature to understand and project land use change dynamics (Moran et al., 2004; Parker et al., 2001). There are many types of models, that can be classified as dynamic systems, discrete finite state, area base, univariate spatial, econometric, spatial dynamic, spatial stochastic, spatial simulation, and cellular automata models. Some of these models can predict land use change patterns, land cover, or land use proportions. Some others can explain frequency of deforestation, change in urban areas, or allocation of land in different sectors (Agarwal et al., 2002). Within the variety of models, agent-based models (a type of dynamic process models) are very important in the literature given their capacity represent human decision making and simulating the aggregated outcomes that result from decisions made by multiple individuals (Brown et al., 2004).

The utility of models goes beyond their capacity to predict, which is not good for all models. Models can be very useful providing insights about the drivers of land use change given their capacity to explore the dynamics of systems and the feedbacks within the systems (Evans et al., 2005). This is a particularly useful quality of models given that land use change is a complex process in which the driving factors interact. While modeling has been critical for the understanding of land use change, it is beyond the scope of this dissertation.

2.2 Dissertation methods

This dissertation combines a case study that systematically analyzes households and communities in the Mayan Forest, with a comparative analysis of internationally adjoining protected areas across the Americas. The analytical strategy seeks to take advantage of the complementarities (data quality and generalizability) between the two methods by deploying them jointly.

Based on disaggregated and representative data provided by 353 households from 46 communities, the case study captures the diversity, variability, and complexity of the causes of land use change, providing insights about causal mechanisms in the Mayan Forest. The use of statistical tools to analyze the large number of households and communities observations allows testing rival explanations, identifying broad patterns in the data to support the generalizability of the findings across the Mayan Forest. However, the level of generalization beyond the Mayan Forest is limited to similar cases, such as protected areas in tropical forests supporting vulnerable populations whose livelihoods strongly rely on seasonal agriculture and natural resources.

The dissertation also includes a systematic analysis of 55 internationally adjoining protected areas from seventeen countries in North, Central and South America. This comparative analysis mostly relies on data provided by the protected area managers, who aggregated data for multiple communities in their responses. Thus, some of the criticisms of large-N studies across countries could apply to the analysis across protected areas. Constraining the research to the Americas, despite its large social and ecological diversity, also limits the generalizability of the findings. Moreover, not having means to triangulate the responses given by the managers about adaptation strategies impacts the quality of the inferences. Nonetheless, by cross checking inferences across the two approaches, the support or refutation of hypotheses can be more powerful when both methods agree. Finding consistent results for both analyses can provide insights about the potential generalizability of the case study findings beyond tropical forests and enhance the confidence in the findings of the comparative analysis across protected areas and the dissertation in general. Moreover this portion of the analysis addresses data conceptualization and measurement problems commonly associated to comparative case studies through the collection of primary data across sites. The use of primary data from each case also approaches the problem of missing the complexity of the area. Likewise, by using the IFRI research tools (see detailed description below) as a guide to collect data from households and managers, the concepts and metrics are homogenized from the case study to the cross-protected area analysis.

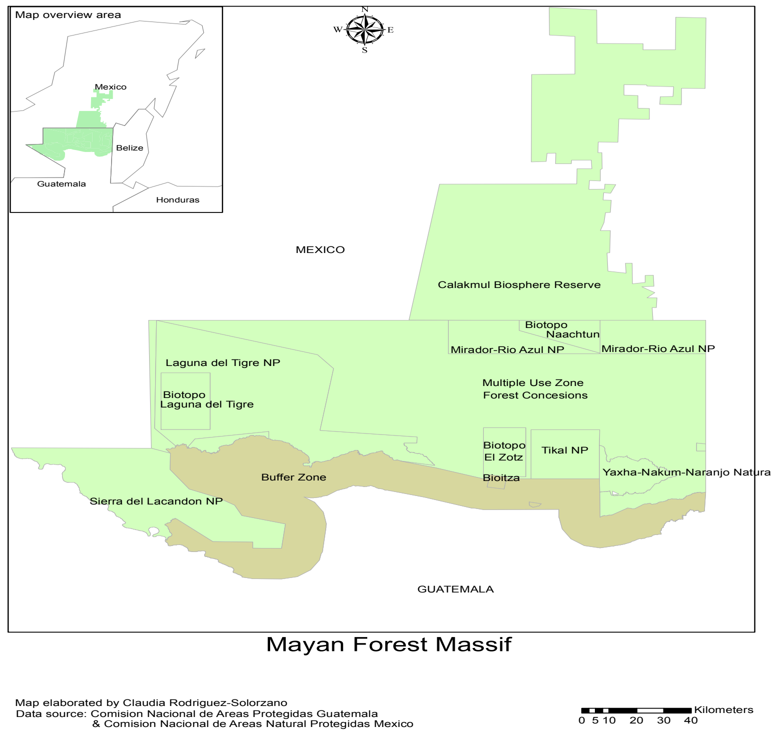
2.2.1 The Mayan Forest

From 2007 to 2009 I conducted field research in 46 randomly selected communities located inside and in the buffer zone of the Calakmul and the Mayan

Biosphere Reserves. Figure 2.1 locates the Mayan Forest. The research included in-depth interviews, in addition to participant observation of councils at the community, municipal, and biosphere reserve level. Three hundred fifty three randomly selected households participated in in-depth interviews, providing information about climate, biophysical, demographic, economic, socio-political, institutional, and governance attributes of their household, their community and their Biosphere Reserve. Likewise, the interviewees explained their interaction with their environment and their livelihood production mechanisms under climate variability pressure and before the climate variability was an issue for them. The household questionnaire was crafted using as a guide the International Forestry and Institutions (IFRI) Program research instruments (www.umich.edu/~ifri), with added questions about climate and adaptation to climate stimuli.

To collect data on governance at multiple levels I observed council meetings. In Mexico all but one of the studied communities have councils to make decisions about multiple community affairs, such as the use of common land, resolution of plots boundary conflicts, or participation of the communities in conservation programs. I observed these meetings in ten communities. I could not observe meetings in every community because they take place every several months and some times they occur simultaneously in several communities. Additionally, in both countries groups of communities are associated to regional, municipal or protected area councils. I also participated as observer in multiple meetings in all the regional and municipal councils in Calakmul and one out of two in the Mayan Biosphere Reserve.

Figure 2.1- Mayan Forest



Secondary sources and in-depth interviews with 53 government and non-government officials linked to both biosphere reserves also support the research. In the Mayan Biosphere Reserve the interviewees include NGOs and protected areas managers, staff in charge of judicial affairs, wildlife, forestry, environmental education, and monitoring, in addition to officials from the central offices representing the National Commission of Protected Areas and the National Institute of Forest. In Calakmul, the interviewees represented the federal, state, and municipal ministries or departments in charge of agriculture and environment. The interviews also include the biosphere reserve and NGOs managers, a donor representative, and members of the Municipal Council for Rural Sustainable Development.

In the statistical model, land use change refers to the number of forest hectares each household has cleared in his/her plot, replacing primary forest for crops, pastures, or tree plantations, for example.. During the interviews households reported the size of their plots and the number of hectares they have under different types of land coverage. Land use change was measured as the difference between the total size of the plot and the remaining primary forest in the plot. For instance, for a given household land use change would be equal to 30 hectares if the household owns a plot with 40 hectares and has 10 hectares of primary forest left. This measurement provides the cumulative land use change since people received their plot fully or mostly covered with primary forest. Households can clear the same area several times, if they let fallows to grow old, but primary forest can only be cleared once. The analysis does not include land use change from crops to secondary forest, which could occur when people let fallows grow old.

Given that interviewees did not assess the quality of the forest, but the number of hectares they had cleared, the likelihood of subjectivity is removed. Households could have incentives to provide inaccurate information given the restrictions imposed by the protected areas to clear the forest. Nonetheless, the interviewees showed strong willingness to speak about their land uses, their antagonism or support towards forest conservation policies, and to account for the number of hectares they have allocated for different uses. No interviewee refused to provide the information and the response rate was surprisingly high. Except for two people who refused to participate without compensation, few women who were not informed about their household land uses and two indigenous households who did not speak Spanish, every household that was requested for an interview kindly participated.

The data provided by the interviewees about their land uses is the best available at the household level. It was not possible to triangulate the interviewee's responses because no official records of forest coverage/ forest clearance exist at the household level. The use of spatial analysis is not possible because there are no registries of the geographical references defining households' plots. The plots boundaries tend to be made through community agreements, often times without government recognition of the boundaries. Furthermore, if the geographical references were registered they would not be open access for confidentiality purposes.

Landowner households in this research refer to landowners holding a land title or de facto landowners. In Calakmul landowners have a title or the legal recognition of their rights. In the Mayan Biosphere Reserve some have title, but many others are *de facto* landowners having no legal registry supporting their ownership. Nonetheless, *de facto* landowners exercise access, extraction, management, alienation and exclusion rights over their plot in the same manner title landowners do. Even if theoretically there could be some distinction between these two types of landowners, in practice there is none. This is the case because any of the communities included in the research is an illegal settlement or faces the risk of eviction because of the Biosphere Reserve. Non-written community rules also encourage community members and outsiders to respect *de facto* landowners' rights claims[3].

Households interviewed were randomly selected, having a mix of landowners and landless households. Landless households sometimes have cleared primary forest in land

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[3] Community members around the MBR reported land rights are enforced by community members themselves and failure to comply has resulted in the murder of the infractor, working as a strong deterrence.

rented or lent by neighbors and relatives. Nonetheless, land use change was only analyzed for landowners. Hence, even though the total number of households interviewed is three hundred fifty three, only two hundred eighty seven were used as observations at the household level in the analysis presented in chapter 4. Land use change could not be accounted for landless households because, in general, the number of hectares landless households have cleared over the years is unknown. Landless households do not keep a record of how many hectares they have cleared since they moved to the region and they do not have a plot where land use change could be registered. On the contrary, land use change can be easily assessed for landowner households by registering the difference between the plot size and primary forest left in the plots. For landless households we can assess land use at the time of the interview, but not land use change.

Landless households were still interviewed because they are part of the communities and the information they provided is useful to learn about the community level variables, such as governance, institutions and socioeconomic dynamics. Particularly in the Mayan Biosphere Reserve, it is common to find communities where landowners are minority, enhancing the importance of accounting for the landless voice in the research.

Not accounting for landless households in the statistical analysis reduces the number of observations and the model prediction power. Nonetheless, the sample is large enough to produce reliable results. Land use change could be overestimated for households who have rented or lent land covered with primary forest to landless households. However, for the most landowners keep for themselves the best soils, which tend to be those available after clearing primary forest, and rent or lend the second best soils. Thus, the chances of overestimating the number of hectares households have cleared exist, but are expected to be low.

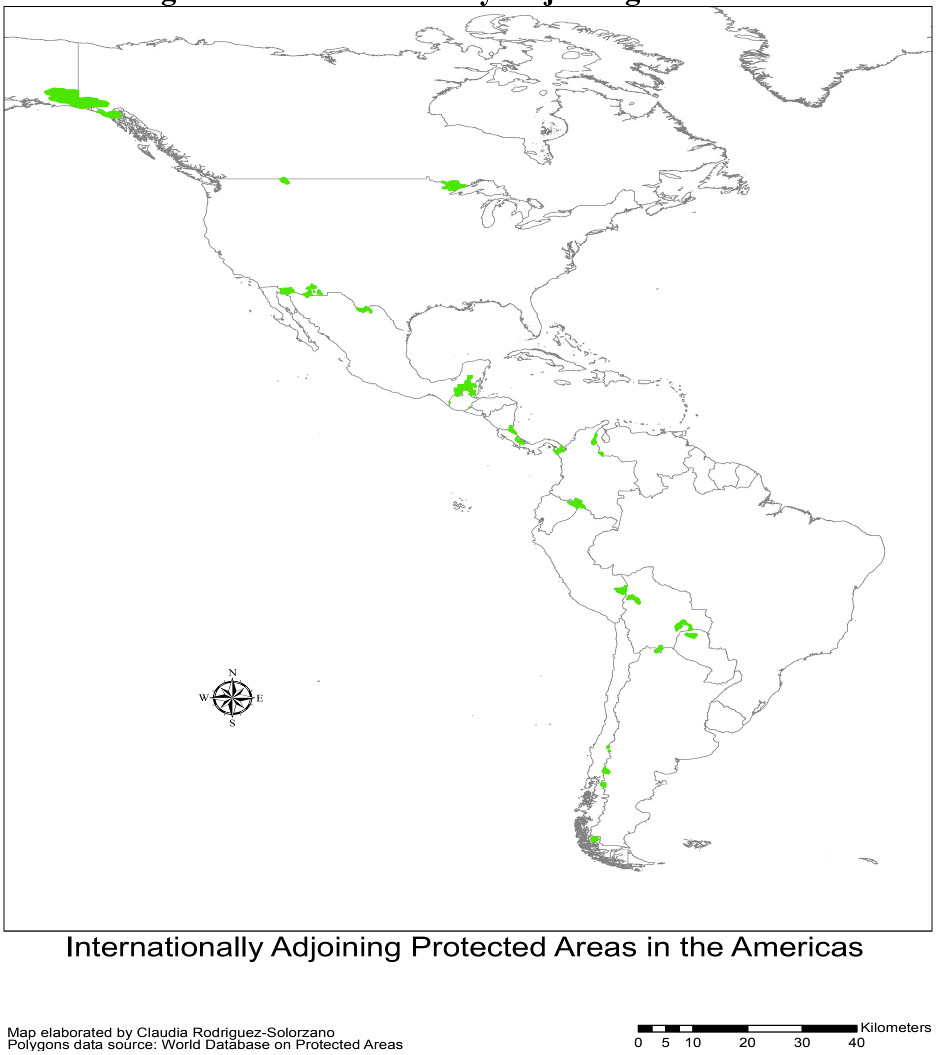
2.2.2 Internationally Adjoining Protected Areas across the Americas

The comparative analysis includes 55 internationally adjoining protected areas from seventeen English and Spanish speaking countries in North, Central, and South America. Internationally adjoining protected areas (IAPAs) refers to neighboring protected areas located by international borders. A group of IAPAs can constitute a transboundary protected area (TBPA) if the IAPAs are managed together through international cooperation (Sandwith et al., 2001)

The IAPAs were identified after reviewing, the list elaborated by Lysenko et al. (2007), which at the time of this research was the latest published TBPAs list. To review the list I called the organization in charge of protected areas in all the English and Spanish speaking countries in the Americas. Before conducting the in depth interviews I talked with the protected area managers or with the people responsible to supervise the managers. These interviewees helped me to develop the list showed in the appendix. The dissertation list includes only those protected areas listed by Lysenko et al. that were already established, and were adjoining to a protected area in a neighboring country or to a domestic protected area adjoining a neighboring country protected area. The appendix list does not count protected areas that were prospective, close to the border but not adjoining to a neighboring country protected area, or close but not adjoining to an internationally protected area. For example Lysenko lists Sian Ka'an and Calakmul within the same potential TBPA, even though these two protected areas are approximately 300 kilometers away from each other, and their management is completely independent. Using the dissertation criteria Sian Ka'an and other protected areas in similar conditions were excluded, resulting in a list substantially smaller and more accurate than Lysenko et al.'s.

After reviewing Lysenko et al.'s list with the information provided by government officials, I identified a total of 29 potential TBPAs, integrated by 81 IAPAs. The 55 analyzed IAPAs represent 67% of the IAPAs, integrating 25 potential TBPAs (85% of the total number of TBPAs). As figure 2.2 shows, these 55 IAPAs are located throughout the continent, covering a wide range of ecosystems, including different types of forests, desserts, and glaciers. Consequently, in this chapter, land use change is defined more broadly than deforestation and refers to the replacement of natural land coverage (e.g. forest, pastures) for infrastructure or agricultural land coverage. The list of protected areas and countries is in the appendix A.

Figure 2.2- Internationally Adjoining Protected Areas



From May 2008 to January 2009, managers from all 81 IAPAs were asked to participate in the research. No sample was generated given the reduced number of cases to study in the selected geographical area. Fifty-five managers out of the total eighty-one IAPAs participated in the research through a phone interview (~70% response rate). The interviewees provided information about socioeconomic conditions of the communities influencing the protected area, institutions regulating social behavior related to natural resources, governance mechanisms and social participation in natural resources management, and natural resources conditions in the protected area.

The dissertation questionnaire used as a guideline the research instruments developed by the International Forestry Resources and Institutions (IFRI) Program (www.umich.edu/~ifri). The IFRI research instruments were designed to collect data in the field and from community members. Another key informant protocol was used to collect data over the phone from managers. These instruments were particularly useful to identify key questions, select variables, and define variables measurements. In addition to the questions included in the IFRI instruments, the dissertation questionnaire asked managers about climate, and what in general were the adaptation strategies used by the communities in and around the protected area.

The analysis includes the land in the protected area and the land in its area of influence. While the jurisdiction of protected area managers falls within the protected area polygon, in most of the studied cases, the protected area management goes beyond its territorial boundary, including its area of influence. Moreover, the protected areas are not isolated spaces; the land use change dynamics in its area of influence affects the sustainability of the protected area (Hansen and DeFries, 2007). It is also common that the protected area limits are unclear to both managers and neighboring communities; in some cases, the protected area polygon is not completely defined or the communities contest it.

The measurement of land use change is registered in an index, based on the responses of interviewed protected area managers. They supported their answers either on technical studies or their extensive knowledge of their working area. Although the use of the interviewees' responses introduces a measure of subjectivity to the analysis, it is a reasonable indicator of land use change because the protected area managers keep careful, informal accounts of land use change for their areas of jurisdiction. Likewise, the interviewees' accounts were the best information that could be collected in many cases, given that many protected areas have no resources to invest in geographical information systems to measure land use change. The data used to measure the independent variables comes mostly from the interviewees, who provided answers indicating what in general occurs in the protected area. Additionally whenever possible, the information was collected from management plans, diagnostic reports or working papers produced by or for the protected areas.

Chapter 3

Analysis

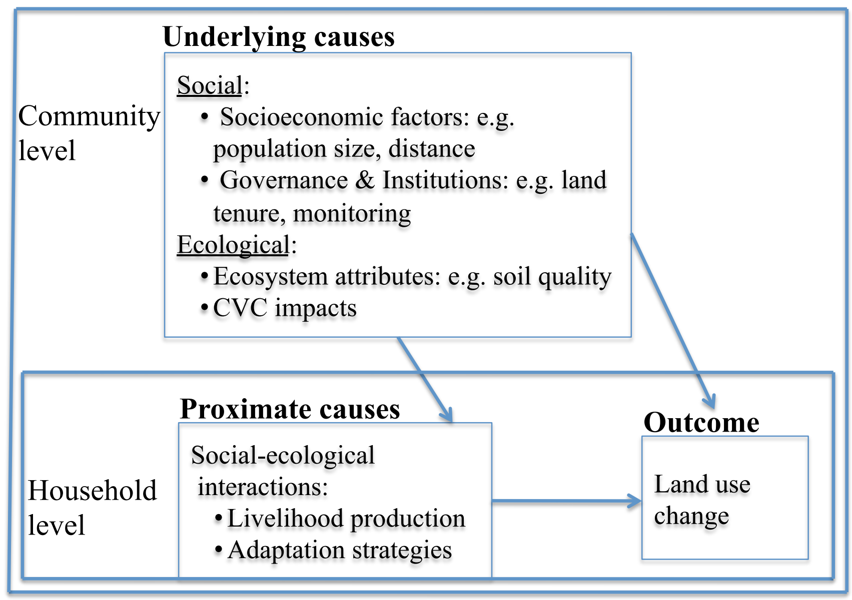
3.1 Analytical Framework

Drawing on the literature on land use change, environmental governance and common pool resources, this chapter proposes an analytical framework to examine the drivers of land use change. The proposed framework is a hybrid analytical framework informed by the Causes of Forest Decline (CFD) (Geist and Lambin, 2001) and the Social Ecological Systems (SES) (Ostrom, 2009) frameworks[4]. The proposed framework, like the CFD framework, suggests that land use change is influenced by proximate and underlying causes. However, the proposed framework has four distinctive qualities. First, following a social-ecological system approach, the dissertation framework defines these causes as social-ecological interactions and social and ecological factors. Second, the framework is multilevel, accounting for interactions occurring at the household level and factors at multiple higher levels. Third, the proposed framework introduces into the analysis the examination of the relationship between adaptation and land use change and makes emphasis on institutions and governance. The framework argues that households' adaptation has a direct effect on land use change, but it does not occur in a vacuum

[4] The SES framework has been developed at the Workshop in Political Theory and Policy Analysis at Indiana University drawing from the Institutional Analysis and Development (IAD) framework.

(Agrawal, 2008). Adaptation depends on a range of social and ecological factors that define the bundle of available alternatives over which people choose how to adapt to deal with the effects of CVC over their livelihoods. The effects of social and ecological factors are suggested to be indirect, mediated by adaptation, in addition to direct.

Figure 3.1- Analytical Framework



For simplicity figure 3.1 provides an overview of the framework; it accounts only for household and community levels and does not include underlying causes at the household level, even though the chapter analyzes some of them. Table 3.1 displays the specific proximate and underlying causes analyzed in the dissertation and the level at which they are analyzed. Feedback from land use change to the proximate and underlying causes may occur too, but the analysis of that relationship is beyond the scope of this dissertation.

Proximate causes refer to social-ecological interactions. These are represented by households' activities entailing the use and transformation of ecosystems aiming to produce their livelihoods and to adapt to CVC (i.e. households' actions taken to minimize the impact or to take advantage of the effects of CVC over their livelihoods). In the context of rural communities associated to protected areas in the tropics such activities may or may not entail land use change. Some examples are farming, cattle ranching, ecotourism, bee keeping, coal production, timber and non-timber extraction, which involve different combinations of labor, capital and land. Of these activities, some are more land intensive than others. Households' choices of livelihood production strategies and adaptation are the activities through which people directly change the use of their land.

Ecological and social underlying causes influence land use change indirectly through their influence on the proximate causes. In some cases, they also have a direct effect. *Ecological underlying causes* refer to attributes of the ecological system, such as soil composition, water availability, slope, availability of commercial forest products, climate and its variability, proneness to floods, hurricanes or droughts (Ostrom, 2009; Zhu et al., 2010). Ecological factors may have a direct effect on land use change, as it is the case with droughts and hurricanes (Kok and Winograd, 2002; Liverman, 1999). When followed by natural fires, droughts and hurricanes can lead to loss of forest previously used as reserve or for timber production, opening the door for alternative land uses. Hurricanes and drought effects on land use change can also be indirect through their influence on livelihood production and adaptation strategies; for example, people may diversify their livelihoods towards less climate dependent activities, which may also be less land intensive. Other factors influence land use change only indirectly, mediated by proximate causes, such as soils quality, water availability and slope. These ecological factors change households' incentives to clear forests to use the land for agricultural purposes. Assuming people can choose where to work, areas with richer soils and more water can be expected to undergo higher land use change rates than areas with poor soils and dry prone, since agriculture would be more productive where water and soils are rich. Likewise, flat areas could be preferable over steep ones as soil erosion is slower, allowing longer use of the same area.

Social underlying causes are related to the attributes of the social system – demographic, economic, political, and governance and institutional factors shaping the social dimension of the system (Agrawal and Chhatre, 2007; Ostrom, 2005). Among social underlying causes population size, heterogeneity of the population, access to markets, infrastructure, and technology have been widely studied by scholars who have contributed to the IAD and SES frameworks, as well as by land use change scholars. Their findings support the selection of these variables for the analysis in this chapter (Abramovitz et al., 2008; Angelsen et al., 2001; Lambin et al., 2001; Poteete and Ostrom, 2004; Rudel, 2005; Sunderlin et al., 2005; Varughese and Ostrom, 2001). Social underlying causes' influence on land use change is mediated by the social-ecological interactions resulting from them. For example, roads construction has a direct effect on land use change by replacing the natural cover, and indirectly by reducing transaction costs. The reduction in costs could provide incentives to community members to harvest the more land or to raise cattle, alternatively it could provide incentives to get jobs out of the farm yielding to lower land use.

3.2 Data

In the Mayan Forest land use change is a continuous variable, reflecting the natural logarithm of the number of hectares each household has cleared, replacing primary forest to develop social uses of land (e.g. agriculture, pastures, timber plantations). Households' land use change occurs in and around the two biosphere reserves integrating the Mayan Forest. For the Internationally Adjoining Protected Areas land use change is measured with an index that reflects the average land use change in the protected area and its area of influence together. The index ranges from 1 for very low (1 to 15% of the land in and around the protected area has replaced its natural cover (e.g. forest, grasslands, wetlands) to develop social uses of land) to 5 for very high (81 to 100%). The average of the values for the protected area and its area of influence yields a continuous measure.

Following the analytical framework presented in figure 3.1, the independent variables are classified into proximate and underlying causes (ecological and social). The selection of independent variables, except for adaptation, was based on previous findings and arguments advanced by the literature on land use change, environmental governance, institutions and common pool resources (Abramovitz et al., 2008; Agrawal and Chhatre, 2007; Agrawal and Goyal, 2001; Geist and Lambin, 2001; Lambin et al., 2001; Ostrom, 2009; Poteete and Ostrom, 2004; Rudel, 2005). The variables and their measurements are summarized in table 3.1. Further detail about adaptation and governance variables is provided when their operationalization is not as straight as for other analyzed variables.

Table 3.1 Description of variables (1/2)

Variable	Mayan Forest	IAPAs
Proximate causes (hh)		
Livelihood production strategies	0 no, 1 yes	NT
Adaptation		
Migration	0 no, 1 yes	0 no, 1 yes
Job	0 no, 1 yes	NT
Storage/ cattle	0 no, 1 yes	0 no, 1 yes
Exchange	0 no, 1 yes	0 no, 1 yes
Diversification	0 no, 1 yes	0 no, 1 yes
Pooling (com)	0 no, 1 yes	0 no, 1 yes
Government disaster aid	0 no, 1 yes	NT
Ecological UC		
Soil quality (hh)	0 rich, 1 poor for agricultural production	NT
CVC impact (hh)	1low – 3 high. Households' assessment of the impact of CVC in their livelihood.	NT
Social UC		
Socioeconomic UC		
Population (com)	Number of people in the community.	Population density: 1 low-3 high
Cash benefits from forest (hh)	0 no benefits to 5 very high	NT
Physical capital		PK=Infrastructure + technology
Technology (hh)	0 no, 1 yes use of mechanized agriculture	1 low- 3 high. General availability of technology to develop economic activities
Infrastructure	NT	Availability of water, electricity, public transportation, telephone signal, roads, health center, schools. 1 low: in general the communities have access to the minimum infrastructure – 3 high: the communities have access to most
Distance to commercial and administrative center (com)	Number of minutes from the community to the administrative and commercial center	1: close: 0 min -1 hr; 2: regular: 1hr< x <2 hrs 3: far: >2hrs

NT: not tested

Table 3.1 Description of variables (2/2)

Variable	Mayan Forest	IAPAs
Governance-Inst. UC		
Government role (hh)	1 if households think the government must compensate them for conservation, 0 if households don't think the government must compensate	
Access to decision making (com)	0 community leaders have no network/connections with government or NGOs providing resources to the community, 1 they have	Average of the type of partnerships existing in the PA between or among government, non-government and community organizations
Government monitoring (com)	0 none, 1 rare, 2 random, 3 community participation/ constant	
Land ownership (com)	Percentage of the households in the community that are land owners	
Community land tenure (com)	0 private property, 1 community property	0: if in general the land is owned exclusively or by combinations of government, NGO, private organizations, large land owners; 1: communal land tenure and/or small land holders in the area
Political competition (com)	0 none -3 high level of interest among households to be elected community leader	0: if in general elites rule the communities influencing the PA 1: if common people generally have access to power positions within the communities

NT: not tested

While both models analyze the same groups of variables, except for ecological underlying causes, the variables included in each group are not always the same or measured in the same way. These differences in variables and measurements are due to differences in data availability for the IAPAs. The variables are labeled as hh or com to denote if the variable is a household or a community level variable. For the case of the Mayan Forest the data has been collected at level indicated by its label. Across the Americas the data was collected aggregating what in general occurs in the areas.

Livelihood production strategies include alternatives such as agriculture, apiculture, timber and non-timber extraction, and tourism. Given the data availability, these were only tested at the household level in the Mayan Forest analysis, but not for the IAPAs analysis.

During the in-depth interview, ninety four percent of the interviewees in both countries said to have perceived changes in the precipitation patterns in the last 5-10 years, to which, in general, they refer as “climate change”. Fifty-four percent of the households defined the intensity of such changes as high, and 39% as medium. Specifically the change consists of having longer dry season; receiving the first rain after the date they historically received it. They claimed they have not been able to figure out a new pattern as there is not a new fix date for the beginning of the raining season and because some times they experienced a gap between the first rain after months of dry season and the actual rain season.

In Calakmul the data provided by the National Water Commission, which is in the agency in charge of recording Mexico’s meteorological data, is consistent with households’ observations of changes in precipitation patterns. Precipitation levels in Calakmul have fluctuated in the last 35 years; however, the average level of precipitation in the last 10 years (by the data collection period in 2007) is lower than the average level of precipitation 30 years ago. For the case of the Mayan Biosphere Reserve the precipitation data was not available in electronic format at the time of the dissertation writing. However, the perception of climate variability and change by households and government officials was consistent. As the data becomes available, households’ perceptions and statistical records will be triangulated to enhance the analysis. Nonetheless, given the ecological contiguity of the Mayan and Calakmul biosphere reserves and the consistency between perceptions and historical data for Calakmul it is likely that perceptions and data are also consistent in the Mayan Biosphere Reserve.

The interviewed household provided information about whether or not they had adopted any or several of the adaptation strategies listed above. All of the considered adaptation strategies could have been adopted to respond to a diverse range of stimuli or before households experienced the climate stimuli they identified as climate change. Thus, to prevent the overestimation of these strategies, migration, storage, exchange, diversification, or pooling were considered climate adaptation strategies only for those households that explicitly said they adopted such strategies, in part or fully, to respond to climate change effects on their livelihoods. The strategies could have been adopted at any moment within the five to ten years period over which households reported they had noticed changes in climate conditions.

In the IAPAs analysis the managers expressed if in their perception or to the best of their knowledge, based on scientific or local knowledge, their protected area has experienced climate variability and change. In general, the managers defined climate variability and change in terms of changes in average precipitation and temperature levels, and natural hazards frequency and intensity. In some cases the managers associated glaciers reduction to climate variability and change.

It was not possible to collect climate data for all the protected areas analyzed to corroborate the accuracy of the managers' responses indicating climate variability and change. Some of the protected areas had no infrastructure to collect climatic data systematically, and in some other protected areas the measurement has been interrupted. However, in some protected areas the managers identified the name of the meteorological stations operating in the protected areas' territory, for which data can be collected in a subsequent research effort. Protected areas' managers also provided information about whether or not the communities tend to adapt to external shocks, including climate variability and change, using any or several of the adaptation strategies listed above.

Migration has been a useful strategy for households to mobilize across the space, where climate stimuli effects are differentiated (migration) (Adger et al., 2002). The information provided by households considered migration within the country or internationally, but, in any case, migration was coded 1 only when the member of the household had left the community for several months or permanently.

Storage refers to adaptation strategies spreading the risk across time by saving (van de Giesen et al., 2010). Among agricultural societies access to financial institutions to save cash earned during good years tends to be scarce leading people to save through other means, such as storing their surplus production, instead of commercializing it, or investing the cash earned in good years on cattle. Cattle ranching is often considered a savings strategy among rural people, because it provides access to cash when they need it given its seasonal independence (Brondizio and Moran, 2008). Raising cattle was spontaneously identified in both countries as a savings strategy that people use as a substitute for financial services where they could save their earnings from good years. Savings in cash or in kind, e.g. corn or cattle, allows the storage of goods to be used in the future and represents a strategy to spread the risk over time.

People were not asked if having cattle was a savings or an adaptation strategy, but whether or not they had cattle. Those that had cattle were asked for the reasons why they had it and for how long they had had it. Some of them had cattle since before they migrated to the Mayan Forest region or for longer before they identified climate variability, for those cattle is not considered adaptation. Some households explicitly said they had started raising cattle to compensate for the losses in agriculture related to the variability in precipitation they had experienced in the last 5-10 years (depending on the location of the community). They considered raising cattle was a good alternative because it is less vulnerable to droughts vis-à-vis crops, and it allows them to save for bad years. Only households saying raising cattle was an adaptation strategy they have chosen because it meant a way of savings were coded with 1. Households coded 1 could have also chosen cattle for other reasons in addition to savings. For instance, cattle ranching is also influenced by the prestige and status associated to it in rural communities. This is so because cattle ranching is not an available alternative for every one, given the high initial costs. Those having cattle increase their liquidity as their ability to earn cash becomes independent of the seasons; cattle ranchers can sell a head at any time, which makes them subject of informal credit markets. Cattle ranching can thus be a multi-fold strategy.

Diversification specifically refers to spreading risk by earning income from different sources, which requires households to diversify their labor, land or capital allocation (Seo, 2009). Diversification can therefore overlap with storage or exchange, as both of these activities represent an additional source of income to whatever they had before their adaptation to climate variability. Off-farm or outside of their farm jobs was used to measure another dimension of livelihood diversification.

Pooling refers to pooling risks across group members by joining households' resources (labor, land or capital) to produce their livelihoods (Agrawal, 2008). This adaptation strategy was not measured at the household, but at the community level. Pooling is not an individual action as the rest of the adaptation strategies; it requires 2+ community members. Some communities show larger degrees of pooling than others, having integrated multiple groups to work together joining their resources, while other communities have integrated just some or no groups at all. The effect of pooling may thus be better captured if the community pooling degree is accounted; however, to maintain homogeneity in the measurement of adaptation strategies, pooling was also coded as a dummy variable.

Exchange is particular because it shares characteristics with diversification, and storage. It spreads the risk by participating in the market, which is a form of diversifying livelihoods; it can also be a substitute of storage as instead of saving assets these get exchanged, or households may need to store a minimum level necessary to have large enough sales to cover the transaction costs of exchange. In the Mayan Forest exchange of goods through local stores has been a common adaptation strategy on both sides of the border. Barter is not a practice among the households in either biosphere reserve.

Government aid was included among the adaptation strategies given that relying on government aid was a common response among the interviewees. Many people compensate all or part of their losses with in-kind or monetary aid provided by the government, which works as an insurance (Burton, 1996).

Governance and institutional variables account for the distribution of operational rights (natural resources access and extraction rights) and collective choice rights (management and exclusion rights) among community people in the protected areas (Schlager and Ostrom, 1992).

The variables community land tenure and land ownership were used to indicate operational rights. *Community land tenure* refers to common ownerships of the community land. *Land ownership* refers to the percentage of households in the communities who claim rights over a plot. In the Mayan Forest, even communities under common property have a percentage of households without land tenure. Information for land ownership was not available at the IAPAs and it was not tested but for the Mayan Forest. Land tenure indicates only operational rights because in and around protected areas land tenure entails the right to access and extract natural resources, even if only for self-consumption due to the protected status of the resources. However, unless community members through their community representatives participate in decision-making process for the management of the natural resources, household and community land tenure does not necessarily grant collective choice rights.

Collective choice rights can be assessed by communities' *access to decision making*. Calakmul has governance structures giving the communities access to decision makers and to make decisions themselves about budget distribution for different land uses and to define the biosphere reserve land use plan. The Mayan Biosphere Reserve has not developed those structures. However, in both biosphere reserves the communities' influence over decision making was related to the communities' leaders networks.

The variable *partnership* also aims to account for collective choice rights by measuring the distribution of steering power among actors related to the protected areas (Lemos and Agrawal, 2006). Partnerships can take multiple forms, such as partnerships between government (PA manager for most of the cases) and communities/ NGOs or with several of these actors simultaneously. In general, the IAPAs studied had more than one type of partnership. To account for all of them, each type of partnership received a value, where partnerships involving community people had larger value than those that simply opened the decision making process from the government to NGOs. The values of each partnership were averaged for each protected area, expecting that the larger the number of partnerships, the lower the rate of land use change, as larger numbers are associated to community-based management.

Government role seeks to capture the likely antagonism between communities and conservation pushing governments. In both biosphere reserves people's position about conservation ranged from strong refusal to stop clearing the forest or even threats to set the forest on fire unless the government compensated them, to willingness and even actual conservation of the forest regardless of the government conservation agenda or support. Government role can also be used as an indicator of collective choice rights, as the level of antagonism can be associated with households' exclusion from the forest management.

3.3 Hypotheses

Proximate causes: livelihoods production and adaptation strategies

In protected areas, timber and non-timber products extraction, tourism, agriculture, and cattle are common households' social-ecological interactions for the *production of livelihoods*. Timber, non-timber, tourism are hypothesized to have a negative relationship with land use change, while agriculture and cattle to have a positive relationship. The cost of opportunity of clearing the forest increases when the households derive part of their income from it, providing incentives to reduce land use change. On the other hand, having agriculture and cattle increases the opportunity cost of keeping the natural land cover.

The scholarship on livelihoods and land use change has argued that the effect of out *migration* on land use change can be expected to be positive or negative (Van der Geest et al., 2010), depending on whom emigrates and how migrants' relatives use their remittances (if any) (Liu et al., 1999). If the migrants constituted the main source of labor used for land use change in the region and no financial resources are used to compensate by getting external labor or technology, land use can be expected to decrease (de Sherbinin et al., 2008). Similarly, land use change is expected to decrease when the remittances provide resources to venture into activities with low or no land requirements, such as apiculture, ecotourism or timber and non-timber managed extraction (Tacoli, 2009). If alternatively, remittances are used to invest in activities such as cattle ranching or extensive agriculture, the relationship between migration and land use change may be positive (Adger et al., 2002).

Diversification is intimately linked with migration when it provides remittances. However, remittances are not the only source of resources people can use to diversify their livelihoods and remittances do not always follow migration. Therefore, these two forms of adaptation should be distinguished in the analysis. Nonetheless, diversification follows a similar pattern of bidirectional relationship with land use change. Diversification towards land-intensive activities increases land use change, as it is the case with renting land to agro corporations, or harvesting in plots in different locations (e.g. flat lands vs. hills to buffer the risk of different levels of precipitation). Alternatively, if diversification entails the reallocation of households' assets to activities that are labor or capital, but not land intensive, it can be expected to have a negative relationship with land use change (Wang et al., 2010). That would be the case if diversification included jobs unrelated to the land, such as off-farm jobs, chicken raising, handcrafts production, non-timber products commercialization, apiculture, or eco-tourism (Soini, 2005). Opening local stores is a livelihoods diversification strategy, as well as a mechanism to *exchange*, which could be expected to reduce the demand for land.

The relationship between land use change and *pooling* is also expected to vary depending on the activity that people pool for, but it is likely they pool for activities with low land use change impact. Community members tend to face difficulties to consolidate groups due to financial constraints, but can get funding through governmental and non-governmental organizations whose work is directed specifically to support community groups around protected areas. Having natural resources conservation as a goal, these organizations tend to fund community groups working on activities that could help reduce land use change. Other organizations do not pursue conservation, but because communities are in or around protected areas, it is likely the funds have to be labeled as "green". Nonetheless, because of policy inconsistencies across sectors, funding for cattle could also be an option. *Storage*, as measured in this chapter through cattle ranching, is expected to have a positive effect in land use change, as it has been in other areas in the world (Barona et al., 2010; Herrero et al., 2009; Schulz et al., 2010; Steinfeld et al., 2006; Wyman and Stein, 2010).

Government disaster aid could create incentives for land use change. When people expect to be compensated per hectare after a disaster or pronounced drought, depending on the scale of the compensation, they could have incentives to use more hectares for productive purposes. If the aid is not per hectare, the incentive to use more land may decrease. However, it could be expected that if people do not increase their land use, they may not decrease it either as the expectation of government aid reduces the risk of loss from CVC; government aid would then function as an insurance substitute (Capitanio and Adinolfi, 2009; Goodwin et al., 2004; Wu, 1999).

As critical as adaptation is argued to be, this chapter acknowledges that adaptation is merely a proximate cause, since it mediates the effects of underlying social and ecological causes.

Ecological underlying causes

In the framework of the Mayan forest, predominantly inhabited by rural communities, it makes sense to analyze the effect of ecological underlying variables, such as *soil quality and climate variability* on land use change. By influencing the likelihood of successful crops, these two variables may have an influence on land use change decisions. It can be expected that, assuming all things constant, the better soil quality, the higher productivity and the larger land use change. On the other hand, lower climate variability represents lower risks and could be associated to larger land use change than when climate variability is large, given that larger risks could discourage the investment in agriculture and encourage the diversification of livelihoods and participation in the off-farm job market. However, higher climate variability could also be associated with large land use change, since cattle ranching (storage) is likely to replace crops as it is perceived to be more resilient to the effects of climate than crops and, at the household scale, it is also more land intensive than agriculture (Zhu et al., 2010).

No ecological variables were assessed for the IAPAs analysis because the ecological and land uses diversity across them made difficult to operationalize a variable to capture the influence of ecological underlying causes.

Social underlying causes

Among social underlying causes socioeconomic factors, such as population, distance to the market and technology have received much attention in the literature. Yet, the direction of the individual relationship between land use change and these three factors has been controversial.

Population has long been argued to have a positive relationship with land use change, even by those who argued it is not as relevant as it was thought (Rudel and Horowitz, 1993; Sunderlin and Pokam, 2002; Zhu et al., 2010). However, institutional theorists have showed that population (size of the group) has a curvilinear relationship with collective action associated to better natural resources conditions (Ostrom, 2005). Land use change may be low when a large group is organized for collective action (pooling) and joins resources for control and monitoring. Alternatively, when no institutions exist to regulate land distribution and to secure the rights of those who keep the forest, grasslands, wetlands, or any other natural land cover in the protected areas, individuals from a small group could have incentives to change the land cover to secure a maximum share of land. In these situations, the relationship between population and land use would be negative. More people could also lead to lower land use change by opening opportunities for exchange and markets inside of the community, which increases the opportunity cost of employing labor and capital on land intensive activities, such as agriculture or cattle ranching.

For *distance to administrative and commercial* (A&C) *centers and technology* arguments have also been made indicating their relationship with land use change can go in both directions (Abramovitz et al., 2008; Angelsen et al., 2001; Ghate et al., 2009; Laurance, 2001). Similarly to population, the sign of the relationship seems to depend on the institutional context under which they take place (Agrawal and Chhatre, 2006; Lambin et al., 2001). Distance and technology have been assumed positively related with land use change due to their potential to increase profits from land intensive activities. However, shorter *distances* can also mean lower costs for authorities to control land use change, as well as larger access to labor markets or livelihood opportunities beyond the land, fostering the diversification of livelihoods and reducing the need to migrate. Access and proximity can also provide more opportunities for people to participate in decision-making bodies and to establish partnerships with governmental and non-governmental actors interested in the protected areas and can free labor and increase profits that can be used to diversify livelihoods.

Technology is argued to reduce land use change, as it would increase the productivity per hectare, requiring less land to produce the same. In contrast others have argued that, households will likely want to increase both their income per hectare and overall output. Given that the production cost per unit drops with the use of technology, more technology could be associated to larger land use change up to the point where marginal costs equal marginal benefits again (Angelsen et al., 2001). It could also be that agriculture revenues using technology allow the investment on activities uncorrelated to agriculture and weather independent, which would add to the opportunity cost of investing labor and capital on extensive agriculture.

Infrastructure can facilitate tourism development and the operation of environmental governmental and non-governmental organizations. The latter often bring resources with potential to reduce the opportunity cost of keeping the land cover through conservation projects. However, infrastructure could also lead to larger land use change by reducing the cost of production and living for land users. Infrastructure was considered in the IAPAs analysis, but not in the Mayan Forest analysis because it was correlated with leaders network.

Benefits from protected areas' natural land cover can be received by households through the provision of environmental goods –e.g. wood, meat, fruits, fibers-, services –freshness, shadow, plagues control, recreation, rain variability regulation-, and cash payments to compensate them for avoided land use change. These are all benefits that create an opportunity cost for households to clear the forest, for example. The benefits derived from the natural land cover in the protected areas need to fulfill several conditions to discourage land use change though. From land cover used for productive purposes (e.g. crops, pastures), households get a range of benefits associated to food, cash, prestige, and the creation jobs for the benefit of the community or family for generations. If products obtained from the natural land cover are not commercial, they are not enough to compensate for cash income. Even if such products have commercial value and market price competitive to those of an alternative land use, it may not be enough to compensate for the loss of prestige associated to activities such as cattle ranching or to motivate people to change their lifestyle (Gibson and Marks, 1995). This is particularly the case in communities of migrants who are not familiar with the ecosystem where they have recently settled and who have supported their livelihood with agricultural activities for generations.

Households also need to receive benefits from the natural land cover at the same time they would receive benefits from alternative land uses. For instance, while the perception of environmental services benefits is common among households, many still perceive them as long-term, especially when compared with the timeframe of other forms of land use. Despite all the factors involved in the households' choice of their optimal land use, it is expected that the larger the benefits from the natural cover, the lower the land use change (Agrawal and Chhatre, 2007). When the natural cover has the potential to generate benefits, it is likely that governmental and non-governmental organizations encourage the creation of groups to work together in the management of the natural resources, fostering households' pooling (Gómez and Méndez, 2007).

Government monitoring of rule compliance in and around protected areas is expected to reduce land use change (Abramovitz et al., 2008). However, if no enforcement follows up the monitoring, it is likely the power of monitoring to deter breaking rules decreases (Gibson et al., 2000).

Land ownership may lead to larger land use change if communities lack collective choice rights. Whereas having the right to access and extract is very important, a number of empirical studies in the literature on common pool resources have found it is not sufficient. Accordingly, to provide incentives to communities to protect natural resources, it is important that communities have collective choice rights, i.e. the right to manage and exclude (Agrawal and Ostrom, 2001; Berkes, 2004; Pinkerton, 1989).

Government role and access to decision making are related to collective choice rights. Households' resentment towards the government and low access to decision making are likely be related to larger land use change. These hypotheses are informed by the extensive literature on common pool resources showing the importance of collective choice rights for the condition of natural resources (Schlager and Ostrom, 1992).

Community land tenure could reduce the costs of collective action to favor the land use the community overall prefers (Berkes, 2004). Community land tenure, such as it occurs at Mexican ejidos or communities holding forest concessions in Guatemala, tends to entail at least informal institutions to regulate community members behavior, in addition to community governance structures to which households are allowed and required to participate in. The level of households' participation at the governance structures, leaders accountability, and the enforceability of the institutions are critical to influence the results meet the communities' objectives (Agarwal, 2001; Chhatre and Agrawal, 2008; Ribot, 2008). Then, the relationship of community land tenure and land use change depends on several factors, being the community's interest in forest conservation one of them.

Communities with *political competition* vis-à-vis communities ruled by elites are expected to offer better opportunities to households to get involved in community politics, increase leaders' accountability, and reduce leaders' ability to keep the funding coming to the community for them selves or only sharing it with privileged groups. The erosion of community leaders power through political competition could also open decision making processes to a wider range of community members, in addition to boost households' opportunities to be part of productive groups, allowing pooling and diversification adaptation strategies. Then larger community political competition is expected to lead to lower land use change.

The inclusion of this variable in the analysis seeks to assess the potential impact of power captured by community elites, which has been found to be a major obstacle decentralization processes have faced to produce positive outcomes for the conservation of natural resource (Ribot, 1999). Decentralization is not part of this research; however, its inclusion is relevant given that the communities associated to protected areas are eligible to receive substantial funds aiming natural resources conservation and specifically to reduce the deforestation rate. The effect that conservation programs have on land use change could be expected to depend on communities' political competition, given that, even if labeled, once the funding is released its use and distribution becomes an internal affair for the community. Those funds are source of power for community leaders; hence the monopolization or distribution of those resources among community members is associated to community politics.

Table 3.2 and 3.3 present summary statistics of the analyzed variables in the Mayan Forest and IAPAs models.

Table 3.2 Summary Statistics for the Variables – The Mayan Forest

Variable	Mean	Std. Dev.	Min	Max
Land use change	2.52	1.38	0	5.36
Proximate Causes				
Livelihood production				
Agriculture	0.76	0.43	0	1
Apiculture	0.14	0.35	0	1
Timber & non timber extraction	0.23	0.42	0	1
Tourism	0.07	0.26	0	1
Adaptation				
Migration	0.34	0.48	0	1
Job	0.55	0.50	0	1
Storage/ cattle	0.18	0.39	0	1
Exchange	0.13	0.34	0	1
Diversification	0.75	0.43	0	1
Pooling	0.29	0.34	0	1
Government disaster aid	0.54	0.50	0	1
Underlying Causes				
Ecological UC				
Soil quality	0.20	0.40	0	1
Climate variability	3.56	0.77	0	5
Social UC				
Socioeconomic				
Population size	621.56	568.64	70	2700
Cash benefits from forest	0.87	1.60	0	5
Technology	0.16	0.37	0	1
Distance to C&A center	51.70	43.63	5	210
Governance-Institutions				
Government role	0.25	0.43	0	1
Access to decision making	0.58	0.49	0	1
Government monitoring	1.56	0.96	0	3
Land ownership	0.71	0.52	0	3.33
Community land tenure	.69	0.46	0	1
Political competition	1.74	1.02	0	3

Table 3.3 Summary Statistics for the Variables – IAPAs

Variable	Mean	Standard deviation	Minimum	Maximum
Average land use change	1.616	1.254	0	5
Proximate Causes				
Adaptation				
Diversification	0.800	0.404	0	1
Pooling	0.479	0.505	0	1
Migration	0.72	0.453	0	1
Storage	0.286	0.456	0	1
Exchange	0.327	0.474	0	1
Underlying Causes				
Social UC				
Socioeconomic				
Income heterogeneity	0.447	0.321	0	1
Market distance	2.143	0.890	1	3
Population density	1.764	0.981	1	3
Physical capital access	3.462	1.650	1	6
Governance-Institutions				
Partnerships	1.210	0.753	0	2.5
Community land tenure	0.554	0.502	0	1
Community democracy	0.353	0.483	0	1

Chapter 4

Model, Results and Discussion

4.1 The Mayan Forest

Following the framework proposed by chapter 3, this section examines how, in the context of the Mayan Forest, households' land use change is influenced by social-ecological interactions and social and ecological factors occurring at two levels: household and community. The data collected are nested with 353 households grouped into 46 communities. Due to the common characteristics between households from the same community, households within communities may have correlated values on the dependent variable, and because of that the independence of observations assumption for standard ordinary least squares (OLS) regression is violated. In this case, a multiple linear regression analysis would produce biased tests of the effects in the model. To address this problem and appropriately model the nested data, this chapter considers a hierarchical linear model (a.k.a. a mixed-effects model) for the dependent variable of interest (land use change), using the independent variables listed in table 1 (each variable is labeled as hh or com to denote its level). Mixed-effects models capture the correlations among households within each community and use nested datasets to shed light about the dependent variable –land use change- at multiple levels (households and communities in this application) (Bauer et al., 2006; Gelman and Hill, 2007; West et al., 2007).

At the household level, these models are useful to answer the chapter's research question, assessing how a range of household and community-level predictors influences households' land use change. At the community level it is possible to assess if the relationship between household-level predictors and land use change is different from community to community, identify what community variables may moderate such variability, and also to assess if the average level of land use change is different between communities. Mixed-effects models do not produce overall R-squared estimates for a given model, but they do make it possible to estimate how much of the land use change variance between households is explained with the household-level independent variables, and how much of the land use change variance between communities is explained with the community level independent variables.

The 46 studied communities are also nested within Calakmul and the Mayan Biosphere Reserves. Variables at a third level are likely to be influential to explain households' land use change, however, those factors could not be assessed in the model because two biosphere reserves are not enough to escalate the model to three levels. Nonetheless, qualitative analysis of the distinctive situations taking place at each reserve can complement the quantitative results of the systematic analysis of household and community factors likely influencing land use change in the Mayan Forest.

Multiple models were tested accounting for all the variables listed in Table 4.1, finding that several variables were consistently not statistically significant and others would lose their relative significance as the model accounted for variables that were consistently significant across models. The omission of those variables had no effects on the significance of the remaining variables and the explanatory power of the model. For that reason, most of them were excluded, such as livelihood production strategies, ecological underlying causes, diversification, and access to decision makers. Proportion of landownership in the community, community land tenure, and population were also not significant but were kept in the model given their foremost theoretical importance. Population and property rights are two of the most extensively studied variables in relation to natural resources conditions and no other variable could capture their influence (Lambin et al., 2001; Ostrom, 1990; Turner, 1997; Varughese and Ostrom, 2001).

Diversification and access to decision making were dropped despite their high importance, as other variables in the model could account for their effect. Storage, savings and job, are statistically significant and contribute to the diversification of households' livelihoods, allowing us to still assess the influence of diversification. Access to decision makers is an important variable to analyze collective choice rights, so is government role, which helps to account for governance and households' involvement in decision making. Evidence of relationship between livelihood production strategies was found, but it vanished once other variables were accounted, thus, in order to minimize the number of degrees of freedom they were dropped.

Table 4.1 displays the estimated coefficients for the independent variables in the mixed-effects model for land use change (natural log transformed)[5], standard errors for the estimated coefficients, and tests of statistical significance (based on t-tests of null hypotheses that the coefficients are equal to 0) for the independent variables. The model

[5] The natural log of land use is a continuous measure, normally distributed around the mean. The transformation was done to normalize the dependent variable.

is robust against changes in model specification, as explained above. Its residuals are normally distributed and no outliers or heteroscedasticity were found (see appendix B)[6].

Table 4.1 Regression model results – The Mayan Forest

Variable	Model		
Proximate Causes	Coefficient	St.Err	Sig
Adaptation (hh)			
Migration	-0.012	0.097	
Job	-0.365	0.123	***
Storage/cattle	0.702	0.109	***
Exchange	-0.441	0.124	***
Pooling	-0.566	0.248	**
Government disaster aid	0.412	0.135	***
Underlying Causes			
Socioeconomic			
Population size (com)	0.000	0.000	
Cash benefits (hh)	-0.080	0.037	**
Technology (hh)	0.203	0.128	
Distance to C&A center (com)	-0.005	0.002	***
Governance-Institutions			
Government role (hh)	0.229	0.106	**
Gov. monitoring (com)	-0.056	0.084	
Landownership (com)	0.003	0.152	
Com land tenure (com)	-0.072	0.211	
Political competition (com)	-0.129	0.077	*
Intercept	3.533	0.309	
Number of hh	287		
Number of com	46		
Prob>chi2	0.000		
Prob>=chibar2	0.000		

Statistical significance at the 0.1 level =*, 0.05 =** & 0.01 =***

The chi2 =0.0000 (based on Wald Chi-square) rejects the null hypothesis that all of the coefficients in the model are equal to 0. The Chibar2=0.0000 rejects the null hypothesis that the variance between communities is equal to 0, suggesting that there is significant variance in land use change values across communities. The community level predictors used in the model explain 32% of that variability. No evidence was found to suggest that the relationship between household-level predictors and land use change is

[6] For hierarchical linear models the available tests to check the regression assumptions are limited to graphical tools, specifically Q-Q plots and residual vs. predicted value plots.

different from community to community. Overall, almost 44% of the variation in land use change occurs across communities and the remaining 56% within communities –i.e. at the household level (see appendix C).

The results showed in table 4.1 can be divided in three major points: First, the statistical significance and coefficients found for the analyzed variables show that it is indeed important to simultaneous assess multiple causal factors, even if the main focus of the analysis is on adaptation. Missing to analyze influential socioeconomic, governance, and institutional factors would have affected the model specification and results, as significant rival explanations would have been dismissed.

Ecological underlying variables were tested and, as mentioned in previous paragraphs, were not found statistically significant. This specific result does not erode the importance of using a social-ecological approach. The fact that the two ecological variables analyzed were not relatively influential does not mean that ecological variables in general are not important explanatory factor. It is likely that the only two ecological variables analyzed in the model are not a representative sample of influential ecological variables. Other studies have found evidence of biophysical factors' influence on land use change. For example, Roy Chowhudry's (2006) study of Calakmul, shows that elevation, upland soil, initial land cover as upland forest, and rain are statistically significant to explain deforestation on households plots. Likewise, Zhu et al. (2010) and Agrawal and Chhatre (2007) found evidence of ecological factors influence on land use change and forest conditions in their case studies in China and India.

Second, the results show that adaptation critically influences land use change. The household level variables fitted in the model explain 19% of the variance in land use change at the household level (see appendix C); 18% of it is associated to adaptation strategies and 1% to cash benefits, technology, and perception of government role combined.

Third, the results indicate that socioeconomic, governance, and institutional factors influence adaptation strategies. Households' adaptations are constrained and supported by prevailing economic and institutional and governance factors (Agrawal, 2008; Eakin and Lemos, 2010; Tucker et al., 2010). The mediation test shows that when accounting for adaptation the *p* values of the social, economic, governance and institutional factors are affected, suggesting that these factors affect land use change through adaptation, as well as directly. Specifically, when accounting for proximate causes in the model, the statistical significance level changed as follows: cash benefits from 0.01 to 0.05, technology from 0.1 to no significance, government role 0.01 to 0.05, and political competition from no significance to 0.1 (this is a case of suppression; see Bauer et al (2006)). Distance to the C&A center maintained significance at the 0.01 level. Population size, government monitoring, land ownership, and community property remained not significant, but their *p* value increased.

All adaptation strategies but migration and diversification were statistically significant. It is likely that diversification was not found significant given that the effect of adding new livelihood production strategies to households' menu was already accounted by the variables storage, exchange and job[7]. Diversification, at least through these three forms of adaptation is highly significant.

[7] The correlation between diversification and job, exchange, and storage is 0.35, 0.17, and 0.24.

Migration's lack of significance came as a surprise given that in both countries it seemed to be a very important factor for the life of the communities. Its lack of statistical significance in this case may perhaps mean that in the context of the Mayan Forest and in relative terms, it is not an important predictor of land use change, once we account for the rest of the variables. This finding could also be associated to the model not accounting for moderation factors[8]. For instance, the relationship between migration and land use change depends on who migrates (labor effect), if remittances follow (capital effect), and if so, how these are invested (de Sherbinin et al., 2008; Liu et al., 1999; Tacoli, 2009). Among the sampled households, 42% had migrated (one or several household members) in response to CVC; of those only 49% received remittances. This is, only 23% of the total number of households surveyed in this analysis received remittances. Those remittances were often used to pay debt, cover basic needs and children education. Sometimes capital from remittances is invested on cattle raising or opening stores, in which case the effect of migration would be mediated through these two alternative adaptation strategies. However, no evidence of strong relationship between migration and cattle or ownership of a store was found. The correlation between cattle and migration was 0.03, cattle and remittances 0.04, store ownership and migration -0.03, and store ownership and remittances -0.08.

The effect of migration on land use change could come from loss of labor. Nonetheless, even assuming that all the families were loosing labor employed in land intensive activities, if only one member migrates per family, it is possible that his share of labor is absorbed by the family members left behind. It could also be that while some

[8] The number of households sampled per community limited the ability of the model to account for moderators.

migrants let the forest to regenerate in their plots, others are clearing more, compensating that way the effect of migration on land use change. Thus, as important as migration seems to be, there are several possibilities to explain why it was not found to be a relatively significant predictor of land use change. The difference between this research findings and some of the studies suggesting a link between migration and land use change (Lopez et al., 2006; Rudel et al., 2005) is likely related to differences in the measurement of land use change. While in those studies land use change includes afforestation, this research measures land use change as the loss of primary forest in exchange to other land uses and it does not consider the transition from crops or pastures to fallows.

The coefficients reported in table 3 are estimates from a model for the natural log of land use change, which requires exponentiating the coefficient to examine multiplicative effects of one-unit changes in the predictors on land use change. For example, exponentiating the estimated coefficient for “job” we get 0.69, which implies that land use change is likely to decrease by 31% for households who get a job to adapt relative to households who do not get a job to adapt, holding other predictors constant. Exponentiating exchange and pooling coefficients the results indicate that if people choose to adapt by exchanging or pooling land use change would decrease by 36% and 43% relative to households who did not choose these adaptation strategies, holding other predictors constant. On the other hand, if households get cattle (store) to adapt or rely on government aid, land use change is likely to increase by 100% and 51% (holding other predictors constant).

Eighty-two percent of the 287 households analyzed by the model derived part of their income from agriculture, 96% of them said they maintain their crops because of tradition, 28% because they did not have other skills to produce their livelihood, and only 30% because of its profitability, even though 49% of them plant commercial crops. Among farmers, 87% of them consider CVC has had an effect on their income and 44% of the farmers have already decided to reduce their agriculture effort due to CVC related losses. These data suggest the cost of opportunity of agriculture in terms of money is low, not so in terms of the value people give to produce their own corn. The drop in rents and even losses the households have been experiencing for the last 5-10 years have provided them further incentives to diversify their incomes with more profitable, less climate dependent, and less uncertain activities, such as off-farm or out- of- their own farm jobs and exchange of non-agricultural goods in stores. These two adaptation options are however substitutes to agriculture to some extent, given that the three of them (agriculture, jobs, exchange) are labor-intensive activities. Then, as people adapt through these alternatives, they pull out their labor and capital resources from low-rent and land intensive activities to relatively higher-rent no land-intensive ones, which can result in a reduction of land use change (Soini, 2005; Wright and Samaniego, 2008).

In the region, it was common to find community groups specialized on honey, sheep, handcrafts, ecotourism, timber and non-timber products, in addition to groups of women raising chickens or working on vegetables and fruit plantations in their yards. Pooling in the region, especially in Calakmul, has grown with the support of governmental and non-governmental organizations supporting and even conditioning the release of funds subject to the organization of several community members to work together in a productive project. Given the institutional framework set by the biosphere reserves, the type of projects that receive funding, for the most part are environmentally friendly. In the case of the Mayan Forest, conservation institutions increase households' opportunities to adapt by pooling, influencing land use change indirectly. The results show that in the Mayan Forest land use change is likely to decrease by 43% when households adapt by joining their resources (labor, land or capital) with other community members to produce their livelihoods relative to when they do not pool their resources.

Government aid is not strictly an adaptation strategy. Those who take it without taking other adaptation strategies choose to rely on government aid, instead of being active, but some may simply rely on it as a safety net to cover losses they may not cover with their alternative adaptation strategies. Finding larger land use change for households relying on government aid suggests a problem of moral hazard (Arrow, 1963). The feeling of certainty of having a backup from the government if the climate does not favor the crops encourages more risk taking by planting more hectares, instead of transferring labor and capital to non climate dependent activities, as could be expected from those that do not count on a safety net from the government. Some people would refer to government aid as "little, but still a big source of relief" given the certainty they had about having at least some if things go wrong for their crops. The effect of aid is similar to what other studies have found about the effects of insurances increasing acreage cultivated or encouraging changes in the crops with adverse effects on soil erosion, increased use of chemicals, and water quality (Capitanio and Adinolfi, 2009; Goodwin et al., 2004; Wu, 1999).

Cattle is considered by 80% of those who own it to be profitable, despite the reduction in utility they have faced due to the low prices of meat in recent years. Yet, cattle rarely substitutes agriculture; in general cattle is adopted as a complementary income (Roy Chowdhury, 2010). Contrary to job or store, cattle is likely to largely increase land use change because it is land intensive and requires less labor than a job or a store leaving time to the ranchers to continue harvesting their plot.[9] Cattle has been widely marked in the literature as a major drive of land use change worldwide (Barona et al., 2010; Herrero et al., 2009; Schulz et al., 2010; Steinfeld et al., 2006; Wyman and Stein, 2010).

The evidence from Calakmul and the Mayan biosphere reserve show that cattle is finding in CVC a further reason to spread, given its perceived higher resilience to drought vis-à-vis crops. Cattle is used as a storage adaptation strategy, providing them a saving mechanism, with high liquidity attributes. Having a mechanism to save for bad years is a need that has been poorly met by the scarce financial resources available for rural communities in the conservation frontiers of Mexico and Guatemala. Households do not live on the edge every year, they have some good years when they produce surplus or market price for their commercial crops is good, the profits from those years have paid for many hectares of pasture in the Mayan Forest.

Cattle ranching is a clear example of how adaptation linked to land use change hurts livelihoods and erodes adaptive capacity by cutting off alternatives available for small landowners and landless. Households in the Mayan Forest have relied on firewood, xate, and bush meat for years, but things are changing as pastures have pushed the forest miles away from communities. As people have fewer goods to cover subsistence needs, cattle ranching has also reduced their job opportunities -once the grass is set one person is enough to take care of 100 hectares or more with one head per hectare. The percentage of

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[9] Cattle ranchers in the Mayan Forest use an average of 20 hectares, ranging from 1 to 160 has per rancher.

cattle ranchers is similar in both countries, approximately 23% of the interviewees; still the concern about loss of alternatives for livelihoods and to cope with changes in climate was strongly felt in Guatemala, but not in Mexico[10]. People in Calakmul complained about the indirect costs of cattle, resulting from the climate change they associate with the loss of forest to employ to cattle ranching, but not about the loss of access to natural resources.

The different degrees of reliance on forest products may partially explain why the concern for loss of opportunities is unequal across Mexico and Guatemala, but there is also an important institutional factor influencing the effects of cattle on livelihoods and adaptation options. In Calakmul, 91% of the interviewees were landowners contrasting with only 64% in the Mayan Reserve. In both biosphere reserves, approximately 60% of the landowners said they had set a forest reserve in their plots, which they will keep untouched to secure their future access to forest products. Landless workers on the other hand, face difficulties. As the forest gets smaller and more distant, it gets harder for the landless to have access to resources, as landowners are less willing to share their scarce forest products. The risk of being caught while harvesting resources illicitly also increases if the forest is small. The households' reserves tend to be left on more distant areas of the plots, making it also difficult for landless workers to have access to resources, even if the owners set no restrictions. Moreover, it is common for landless workers to

[10] Ninety four percent of the interviewees in both countries said to have perceived changes in the precipitation patterns in the last 5-10 years, to which they refer as "climate change". Specifically the change consists of having longer dry season; receiving the first rain after the date they historically received it. They claimed they have not been able to figure out a new pattern as there is not a new fix date for the beginning of the raining season and because some times they experienced a gap between the first rain after months of dry season and the actual rain season.

loose access to the resources once cattle is grazing since access areas get fenced and strict control over crossing is exercised to protect the animals.

This chapter has argued that the influence of adaptation on land use change is direct and significant, yet adaptation is not the main explanation of why some households have larger land use change than others. Adaptation depends on social and ecological factors and mediates the effect of these factors on land use change. Statistically, as pointed out earlier in this section, the model has found evidence to support this argument. In the next paragraphs the chapter delves into the explanation of the relationship between social underlying causes and land use change.

The results found through the statistical analysis indicate that land use change is likely to decrease by 8% when households' cash benefits increase in one unit, holding other predictors constant. Land use change would also decrease when the distance from the community to the administrative and commercial center increases in one unit, however the change is only 0.50%. If community political competition increases, land use change is likely to decrease by 12%. In contrast, land use change would increase when people feel the government must compensate them for stopping forest clearance by 26%.

It comes as no surprise that land use change decreases when cash benefits increase. In the Mayan Forest cash benefits are associated to forest concessions, tourism, or honey production, which are activities developed by community groups (Garcia-Marmolejo et al., 2008; Gómez and Méndez, 2007)[11]. While the development of these

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[11] In Calakmul several communities have reserved some of its land for the establishment of UMAs. These are areas where hunting is allowed by the environmental ministry after having studied the relative

groups has been promoted by governmental and non-governmental organizations to support conservation, people have joined them in good part because of their need of diversifying their income in the mist of CVC impact on their livelihoods. In this case, cash benefits provide enough incentives to adapt by diversifying and pooling, which is an option those without capital to invest in cattle are likely to take. The reduction in land use change when cash benefits increase can also be explained by the awareness among many people in Calakmul about the importance of the conservation of the biosphere reserve and the forest remaining in their plots to keep the attention of governmental agencies and donors for further support of productive projects and community infrastructure.

If the distance to the administrative and commercial center increases, we can expect land use change to decrease, holding other predictors constant. The change is minimal though. This result may be associated to the two directions that distance can have on land use change, as explained in section 3.3 (Abramovitz et al., 2008; Agrawal and Chhatre, 2006; Lambin et al., 2001). On the one hand, distance reduces the cost of commercialization of agricultural products and cattle, but on the other, it also reduces the distance to jobs in the commercial and administrative center. Overall, it seems that the effect of lower commercialization costs increasing agriculture and cattle revenues is dominant, even if only marginal.

Community political competition is likely to reduce land use change by 12%. The effect is related to the opportunities households have to participate in groups and receive

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abundance of specific species. Communities have the right to take hunters, guide them, lodge them and sell wildlife or alternatively the community hunts and sells the animals, for example birds. The revenues derived from the UMAs are distributed among community members, additionally households participating in what they call "tourism groups" can also be benefited with training and wages for their work as tourist guides or cooks.

benefits from conservation efforts carried within the community. Cases of abuse of power from community leaders in both biosphere reserves have eroded collective action efforts to maintain timber and non-timber products managed extraction, and encouraged deforestation. In those cases, interviewees expressed strong resentment, as they perceived elites in their communities were taking advantage of the cash benefits associated to the forest conservation. In the view of interviewees, the cost of conservation was being paid by community members without voice, that is those, who by conserving the forest, have to work on tired and labor intensive soil instead of working on richer and less labor intensive soil available after clearing several hectares of primary forest every two or three years. Hence some of them expressed they clear primary forest every year, even if at small rates, arguing that it was necessary for the support of their families.

Sometimes the resentment was not towards community leaders, but towards government officials. When people considers the government had the obligation to compensate them for not clearing the forest, land use change likely increases by 26%, holding other predictors constant. This positive relationship is consistent with the hypothesis and is supported by the literature on environmental governance and common pool resources (Agrawal and Ostrom, 2001; Schlager and Ostrom, 1992). When the households in the Mayan Forest are forced to stop clearing through regulation, they feel the government is taking away their right to use better soils and to make decisions about how to use the land in the best way to meet their needs; their inability to have a say in the rule making does not surprisingly erodes their incentives to take care of the forest. Loosing access to the resources without getting benefits from it either because community elites capture them or because government officials impose conservation restrictions creates similar effects in terms of incentives to clear the forest against the rules, even if it is only one hectare at the time.

The findings from the model suggest that the effect of technology was fully mediated by adaptation. It lost its 0.1 significance level once we accounted for the adaptation strategies. However, the sign of the coefficient indicate that having access to technology would increase households' land use change. This result is consistent with Angelsen et al. (2001), who argue that households' optimal decision is to produce up to the point where marginal costs and marginal benefits equalize. This decision is not only efficient from the economic theory point of view, but it is a much-needed action. The magnitude of the economic needs households in the Mayan Forest face is so pronounced, that it is likely that even the extra revenues derived from technology use in a larger area, may not be enough to meet them.

Communal property could affect land use change by providing an institutional framework and governance structures that bring together community members, facilitating collective action, pooling, exchange, migration, and diversification. However, no evidence of these effects was found in the analysis. Communal property relative importance to influence land use change is not statistically significant. In the Mayan Biosphere Reserve, communities under communal property regime did have a significantly lower percentage of their land cleared, but the per capita number of hectares cleared in those communities could be larger than for the average private property community, given that the size of communal property communities is large –over 5,000 has for the smallest of them. However, by looking only at private property communities--82% of the sampled communities in Guatemala-- we find that the percentage of community land cleared ranged between 75 to 100%, having other factors besides property regime to explain for that the variation.

In Calakmul the answer may be similar, 90% of the communities are communal property and the percentage of community land cleared in those communities ranged between 12 to 100%. The number of hectares cleared per capita in communal property communities could also be larger than in private property communities. Size of the community could be an important factor to explain the number of hectares per capita in both biosphere reserves; it was considered but not included in the model because it did not show statistical significance and its coefficient was 0. Looking at the Mayan Forest as a whole, we find large variability within communal property and private property communities in terms of the number of hectares cleared per capita. Despite its theoretical relevance, the empirical evidence of the Mayan Forest shows that governance variables, such as the variance in community politics, feelings about government obligation to compensate them, as well as economic factors, especially cash benefits, carry relatively more weight on households' land use change than the property regime.

The relationship between land use change and land ownership shows a positive sign in the results displayed in table 4.1. Having rights over land allow people to do with it whatever they consider the best for themselves, subject to the enforcement of conservation regulations. Given the agricultural vocation and development of cattle ranching in the area, it is not surprising to find more land use change as the number of land owners increases in the communities, holding other predictors constant. What is surprising is to find the relationship not significative. Evidence and theory supporting the importance of property rights to protect natural resources is extensive, ranging from those supporting Hardin's tragedy of the commons (1968) to Ostrom's governing the commons (1990). The explanation for this finding could be associated to the nature of the property rights, institutions and governance within the communities, and the governance structure linking the community with the government. These predictors may carry a larger relative weight in the explanation of land use change also leading landownership to be relatively not statistically significant in the Mayan Forest.

Having property rights in these communities does not grant the holders full operational and collective choice rights. Households have the right to use the resources in their plots for subsistence purposes and the soil for the production of their livelihood through agriculture or cattle ranching (in some cases, not in the core areas of the biosphere reserves). Cutting primary forest or old fallows and commercializing forest resources from their plots is restricted to getting a government permits or do it illegally without permit, but risking a sanction or a bribe, or clearly confronting the authorities. Again, Schlagger and Ostrom (1992) and Agrawal and Ostrom (2001) have argued that holding access and extraction rights (operational rights) is not enough, the condition of natural resources is influenced by the tenure of rights to decide where, how and when to use the resources and to exclude others from using them (management and exclusion rights), which households do not quite have in the Mayan Forest, even if they are landowners.

Despite the regulations households are subject to, collective choice rights can be boosted by governance mechanisms linking the communities to the decision making around natural resources management (Lemos and Agrawal, 2006). Protected area councils bringing together community members, decision makers, non-governmental organizations and donors can aid the process of local participation in decision-making. However an emerging problem of increasing participation is that of the representation of households by their community leaders (Agarwal, 2001; Ribot, 2008). Once we account for horizontal (within community) and vertical (between communities and government) governance finding that households' property rights do not show statistical significance, but political competition and government role do, becomes less surprising.

Finally, differently from most of the literature that remarks on the importance of population and monitoring to explain natural resources conditions and land use change (Rudel and Horowitz, 1993; Sunderlin and Pokam, 2002; Zhu et al., 2010), this research did not find them statistically significant. The result is not that unusual; for instance some authors have found that monitoring without enforcement is not enough (Gibson et al., 2000). Likewise, several scholars have found that the effect of population on land use change and natural resources is mediated by institutions, that its effect is not as significant as once was thought, or that its effect is complex, indirect and hard to measure (Agrawal and Chhatre, 2006; Carr et al., 2005; Lambin et al., 2001).

The model could predict variability in the average level of land use change between communities and 32% of such variability can be explained with the community predictors analyzed. The remaining 68% could be explained in part by a range of variables, such as soil fertility, water availability, the diversity of productive techniques employed by the also diverse immigrants that have come to the region in the last four to five decades, or by the fluctuation in prices affecting the market of chili, cattle, precious woods, chicle and xate, social welfare and agriculture public policies like PROCAMPO and Oportunidades in Mexico (Keys and Roy Chowdhury, 2006; Radel et al., 2010; Roy

Chowdhury and Turner II, 2006; Schmook and Vance, 2009). Likewise, major governance changes have occurred. Particularly important for the case of Calakmul are the establishment and collapse of the Regional Council for Agriculture, Silviculture, Livestock and Services of Xpujil (CRASX); the creation of the Regional Indigenous and Popular Council of Xpujil (CRIPX); the establishment of a municipal government containing the whole biosphere reserve; the on and off non governmental and donor funding; the creation and blossoming of the Municipal Council of Sustainable Rural Development CMDRS; and, the involvement of communities in land use planning (Arreola et al., 2004; Ericson, 2006). For the case of the Mayan Reserve, governance and institutional changes have come together with the establishment of the forest concessions, the change in enforcement methods for natural resources conservation, the creation of councils for specific regions within it, such as the Consult Council of Yaxha National Park or the Multi-sectoral Group for El Mirador-Rio Azul Natural and Cultural Zone, or the development of illegal activities on the west side of the biosphere reserve (Bray et al., 2008; Carr, 2006; Gómez and Méndez, 2007).

For both countries these economic, political, institutional and governance changes have shaped different relationships between communities and government but also between households and forest. The number of hectares households reported to have cleared since they moved in the region has been the result of all these historic changes, for which the model is not accounting and which represents a limitation that should be addressed in subsequent studies integrating metrics for some of the variables and qualitative analysis for those that could not be captured numerically. Nonetheless, the model is powerful enough to support the analytical framework arguing that adaptation is a critical and direct cause of land use change, influenced by underlying economic, institutional and governance factors.

4.2 Internationally Adjoining Protected Areas across the Americas

The quantitative analysis of the IAPAs across the Americas faces an important data challenge due to the strong reliance of the research on the information provided by the protected areas managers. One important limitation of the data is lack of triangulation of the information provided by the interviewees for adaptation strategies with other sources. While further data collection, especially at the community level in these IAPAs will be necessary to enhance the robustness of this analysis, a comparative study of 55 adjoining protected areas has been carried out using a Tobit regression model operationalized aiming to gain some insights about the drivers of land use change. At this stage, the presumption of causality between land use change and adaptation strategies is mostly informed by the findings from the Mayan Forest case study, which with in-depth, disaggregated data produces inferences similar to those produced by the Tobit model.

The selection of a Tobit model was based on the dependent variable lower and upper limits of “0” and “5”. The dependent variable (average land use change) is continuous and symmetric around the mean. Multiple models were tested accounting for the variables listed in the Table 3.1. The maximum number of observations that any of the models could use was 43 due to missing information about any of the variables for 12 of the 55 protected areas that participated in the research. This number of observations constrained the amount of variables that could be used to explain land use change. Nonetheless, the chosen model (“the Model”) includes nine independent variables due to their theoretical relevance and statistical significance. The Model is robust and constitutes the best choice. Tests of alternative models showed that adding variables, such as size or adaptation through pooling or storage, would increase the degrees of freedom, without changing the significance of the nine variables already included, or increasing the R2 of the model. On the other hand, omitting any of the independent variables included in the Model would have reduced its overall significance and overestimated the effect of some of the remaining variables.

Table 4.2 displays the coefficients, standard errors, and statistical significance for each variable. Additionally, Table 4.2 illustrates the robustness of the model through the inclusion of some indicators of the Model fitness, including the pseudo R2 calculated for Tobit models, and R2 calculated on the side using predicted and observed value[12]. The Model residuals are normally distributed and no outliers or hetersokedasticity were found (see appendix B)[13].

The results of the Model show that adaptation, as a proximate cause, could have an effect on land use change around protected areas. Diversification, migration, storage, exchange, and pooling were tested in alternative models, finding only two of them consistently statistically significant. Pooling and storage were uncommon in the studied protected areas and lacked of statistical significance to explain land use change. Exchange was simply not significant, which could be due to the data quality problem.

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12 To learn about the method to estimate R2 from a Tobit model, see http://www.ats.ucla.edu/stat/stata/dae/tobit.htm

13 The tests available for Tobit models are limited and graphic tools were used to test all of the regression assumptions, specifically Q-Q and residual vs. predicted value plots.

Table 4.2 Regression model results – IAPAs

Variable	Model
Proximate Causes	
Adaptation	
Diversification	-1.654(0.458)***
Migration	-0.618(0.354)*
Social Underlying Causes	
Socioeconomic	
Income heterogeneity	1.003(0.411)**
Market distance	-0.708(0.167)***
Population density	0.436 (0.165)**
Physical capital	-0.307(0.106)***
Governance-Institutions	
Community land tenure	0.609(0.307)*
Partnerships	-0.326(0.182)*
Community democracy	-1.359(0.305)***
Intercept	-4.655(0.710)***
No. of observations	43
Pseudo R2	0.2680
R2	0.594
Prob > chi2	0.0000

Diversification has a negative relationship with land use change and it is highly statistically significant. Migration, on the other hand, displays a positive relationship and it is just slightly significant. This finding means that, in general, in the communities influencing the protected areas studied, the diversification would be towards more labor or capital intensive rather than land intensive activities. The positive relationship between migration and land use change could mean migrants send remittances used on land intensive activities that compensate for the labor loss. These results support arguments made by McCusker and Carr (2006) about the potential of diversification to reduce people's reliance on natural resources, but differs from Van der Geest et al.'s (2010) findings of negative correlation between migration and vegetation cover. As Tacoli (2009) and de Sherbinin et al. (2008) have suggested, the environmental impact of migration and adaptation depends on the context within which they are implemented.

The findings for the socioeconomic variables support arguments about the positive influence of population and the negative influence of proximity to the market on land use change. However, the findings for physical capital depart from prevalent views of the relationship, supporting the alternative explanations provided in section 3.3 about the relationship between physical capital and land use change.

The coefficient for community land tenure has a positive sign, which may be related to the type of rights associated with the tenure of land in and around protected areas. Generally, local people are allowed to use the resources for subsistence, but not for commercial purposes. Collective choice rights tend to be shared (when shared) through the use of multi stakeholder councils or partnerships where local leaders participate in defining land use plans, protected area management plans, specific timber or non timber resources management plans, or decide how to allocate funds for productive projects among the communities involved. The findings suggest that the larger the empowerment of communities through partnerships, the lower the rates of land use change.

The negative relationship between land use change and community democracy is consistent arguments advanced by the literature on the commons regarding the importance of considering local institutions to explain land use change. These findings, together with the high statistical significance and positive relationship of income inequality and land use change, could add to the evidence found by Agrawal and Varughese (2000) about the importance of perverse incentives held by community powerful groups. Across the Americas internationally adjoining protected areas, the findings suggest land use change is likely to be larger when inequality and lack of power increase. These results indicate that extraction and access rights without authority could become counterproductive for protected areas.

The negative relationship between partnerships and community democracy (access to decision making at the community and protected area levels) may explain why adaptation through diversification has the potential to reduce land use change. Like in the Mayan Forest case study, participation may increase incentives and opportunities to invest labor and capital in productive activities uncorrelated to land use. Similarly, larger access to infrastructure and technology (larger physical capital) could increase opportunities to lead livelihood diversification beyond land intensive activities when adapting to climate variability and change.

Likewise, if income inequality is associated to land tenure inequality and access to benefits from natural resources, then households' means to diversify their livelihoods and cover the cost of migrating may be associated with income inequality. In such case, larger income inequality would lead to lower diversification, less migration and higher land use change. The consistency in the relationships between land use change, diversification, and access to decision making found across the IAPAs and the case study offers further evidence to argue that land use change is explained by proximate and underlying causes.

Table 4.3 displays the relative contribution of proximate and social underlying causes. These findings, together with those derived from the Mayan Forest analysis, highlight the importance of assessing the likely influence of adaptation on land use change. Even though the data available could only explain the influence of two adaptation strategies, adaptation explains 9% of the variability in land use change across the Americas' IAPAs.

Table 4.3 Effects of Independent Variables on Land Use Change – IAPAs

Variable	Model coefficients	25th Percentile	75th Percentile	Effect on land use change	Mean effect	Combined effect
Proximate Causes						
Adaptation						
Diversification	-1.653	1	1	0.000	-1.653	0.618
Migration	0.618	0	1	0.618	0.309	9%
Social Underlying C						
Socioeconomic						
Income heterogeneity	1.003	0.200	0.600	0.401	0.401	3.610
Market (distance to)	-0.708	1	3	-1.415	-1.415	54%
Population density	0.436	1	3	0.871	0.871	
Physical capital	-0.307	2	5	-0.922	-1.076	
Governance-Inst.						
Partnership	-0.326	0.571	2	-0.465	-0.418	2.433
Community land tenure	0.609	0	1	0.609	0.304	37%
Community democracy	-1.359	0	1	-1.359	-0.680	

Chapter 5

Conclusions

The examination of the drivers of land use change developed in the dissertation shows that adaptation to climate variability and change plays an important role in land use changes in the Mayan Forest Massif. Adaptation is leading land use change in both directions. When households choose diversification, exchange, or pooling adaptation strategies, land use change would decrease relative to households who do not choose these adaptation strategies. Alternatively, when households prefer government aid or storage-related adaptation strategies, land use change would increase.

Socioeconomic factors, governance, and institutions, including economic benefits, distance to markets and administrative centers, and political competition within the communities, are also important drivers of land use change in the Mayan Forest. These factors influence land use change directly, as well as indirectly by defining bundles of alternatives from which households choose their adaptation strategies.

Larger distances between communities and administrative centers and markets are associated with less land use change. The literature argues that shorter distances increase deforestation due to the increase in agricultural trade. However, in this case, the direct negative effect of distance is only marginal. In the Mayan Forest shorter distances to commercial and administrative centers get households close to goods and labor markets, alike. Then, the low direct effect of distance can be explained by the diversification of economic activities that becomes available to households.

Cash benefits in the region are associated to lower land use change. Donors and governments have invested significant resources in the Mayan Forest with the objective of conservation of the two biosphere reserves. Over the years this funding has changed the perception of households about conservation, especially of those who have received cash benefits from conservation projects, in addition to the commercialization of forest products. In both biosphere reserves, but more in the case of Calakmul, it is common to find households recognizing the importance of the biosphere reserve for the communities. Households acknowledge that the attention they receive from donors and governments that has helped them to improve their life conditions with infrastructure, and social and environmental programs is due to the conservation interest of these organizations. The funding for conservation projects has also been critical for the development of community organizations. Even though, households have possibilities to receive cash benefits individually, for the most part, community members who pool their human and financial resources to work together in a conservation-oriented project are favored by environmental donors.

Political competition within communities tend to reduce leaders' ability to keep community resources for themselves and other privileged groups and to offer better opportunities to households to get involved in productive projects coming to the community. Political competition opens possibilities for pooling and diversification adaptation strategies.

Households' perception of the role of government in relation the implementation of conservation rules varies. The perception tends to be associated with the level of access the household and the community has had to decision making processes or participated in the distribution of resources coming from conservation organizations or for conservation projects. Those who have been excluded or remained marginal to decision-making are also more resentful, tend to demand compensation, and to clear small portions of the forest every year.

In addition to the statistical findings supporting the results just summarized, in depth knowledge obtained while in the field provide evidence to argue that institutions and governance can explain why households choose different adaptation alternatives and therefore why deforestation varies across households and across communities. For instance, lack of access to financial capital encourages households to seek savings alternatives, such as cattle, which has had a large effect on households' deforestation levels.

The rules for conservation associated to the biosphere reserves constrain the scope of the projects that can be funded. Whereas there is some funding for cattle due to political revenues, for the most part, the funding is directed to environmental projects, specifically targeted to reduce land use change. This funding is also mostly targeted for the most for community groups, which facilitates pooling adaptation strategies, in addition to encouraging diversification. Many of these projects seek to provide alternative livelihoods that could encourage people to reduce their agricultural effort or to use organic fertilizers that could also reduce the need to clear new land when the soil gets tired.

Community institutions may be linked to exchange. The local stores mostly sell on credit. Therefore, having rules to enforce payment is critical for them to be sustainable. The merchant can always choose to whom to extend credit, but having norms to minimize the chances of losses reduces risks and increases the market size.

The results from the analysis of data for protected areas across the Americas are consistent with those for the Mayan Forest. Diversification, distance, political competition, and access to decision making are also associated to lower land use change. Although broad generalizations are difficult, these results provide some insights into how relationships between land use change and adaptation strategies might unfold at a larger scale in the context of protected areas.

Adaptation is not only a driving factor of environmental change. Adaptation can offer the opportunity to conserve natural resources in biologically diverse regions, which provide livelihoods to vulnerable populations and environmental services with local and global benefits. In the context of transboundary protected areas, the conservation of natural resources through adaptation could not only maintain natural resources to support households' adaptive capacity to future climate change, but also to buffer the effects of climate change on endangered flora and wildlife.

Alternatively, adaptation can also be a significant driver of environmental change through land use change. Adaptation strategies that manage environmental risks in the short run at the expense of forest cover can fire back through its effects on biodiversity loss, soil degradation, and alterations in biochemical cycles. The consequences of letting adaptation to develop without anticipating its possible consequences can be also a major factor reinforcing climate change, the mere process that unleashes the need to adapt.

Furthermore, failing to prevent the development of adaptation strategies associated to forest loss or to encourage strategies with lower rates of land use change can be a factor eroding adaptive capacity of rural communities dependent on natural resources for their livelihoods. The case of Guatemala's Mayan Biosphere Reserve where households face natural resources scarcity and challenges to produce their livelihoods and adapt due to the extensive land use change associated to cattle offers evidence of the likely effects of adaptation based on deforestation. Cattle raising is a complex process that has developed in the region for several reasons, in addition to adaptation. Nonetheless, it is a very important adaptation strategy and is contributing to the deforestation in the region.

Specifically in this context, for Mexico and Guatemala, it is highly important to learn how, through households' adaptation, climate variability and change is affecting the largest remaining forest massifs in these countries. Knowledge about the likely relationship between land use change and adaptation can help to design government led adaptation strategies with lower land use change implications and also to prevent that agriculture or social welfare policies inadvertently erode households' adaptive capacity by encouraging households' investment in cattle or reliance on government aid.

In summary, the dissertation provides evidence about the importance of adding to the adaptation and land use change research agendas the study of the feedbacks between adaptation and natural resources by systematically analyzing the environmental impacts of households' adaptation. In addition to providing evidence of the relationship between adaptation and land use change, the dissertation findings also permit to suggest that working towards increasing households' access to economic benefits from the forest, and their inclusion in decision-making process can increase the likelihood of adaptation strategies capable of helping households to manage risk, while also helping to reduce forest loss. This way, within the context of adaptation to climate variability and change, the dissertation provides further evidence to support the argument advanced by the common pool resources and environmental governance scholarship about the importance of communities' participation in natural resources management.

Appendices

Appendix A: List of Internationally Adjoining Protected Areas

TBPA	IAPA	Country
North	***America***	
1	Wrangell-St Elias	US
	Glacier Bay	US
	Kluane	Canada
2	Waterton Lakes	Canada
	Glacier	US
3	Superior	US
	Voyageurs	US
	Quetico	Canada
4	Cabeza Prieta	US
	Organ Pipe	EU
	El Pinacate	Mexico
5	Coronado National Forest	US
	Coronado National Memorial	US
	Sierra de Ajos	Mexico
6	Big Bend	US
	Cañón de Santa Elena	Mexico
	Maderas del Carmen	Mexico

TBPA	IAPA	Country
Central	***America***	
7	Calakmul	Mexico
	Mayan	Guatemala
	Rio Bravo	Belize
	Aguas Turbias	Belize
8	Montañas Mayas	Guatemala
	Maya Mountains	Belize
9	APs Sierra del Lacandón	Mexico
	Sierra del Lacandón	Guatemala
10	Volcán Tacaná	Mexico
	Volcán Tacaná	Guatemala
11	Montecristo	El Salvador
South	***America***	
15	Tama	Colombia
	Tama	Venezuela
16	Catatumbo Bari	Colombia
	Perija	Venezuela
17	La Paya	Colombia
	Cuyabeño	Ecuador
	Gueppi	Peru
18	Bahuahua Sonene	Peru
	Apolobamba	Bolivia
	Madidi	Bolivia
19	Kaa-iya del Gran Chaco	Bolivia
	Mudanos del Chaco	Paraguay
20	Tariquia	Bolivia
	Baritú	Argentina
21	Torres del Paine	Chile
22	Nahuel Huapi	Argentina
23	Alerces	Argentina
24	Villa Rica	Chile
25	Nuble	Chile
	Copahue-Caviahue	Argentina

List elaborated by the author through primary research and reviewing the list elaborated by Lysenko et al. (2007).

Appendix B: Diagnostics for Models

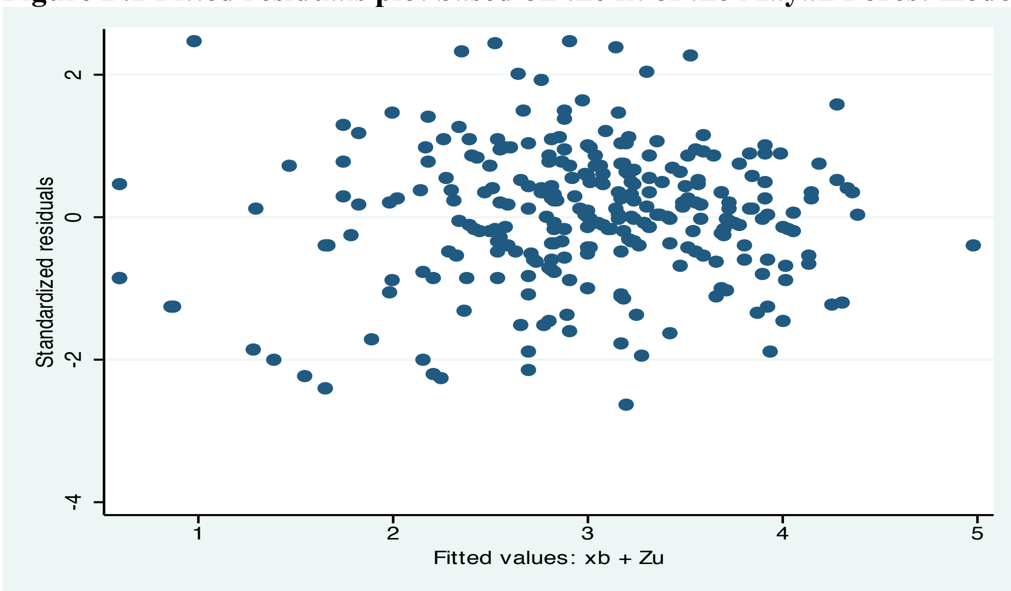
This appendix presents diagnostics for the models fitted for the Mayan Forest and the IAPAs analyses. Due to the unavailability of formal tests to check regression assumptions for mixed-effects models as well as for Tobit models, the dissertation used informal graphical procedures available in Stata 11 (software used for the dissertation statistical analysis (West et al., 2007).

B.1 The Mayan Forest

Residuals diagnostics

The assessment of whether the *variance of the residuals is constant* in the Mayan Forest model can be done graphically using a plot of the conditional residuals vs. the conditional predicted values. After fitting the model, the fitted residuals scatterplot shown in figure B.1 was generated plotting a variable named ST_RESID (standardized residuals) and the variable PREDVALS (conditional predicted land use change values). Figure B.1 suggests constant variance in the residuals as a function of the predicted values, discarding the possibility of heteroscedasticity in the model.

Figure B.1 Fitted residuals plot based on the fit of the Mayan Forest model



The assumption of *normality* for the conditional residuals was checked generating a normal Q-Q plot of the standardized residuals. Figure B.2 suggests that the distribution of the conditional residuals is normal.

Figure B.2 Normal Q-Q plot of the standardized residuals of the Mayan F. Model

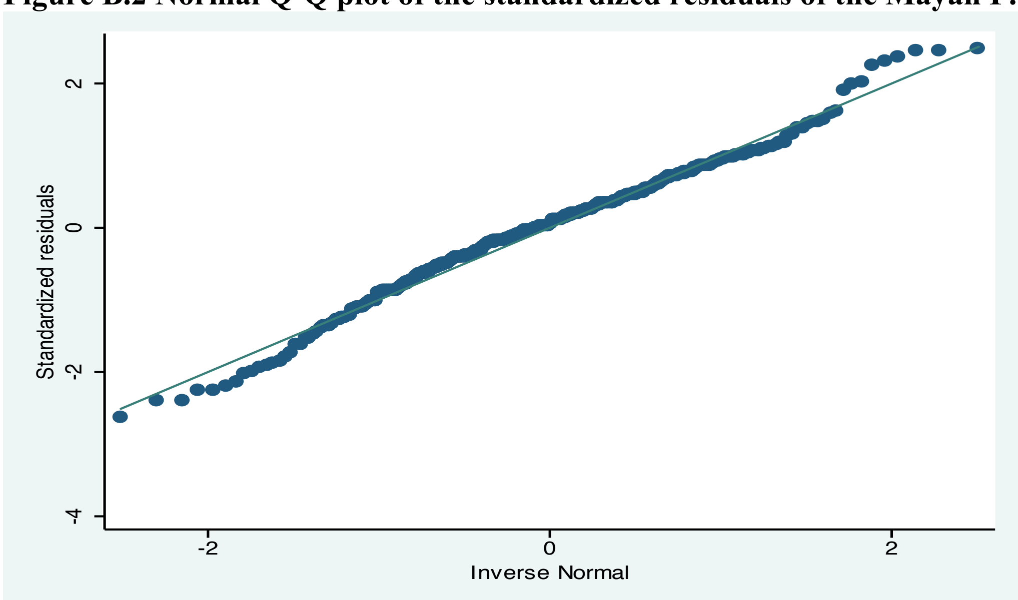


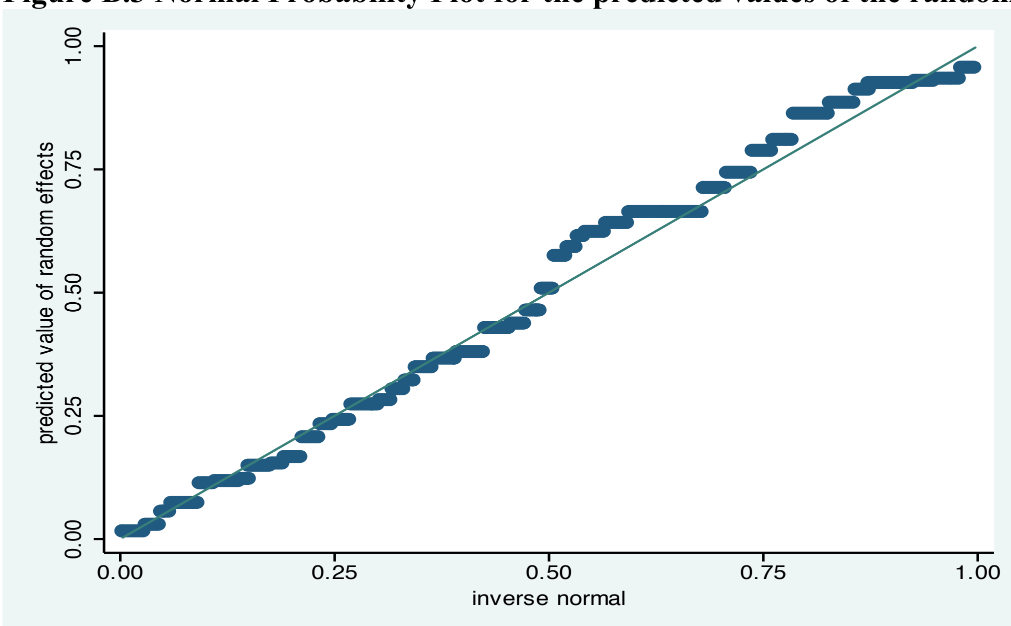
Figure B.1 and B.2 also allow to observe that there are no outliers in the data.

Diagnostics for the Random Effects

The Model found evidence of random effects for the intercept, meaning that there is significant variance between communities in terms of land use change values. No evidence was found to suggest that the relationship between household-level predictors and land use change is different from community to community, which would indicate random effects for the slopes.

The distribution of the predicted values for the model random effects was checked using a normal probability plot showed in figure B.3. The figure suggests that the model random effects are normally distributed.

Figure B.3 Normal Probability Plot for the predicted values of the random effects



B.2 IAPAs

Residuals diagnostics

Following similar procedures to those used for the Mayan Forest the variance of the residuals was tested using a plot of the residuals versus the predicted values. Figure B.4 suggests constant variance in the residuals as a function of the predicted values, discarding the possibility of heteroscedasticity in the model. Figure B.5 shows a normal Q-Q plot of residuals and suggests that the model residuals are normally distributed. In both figures it is also possible to observe that there are no outlier points in the data.

Figure B.4 Residuals plot based on the fit of the IAPAs model

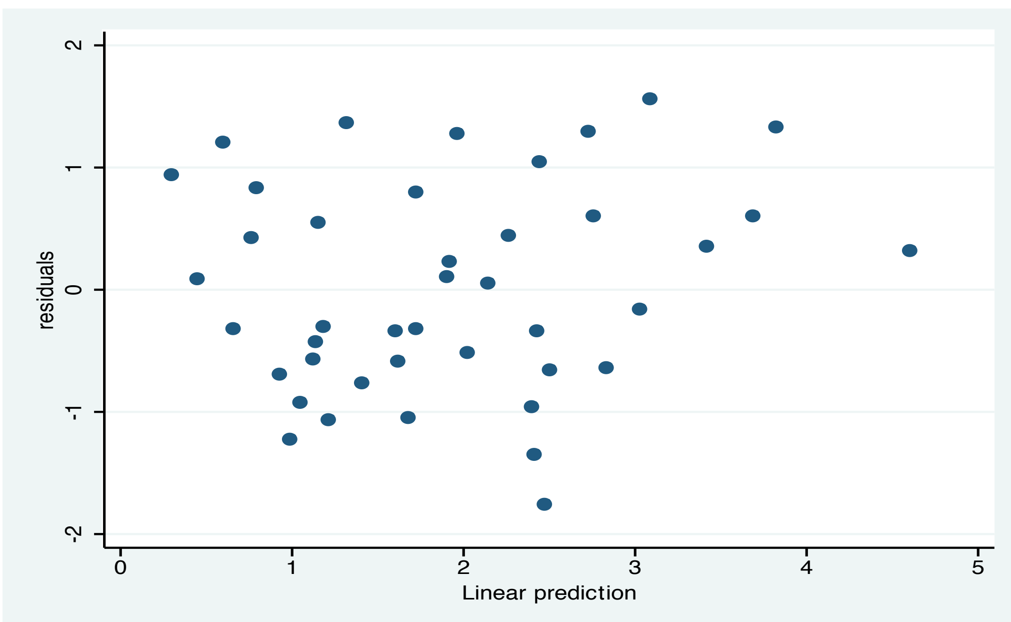
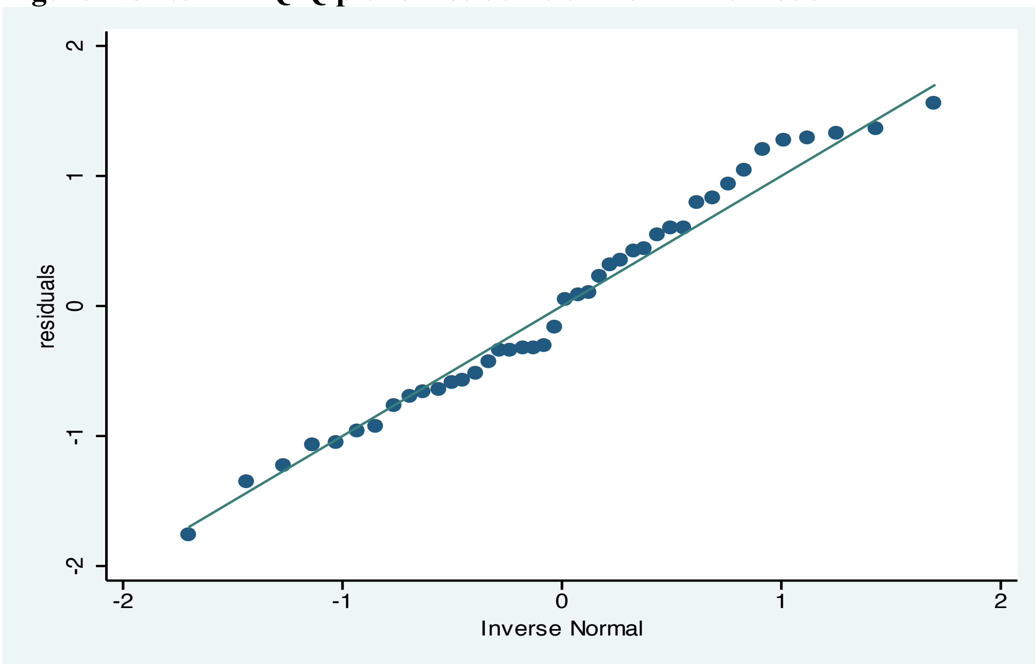


Figure B.5 Normal Q-Q plot of residuals of the IAPAs model



Appendix C: Mayan Forest Household and Community Level Predictors Explanatory Power

Household predictors contribution to explain household land use change

The contribution of household level predictors to explain land use change at the household level can be assessed by estimating the change in the residuals variance when we account only for household level predictors vis-à-vis a model that does not account for any household or community level predictors (i.e. an empty model). Equation 1 shows the algorithm used to estimate that the analyzed household level predictors contribute to explain 19% of household level land use change.

Equation 1:

(Empty model Var (Residual) – Household level model Var (Residual)) / Empty model Var (Residual) = % of household land use change explained by household level predictors

= (0.5878059 - 0.4769117)/ 0.5878059 = 0.19

Community level predictors contribution to explain land use change variability across communities

The results displayed in table 4.1 indicate the model Chibar2=0.0000, which rejects the null hypothesis that the between-community variance is equal to 0 and suggests that there is significant variance between communities in terms of land use change values. This indicates that the model found evidence of random effects, particularly random intercepts. The contribution of community level predictors to explain the variability in land use change across communities can be estimated comparing the intercept random effect variance obtained in 1) a model without community level predictors and 2) the final model fitted for the Mayan Forest analysis including community predictors. See equation 2.

Equation 2:

(Household level model Var (_cons) - Mayan Forest Model Var (_cons)) / Household level model Var (_cons) = % of land use change variance across communities explained by community level predictors

(0 .230963 - 0.1571528)/ 0.230963 = 0.32

Data variation across communities and within communities

The variability in land use change in the Mayan Forest occurs at the two levels of analysis. Figure C.1 indicates that almost 44% of the variation in land use change is across communities and the remaining 56% within communities, i.e. at the household level.

Figure C.1 Data variation across communities and within communities

One-way Analysis of Variance for luch:

Number of obs = 287
R-squared = 0.5218

Source	SS	df	MS	F	Prob > F
Between com	154.77563	45	3.4394584	5.84	0.0000
Within com	141.83242	241	.58851627		
Total	296.60805	286	1.0370911		

Intraclass correlation	Asy. S.E.	[95% Conf.	Interval]
0.43791	0.07110	0.29856	0.57726

Estimated SD of com effect	.6771228
Estimated SD within com	.7671481
Est. reliability of a com mean (evaluated at n=6.22)	0.82889

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