Improving Forest Conservation in Frontier Environments: A Global Review and Case Studies from the Peruvian Amazon

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Abstract

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The global conservation of intact forest ecosystems has been recognized as an important goal due to the many benefits they provide to people and biodiversity conservation. Despite their importance however, intact forest ecosystems continue to be cut and degraded globally at an unsustainable level. To improve the policies and strategies applied to conserve intact forest ecosystems, this dissertation seeks to improve our understanding of the design and selection of forest conservation policies in frontier environments. Frontier environments were selected as the focus of this dissertation due to their importance in buffering intact forests from human influences and because they are a frequent site of expanding

deforestation hotspots. To better understand the dynamics of frontier environments and what forest conservation policies and strategies are likely to be effective, three case studies are presented. The first study presented is a meta-analysis of 81 case studies of deforestation in frontier environments. The results of the study highlight the importance of national politics, institutions, and international markets as important drivers and solutions to frontier deforestation. The second study is a regional-scale analysis focused on understanding deforestation and conservation policy dynamics on the frontier of Madre de Dios, Peru. The results of this study show the primary driver of frontier expansion changed from agriculture to gold mining during the study period and that the region's protected areas network had varying levels of effectiveness due primarily to the gold rush and government authorizations of gold mining concessions inside designated conservation areas. The third study presented analyzes conservation opportunities and challenges in a proposed biological corridor in Madre de Dios. The results of this study highlight the importance of fitting conservation policies to local land-user preferences and circumstances, as well as accounting for the variable preferences and circumstances of local land-users, the high opportunity costs facing selected land-users (especially gold miners), and uncertainties regarding future socio-economic conditions. Collectively, these studies describe the multitude of challenges and opportunities for successful conservation efforts in frontier environments and provide a foundation from which to establish principles for the design and selection of high-impact forest conservation policies for the frontier.

DEDICATION

To all who have fought for a better world, especially one with wild forests and animals

ACKNOWLEDGEMENTS

In addition to the co-authors listed in each chapter, many people and institutions have spent their time and effort in helping to make this dissertation a reality. I am deeply grateful to all of them.

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LIST OF ABBREVIATIONS:

- Global Positioning System (GPS)
- Geographic Information System (GIS)
- Hectare (ha)
- Land-Use and Land-Cover Change (LULC)
- National Aeronautics and Space Administration (NASA)
- Madre de Dios, Peru (MdD)
- Manu-Tambopata Biological Corridor (MAT)
- Payments for Ecosystem Services (PES)
- Reducing Emissions from Deforestation and Forest Degradation (REDD+)
- Return-on-Investment (ROI)
- Root Mean Square Error (RMS)
- Landsat Enhanced Thematic Mapper Plus (ETM+)
- Landsat Thematic Mapper (TM)
- United States Dollar (USD)

KEY WORDS

Frontier, forest conservation, Madre de Dios, Peru, additionality, policy design, leverage point, land conflict, remote sensing, matching, forest governance, REDD+

INTRODUCTION

The Beginning

The story of people and forests extends back to our inception as a species and continues today through thousands of unique yet interconnected narratives. Modern day stories of humans deep relationship with forests manifest in many ways, including human triumphs of establishing national protected areas networks that include millions of hectares of ancient forests (USDA 2010) and other triumphs that include creating clear-cuts so large they can be viewed from space without aid (Crosscurrents 2012). The written history of humans' relationships with forests extends back more than 2000 years and includes what is considered the first known work of literature, the Epic of Gilgamesh (Dalley 2009). As the world's first known story, the Epic of Gilgamesh is also the first know story of people and forests. Interestingly, the poem's narrative describing an epic battle for the fate of the great cedar forests of Lebanon between the forest guardian, Humbaba, and the hero King Gligamesh was just the first story highlighting what has become the standard human-forest narrative. A narrative that includes both love and conflict due to the inherent trade-offs that exist between human benefits from standing forests and human benefits from logged forests, and the relative value different people and cultures place on each.

Today, the narrative of people and forests continues its long tradition with countless examples of forests providing people with multitudes of benefits, and meanwhile the extent and health of the earth's remaining 1/5 of ancient and intact forests continues its historic decline (Bryant 1997; Popatov et al. 2008). Forest destruction today is centered in the tropics, but it is by no means limited to this region of the world as intact forests continue to be logged around the world (Bradshaw et al. 2009; Hansen et al. 2010; Hansen et al. 2013). However, at the same time a strong crosscurrent of human efforts to conserve and protect intact forests is also ongoing throughout the world.

Forest conservation organized by governments has existed for hundreds of years through forests reserves established for royalty and military use and forest conservation has been practiced in various indigenous cultures for thousands of years (Vogt et al. 2007). Today the tradition of forest conservation has expanded to include national protected areas networks, diverse forms of collaborative forest management, and a broad network of supporting actors that includes indigenous communities, scientists, policymakers, and various elements and organizations from civil society (Vogt et al. 2007; Agrawal et al. 2008; Vogt et al. 2013). The efforts of these groups and individuals have lead to many great successes in conserving high value forests and balancing human needs with ecological realities, but at the same time the loss of ancient intact forests continues at an unsustainable level (Bryant 1997; Popatov et al. 2008). The roots for continued modern-day forest destruction are many, but as this dissertation shows most certainly include insufficient political will, poor economic incentives, and incomplete science, particularly forest conservation science.

Forest conservation is not a formal scientific discipline yet this dissertation demonstrates the need for the expansion of forest conservation science efforts and the number of participants who practice it. While scientists and conservation practitioners have done much in recent decades to improve the theory, tools, and technologies used in conservation science (Vogt et al. 2013), much remains to be done in learning how to sustainably manage forests, particularly in developing the science needed to support, design, and select effective forest management and conservation policies (Pullin and Knight 2001; Schulte et al. 2006; Lindenmayer and Laurance 2012). To contribute to the growth of conservation and forest science, specifically the conservation of intact forests, this dissertation undertakes as its central objective the development of a greater understanding of forest conservation and land-cover dynamics in frontier environments to improve the design, selection, and implementation of forest conservation policies and strategies in frontier environments. Frontier environments have been selected as the focus of this dissertation due to their importance as frequent sites of deforestation hotspots as well as their inherent buffering effect on most of earth's remaining intact forests (Scullion et al. forthcoming). To achieve the objectives of this dissertation in improving forest conservation in frontier environments, three case studies of forest conservation are provided and analyzed. Each case presented is nested at one of three institutional scales, specifically: Global, Regional, and Local. Likewise, each study is place-based and focused on the research question of "getting the policy right" for forest conservation efforts in frontier environments.

Case Study Descriptions and Methods:

1. The first case study presented, "***A Review and Meta-Analysis of Deforestation and Forest Conservation in Frontier Environments***," is nested at the global institutional level and asks the question:

   "*Can a meta-analysis of case studies of forest conversion on the frontier yield novel insights into how to improve forest conservation practices in frontier environments*?"

   To answer this research question, the study design includes the development of a database of variables extracted from 81 published case studies of forest conversion in frontier environments.

2. The second study presented, "***The Influence of Land-Cover Change and Conflicting Land-Use Authorizations on Forest Conservation Outcomes in Madre de Dios, Peru***," introduces a case study at the regional scale that is focused on exploring the question:

   > "*Can the efficacy of local forest conservation efforts can be improved through the place-based study of conservation policies and land-use and land-cover change dynamics?*"

   This question is examined through a detailed analysis of the influence of land-cover dynamics on designated conservation areas and includes the methods of: (1) Image Classification, (2) Land-Cover Change Analysis, and (3) Statistical Matching.

3. The third and final case presented, "***Identifying Leverage Points to Improve Forest Conservation Outcomes***" provides a case study focused on the local institutional scale to ask the question:

   > "*Can field interviews of local land-users in the proposed Manu-Tambopata biological corridor be used with precision to identify leverage points, or high-impact forest conservation strategies and policies*?"

   This study question is explored through field surveys of a 120 subsidence and commercial farmers living in the proposed MAT corridor and 199 artisanal gold miners working in Madre de Dios.

CHAPTER 1

Intact Forest Conservation in Frontier Environments: A Review

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KEYWORDS:

Frontier, meta-analysis, conservation instruments, policy design, governance, forest conservation

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ABSTRACT:

The global conservation of intact forest ecosystems has been recognized as an important goal due to the many benefits they provide to people and biodiversity conservation. Despite their importance however, intact forest ecosystems continue to be cut and degraded globally at an unsustainable level. To improve the conservation policies and strategies applied to conserve intact forest ecosystems, this review and meta-analysis explores what is known about forest conservation and land-cover dynamics in frontier environments. Frontiers were selected as the focus of this study due to their importance in buffering and influencing the conservation and vulnerability of intact forests. The central finding of this study is that the conversion of forests in frontier environments is often the result of diverse yet frequently consistent sets of social and economic conditions, particularly the indirect drivers of economics, politics, and population related pressures. Importantly, it was

found that indirect deforestation drivers were consistently concentrated at the national level, indicating the importance national politics and social conditions for frontier expansion and effective forest conservation efforts. Another important insight provided is the identification of institutional failure as the most important failure leading to deforestation in frontier environments. This finding implies that institutional development and support of government agencies charged with forest management may be an important leverage point to advance intact forest conservation. Additionally, the most frequently cited conservation strategy to conserve forests in frontier conditions was protection and management. Again, this finding highlights the importance of protected areas management and resource management agencies in forest conservation outcomes. Taken together, the findings of the meta-analysis and review show that frontier regions are complex, dynamic, and exhibit some elements of consistency in their social and environmental conditions that may provide opportunities to design and select policy instruments and strategies to improve forest sustainability goals, including an emphasis on policies targeted at national-level politics and supporting forest managers and agencies.

Introduction

Frontier environments buffer most of earth's intact forest ecosystems, which makes them a priority to achieve global biodiversity targets and reduce deforestation rates. Also, as frontier environments, also known by other names, such as "forest frontiers," "agricultural frontiers," and "resource frontiers," are inherently situated at the zone of convergence between human and natural systems (Lower 1936; Armstrong 1991), they are frequently the site of expanding deforestation fronts (Meyers 1993; Barbier 2012). As such, the conditions and incentives present in frontier landscapes are an important determinant of the conservation status of nearby intact forests ecosystems, hereafter referred to "intact forests." To improve forest conservation strategies and policies for forest frontiers and adjacent intact forests, this review examines the dynamics of frontier land-use and land-cover change (LULC) and forest conservation policies through a meta-analysis and literature review.

It is important that the loss of intact forests is limited because they contribute to the conservation of biodiversity by providing core habitat for species with extensive home ranges (Kinnaird et al. 2003; Thornton et al. 2011), for species associated with or dependent on mature forests (Jong et al. 2005; Barlow et al. 2007), and for species sensitive to forest disturbances (Laurance et al. 2011; Martensen et al. 2012). Likewise, intact forests, referred to as "frontier forests" by provide a range of human benefits at multiple spatial scales (MEA 2005), including the provision of essential natural resources for millions of forest-dependent people, particularly the poor and forest-dwelling indigenous groups (Sponsel 1996; MEA 2005). Intact forests also play a critical role in the global carbon cycle through avoided deforestation and the maintenance of terrestrial carbon stocks (Van der Werf et al. 2009

Despite the multitude of benefits provided by intact forests, they are still being converted to other uses at a rapid rate (Potapov et al. 2008; FAO 2012). Intact forest loss in the 21st century can be approximated by many measures, including the net loss of 40 million hectares of primary forests worldwide for the years 2000-2010 (FAO 2010). In the tropics, where intact forest loss is globally the highest and driven largely by agriculture expansion (Geist and Lambin 2002; Defries 2010), the net loss of forests in the 1990's averaged 4.9 to 5.7 million ha annually (Mayaux 2005), and from 2001-2005 it averaged 5.4 million ha annually, which for 2001-2005 was equivalent to a 2.4% loss in the global area of humid tropical forest (Hansen et al. 2008). The concentration of tropical deforestation is in Latin America, primarily in Brazil, and the remainder is scattered across deforestation hotspots in Africa and Asia (Hansen et al. 2008; Hansen et al. 2013). Likewise, deforestation frontiers are concentrated in tropical regions, particularly in the Amazon Basin and Southeast Asia (Lepers et al. 2005; FAO 2010; Gibbs et al. 2010). The loss of intact forests continues also continues however in the boreal and temperate regions through hotspots of frontier expansion caused by timber extraction, new industrial facilities, and other land-use changes (Bradshaw et al. 2009; Hansen et al. 2010; Hansen et al. 2013).

Importantly, intact forests are becoming regionally rare, or in many cases lost altogether, with only about 1/5 of the earth's original forests remaining in a natural and intact state (Bryant et al. 1997). Of the intact forests that remain, an estimated 40% are threatened by human activities (Bryant et al. 1997). Perhaps the largest threat to intact forests comes from the cultivation potential of many tropical forests and the demand for food production, which is projected to require a 70% increase in global food production by 2050 (FAO 2009; Keleman et al. 2010; Phalan et al 2013). To meet this need for food, a projected 300 million ha of currently undeveloped land will be put into agricultural production (Lobell et al. 2013). Most of this new agricultural land is likely to come from existing undeveloped lands capable of supporting rainfed cultivation, with 2/3 currently covered with forests and wetlands (Fisher and Heilig 1997). Along with agricultural expansion, the construction of new road networks and industrial facilities into frontier regions also poses a major threat (Killeen 2007; Laurance et al. 2009; Laurance et al. 2014). Collectively continued human development in frontier regions threatens to expand frontier regions and decrease the extent of intact forests. This frontier forest expansion is expected to continue primarily in developing regions across Latin America, Africa, and Asia (Barbier 2005). Projected intact forest loss is not limited to the tropics however; as intact forests are expected to continue being converted in a variety of developed countries, e.g., the United States (Theobold et al. 2011) and Russia (Smirnov et al. 2013).

In summary, intact forests are important for humans and biodiversity but they are threatened around the world as development frontiers expand. To enhance the foundation upon which intact forest conservation is practiced in frontier environments, this literature review and meta-analysis of 81 case studies of LULC and conservation policy dynamics seek to examine the following topics: (1) How can the study of the patterns and features of LULC in the frontier context inform the design and selection of forest conservation policies and strategies?; and (2) What are the causes and solutions for deforestation in frontier environments reported by the scientific community? To analyze contemporary case studies describing forest conservation dynamics in frontier environments, we sought case studies describing processes of deforestation in a frontier context. The hypothesis guiding this research approach is that the authors of each case study would likely provide case-specific information (intentionally or unintentionally) that, if synthesized, could be used to detail the causes of deforestation and inform forest conservation efforts in frontier environments.

Methods

Meta-analyses of case studies have been used for decades to provide systematic reviews of scientific knowledge (Khan 2012) and have also been used previously to understand how environmental and social systems change and can be influenced, such as case-based analyses of the drivers of tropical deforestation (e.g. Rudel 2007; Rudel 2008; Geist & Lambin 2002). Like all research methods, the meta-analysis case study framework has both strengths and limitations (Rudel 2008). The strength of the meta-analysis approach in informing policy development is that syntheses of local case studies can provide new insights (Rudel 2008). However, drawing inferences from a variety of different cases can also present methodological challenges, including potential issues with inter-coder variability of case studies (Rudel 2005), variables no longer being reported because they have "gone out of fashion" (Rudel et al. 2007), and the potential bias introduced if cases are focused primarily on popular issues or regions of interest (Rudel 2008).

To overcome the methodological challenges of case study-based meta-analysis and develop a comprehensive set of case studies of forest conservation dynamics in frontier environments, we undertook a multistep case selection and review process. To identify potential cases, articles were found with Google Scholar and ISI Web of Science using keyword searches of the following keywords: "Agricultural Frontier," "Agro-Industrial Frontier," "Transitional Landscapes," "Forest Frontier," "Intact Forest," and "Deforestation." The bibliographies of all the case studies were then further reviewed to search for any additional cases that might have been missed during the initial search. The Google search engine was also used to identify other non-refereed case studies written as reports for NGOs or published in books. Once all possible cases were identified, cases were filtered using an additional set of criteria to ensure they described the conversion of forests in a frontier environment. To meet the additional criteria, each case had to be published within the last 25 years and include phrases indicating the presence of intact forests and deforestation, such as, "old growth forests + deforestation," or "frontier forest," "primary forest," "native forest", and "wilderness area."

Using those selection criteria, 81 cases were identified for this study (See Appendix 1 for a complete list of cases included). To evaluate patterns and synthesize insights from the selected cases, variables of interest were extracted and coded from each case study using a framework from the published literature, as well as those developed explicitly for this study (Table 1). Extracted variables represented a host of hypothesized factors of importance in understanding LULC and forest conservation in frontier environments, including the stage of frontier conversion and direct drivers of deforestation. To limit inter-coder variability, each case study was coded twice and crosschecked between the paired reviewers to eliminate potential discrepancies and errors. Finally, frequency analyses of the dataset were completed using Excel.

Table 1. Definitions, descriptions, and sources of variables extracted in meta-analysis of this study used to assist conservation efforts of intact forests and that identify common causes and effects of land-use and land-cover changes globally.

Variable Name	Description	Examples	Source
Economic Development	This variable describes the economic development status of the country (or countries) in the case study.	*Developing Countries* = Brazil and Indonesia. *Developed Countries* = Canada and Russia.	(World Bank 2014)
Direct Driver	This variable describes the explicit local cause of forest conversion or degradation.	Agricultural expansion, logging, and "nonhuman" events such as natural fire	Modified from Geist and Lambin (2002) to include distinct variables for pasture/ranching and mining/hydrocarbons

Indirect Driver	This variable describes the factors that influence the direct drivers of forest conversion or degradation	Population growth and commodity prices	(Nelson et al. 2002)
Conservation Approach	This variable describes the conservation instrument or tool proposed to address the deforestation in the case study	*Protection & Management* (e.g., protected areas and species management), *Law and Policy* (e.g., legislation and treaties), *Education and Awareness (*formal education and public outreach), and *Changing Incentives* (e.g., certification and boycotts)	(Salafasky et al. 2002)
Phase of Frontier	This variable describes the degree of forest conversion and human development due to frontier expansion	*Phase 1.* Exploration and Surveying. *Phase 2.* Large Scale Extraction and Transportation Networks. *Phase 3.* Agricultural Conversion and Permanent Settlements	Adapted from Barbier (2011)
Conservation Failure	This variable describes the structural context that resulted in forest conversion.	*Institutional* (e.g., weak enforcement, absence of authority or institutions), *Political* (e.g., corruption or pro-development bias), M*arket* (e.g., an increase in international commodity pricing), *Social* (extremely high population growth and lacking informal governance)	Developed from literature review of failures in environmental policy. See table description below for overview of categories and indicators

Results

The results of the meta-analysis show a diversity of approaches have been used to document frontier forest expansion. Relative to the case studies compiled in this meta-analysis, the production of publications documenting land-cover change in frontier environments was lower for the period 1998-2000 (44%) compared to 2000-2012 (56%). All phases of frontier expansion were included in the case studies with 14% of the cases in Phase 1 of frontier expansion, 47% in Phase 2, and 39% in Phase 3. The majority of cases were from the Americas (64%), followed by Asia (20%), and Africa

(15%). Most cases focused on the conversion of tropical forests (91%), followed by boreal forests (5%) and temperate forests (4%). Case studies primarily focused on economically developing nations (89%) versus developed nations (11%).

Both indirect and direct drivers of forest conversion were identified in the case studies, i.e., 100% of the cases documented direct drivers and 95% included indirect drivers of deforestation. Economic and demographic factors were cited as the most important indirect drivers of deforestation in all three phases of frontier expansion. Indirect drivers of change focused on national level factors, followed by the international, and lastly the local level factors (Figure 1). Moreover, indirect drivers at the national level were cited most frequently as important drivers of deforestation across all three phases of frontier expansion. The second most frequently cited drivers of deforestation were international level indirect drivers, followed by local indirect drivers. The most frequently cited direct driver of forest conversion was agriculture, followed by infrastructure expansion, logging, and ranching (Figure 2). More specifically, logging, infrastructure, and non-human drivers were the most frequently cited direct drivers in Phase 1, followed by agriculture, logging, and infrastructure in Phase 2, and agriculture, infrastructure and logging in Phase 3.

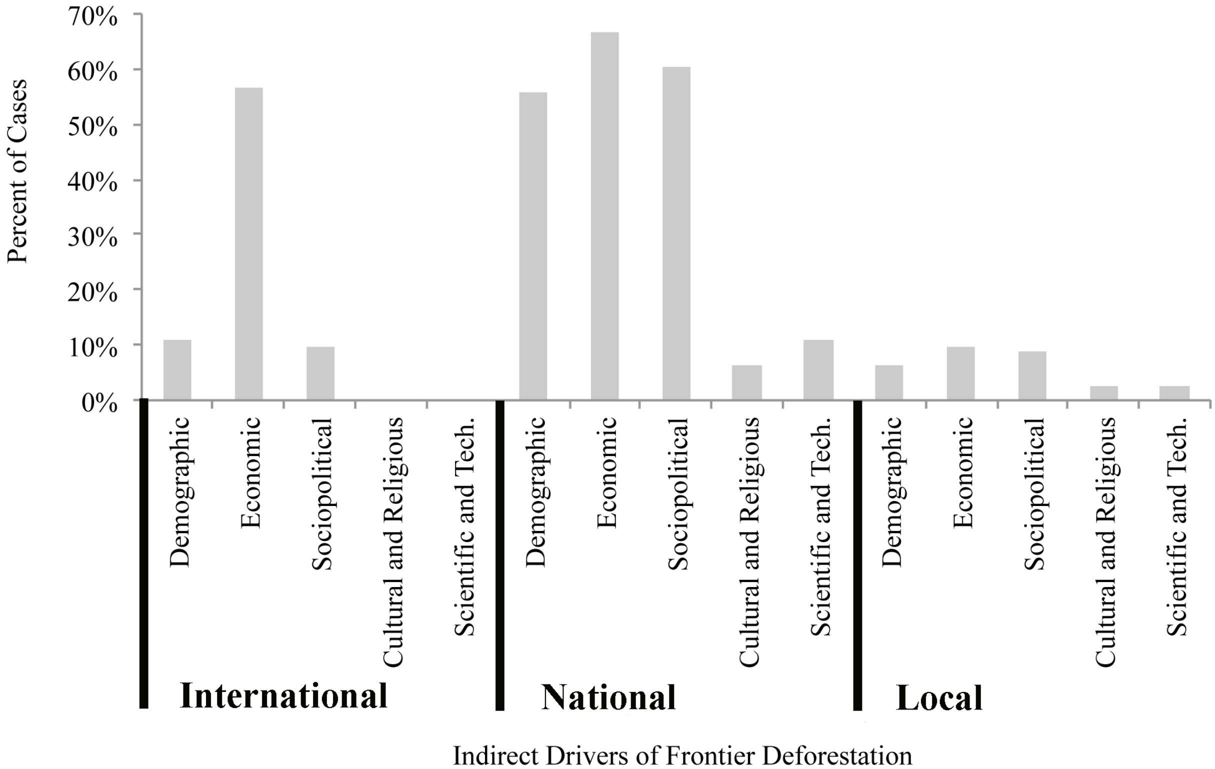


Figure 1. Case studies that refer to the resolved indirect drivers of deforestation sorted by their reported institutional scale

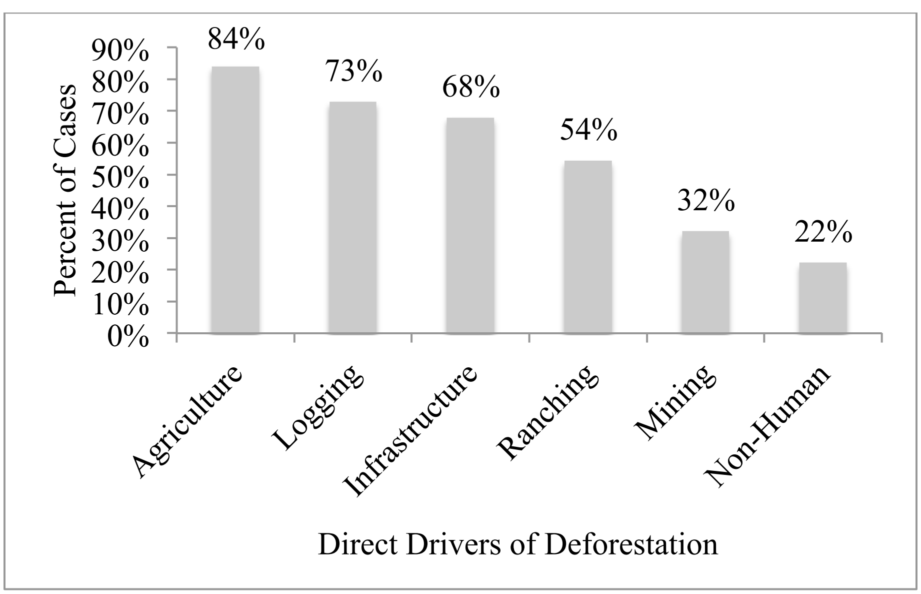


Figure 2. The percent of cases that documented these direct drivers as the cause(s) of deforestation.

Conservation failures associated with frontier expansion were noted in 86% of the case studies. In 77% of cases, the most important conservation failure was reported as being institutional, followed by political (51%), social (27%), and market-based failures (27%)(Figure 3). Across all three stages of frontier expansion, institutional failure was cited most frequently followed by political failure causing frontier expansion. Market failure was cited more frequently than social failure in Phase 1 and Phase 2 of frontier expansion, but it was less frequently mentioned in the Phase 3 of frontier expansion. Institutional failure and political failure were also coupled most frequently, with 42% of cases having both failures occurring together. The most frequently recommended conservation approach to conserve forests in all three stages of frontier conversion was for forest protection and management. The second most frequently cited approach to conservation was through law and policy changes, followed by changing incentives, and through education and awareness (Figure 4).

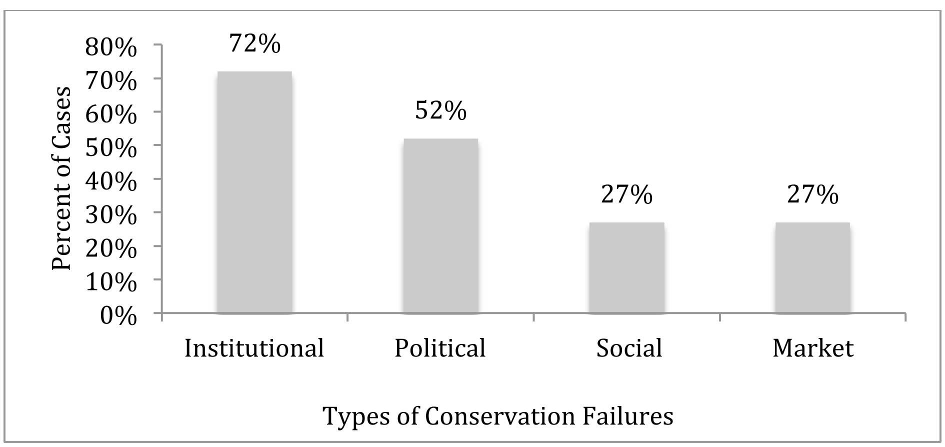


Figure 3. The percent of cases in this study that mentioned these specific conservation failures (See Table 1 for a description of the processes included in each failure type)

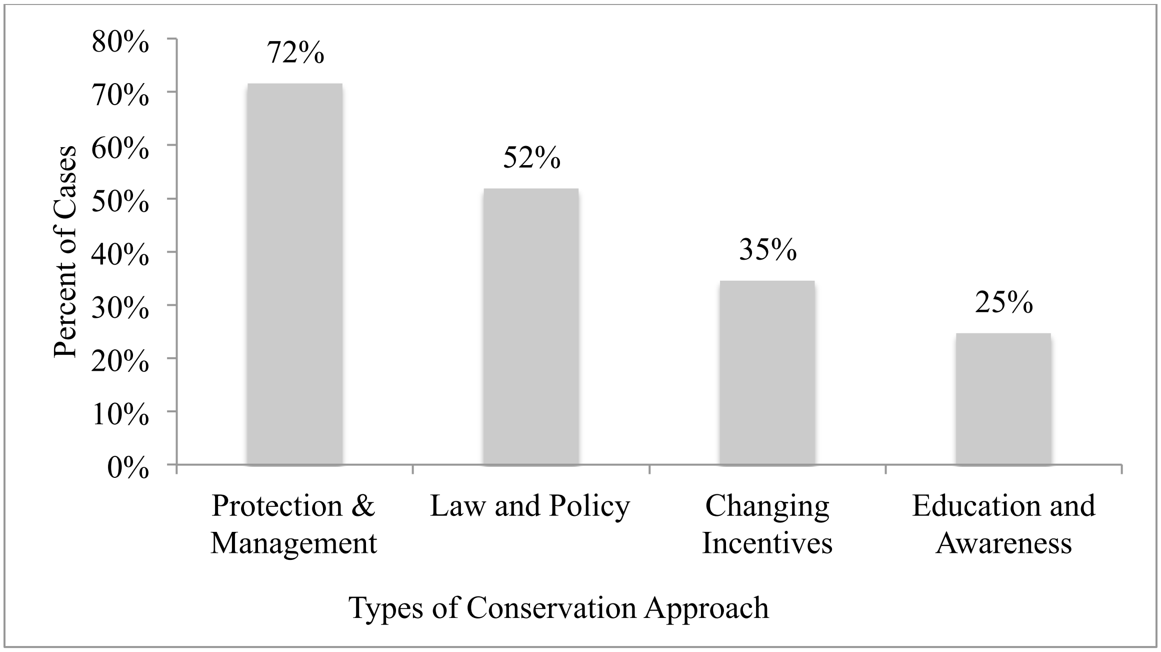


Figure 4. The figure shows the percent of cases that identified and recommended a particular approach to increase forest conservation.

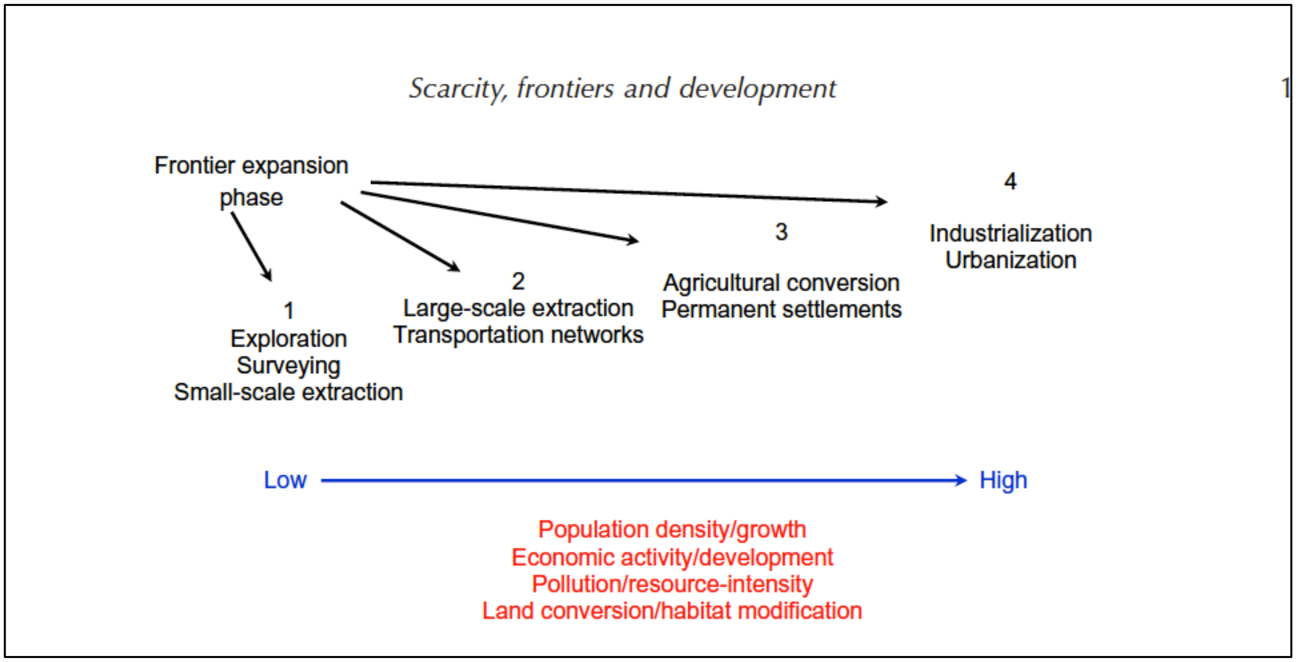
Discussion:

A Synthesis of Forest Conservation Case Studies from the Frontier

The study of frontier environments has a long history and has invited a diversity of scholars and theories (e.g., Lower 1936; Pinchón 1996; Hirsch 2009). For example, economic geographers tend to explain the expansion of frontiers using the (1) land-rent approach, which defines the frontier in terms of land costs and distance to markets, or with (2) political economy, which focuses on other factors, such as national politics and macro-economic policies (Jepson 2006). Alternatively, other studies of the frontier include the study of place and its interactions and relationships between people and the environment (e.g., Hirsch 2009). The contribution of this meta-analysis to our understanding of frontier environments is that it provides further support and broadens the findings of previous meta-analyses of tropical deforestation, as well as provides new insights into the processes that lead to the conversion or conservation of forests in frontier environments.

The results of the meta-analysis study show that frontier environments are diverse in their socio-environmental conditions, but can also be broadly homogenous because frontiers often emerge from similar combinations of social and economic factors (Figure 4). One benefit of the unique conditions of frontier environments, including both shared diversity and consistency, indicates that frontiers may offer unique opportunities to evaluate, design, and target conservation policies and strategies. In particular, the extreme nature of many frontiers in terms of their rapid change and intense socio-economic pressures may highlight more clearly the impacts and effectiveness of conservation policy instruments on socio-environmental systems e.g., Haruna et al. (2014); Scullion et al. (2014).

Figure 4. Conceptual diagram of frontier expansion phases from Barbier (2011)



As highlighted in previous meta-analyses of tropical deforestation e.g., Lambin and Geist (2002), this study found that case studies of forest conversion in frontier environments are concentrated in specific regions of the world, particularly the Neotropics. In this study, 62% of the cases were from this region of the world. Likewise, case studies were heavily skewed towards research conducted in tropical forests, 91% of the total cases were from tropical forests in this study. In this study, cases were also highly concentrated in the Phase 2 and Phase 3 of frontier expansion, with only 14% of cases reporting research from Phase 1 areas of frontier expansion. Collectively, these results suggest conversion of forests to alternative uses in frontier environments is common around the world, but they are especially prevalent in a few select regions of the world.

It should also be noted that relatively few case studies have been published on frontier deforestation in the temperate and boreal climatic regions of the world, tropical regions in Asia and Africa, and for the Phase 1 of frontier expansion. However, the number of case studies produced in the last 25 years has gradually increased, which indicates that if this trend continues future research efforts can be targeted at existing gaps in the literature. Addressing these gaps through the production of additional case studies would provide a stronger foundation from which to better understand the effectiveness of different conservation policy instruments under the heterogeneity of conditions found in frontier forest regions (Miteva et al. 2012). In particular, further research exploring Phase 1 of frontier expansion are needed to improve our understanding of the triggers of frontier expansion.

As widely reported elsewhere, this meta-analysis again highlights that the vast majority of global deforestation is concentrated in the tropics (Hansen et al. 2013). The cause for the concentration of deforestation in the tropics has been the subject of much research and debate (Vandermeer and Perfecto 2005; Terborgh 2004). One school of thought argues using "world systems theory" that tropical deforestation patterns draw from the power imbalance in economic and political relations between the developed countries and developing nations, whose economies are often dependent on the export of their natural resources (Vandermeer and Perfecto 2005). Others view the contemporary concentration of deforestation in the tropics as just another phase in the long story of the earth's expanding frontiers, with tropical nations now taking their turn in developing economically by meeting the world's demand for natural resources (Mather 1992). Still others point to the intensity of tropical deforestation as primarily due to the availability of accessible natural resources that are in high demand, which will not end unless "something fundamental changes" (Laurance et al. 2012).

The observed dynamics of indirect and direct drivers of frontier expansion documented in this meta-analysis have been previously identified as drivers of tropical deforestation (Lambin and Geist 2002; Rudel 2007). This study, however, extends this early research by highlighting and identifying the importance of specific drivers associated with frontier expansion across different spatial scales and phases of frontier expansion. For example, the finding that national-level indirect drivers are of primary importance across all three phases of frontier expansion provides empirical support to the argument that national policies are often a major catalyst and important driver of frontier expansion. This finding indicates the importance of addressing the indirect drivers of deforestation at the location where they most frequently reside: At the national and international levels. Likewise, this meta-analysis also highlights how frontier expansion is often due to the consistent combination of three indirect drivers of change at each stage of frontier expansion: economics, politics, and population growth. Interestingly, the direct drivers of frontier expansion were also consistent across all frontier stages, with agriculture, infrastructure expansion, and logging being the dominant direct causes of forest loss depending on the frontier phase of expansion. These findings indicate that policies targeted at specific combinations of indirect and direct drivers are likely to have the highest impact in reducing the expansion of development frontiers and thus reducing the loss of intact forests. In summary, while frontier expansion is often diverse in its causes and trajectory, the patterns of expansion are generally consistent and may thus offer unique opportunities to design and evaluate forest conservation strategies.

Analyzing the causes of frontier expansion through the lens of conservation failures shows that consistently the most important failure influencing the conversion of forests in frontier environments is institutional failure. Political failure was also cited with a relatively high frequency indicating its importance as well. Even more, a finer assessment of the case studies revealed that political failure was often coupled with institutional failure, e.g., either as a combination of prevailing political support for forest conversion and/or a lack of adequate development policies and/or weak enforcement. Market failure and societal failure were also identified and reported by a number of authors in their publications, but both factors were not identified as the primary drivers of reduced conservation efficacy. The central practical conclusion from the findings of our study is the importance of reforming national forest governance institutions and strengthening national constituencies that support forest conservation efforts.

Additionally, making forest governance institutions and national pro-conservation constituencies more effective could also reinforce support for and the provision of resources towards using Protection and Management as frontier conservation instruments. Likewise, this study indicates higher levels of political will and institutional efficacy are required across governance scales to achieve sustainable forest management objectives (Montreal Process 2009) and Millennium Development Goals to conserve biodiversity (United Nation 2014). Also, this meta-analysis highlights the importance of education, incentives, and politics as critical policy instruments in frontier conservation efforts. Even if protection and management are likely the optimal solution, strict protection is not always feasible, nor always the best solution, especially when local people have legitimate land claims (Sarkar and Montoya 2011).

Frontier Landscape Dynamics and Conservation Challenges

The socio-environmental processes that drive deforestation have been described at length in other publications (See reviews: Geist and Lambin 2002; Lambin et al. 2003) so our coverage of this topic has focused exclusively on processes driving forest vulnerability in frontier environments and their impacts on conservation outcomes. Perhaps the most important factor influencing forest vulnerability and conservation outcomes is the reality that when standing forests become worth less than alternative land-uses they are vulnerable to conversion (Barbier et al. 2010). The processes that lead up to forest conversion often include a combination of factors such as resource scarcity, opportunities created by markets, and changes in institutions and beliefs (Lambin et al. 2003). Additionally, frontier expansion is often fueled by markets and population growth (Barbier 2004) and natural resource boom-and-bust cycles (Rodrigues et al. 2009).

Frontier expansion and deforestation are frequently catalyzed on the ground by the construction of new roads for logging operations or infrastructure expansion (Geist and Lambin 2002). Once the new roads have penetrated the forest, a number of outcomes can emerge depending on the location and the underlying drivers of change (Lambin et al. 2003). What often follows is agricultural expansion by smallholders or large corporations (Rudel 2007), which can then include the consolidation of property ownership (Carr 2006; Barbier 2012) and eventually, afforestation (Mather 1992). The global-scale pattern of concurrent frontier expansion and deforestation followed by afforestation is known as the “forest transition hypothesis,” which describes the what occurred in most developed countries where forests were largely cut and are now recovering and are managed and protected (Mather 1992; Rudel 1998).

Achieving success in forest conservation efforts can be a difficult in any context, but may be especially challenging in frontier environments due to the particularities of the frontier, such as frequent confluence of powerful social and economic incentives that favor forest conversion. Also, another major challenge thwarting forest conservation efforts in frontier environments is the existence of weak governance institutions responsible for developing policies related to forest use and conservation (Barbier et al. 2010; Peres and Schneider 2011; Celentano 2012). A host of factors can contribute to weak governance in frontier environments, including low social and economic capital (Barbier 1997; Keleman 2010), high levels of social and political conflict (Finer et al. 2008; Global Witness 2012), a frontier mentality of open access and lawlessness (Goza 1994, Chai 2001), and the rapid pace of social, political, and environmental change, particularly during resource booms (Maertens 2006; Barbier et al. 2010; Motzke 2012,). An additional factor challenging forest conservation efforts in frontier environments is that local decision-makers often have few incentives to conserve forests when faced with intense local demands for land access and resource extraction (Skole 1994; Barbier et al. 2010). Also, local decision-makers may also have a limited ability to achieve conservation objectives due to strong socio-economic incentives at national and international levels that encourage local forest conversion, such as global commodity prices (Swenson 2011) and entrenched poverty (Humphries 1998; Maki 2001).

Conclusion

To improve the conservation of intact forests in frontier environments, this review shows that great progress has been made but also that much work remains. For scholars interested in advancing conservation efficacy on the frontier, this research shows summarizing and gleaning insights from previously published research are invaluable to gain insights into frontier deforestation and conservation policy dynamics. Already the existing literature shows us that frontier expansion is complex, global, and that much remains to be understood. To improve the development and selection of forest conservation policies optimized for frontier environments, this meta-analysis shows that case studies are most needed that encompass Phase 1 of frontier expansion, the temperate and boreal forests, and tropical deforestation outside of Latin America. An analysis of the barriers to case study development and any potential biases in study areas and topics may help to identify gaps in ongoing and planned research efforts focused on policy efficacy and LULC in frontier environments.

This review also shows that frontier environments can teach us much about how to improve forest conservation policies and strategies in general. To this end, the central finding of this study is the importance of the link between national policies and forest conversion in frontier environments. This finding highlights the importance of politics for forest conservation and may indicate that national politics is an important leverage point to improve intact forest conservation globally. Also, the finding that the most important failure associated with frontier expansion is institutional failure, which highlights the importance of efforts focused on improving existing forest governance systems at all levels. Governance is needed at all scales because as this analysis shows, the causes of frontier expansion include local, national, and international factors. Likewise, this analysis provides a reminder that the most important direct driver of frontier expansion is often agriculture, but other drivers are usually involved and can dominate (Lambin 2003). Lastly, the finding that protection and management was the most cited conservation approach emphasizes the value and attraction of protection and management as a policy instruments for advancing intact forest conservation in frontier environments. Thus, improving the effectiveness of protection and management policies and practices in frontier contexts, as well as mitigating its negative impacts on rural communities and livelihoods, are of critical importance to the global conservation of intact forests and forests in frontier environments.

CHAPTER 2

Assessing the influence of land-cover change and conflicting land-use authorizations on ecosystem conversion on the forest frontier of Madre de Dios, Peru

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ABSTRACT:

Despite the many benefits natural forests provide, they are being lost worldwide at unsustainable rates as development frontiers expand. One approach to improving the efficacy of natural forest conservation efforts is to refine local forest conservation policies based on insights from the place-based study of conservation policies and land-use and land-cover change (LULC) dynamics. To demonstrate the strength of this approach, this research explores the dynamics of LULC and conservation policies on the forest frontier of Madre de Dios, Peru. The main objectives of this research are to evaluate the efficacy of designated conservation lands in a rapidly expanding frontier landscape and to assess the effect on ecosystem conversion of granting conflicting land-use designations, such as mining concessions, inside conservation areas. Using statistical matching and a GIS-based analysis of LULC, this research shows that for the period 2006-2011, designated conservation lands on the forest frontier of Madre de Dios significantly reduced ecosystem losses compared to non-conservation lands, but the effect was highly variable across conservation designations. Also, when present, conflicting land-use authorizations inside conservation areas, specifically overlapping mining and agricultural titles, eliminated the policy additionality of designating lands for conservation. This finding demonstrates that authorizing conflicting land-use rights inside conservation areas should be avoided to ensure intended land conservation outcomes. This case study also provides examples of how local forest conservation policies can be improved through detailed and frequent analyses of LULC and conservation policies, particularly in dynamic frontier landscapes where LULC and socio-economic conditions are rapidly changing.

Introduction

Globally, forest ecosystems provide a myriad of human benefits at multiple spatial scales, including the provision of ecosystem goods, such as timber and clean water, and the delivery of ecosystem services, such as carbon cycling (MEA, 2005). However, the widespread continued loss and degradation of forests around the world, particularly tropical rain forests, has led to calls for the adoption of additional forest conservation measures (e.g., Shearman et al., 2012;

Laurance et al., 2012). Frequently, actions taken to advance forest conservation include implementing new conservation policies, including: new protected areas, international treaties, and payment for ecosystem service programs. Unfortunately, for most conservation policies, scientists and policy-makers still do not have a full understanding of their likely socio-environmental impacts and the optimum conditions for their application (Pullin and Knight, 2001; Parrish et al., 2003; Pattanayak et al., 2010; Miteva et al., 2012).

Over the last decade, in response to increasing awareness that conservation efforts could be improved with more empirical evaluation, a variety of studies evaluating the efficacy of conservation policies have been undertaken (e.g., Pattanayak et al., 2010; Miteva et al., 2012; Blackman, 2013). Frequently these studies have focused on assessing the effect of designating lands for conservation, including the global protected areas network (e.g., Joppa and Pfaff, 2010) and regional protected areas networks (e.g., Vuohelainen et al., 2012). Studies designed to assess the impact of designating lands for conservation suggest designated protected areas often have lower levels of land conversion than unprotected areas. Collectively, this body of research suggests that land designation can be an important factor influencing land conservation outcomes, but also that designation is only one factor among many that determine the efficacy of conservation policies (Scullion et al., 2011; Vuohelainen et al., 2012).

Since land designation is simply a title conferring a “bundle of rights” that legally determine who benefits from the land and how that land can be used (Robinson et al., 2011), targeted analyses of the systemic factors that determine the environmental outcomes of land designations are likely to yield insights that can inform comparable conservation activities. An important factor likely to influence the efficacy of designated conservation lands occurs when government agencies grant land-use rights to different parties that conflict, such as granting mining concessions inside authorized ecotourism concessions. Given that conflicting land-use authorizations are common in many parts of the world (e.g., Finer et al., 2008), it is surprising that the role of overlapping land designations on the efficacy of conservation outcomes has been poorly researched (but see Holland et al., 2013).

The great potential for unintended environmental outcomes resulting from authorizing overlapping and conflicting land-use rights within conservation areas suggests that conservation outcomes should be sensitive to the influence of conflicting land-use authorizations. In the Amazon region alone, many large-scale and conflicting land-use authorizations have already been implemented on designated conservation lands. Examples in Amazonia include: the Ecuadorian government's recent zoning of 65% of its Amazon territory, e.g., Ecuador's famous Yasuni National Park (Bass et al., 2010), for oil extraction; and the government of Peru granting oil leases on 72% of its Amazonian territory that includes designated conservation areas (Finer et al., 2008).

Because of the high potential for negative impacts from overlapping and conflicting land-use designations on the conservation and management of forests globally, this research examines this issue locally in Madre de Dios, Peru. In Madre de Dios, various affected land users have already identified overlapping land designations as problematic. For example, local Brazil nut gathers are facing logging threats from authorized forest concessionaires who have rights to harvest timber on approximately 1.3 million hectares of Brazil nut concessions, as well as from gold miners because mining concessions have been granted on top of 47,000 hectares of Brazil nut concessions (Fraser, 2013).

To better understand how conservation designations and overlapping land conflicts influence conservation policies in Madre de Dios, this study used a mixed-methods approach to answer the following questions: (1) What is the efficacy, or policy additionality, of designated conservation lands on the rapidly expanding frontier of Madre de Dios for the period 2006-2011?, (2) What are the main factors influencing the efficacy of designated conservation areas?, and (3) How does granting conflicting land-use rights inside conservation areas, particularly mining concessions and agricultural titles, affect ecosystem conservation outcomes in areas designated for conservation?

Methods

Study Area

Located in Peru's southeast Amazonian province of Madre de Dios, the 2,060,000 ha study area includes the majority of the province's contemporary LULC dynamics (Figure 1). Madre de Dios is Peru's designated "Capital of Biodiversity'' and part of the Tropical Andes Biodiversity Hotspot (Myers, 2001) (Federal Law 26311). Madre de Dios is also recognized worldwide as a conservation priority due to its relatively intact forests, exceptionally high levels of biodiversity, strategic location in connecting large wilderness parks in Peru, Bolivia, and Brazil, and projected resilience to climate change (Malhi, 2008; Killeen et al., 2008; Rosenthal et al., 2012). In addition to the high biological value of Madre de Dios and the western Amazon in general, the region is also home to a rich mosaic of cultural diversity that includes some of the last uncontacted indigenous groups living in voluntary isolation (Wessendorf, 2008; Shepard et al., 2010).

Prior to mid-1960, Madre de Dios had few inhabitants and little development. This changed after the construction of a road leading into the province. Since then, human population and land-cover conversion have increased substantially, and the region has experienced comparatively high levels of forest disturbance and deforestation within Peru (Oliveira et al., 2007). During the 1980's and 1990's, the loss of natural forests in Madre de Dios was primarily caused by government subsidized agricultural expansion (Alvarez and Naughton-Treves, 2003; Chavez, 2012). In the 2000's, gold mining became an important driver of regional LULC following the discovery of gold deposits and an increase in the international price of gold (Swenson et al., 2011; Asner et al., 2013). Since the discovery of gold, an estimated 30,000 artisanal miners have migrated to Madre de Dios (Webster, 2012). It is thought that ~95% of gold mining operations in the region are illegal because the miners either lack the proper permits to run their operations or because they are working outside authorized mining concessions (Keane, 2009).

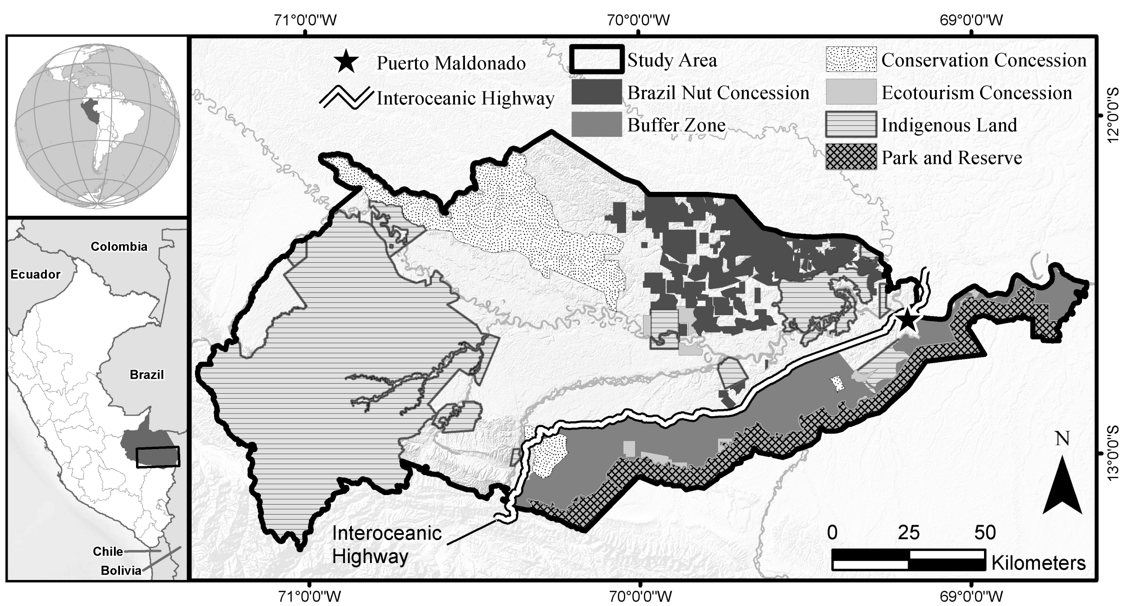

Figure 1. Map of study area in Madre de Dios, Peru. The grey rectangle in the country map outlines the study area. The study area map shows the distribution of all designated conservation lands and their orientation relative to the Interoceanic Highway and the capital city of Puerto Maldonado.

In addition to the expansion of gold mining, the recent completion of the Interoceanic Highway is also an important contributing factor to regional LULC due to its central role in facilitating local trade and resource extraction (Southworth et al., 2011). In 2011, approximately 68% of the study area was under one of six land designations that defined ecosystem conservation as a primary land-use objective (Table 1). At the same time, 94% of the study area was covered by natural ecosystems, including mature lowland rainforests, which comprised 69% of existing natural ecosystems, followed by montane forests, which were the second most abundant ecosystem (23.3%). The other existing natural ecosystems covered less than 3% percent of the total study area and included: palm swamps (2.9%), secondary lowland rainforests (2%), bamboo groves (1.6%), and riparian forests (0.9%).

Table 1. The table shows the total area and percent coverage of lands designated for conservation and non-conservation. See Vuohelainen et al. 2012 for a description of designated conservation lands and their authorizing legislation. Total land area in this table does not equal 100% due to rounding and missing coverage data for 2.5% of the study area (51,482 ha) and extensive overlapping between land-use designations. Also, because the majority of mining concessions overlap conservation and non-conservation lands, mining concessions were not evaluated as an independent land-use class outside of the land conflict analyses.

		Hectares	**Study Area (%)**
Conservation Lands	Indigenous Lands	679,784	33
	Reserve and Park Buffers	233,224	11
	Brazil Nut Concessions	184,365	9
	Conservation Concessions	162,430	8
	Park & National Reserves	128,589	6
	Ecotourism Concessions	18,255	1
Non-Conservation Lands	Forest Concessions	375,791	18
	Agriculture Titles	187,939	9
	Reforestation Concessions	64,369	3
	Mining Concessions	155,596	7

In recent years, efforts by the government to regulate mining activities in Madre de Dios have led to intense social and political conflict. Much of this conflict is because the mining industry has created tens of thousands of local jobs, generates an estimated $369 million (USD) in annual revenue, and accounts for greater than 50% of all regional economic activity (Mosquera et al., 2009; GOREMAD, 2009). Due to the jobs and revenues generated, the local mining industry has become the region's dominant socio-political force, surpassing the economic importance of other local industries, including ecotourism, which still brings an estimated 50,000 tourists to the region each year (Kirkby et al., 2010). In addition to continued conflict over where gold mining should occur in the study area (e.g., in rivers and protected areas), a major socio-political issue facing the region is how several government agencies have authorized conflicting land-use rights to different parties for the same land. A recent example illustrating the local challenges presented by conflicting land-use authorizations is the ongoing dispute over forest management between Brazil nut harvesters who depend on specific large standing trees inside closed canopy forests and gold miners whose land-use activities generally require removing forest cover (Fraser, 2013).

Image Classification and Analysis

To analyze changes in land-cover over the study period, images acquired by NASA's Landsat sensors were classified for the years 2001 (ETM+ & TM), 2006 (TM), and 2011 (TM) (Path/row 2/69, 3/68/, & 3/69). To ensure image comparability across sensors and acquisition dates, each scene was acquired during the same season (March-June). Each image was preprocessed using the following procedures: geo-rectification (< .5 RMS error), radiometric calibration, and atmospheric correction. Images were classified using a supervised classification approach in the spatial analysis software ENVI using the RuleGen decision tree classifier (RuleGen, 2004). RuleGen was trained iteratively based on a combination of (10-15) training samples, user and expert knowledge of the study area, and histogram enhanced Landsat images. Each classified land-cover map included "natural land-cover" (i.e., Primary Rain Forest, Secondary Rain Forest (<15 years old), Aguajale Swamps, Montane Forest, Riparian Forest, and Bamboo Forest) and "anthropogenic land-cover" (i.e., Agriculture, Infrastructure, and Mining), as well as Water (See Appendix 3 for classified maps).

Post-processing of the classified maps included a 3x3 majority filter to reduce noise, and extensive manual editing in ArcGIS version 10.1 (ESRI, 2012). Manual map editing was used to remove image classification errors and to delineate the natural bare-earth of riverbanks and streams from anthropogenic bare-earth resulting from artisanal mining (Swenson et al., 2011). Two local experts also improved the classified land-cover maps by identifying classification errors at several stages in the editing process. The final accuracy of each classified map was assessed using sixty reference points for each land-cover class, with the exception of the mining class in 2001, which only had 30 reference points, due to available imagery and the low number of clearly identifiable mining sites in 2001.

Reference points and training data for all land-cover classes were collected in the field using a hand-held GPS through a series of expeditions October-December 2011. The algorithms used to classify the land-cover classes Bamboo, Secondary Forests, Riparian Forests and Mining were developed by the authors using field validated training data collected throughout the study area. Reference points for these land-cover classes were user-generated based on histogram enhanced Landsat mosaics for each time period and field notes locating the land-cover in the field. The remaining forest cover classes, as well as the land-cover classes Infrastructure and Agriculture, were assessed entirely from GPS verification samples collected from the field. For all training data and verification samples taken with the GPS receiver, reference coordinates were only collected in areas that were unlikely to have changed land-cover classes before the beginning of the study. Overall accuracy for each map was: 87.7%, kappa 86.3 (2001), 86.5%, kappa 85.1 (2006), and 86.1%, kappa 84.6 (2011) (See Appendix 4). Land-cover change and land-use conflict were assessed using the spatial analysis software ENVI version 4.7 (Exelis Visual Information Solutions, 2009) and ArcGIS 10.1 (ESRI, 2012), respectively.

Statistical Matching

To assess the additionality of designating lands for conservation and the influence of conflicting land authorizations on the efficacy of designated conservation areas, statistical matching was used (Ho et al., 2007; Ferraro, 2009). Matching is a robust statistical approach that can be used to assess the additionality of conservation designations because it provides an unbiased estimate of the treatment effect of land designation policies and allows for the user to control for the nonrandom distribution of designated conservation areas (Alix- Garcia et al., 2008; Joppa and Pfaff, 2010), which is particularly important given the tendency of protected areas to be located in more remote locations with lower risks of ecosystem loss (Pfaff et al., 2009; Joppa and Pfaff, 2009). Matching works in practice by using software to combine random samples of treatment and control variables into matched pairs to undertake an "apples-to-apples" comparison of their differential outcomes. This comparison is then used to estimate the treatment effect of the policy intervention (Joppa and Pfaff, 2011; Blackman, 2013).

To account for other factors that drive conservation outcomes besides the policy treatment, such as distance to major roads and population centers, pixel pairs are matched based on all observed covariates of ecosystem loss. After all possible pixel matches are made unmatched pixels are discarded. Policy additionality is estimated using a difference in means test of the matched samples, or the "average treatment effect on the treated" (ATT). In this study, ATT is used to measure the difference in outcomes of ecosystem loss for the 2006-2011 study period between: (1)

lands designated for conservation versus non-conservation lands, and (2) lands designated for conservation versus lands designated for conservation overlapped by authorized land-use designations that generally "conflict" with ecosystem conservation objectives, i.e., mining concessions and agricultural titles.

For matching to provide an accurate measure of policy additionality, two underlying assumptions must be met: (1) all factors explaining ecosystem loss are the same for each set of matched pixel pairs, and (2) all observable covariates of ecosystem loss are included in the analysis (Blackman, 2013). To undertake a matching analysis in the study area, the covariates of ecosystem conversion were identified using a scatterplot matrix, which was used to test the collinearity of the selected spatially explicit variables (e.g., distance to roads and rivers). The final matching analysis included seven spatially explicit variables that were collinear with regional ecosystem conversion from 2006-2011 (Appendix 2). All the covariates created and tested in the data creation process were independently correlated with regional ecosystem conversion and thus included in the final matching analyses.

The covariate variables used in this study were developed from a spatially explicit dataset created from a variety of sources, including public agencies in Peru and the United States (See Table 2). Most of the variables representing land-use designations were current in the year 2011 and thus may contain an incomplete record of land-use distribution in the year 2006. The effect of this time lag in available data is unknown, but likely to be minimal due to the low number of major changes in land-use designation 2006-2011. Also, due to the high level of land-use overlap in the study area, a caveat of this research is that some pixels used in the matching analyses were assigned several land-use classes. However, the potential influence on the matching analyses of dual land-use classifications for the same pixel is likely to be low due to the matching sampling design and the specific analyses undertaken. Each of the spatially explicit variables was created using the Zonal Statistic tool in ArcGIS 10.1, which allowed for features for each control variable to be extracted for each 30x30m grid cell of the 2006 and 2011 land-cover maps. ArcGIS 10.1 was also used to standardize all data layer projections to WGS1984. To test the sensitivity of the matching results to the potential of unobserved confounders, a Rosenbaum Bounds test based on the Wilcoxon sign rank test p-value was used.

Table 2. The table shows the data sources used to estimate conservation effectiveness in Madre de Dios, Peru. The table lists the sources of each data type, the derived data value for the matching analysis, and the GIS variable name. Note Spanish acronyms for Peruvian data sources.

GIS Variable	Derived Value for Matching	Data Source
Distance to Highways	Euclidean distance to secondary roads and Interoceanic Highway.	Ministry of Transportation and Housing (MTV).
Distance to Rivers	Euclidean distance to rivers.	Peru National Chart (scale 100,000). From Peru's National Geographic Institute (IGN). Produced 1960's through 1990's depending on topographic sheet.
Elevation	Digital elevation value at 30m intervals.	ASTER GDEM. From The Ministry of Economy, Trade, and Industry (METI) of Japan and the United States National Aeronautics and Space Administration (NASA). 2011.
Conservation Status	Binary value of being conservation lands or non-conservation lands. See Table 1 for description of conservation and non-conservation lands All land-use coverage data was current in 2011 unless noted.	▪ Regional Directorate of Agriculture (DRA) ▪ Regional Program of Forest Resource Management (PRMRFFS) ▪ National Protected Areas Service (SERNANP) ▪ Ministry of Culture

Conflict	Binary value based on the presence/absence of conflicting land rights overlapping at the same location. These “conflict lands” unless otherwise noted include designated conservation lands overlapped by mining concessions and/or agricultural titles. The conflict analysis was based on land-use data current in 2011 unless noted.	▪ Regional Directorate of Agriculture (DRA) ▪ Regional Program of Forest Resource Management (PRMRFFS) ▪ National Protected Areas Service (SERNANP) ▪ Ministry of Culture
Soil Type	Soil Type is a measure of soil fertility based on the site-specific soil classification of semi-fertile riparian soils or nutrient poor upland soils.	National Institute of Mining Geology and Metallurgy (INGEMMET). Production date unknown.
Deforested ‘01-‘06	Binary value indicating the presence or absence of ecosystem conversion during the 2001-2006 study period.	2001-2006-2011 NASA Landsat TM and ETM+ Classified Land-Cover Maps. Maps produced 2012.
Distance to Deforestation	The Euclidean distance to the nearest occurrence of ecosystem conversion during the 2001-2006 study period.	2001-2006-2011 NASA Landsat TM and ETM+ Classified Land-Cover Maps. Maps produced 2012.

All matching procedures were performed in R using the ‘matching’ package (Sekhon, 2008), including the use of ‘GenMatch,’ which seeks optimal matched pairs using a genetic search algorithm (Diamond and Sekhorn, 2005). To generate a robust sample of grid cells in the treatment and control groups, a random sample was drawn from 10% of the cells in the treatment areas and five times more cells in the control areas. The larger proportion of sample cells drawn from the control was designed to account for the highly skewed distribution of conservation lands in the study area, with most being located in more remote locations compared to non-conservation areas near the highway (Figure 1). For each matching analysis performed, random samples of 100,000 cells were drawn from both the treatment and control groups. To account for the relatively small land area covered by ecotourism concessions in the study area (only 34,830 total cells) 200,000 cells were drawn to increase the number of potential matches available.

Results

Land-Use and Land-Cover Change 2001-2011

Landscape dynamics for the period 2001-2011 were complex and changed rapidly. Mining was the dominant driver of anthropogenic land-cover change, increasing during the period by 239% (9,642 to 32,642 ha), while infrastructure, e.g., roads, buildings, and industrial areas, expanded by 44%, (1,569-2,264 ha). In contrast, agricultural lands declined by 10.8% (24,115-21,504 ha). The rate of ecosystem conversion, defined as the replacement of native vegetation by anthropogenic land-cover, was comparable between 2001-2006 (-0.5%) and 2006-2011 (-0.4%), but a major shift in the dominant driver of ecosystem conversion occurred with mining becoming more important than agriculture. From 2001 to 2006, agriculture was the dominant driver of LULC, explaining 53% of ecosystem conversion, whereas mining was the most important driver from 2006-2011, explaining 68% of ecosystem conversion.

A detailed analysis of ecosystem conversion for the period 2001-2011 shows that the total extent of natural ecosystems in the study area declined by 18,944 ha (-1.0%) and four of the five classified forest-cover types also declined in extent: riparian forests (-3.1%), lowland primary rainforests (-1.5%), palm swamps (-1.3%), and montane forests (-0.9%). Across the study area, a loss in the extent of cover for most forest ecosystems was contrasted by a 22% (7,155ha) increase in area of secondary forests. Overall, during the 10-year study period, substantial changes in the character and extent of local forest ecosystems occurred.

Influence of Conservation Designations on Ecosystem Conservation 2006-2011

A GIS analysis comparing ecosystem conversion levels between conservation areas and non-conservation areas found the total amount of ecosystem conversion and the overall rate of ecosystem conversion was higher inside conservation areas (-0.46%) compared to non-conservation areas (-0.09%) (Figure 2). Also, total rates of ecosystem conversion, overall amounts of ecosystem conversion, and the direct drivers of ecosystem conversion all varied by the type of conservation designation (Table 3 and Figure 3). During the study period, an overall loss of ecosystem area occurred in 4 out of 6 types of designated conservation lands, including native lands, buffer zones, and ecotourism and conservation concessions (Table 3).

To assess the additionality of designating lands for conservation in the study area, matching was used to estimate the effect of the conservation designation policies in reducing the rate of ecosystem conversion (Ho et al., 2007; Ferraro, 2009). The results of the matching analysis show that the additionality of designating lands for conservation reduced ecosystem conversion inside designated conservation areas by 1.53% compared to non-conservation areas. Additionally, an evaluation of the relative conservation outcomes of each type of conservation designation shows the performance of each designation in preventing ecosystem conversion was highly variable (Table 3).

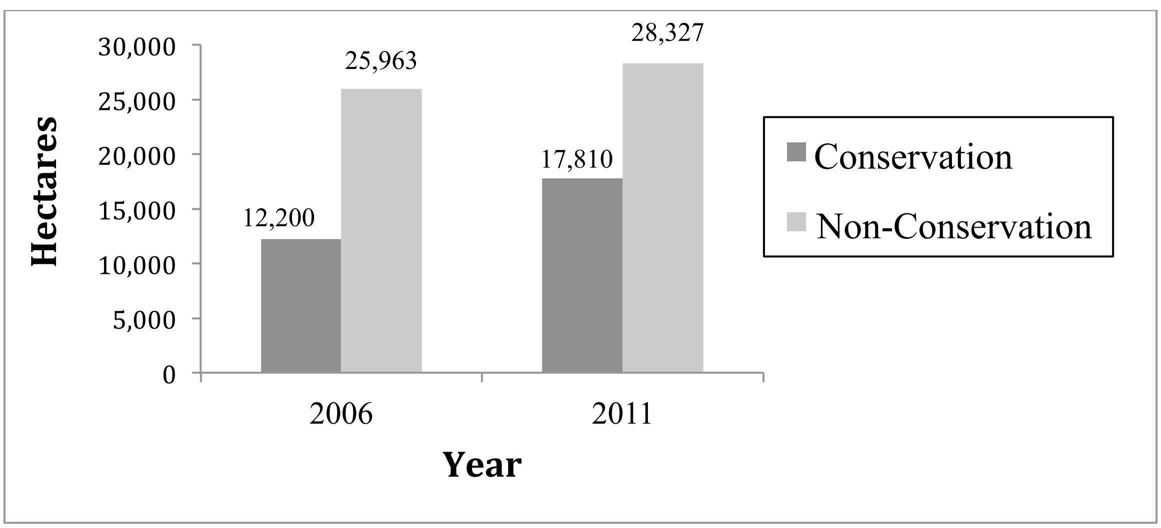

Figure 2. The figure above shows total ecosystem conversion that occurred by area between designated conservation areas and non-conservation areas for the study period 2006-2011.

Table 3. The table shows total ecosystem conversion, percent ecosystem conversion by designation, and the estimated conservation effectiveness for all designated conservation areas for the period 2006-2011.

Land-Use Type	**Ecosystem Conversion** ha	% Designation	Estimated Effect
CONSERVATION AREAS			
Indigenous Lands	-4,314	-0.63	0.59%
Buffer Zones	-714	-0.30	2.19%
Ecotourism Concessions	- 550	-3.01	2.86%
Conservation Concessions	-188	-0.12	2.61%
Park & National Reserves	54	0.04	3.14%
Brazil Nut Concessions	102	0.05	2.76%
NON-CONSERVATION AREAS			
Forest Concessions	-3,133	-0.83	
Reforestation Concessions	-1,944	-3.02	
Agricultural Concessions	2,711	1.44	

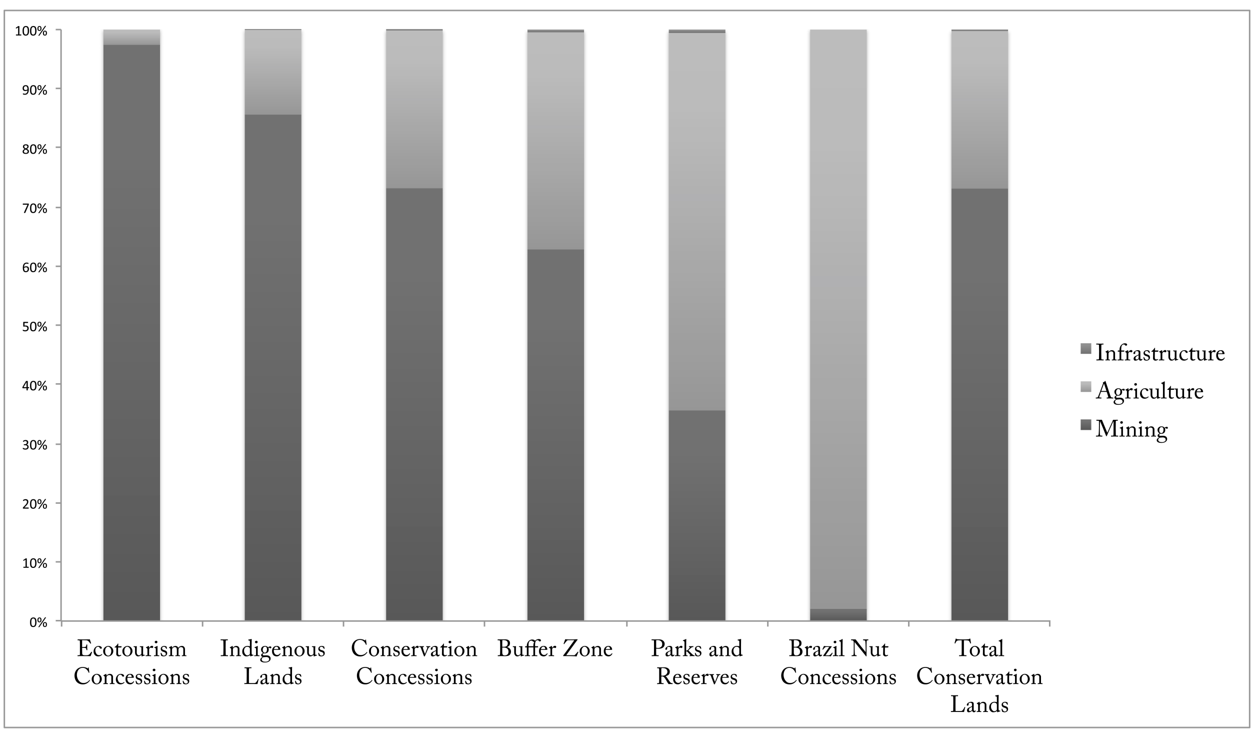

Figure 3. The figure above shows the variation in the types of direct-drivers of ecosystem conversion between conservation designations for the study period 2006-2011.

Influence of Conflicting Land Authorizations on Conservation Additionality

Using GIS, it was estimated that in 2011, 64% of all designated conservation lands in the study area were overlapped by land designations granting conflicting land-use rights for resource extraction or land conversion, with nearly 49% of conservation lands overlapped by oil concessions, 13.3% by mining concessions, and 4.5% by agricultural titles (Table 4). Overlapping land designations authorizing conflicting resource extraction or ecosystem conversion were also found on 63% of non-conservation lands (549,242 ha). Moreover, even within conservation lands, an estimated 7% (88,435 ha) had two or more distinct conservation designations (e.g., Brazil nut concessions and national reserve).

The results of the matching analysis in estimating the impact of conflicting land authorizations on reducing ecosystem losses inside conservation lands, shows that conservation lands with no conflicting authorizations had an estimated 1.93% reduction in the rate of ecosystem conversion compared to a rate of 1.53% for all conservation lands, which included lands with conflicting land-use authorizations. Most importantly, the matching-conflict analysis shows that designated conservation lands with overlapping conflicting authorizations that authorize mining and/or agricultural activities on the same parcel had no significant effect on reducing the rate of ecosystem conversion. In other words, the matching-conflict analysis shows that from 2006 to 2011 there was no additionality of conservation designations in preventing ecosystem conversion in locations that were also overlapped by land designations that authorize resource extraction or conversion, specifically mining and agricultural activities.

Table 4. The table shows the percent coverage of conservation lands in 2011 with existing overlapping or "conflicting" land designations in total hectares and as a percentage of overlap by the total area of each designation type. The Total Land Conflict (ha) value included in the category Overall Conflict includes the total number of hectares of conservation lands that have one or more forms of conflicting land-use authorization, not the sum extent of all authorized land conflicts. Additionally, an estimated 105,901 hectares of conservation lands have at least two overlapping and conflicting land-use authorizations. Value represents total amount of conservation lands in the study area impacted by conflicting land designations.

Land Designation	**Overall Conflict (%)**	**Mining Conflict (%)**	**Agriculture Conflict (%)**	**Oil Conflict (%)**
Indigenous Lands	87	9	1	91
Ecotourism Concessions	87	71	3	46
Reserve and Park Buffers	56	27	20	15
Parks and National Reserves	35	5	1	30
Brazil Nut Concessions	28	18	1	13
Conservation Concessions	28	6	1	21
Total Land Conflict (ha)	838,767*	187,186 (13.3%**)	64,276 (4.5%**)	693,206 (49%**)

The GIS results of this study show that mining expansion was the dominant driver of ecosystem conversion during the 2006-2011 study period. During this period, 81% of all new mining activity that occurred inside conservation lands was inside authorized mining concessions. Similarly, mining expansion being concentrated inside authorized mining concessions was also more common within non-conservation designations. Overall, across the study area, the likelihood of new mining occurring inside mining concessions was 2.6 times greater than mining occurring outside mining concessions. While most of the new mining expansion inside conservation areas did occur in authorized mining concessions, 19% of new mining occurred outside mining concession areas. Conservation areas with the highest levels of new mining outside authorized mining concession were indigenous lands (24.4%) and the park and reserve buffer zones (15.9%).

Discussion

A major goal of this research is to identify policy recommendations, or "best practices," to improve forest conservation policies in frontier environments. Likewise, an important goal is to demonstrate the value of combining analyses of policy efficacy with studies of LULC to improve the design of forest conservation policies. To this end, the explicit objectives of this research are to evaluate the influence of conflicting land-use authorizations on ecosystem conversion and extend the work of Vuohelainen et al. (2012) to assess the additionality of designating lands for conservation in Madre de Dios, Peru, particularly in light of the rapid expansion of new gold mining areas.

The Additionality of Conservation Designations and the Underlying Drivers

A primary finding of this study is that despite widespread and increasing ecosystem conversion across the study area for the period 2006-2011, the additionality provided by designating lands for conservation was significantly greater than non-conservation lands. However, the rate and total area of ecosystem losses inside designated conservation lands was still higher than inside non-conservation lands. More specifically, this study's update on the 2005-2008 matching results reported by Vuohelainen et al. (2012) concurs that designated conservation lands still had an overall positive effect in preventing ecosystem conversion relative to non-conservation lands. Yet, conservation lands still experienced widespread ecosystem losses and had greater overall losses than non-conservation lands. These contrasting results are likely the result of mix of factors, including the distribution and concentration of new mining expansion and the widespread variability in local land conversion risk.

Examining the explicit reasons that explain the relative performance of the conservation designations is informative for local policy-making and it also highlights a suite of broader policy insights for assessing and implementing ecosystem conservation policies in frontier landscapes. For example, within the park and reserve areas, specifically Peru's Tambopata National Reserve and Bahuaja-Sonene National Park, an important finding of this analysis is that despite the rapid increase in gold mining near designated park and reserve areas, the park and reserve still provided the best overall conservation outcomes. The strong performance of the national park and reserve is likely related to several factors, including the increasing presence of park guards, park managers' recent engagement in resolving land disputes, and the relatively consistent presence of scientists and eco-tourists (personal communications).

Like parks and reserves, Brazil nut concessions also experienced an overall increase in ecosystem area. This finding of additional land-cover protection being conferred by Brazil nut concessions is particularly interesting given the results of a recent study finding that the amount of wood being extracted from Brazil nut concessions in Madre de Dios was comparable and in some cases even higher than the amount being extracted from logging concessions (Cossío-Solano et al., 2011). Unfortunately, this pattern of ecosystem change was not detected in this study due to the unique challenges of identifying the occurrence of selective tropical forest logging using traditional remote sensing approaches. Principally, the diffuse nature of selective logging and the fast closure of tropical canopy gaps following selective logging (Asner et al., 2006; Montellano and Armijo, 2011) can make it challenging to detect this form of land-use change.

The two poorest performers among designated conservation areas were the buffer zones of the national reserve and park and indigenous lands. The reasons why the park and reserve buffer zones experienced relatively high levels of loss and low policy additionality is also likely due to high occurrence of mining authorizations inside the buffer areas, the relatively high levels of unauthorized mining outside mining concessions, and the presence of extensive and newly discovered gold deposits. Surprisingly, indigenous lands were estimated to be the least effective conservation designation. The low efficacy of indigenous lands in Madre de Dios preventing ecosystem conversion differs sharply with findings in the nearby Brazilian Amazon. In Brazil, indigenous lands have been shown to perform as well or better than other land-use designations under high deforestation pressure (Nepstad et al., 2006; Nolte et al., 2013; Schwartzman et al., 2013). Several explanations can be posed for the low conservation performance on indigenous lands in Madre de Dios, including unauthorized mining by non-indigenous people inside indigenous territories and the active participation in mining activities of ten local native communities (MINAM, 2011).

Overall, despite the widespread conversion of native ecosystems inside designated conservation lands, this study shows that designating lands for conservation can result in intended conservation outcomes even in frontier landscapes with high conversion pressure and the widespread occurrence of conflicting land-use authorizations. This study also supports other research reporting that the efficacy of land designations leading to ecosystem conservation is tightly linked to many other site-specific socio-environmental factors (e.g., Joppa et al., 2008; Nolte et al., 2013). Collectively, these findings suggest that policy-makers and resource managers working in frontier landscapes must develop ways to adapt to the dynamic and diffuse nature of land-use pressures. If the local context surrounding dynamic land-use pressures is not consistently considered in conservation policy design and resource management, many frontier conservation goals may not be maintained over the long-term.

Impacts of Conflicting Land Authorizations on Ecosystem Conservation

In addition to highlighting the complexity of competing factors influencing the efficacy of conservation designations, this research also shows the significant influence and extensive coverage area of conflicting land-use authorizations in the study area. Of principal importance, this research shows that the additionality of designated conservation lands is effectively negated when conflicting land-use designations are overlapped in the same location, specifically agriculture and mining areas. This finding is largely the result of new gold mining expansion inside conservation areas, which is concentrated primarily inside authorized mining concessions. Also, the greater overall effectiveness of all conservation lands without conflicting authorizations compared to all conservation lands including conflicting authorizations shows that conservation lands without conflicting authorizations are generally more effective in ecosystem conservation than conservation lands with conflicting authorizations. This analysis thus supports the conclusion that efforts towards improving conservation outcomes inside designated conservation areas in the study area would benefit from mitigating and/or reducing overlapping land-use conflicts.

This study's GIS and LULC analyses also demonstrate the linkage between new gold mining primarily occurring inside authorized mining concessions inside conservation and non-conservation lands. For the period 2001-2011, the areal extent of gold mining across the study area increased by 239%. Of the new mining that occurred inside designated conservation areas, 81% was located inside authorized mining concessions. Also, mining was responsible for greater than 70% of the ecosystem conversion that occurred from 2006 to 2013 in 4 out of 6 conservation designations, including the buffer zones, ecotourism and conservation concessions, and indigenous lands. These same 4 of 6 designations were also the only conservation designations to experience net ecosystem losses during the study period. In other words, while mining concessions overlap only 14% of total conservation lands, the presence of mining concessions inside conservation areas was significantly related to the overall effectiveness of conservation lands in preventing ecosystem conversion.

Most likely, the link between authorizing mining concessions in conservation areas and new gold mining is the result of a combination of factors specific to each location, such as the location and extent of gold discovered, the ease of industrial access, and the existence of existing mining concessionaires, among other socio-environmental factors. An insight that flows from this analysis of the influence of mining concessions on conservation policy efficacy is that while illegal mining outside of authorized mining concessions explains some of the increase in ecosystem loss in conservation areas in Madre de Dios, the majority is explained by the presence of authorized gold mining concessions. In turn, this study shows that authorizing gold mining concessions inside conservation areas is likely to result in reduced protected areas effectiveness and increased ecosystem losses.

Given the extent of conflicting land-use authorizations in Peru and other Latin American countries (e.g., Finer et al., 2008), it is surprising that so few studies have been published on the impacts of overlapping land-use designations on conservation policy efficacy (Holland et al., 2013). Holland et al. 2013, which explored and identified overlapping land tenure regimes and also controlled for the nonrandom distribution of protected areas, found that overlaps in parks and indigenous lands actually provided greater conservation benefits compared to "pure" park areas without overlapping indigenous lands. Of course, this positive report of Holland et al. (2013) contrasts sharply with the negative environmental outcomes highlighted in this study. These differences point to the need to further explore how conflicting (or co-benefiting) land-use designations can influence conservation outcomes. This conclusion is further bolstered given ample evidence demonstrating the importance of social conflict and land tenure claims in driving conservation outcomes, including degazettement of parks (Mascia and Pailler, 2011), increased land clearing to demonstrate ownership (Aldrich et al., 2012), and reduced deforestation due to increased tenure security (Robinson et al., 2011).

Policy Insights to Advance Forest Conservation in Frontier Environments

In addition to the support this research provides in identifying the negative effect of conflicting land-use authorizations on local conservation areas, the results of this study also highlight several policy recommendations for managing and assessing forest conservation policies in frontier environments.

First, to ensure forest conservation policies are tightly and continuously matched to the dynamic forces of local LULC, frequent analyses of LULC dynamics are critical. In this case study the importance of a high frequency of land cover analysis is illustrated by the rapid shift in LULC dynamics over the ten year study period, particularly the shift from a dominance of agricultural expansion to a decline in agricultural areas and the rapid expansion of gold mining. Unraveling the reasons for this shift is difficult with this study design, but the reasons likely rest on the relative economic returns of gold mining compared to agriculture. For example, a typical miner in Madre de Dios makes approximately $10-230 USD per day (Keane, 2009; PBS, 2011; Sapienaza, 2011) whereas a typical manual farm laborer earns $15-18 USD per day (personal communications). Given the high wage disparity between gold miners and low skilled labors outside the mining industry, it is likely that the higher wages and profits earned by gold mining was a major factor driving the shift in LULC dynamics from agriculture to mining. This conclusion is further supported by government data showing field prices paid to farmers in

Madre de Dios actually went up for 18 out of 19 crops grown in the region from 2006 to 2011 (MINAG, 2013), but still remained low compared to economic returns from gold mining.

A second policy recommendation highlighted by this case study is that detailed analyses of the impacts of LULC on local ecosystems are critical to identify conservation priorities and design effective conservation and development policies. A familiar example supporting this finding is how during the study period 2001-2011, the area of several ecosystem types decreased at a higher rate than the overall rate of ecosystem conversion of the study region (-1%). For example, higher decreases in areas were found for the particularly species rich primary rainforest (-1.5%) and riparian forests (-3.1%). These more detailed results show not only what ecosystems are being lost at the highest rates, but also the speed and widespread impact of ongoing gold mining activities on priority ecosystems.

Conclusion

LULC dynamics and conservation additionality in the study area are the direct result of a complex interaction of local, regional, and international factors. This case study shows that like many active forest frontiers around the world, the efficacy of the conservation area system in Madre de Dios would benefit from rigorous and frequent analyses to monitor LULC and conservation policy outcomes. This case study also shows that conservation areas in the study area faced intense land-conversion pressure and experienced high rates of ecosystem loss, even compared to non-conservation lands, but overall regional conservation areas policies had a positive effect on ecosystem conservation. Likewise, this case study shows that to ensure the policy additionality of designating lands for conservation, authorizing conflicting land-use authorizations should be avoided when possible.

These findings also indicate that much greater attention should be given to the study and management of conflicting land-use authorizations in Madre de Dios and beyond, especially given the great negative impact conflicting land-use authorizations may have on future social conflict and global conservation outcomes. Likewise, given the potentially large negative effects of conflicting land-use authorizations on people, communities, and conservation outcomes within the Amazon region for the foreseeable future, robust strategies for mitigating and resolving this form of land-use conflict are needed. Such strategies should include efforts to develop refined approaches for micro zoning, habitat corridor planning, and targeted site selection of conservation and development activities. Also as highlighted by Fraser (2013), the creation of an integrated government land registry system in Madre de Dios could help resolve existing land conflicts and avoid future ones. Lastly, this study again makes clear that designing effective forest conservation strategies requires the intelligent combination of mutually supporting conservation and development policies (Porras et al., 2011; Scullion et al., 2011).

CHAPTER 3

Identifying Leverage Points to Improve Forest Conservation Outcomes

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ABSTRACT

The focus of this study is the identification of high-impact forest conservation policies for a proposed biological corridor in Madre de Dios, Peru. To identify high-impact conservation policies or "leverage points," as well as potential barriers to policy implementation, field interviews of local gold miners and farmers were conducted. The field interviews were designed to understand the respondents' demographics, current land-use practices, preferences for proposed conservation policies, and probable decisions under alternative future economic and policy scenarios. Results show that even under active conditions of frontier expansion and deforestation a variety of forest

conservation policies could be implemented with potentially high levels of land-user enrollment and policy additionality. For example, interviews with local farmers found that most were interested in the proposed forest conservation programs, particularly technical assistance in exchange for private forest conservation (97%), followed by an alternative jobs program (73%), ecosystem service payments at twice voluntary carbon market pricing (67%), and payments comparable to voluntary carbon markets (40%). More broadly, this study found that potential leverage points to improve forest conservation outcomes in the study area include a range of economic and technical incentives and the ability to capitalize on existing land-user practices and preferences for forest conservation. Barriers to long-term success were also identified, including the variable preferences and circumstances of local land-users, high opportunity costs facing selected land-users and user-groups (especially gold miners), uncertainties regarding future socio-economic conditions, and the atmosphere of complex tenure agreements and land conflict. Collectively, this research suggests that the leverage point framework can be useful in identifying high-impact forest conservation policies matched to the preferences and needs of local land-users. However, variable socio-economic conditions and future economic and political uncertainties challenge place-based policy design and selection processes.

Introduction

Despite numerous efforts and commitments to conserve forests around the world (Cubbage et al. 2007; Lawlor et al. 2009), global forest cover declined from 2002 to 2012 at a rate nearly three times faster than forest regrowth (Hansen et al. 2013). Likewise, net deforestation continues in the tropics (Hansen et al. 2013) as does the global losses of primary forests (FAO 2010). Taken together, these continuing patterns of forest loss indicate that existing forest conservation policies not only require additional funding (Lawlor et al. 2009) but also targeted improvements.

Considerable effort has already been focused on the development of frameworks to improve the practice of conservation, including frameworks focused on reserve planning (Sewall et al. 2011), the explicit integration of local communities into resource management (Lynam et al. 2007), and the development of standardized conservation practices (Conservation Measures Partnership 2013). However, explicit frameworks to identify high-impact and place-based policy recommendations to advance conservation objectives are relatively few. Important exceptions exist however, including evidence-based policy design (Pullin and Knight 2001), benefit-cost analysis (Kirkby et al. 2010), and the return-on-investment (ROI) framework (Withey et al. 2012 & Murdoch et al. 2012; Tear et al. 2014). Similar to the ROI framework, but still unique, is the leverage point framework, which has attracted practitioners and researchers from a variety of disciplines, including political science (Bunker 1972), military strategy (Burton 1995), and sustainability science (Clay et al. 2005), but surprisingly few from conservation.

While largely untested in conservation, focusing on leverage points, or places in complex systems where small interventions can result in large-scale changes (Meadows 1999), may provide a useful approach to improve conservation outcomes. The framework may be particularly useful in resolving landscape-scale conservation issues because it incorporates the complex nature of coupled human and natural systems (Liu et al. 2007) and can highlight variables of systemic importance across multiple spatial scales. The attraction of using the leverage point framework to identify high-impact conservation activities is analogous to the efficiency of using a lever to lift a heavy item, which inherently provides a higher return on investment (Meadows 1999). The conceptual basis for understanding the nature of leverage points draws largely from literature on "systems thinking" (e.g., Meadows 1999) and is predicated on the presumption that the variables controlling the state of a complex system can be more or less influential, so targeting the most influential variables will likely yield the best results. Surprisingly, while the literature on the design of forest conservation approaches is vast (e.g., Lindenmayer et al. 2006 and Lawlor et al. 2009), few, if any, of these studies have undertaken explicit efforts to identify leverage points to improve forest conservation outcomes. Instead, most efforts identifying leverage points to improve environmental protection have focused more broadly on efforts to improve environmental management or sustainable development (e.g., Mitchel and Pigram 1989; Margerum & Hooper 2001; Nguyen et al. 2011; Nguyen & Bosch 2013).

As the factors influencing land-use practices of land-users (Greiner and Gregg 2010) and the efficacy of forest conservation policies are often highly variable (Nolte et al. 2013; Scullion et al. 2014), the design of local forest conservation policies can benefit from a place-based understanding of local land-users. To illustrate how understanding the perspectives and preferences of local land-users can be useful in identifying leverage points for improving forest conservation policies and strategies, we present a case study from the Amazonian state of Madre de Dios, Peru. Madre de Dios (MdD) is an ideal location to identify opportunities for high-impact forest conservation activities because it is located within the Tropical Andes biodiversity hotspot area (Myers 2001) and has experienced a 239% increase in gold mining activities between 2001-2011 (Swenson et al. 2011; Scullion et al. 2014).

The proposed 266,400 ha Manu-Tambopata corridor (MAT) was selected as the primary focus area of this study because it includes rapid gold mining expansion and is the last officially unprotected forested corridor linking mega-diverse forest parks in Peru, Brazil, and Bolivia, known as the Vilcabamba Amboro Corridor (Rosenthal et al. 2012)(Figure 1). Also, the MAT is an attractive study area because within the region there exists multiple types of land-uses and land-tenure regimes, which requires that conservation efforts work with the existing mosaic of land-uses to preserve forest connectivity. To identify policy instruments with a high likelihood of ensuring continued forest connectivity across the proposed MAT corridor, this study had three primary objectives: (1) Assess land-user interest in proposed forest conservation policies and practices; (2) Understand the socio-demographic characteristics of local land-users and how they interact with and influence regional deforestation processes; and (3) Evaluate the utility of the leverage point framework to generate policy-relevant and place-based recommendations to improve forest conservation outcomes. Additionally, the central hypothesis tested in this study is the assumption that local land-users in MdD engaged in deforestation are acting in response to their personal circumstances and the absence of better alternatives, and by understanding their circumstances and beliefs we can identify effective place-based forest conservation strategies and policies.

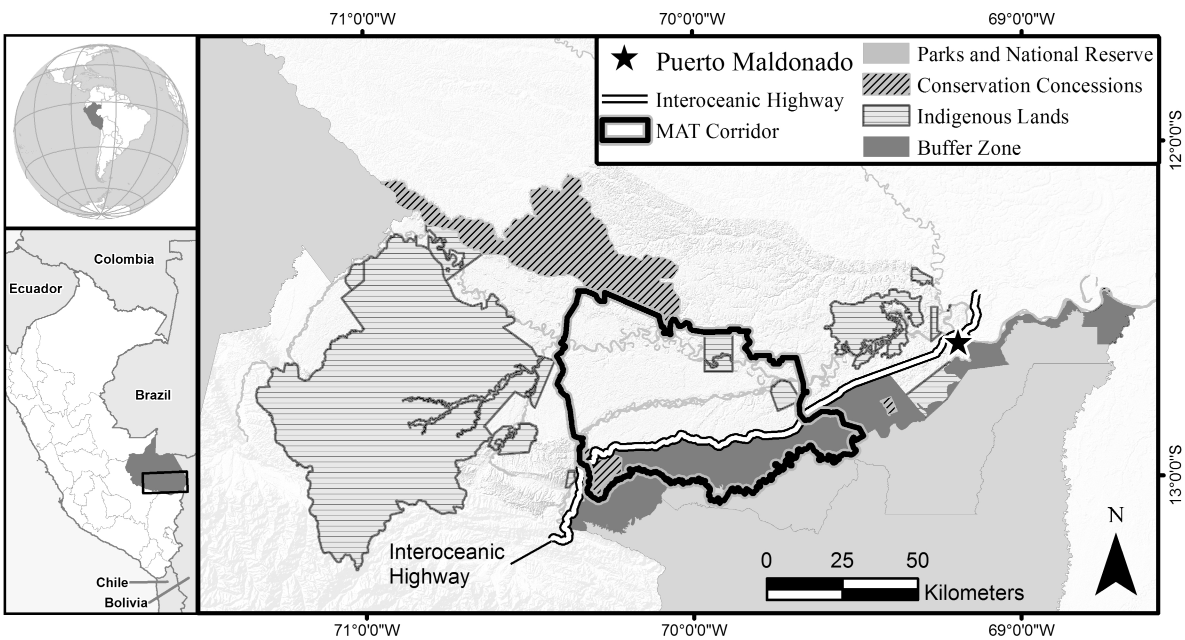

Figure 1. Map of the proposed MAT corridor and Surrounding Protected Areas

NOTE: Figure 1 shows a map of study area focused on the proposed Manu-Tambopata (MAT) corridor and the surrounding network of protected areas in Madre de Dios, Peru. The map highlights how the proposed corridor includes the last unprotected forest linking protected areas in Madre de Dios and beyond.

METHODS

To identify high-impact forest conservation policies for MdD and the proposed MAT corridor, active gold miners and farmers were interviewed using semi-structured interviews. The primary goals of the interviews were to understand farmers' and miners' demographics, current land-use practices, preferences for hypothetical conservation policies, and probable decisions under alternative future economic and policy scenarios. Farmers and miners living and working in MdD were targeted for interviews because they are the principal landholders engaged in forest conversion in the region (Swenson et al. 2011; Vuohelainen et al. 2011). Semi-structured field interviews were obtained from 120 farmers dispersed across 10 of the 30 communities found in the MAT. In 2009, the 30 communities in the MAT were estimated to include 558 families and 604 agricultural parcels (MINAM 2009). Farmers interviewed included those who farm for subsistence, farm commercially, or both. Ten communities in the proposed corridor were targeted for interviews to ensure a representative sample of communities located both on and off the Interoceanic Highway. Farmers in the targeted communities were identified and asked to be interviewed using a random approach where field assistants, familiar with the local communities, walked through each community on 2-3 occasions and asked each farmer they encountered whether they were willing to be a part of the interview process.

Semi-structured interviews were also conducted with 199 artisanal gold miners working inside the proposed corridor and at other mining sites in MdD. Trained field assistants familiar with the mining community completed 124 interviews of miners by visiting local mining camps, community centers, and other known gathering places. Additionally, a three-person research team associated with a local university conducted an additional 75 interviews. This team interviewed miners they knew through personal relationships and by visiting mining association meetings and worksites. Overall, interviews with gold miners in MdD occurred in more than 30 locations. Miners interviewed included those with ownership rights to authorized mining concessions in MdD, those renting authorized mining concessions, and those operating informally on lands in MdD outside of the government mining concession system. While our surveys did not ask local miners about the legality of their operations, it should be noted that gold mining in MdD is largely illegal, or "informal," due to miners lacking proper permits or concession titles (MINAM 2011). Response rates to the field interview questions were variable depending on the question asked. Together, farmers and miner response rates ranged from 56%-100%, with an average response rate of 96.6% for farmers and 80% for miners. Response rates varied due to the difficulty of the field conditions, the addition of interview questions as the study progressed, and the removal of explicit errors, e.g., a response indicating the respondent did not understand the question.

RESULTS

Landholder Demographics

Results from the field interviews show that the individual groups of farmers and miners are unique demographically in several ways, particularly in terms of their annual income, education, and primary sources of income (Table 1). For example, the surveys found that on average farmers tend to be older, less educated, and earn far less income than gold miners. In contrast, farmers reported more diverse sources of income and owned larger land parcels compared to miners. Similarly, within the respective groups, the demographic statistics of both farmers and miners were also highly variable (Figure 2).

Table 1: The table compares farmers and miners in terms of reported age, education, income, owned parcel size or concession size, and land-use practices.

Basic Demographics	**FARMERS (n = 120)**	**MINERS (n = 199)**
• Age	51.6 years	43.6 years
• Years Living in MdD	-	24.5 years
• Number of Years Mining	-	11.7 years
Education Level (% of respondents)		
• Primary Education or Lower	47.5%	42.9%
• Secondary Education	51.7%	35.7%
• Higher Education	1.7%	21.4%
Personal Income		
• Average Annual Income	$3,528(USD) (Range = -$1,197 – $33,194 (USD)	$40, 988* (USD) (Range = $453 to $619,582 (USD)
• Primary Source of Income	Agriculture (58%), Livestock (19%), Lumber (16%), Other (6%)	Gold Mining (88%) & Agriculture (12%)
Parcel Size and Land-Use Practices		
• Land size	66 ha (Range = 17 ha – 170 ha)	53 ha (Range = 1 ha - 1,000 ha)
• Land Use Practices	Subsistence (61%), Commercial (32%), and Subsistence /Commercial (6%)	Work in a Group (77%) & Work Independently (23%)

*Some miners in Madre de Dios (MdD) provided their earnings in grams of gold relative to the number of people working inside their concession. In these cases, the number of people the respondent said worked in the concession was used to divide the average amount of gold found per individual. The value was priced in dollars at international gold prices listed on November 7th, 2012 ($1,715 USD per ounce). Conversion from soles to dollars was based on currency conversion rates for November 15th 2011 ($2.708 Soles = $1 USD). For miners that reported their income in daily low and high earnings, these values were averaged for one day and multiplied by a 25-day work month.

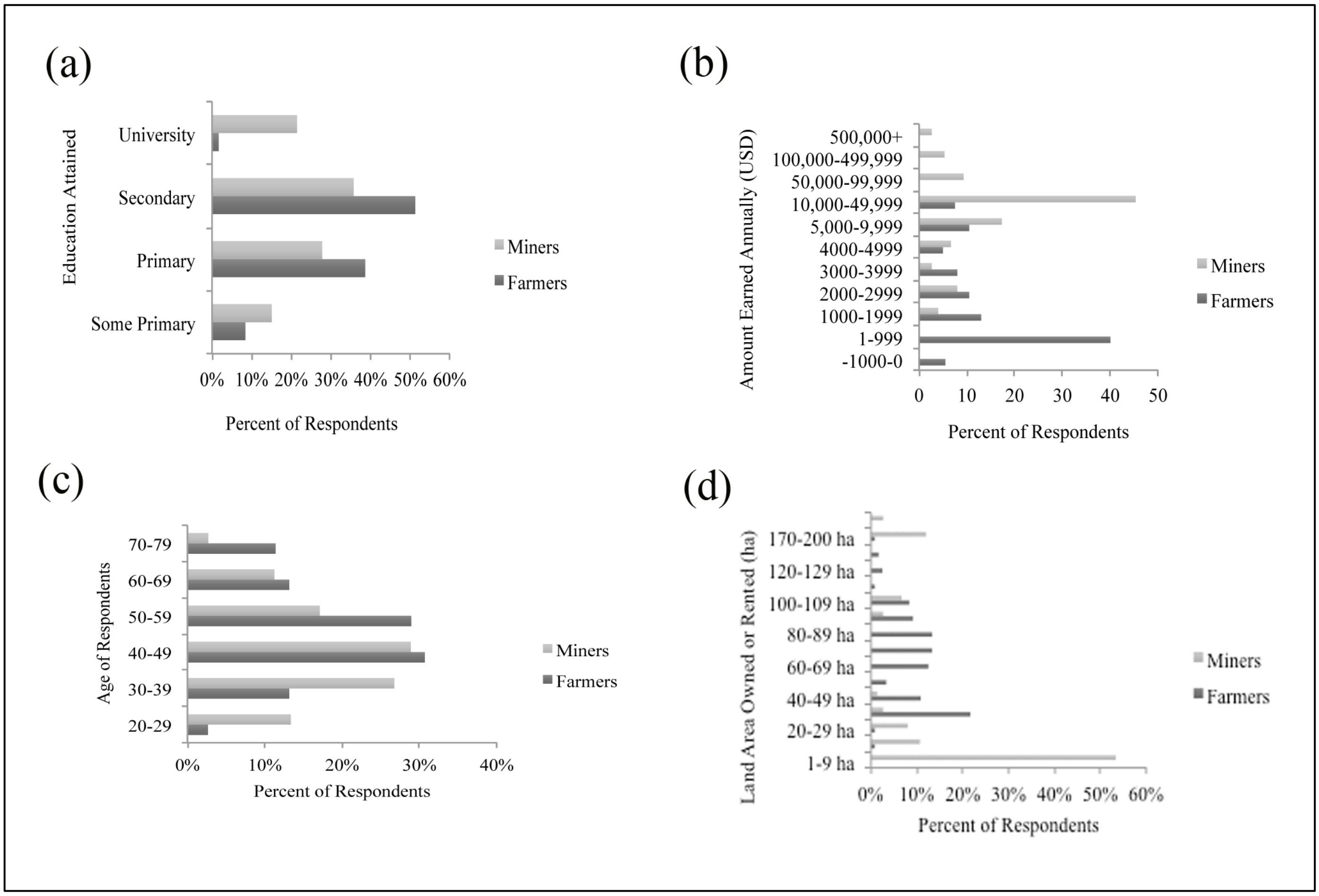

Figure 2. The figures above show the variability in personal demographics within and between the interviewed groups of miners and farmers. Figures: (a) Highest Level of Education Attained, (b) Annual Income, (c) Age, and (d) Size of Land Parcel or Concession

Contemporary Land-Use Practices of Gold Miners

When asked if they would take a job that paid the equivalent to their current income from gold mining, 66% of miners said they would take the alternative job. Also, when asked if they would take a job outside of mining that paid half as much as their current earnings, a majority (53%) of miners said they would accept the alternative job. When asked if they were currently engaged in forest conservation in their mining activities, 63% stated they were. Of those who reported practicing forest conservation, 50% stated they were reforesting or vegetating their concession, 22%

said they were "caring for their forest" (e.g., maintaining biodiversity and keeping people out), 14% were selectively cutting trees to avoid unnecessary tree damage, and 5% were restoring their mining sites after their work was completed. When asked whether they had any agreements with local farmers to mine gold on the farmer's properties, 72% stated they had such existing agreements.

Farmer Preferences for Proposed Forest Conservation Programs

Results from the interviews with farmers show a strong interest in the proposed forest conservation programs overall, but also high variability in the preferences favored by individuals (Figure 3). The hypothetical forest conservation program that gained the highest interest among farmers (97%) was trading technical assistance to improve agricultural practices in exchange for private forest conservation. The second most favored program was the alternative jobs program that matched their current salary (73%), followed by Payments for Ecosystem Services (PES) at \$145 ha yr^{-1} (67%), and lastly PES payments at \$72 yr^{-1} (40%), which are comparable to voluntary carbon payments paid by PES programs like REDD+ in 2011 (Butler et al. 2009)(see Figure 3 description).

Analyzing farmers' interest in PES payments relative to their individual parcel size and agricultural intensity highlights several patterns (Table 2). First, farmers with smaller parcels were more interested in PES than farmers with larger parcels. Second, commercial farmers were in general more interested in PES than subsistence farmers. Among farmers that said they would accept PES payments, reasons given were to increase forest conservation on their lands (53%), increase their personal income (20%), increase crop yields (12%), limit climate change (8%), and improve their ability to practice sustainable agriculture (4%).

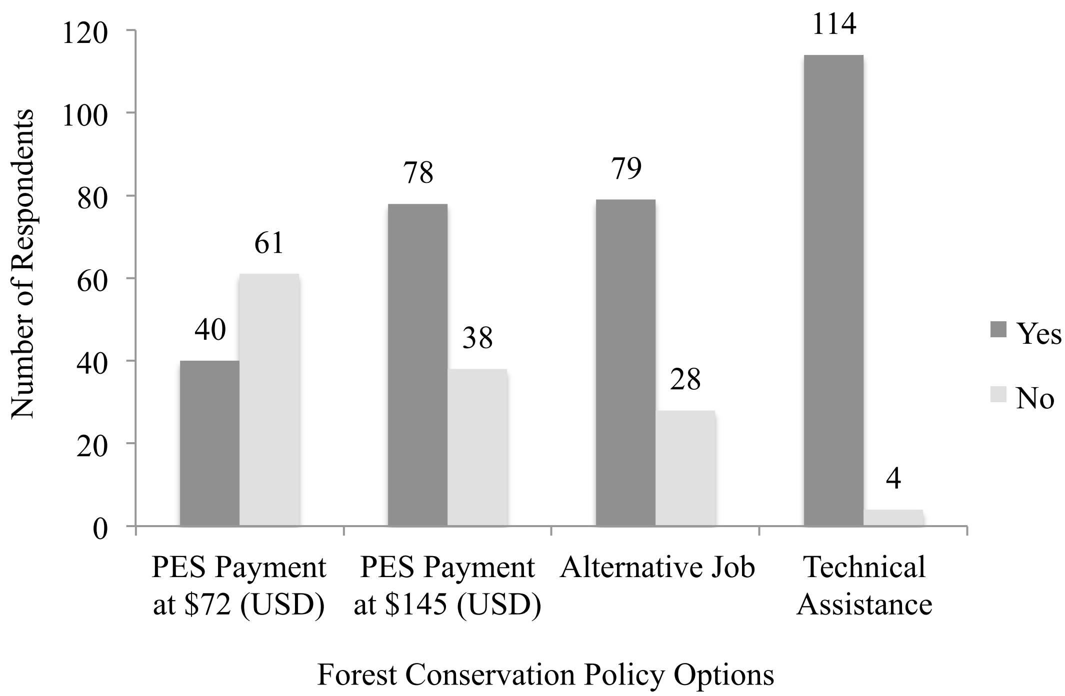

Figure 3: Farmer Preferences for Proposed Conservation Programs

The figure above shows farmers' stated interest in four hypothetical conservation programs. The average PES price per hectare paid is based on Butler et al. (2009), which provided an estimated per hectare voluntary carbon markets price of $72.54 (USD). For the policy option of 2x current PES prices, the estimated voluntary carbon market price provided by Butler et al. (2009) was doubled ($145.09). Prices were then rounded to the nearest US dollar. For the survey questions in the field, estimated prices were converted to the value of Peruvian Soles using the international exchange rate on November 15th 2011 ($2.708 Soles = $1 USD).

Table 2: Farmers Interest in PES Payments by Parcel Size and Agricultural Intensity

Interest by Parcel Size / Price	**≤60 ha**	**>60 ha**
PES at $72 (USD)	57%	26%
PES at $145 (USD)	77%	64%
Interest by Land-Use	**Commercial**	**Subsistence**
PES at $72 (USD)	42%	35%
PES at $145 (USD)	78%	63%

Table 2. The table above compares the interest of local farmers in PES payments relative to their self-reported parcel size and farming practices, i.e., commercial sales or subsistence. The analysis includes: (a) farmers with parcels ≤60 ha versus >60 ha, and (b) commercial farmers versus subsistence farmers. Sample sizes for each group were: Farmers with less than 60 ha (n=64); farmers with more than 60ha (n=55); commercial farmers (n=45); and subsistence farmers (n =75).

Future Land-Use Practices of Farmers

Farmers were asked to estimate the amount of forest cover they would retain on their property under several alternative future policy and economic scenarios (Figure 5). Farmers were asked to give an annual estimate of their forest clearing and the amount of forest allowed to recover over the last five years and results show they may be overestimating the amount of forest they will have in 2021. This conclusion is based on the farmers' survey responses, which showed a general belief that they would have an average of 33 ha of forest on their parcel by 2021. However, based on an extrapolation of their annual rates of forest clearance (2.5 ha per year) and forest recovery (0.9 ha per year) over the previous five years, farmers would not have any forest cover. Using the same estimation approach, only under the adoption of PES payments would individual farmers have net forest cover in 2021.

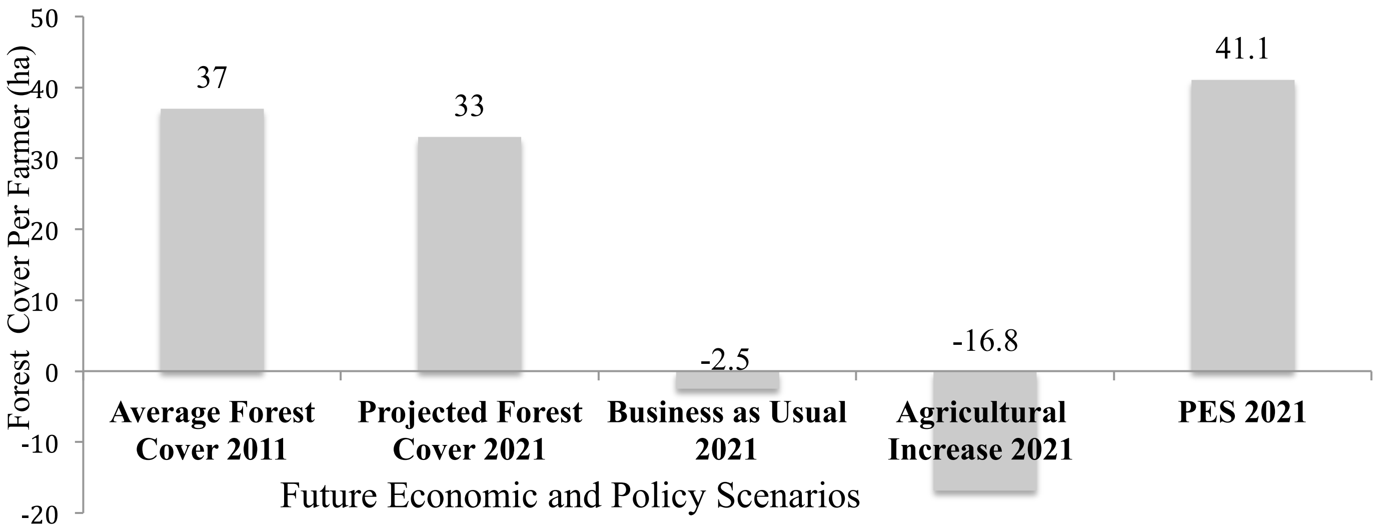

Figure 5. Forest Cover Projections for Private Agricultural Lands for the Year 2021

The figure above shows the estimated amount of forest cover in 2011 on farmers' private parcels compared to projections of forest cover for the year 2021 under alternative economic and policy scenarios. "Average Forest Cover 2011" is the average forest cover the farmers estimated on their properties in the year 2011. "Projected Forest Cover 2021" is an average of estimated forest cover reported by interviewed farmers for the year 2021. "Business as Usual" is based on farmers annual reported rates of forest clearing (2.4 ha) and regrowth (0.9 ha) from 2006-2011 and extrapolated to the year 2021 using forest cover in 2011 as the base year. "Agriculture Increase 2021" is an extrapolation to 2021 of the average increase in forestland farmers reported they would bring into agricultural production each year with increased crop prices. "PES 2021" is based on the average amount of forest cover farmers interested in PES payments who said they would enroll in a hypothetical PES program.

Discussion

Identifying High-Impact Forest Conservation Policies

To improve forest conservation outcomes through the refinement of existing policy instruments, frameworks are needed to support the design and selection of policies optimized for different conditions. Building on previous work to apply the leverage point framework to improve environmental policy outcomes (e.g., Margerum & Hooper 2001; Nguyen & Bosch 2013), this case study shows how field surveys of local land-users can identify leverage points to influence the local sustainability of forest resources and land-use choices.

To address ongoing forest governance challenges in the proposed MAT corridor, this research suggests important leverage points to improve forest conservation including the design of policies that focus on: (a) *economic incentives* for forest conservation, (b) *existing community norms and personal perspectives* on the values of forests, (c) *interest in technical knowledge* and acquiring the resources to implement sustainable farming and forest conservation, and (d) *existing forest conservation practices* (Table 3).

Table 3. Examples of Policy Options to Target Leverage Points in MAT Region

Leverage Point in MdD	**Example Conservation Policy Instruments**
Economic Incentives	PES payments, jobs programs, and tax incentives
Existing Norms and Values	Support co-benefiting projects, such as planting fruit trees, beekeeping, ecotourism, and handicrafts from native plants
Interest in Technical Knowledge	Support farmers in agroforestry, soil management, improving seeds, and other actions to increase agricultural productivity in exchange for forest conservation contract
Ongoing Conservation Practices	Identify and protect sensitive areas and large trees and encourage and support reforestation of mining sites

The table above shows example conservation policies that could be matched to probable leverage points to improve forest conservation outcomes in MdD.

Interests of MdD Land-Users in Forest Conservation Programs

As hypothesized, this study shows that forest conversion in MdD is not due to anti-environmental attitudes of land-users, but rather their personal circumstances (Moon & Cocklin 2011). For both gold miners and farmers surveyed, majorities within each group were interested in forest conservation activities or were actively engaged in them. Perhaps the most surprising result of this study, due to the intense expansion of the gold rush in MdD, is that 63% of the miners surveyed reported they were practicing some form of forest conservation on their lands. Given the limited influence of existing financial and regulatory incentives for forest conservation in MdD beyond ecotourism and protected areas (Kirkby et al. 2010), this finding indicates that some miners may hold intrinsic motivations for forest conservation. It is unclear however how accurate the stated responses are and how representative they are of gold mining activities regionally, which are known for their central role in regional environmental damage and deforestation (MINAM 2011; Swenson et al. 2011). Local farmers expressed high levels of interest in hypothetical conservation policies and a majority of those interested in PES payments (53%) said their rationale was to improve forest conservation on their properties. Other farmers reported similar conservation-oriented rationales in stating they would take the PES payments to combat climate change (8%) or to improve the sustainability of their agricultural operations (4%).

Together, these survey findings suggest that an important leverage point to improve forest conservation outcomes in MdD is to target new forest conservation policies at farmers and miners who have already expressed an interest or preference for forest conservation. This conclusion is also supported by the landholder literature, which shows that various groups of landholders have a high interest in conservation practices and issues (e.g., Tosakana et al. 2010; Greiner & Gregg 2010; Blackmore & Doole 2013) and that policies designed to build on an existing land ethic may be more effective than alternative strategies (Ahnstrom et al. 2007; Greiner et al. 2008).

This study found that farmers working in the proposed corridor are interested in a variety of forest conservation programs, including 97% who stated they would participate in a conservation program that exchanges access to agricultural technical assistance in exchange for conserving some of their private forests. In addition to the strong interest among farmers to receive technical assistance to improve their agricultural practices, a majority of farmers were also interested in alternative jobs programs equivalent to their current income (73%) and direct PES payments for conserving their forests at a price of \$145 ha yr^{-1} (67%). The only policy proposal that did not receive a majority of interest was PES payments at \$72 yr^{-1} (40%).

In addition to the conservation policies proposed in this study, other research conducted in MdD shows that local farmers are also interested in other types of forest conservation activities. For example, 70% of 359 farmers in Madre de Dios interviewed in another study in MdD expressed an interest in implementing agroforestry practices on their lands (A. García-Altamirano, unpublished data). Also, at a 2013 conservation planning workshop in the MAT region, a group of farmers meeting with the lead author proposed the creation of mutually beneficial forest conservation projects that could include receiving tree seedlings for forest restoration, planting fruit trees to co-benefit wildlife and personal incomes, and financial support to initiate ecotourism activities that would include the protection of biologically valuable areas (J.S., unpublished data). Collectively, these results show a strong interest among farmers in MdD for forest conservation policies compatible with their personal needs, preferences, and ethics. However, identifying the optimal policy choices remains a challenge, as the introduction of new incentives to conserve local forests could themselves incentivize practices that negatively impact forest conservation. For example, one concern is that increasing the technological capacity of local farmers could lead to increased deforestation through new profit-seeking behavior (See Villoria et al. 2014). Another concern related specifically to introducing PES payments is the risk of inadvertently influencing local land-user motivations for conservation and their perceptions of ecosystem value (Kosoy et al. 2008; Vatn 2010).

In MdD, engaging gold miners in forest conservation activities may prove more difficult compared to farmers given their comparatively high income and the low number of opportunities for co-benefiting production activities. This study nevertheless suggests that forest conservation leverage points exist even within local mining communities. An important conservation leverage point identified among this group is to scale up, reinforce, and expand existing forest conservation practices, such as reforestation and protecting sensitive areas. Additionally, as a majority of interviewed miners stated they would be willing to accept an alternative job at half their current income, another leverage point for miners may be policies focused on alternative job development and training.

Challenges to Conservation Policy Design and Implementation in MdD and Beyond

While various leverage points to improve forest conservation exist in MdD, this study also highlights several challenges that regional forest conservation policies must overcome. First, the results of this study show that PES payments at pricing comparable to existing voluntary carbon market payments (e.g., REDD+) may generate limited interest among farmers in the proposed corridor because PES payment pricing may not be competitive with local alternative land-uses or opportunity costs for forest conservation. The situation of PES payments being too low to compete with other land-user options has been highlighted in other contexts (e.g., Kosoy et al. 2007; Scullion et al. 2011; Alix-Garcia et al. 2014), which raises questions about the effectiveness of PES payment programs in landscapes with high-value land-use alternatives (Butler et al. 2009; Scullion et al. 2011). It has also been shown however that PES payment levels are only one reason among many that incentivizes land-users to enroll in PES programs, including social norms (Chen 2009) or being opposed to alternative land-use options, such as palm oil (Terauchi et al. 2014).

In addition to the high opportunity costs facing many land-users in MdD to engage in forest conservation, implementation of a regional PES program is also challenged by the high prevalence of conflicting land-use authorizations, e.g., mining concessions overlapping with agricultural and designated protected areas (Scullion et al. 2014). For example, in MdD some farmers stated they could not accept PES payments due to existing agreements with miners. This is likely a widespread phenomenon in MdD since 72% of miners interviewed stated they have agreements with farmers to gain access to their lands. In contrast, and importantly, some farmers commented they would enroll in a PES program to strengthen their tenure rights with the aim of keeping miners off their land.

Another factor likely to challenge the implementation of forest conservation policies in MdD is the variability of local landholders in their demographics, interest in conservation programs, and current practices. For example, farmers tended to be older, less educated, and earn far less income than gold miners, but they also reported more diverse sources of income and operated on larger land parcels compared to miners. Also, on average farmers with smaller parcels of land ownership were more interested in PES than farmers who owned larger parcels while commercial farmers were more interested in PES than subsistence farmers. The reasons underlying local differences in land-user demographics and policy preferences remains largely unknown but are likely to have important consequences for conservation policy design and selection. Similarly, the spatial heterogeneity of land-use practices in Amazonia has been highlighted as a challenging problem facing the implementation of new forest conservation policies, such as payments for ecosystem services (e.g., REDD+)(Eloy et al. 2012).

Also, while identifying the policy preferences of local farmers can be very helpful to inform policy-making at the local level, if such preferences are scaled to larger regions, the value of such "predictor variables" may be limited. The need for conservation policy design to account for land-user variability over large regions is supported by other studies, including a meta-analysis conducted by Knowler & Bradshaw (2007) that examined 31 conservation policy adoption studies and tested 167 distinct variables. They found the predicator variables that best explained the adoption of conservation practices were often inconsistent in whether an individual would select a particular policy option (Knowler & Bradshaw 2007). Research focusing on land-user variability and how it impacts land-use behavior tends to reinforce the principle that conservation policies are likely to work best when they are matched to local conditions (Cocklin et al. 2007; Ahnstrom et al. 2009).

This case study also highlights how an intelligently designed portfolio of policy instruments, or a "policy mix" (Chapman 2003), is likely to achieve the highest levels of enrollment and effectiveness. These findings also indicate that other approaches to designing robust forest conservation policies beyond calibrating policies with land-user demographics should be considered. For example, focusing on identifying the most effective conservation policies that change specific activities has been cited as an important alternative criterion for selecting conservation policies (Schirmer et al. 2012). An illustration of this approach in MdD is the Peruvian government's low taxation rate on tourism (Law 27037, "Promoting Investment in Amazon"), which has increased profit margins for the regional ecotourism industry that manages and conserves thousands of hectares of forestlands in the region (Kirkby et al. 2010).

Another important finding of this study is to show how uncertainty in future economic and political conditions can limit the ability to identify optimal conservation policies and whether local forests are actually vulnerable. In particular, the field surveys of farmers suggested the average amount of forest conserved on farmers' private lands in 2021 is likely to range widely (from 0 ha to 41 ha) depending on the economic and policy scenario selected. In turn, if one accepts farmer projections that in 2021 they would have an average of 33 ha of forest cover, one could likely assume forest connectivity in the proposed corridor is assured. However, if one assumes crop prices will double in the medium-term (or farmers will change their crops to earn higher returns), it is likely forests on agricultural lands in MdD are highly vulnerable to conversion, particularly those located next to roads (Laurance et al. 2009). An important lesson to draw from this finding is that policy design and selection at the local level should aim to identify what future uncertainties are likely to be most important and develop place-based policy portfolios accordingly.

Conclusion

This case study illustrated how the leverage point framework can be useful in identifying high-impact forest conservation policies available in this multi-use frontier landscape, including: economic incentives, technical incentives, and capitalizing on existing practices and preferences for forest conservation. It was also found that both local miners and farmers are interested in, or currently practice, a variety of forest conservation activities. The central policy suggestion is that even under the complex and rapidly changing landscape of MdD, a number of leverage points to improve forest conservation currently exist. To capitalize on such opportunities, efforts are required to address the existing socio-economic barriers and future economic and political uncertainties that challenge local policy design and selection processes.

This research shows that many local people in MdD are committed to working and living in the rural areas of the state, including in the proposed MAT corridor. This reality means that future forest conservation efforts in the region must create and sustain policies that mediate external incentives for forest loss and enable local people to sustainably manage local landscapes. Additionally, the diversity of landholder preferences for conservation in MdD highlights how the state includes a heterogeneous landscape populated by landholders making social and environmental tradeoffs based on a number of factors. Given that many of these factors, such as gold and crop prices, are in many respects outside the control of local and national governance systems, efforts to understand how forest conservation policies can be designed to moderate external incentives are a high priority. Additionally, efforts to identify leverage points to improve forest conservation outcomes would benefit from more place-based analyses of socio-environmental change and the efficacy of forest conservation policies.

CONCLUSION

The body of work presented in this dissertation highlights both the opportunities and challenges in achieving high-impact forest conservation outcomes in frontier environments. Each study presented provides a unique view on the causes and solutions to deforestation in frontier environments. Perhaps most importantly, this body of research shows that forest conservation efforts in frontier environments are not a lost cause. Rather, with ample resources, political will, and policies and strategies firmly guided by place-based and applied forest conservation science, the future of the earth's remaining intact forests can likely be assured.

This dissertation also shows however that the future of earth's intact forests is not assured. To get to such a day where earth's remaining intact forests are conserved, much progress is needed in developing the policy and conservation science vital to the design and selection of effective conservation policies and strategies. Below the key takeaways from each study are provided, followed by a set of design principles for forest conservation efforts in frontier environments.

Chapter 1. A Review and Meta-Analysis of Deforestation and Forest Conservation in Frontier Environments. Key takeaways from this study include:

a. There are few recent cases studies of frontier expansion in the developed world and most cases overall are from Latin America
b. Frontier environments exhibit dynamic and diverse processes, but also follow comparable trajectories with similar sets of drivers
c. Forest conservation strategies should address national politics and institutions, as well as international market incentives
d. Institutional and political failures are important factors in forest conservation outcomes and should be studied and mitigated

e. Protection and management are integral components of effective policies and strategies for forest conservation on the frontier

Chapter 2. The Influence of Land-Cover Change and Conflicting Land-Use Authorizations on Forest Conservation Outcomes in Madre de Dios, Peru. Key takeaways from this study include:

a. From 2006-2011, the protected area network in Madre de Dios experienced variable effectiveness and land-cover change processes

b. The importance of frontier governance is illustrated by the success of the parks and the failure of government to resolve conflicting land-use mandates

c. Ecosystem drivers were diverse and changed over time, highlighting the need for adaptive management strategies and frequent landscape monitoring

d. The presence of conflicting land-use authorizations, specifically gold mining concessions, is a significant factor in regional ecosystem loss and protected areas effectiveness. And an issue of growing global importance for conservation efforts.

Chapter 3. *Identifying Leverage Points to Improve Forest Conservation Outcomes*. Key takeaways from this study include:

a. Policy design and selection can benefit from understanding the practices and preferences of local land-users

b. A host of leverage points exist to conserve intact forests in the MAT and Madre de Dios, including:

    i. *(a) Economic incentives for forest conservation,*

    ii. *(b) Existing community norms and personal perspectives*

    iii. *(c) Interest in technical knowledge*

iv. *(d) Existing forest conservation practices*

Collectively, the studies presented in this dissertation highlight the opportunities and challenges of forest conservation in frontier environments. They also highlight how the unique features of frontier environments in both their diversity and similarity of landscape dynamics, which may offer the ability to design forest conservation policies and strategies optimized for use in frontier environments. To aid in the effort of designing conservation policies and strategies fit to local frontier conditions, the studies included provided the foundation from which to identify design principles for forest conservation in frontier environments. These **Design Principles for Forest Conservation in Frontier Environments** include and are not limited to:

- ✓ Policy design and selection should integrate local conditions and preferences of local land-users
- ✓ Conservation strategies should include a focus on governing institutions, national politics, and international markets
- ✓ Mutually reinforcing and diverse conservation policies should be implemented to account for the variability of frontier landscape dynamics and people
- ✓ Relevant management institutions should be adaptive and interact in a polycentric approach building on their respective institutional strengths and weaknesses
- ✓ Conservation efforts should aim to collaborate with and support local people and organizations that support forest conservation and sustainable resource use

In closing, the future of the earth's remaining intact natural forests remains in question, but with more informed and better resourced conservation efforts, their future can be assured. Perhaps what this dissertation teaches us most about forest conservation is that conservation science can provide the ability to improve our current efforts and make future efforts have even greater impact. Ultimately, however the future forest conservation efforts does not depend most on the state of our science, what matters more is the strength of forest governance institutions and pro-forest political constituencies. Unfortunately, all too often strong governance institutions pro-forest constituencies don't exist in sufficient strength where they are most needed, including regions throughout the developing world, the world's forest frontiers, and rural areas in the developed world. To develop both the science and political constituencies needed to conserve the last of the earth's great natural forests, the existing network of scientists focused on such efforts must be expanded and better resourced. Equally important, is imperative that greater effort is applied to growing and strengthening constituencies for forest conservation in frontier environments and beyond. Taken together, it is clear that conservation, forests, and people can co-benefit from well-designed forest management policies, and the perhaps the greatest challenge we face is how to develop and implement the balanced solutions required in the thousands of instances where they are currently needed. Through thoughtful science, advocacy, and politics, I remain optimistic we will get there.

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APPENDICES

Appendix 1. List of 81 Meta-Analysis Cases

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Appendix 2. Pre- and post-matching results from 'Match' study of conservation additionality

Designation Type	Control and Treatment Matches		Covariates	Before Treatment	Before Control	SD	T stat	After Treatment	After Control	SD	T stat
			Conflict	1.071	1.0269	17.172	3.20E-14	1.0278	1.0262	0.94442	0.086943
Indigenous Lands	Original number of observations (obs.)	100000	Deforested 01-06	0	0.014234	Inf.	< 2.22e-16	0.013695	0.016563	-2.4673	2.83E-05
	Original number of treated obs.	74831	Distance to Deforestation	1297.5	10316	-433.2	< 2.22e-16	10159	10055	0.81052	0.14412
	Matched number of obs.	63992	Distance_to_Highway	6797.4	15659	-147.12	< 2.22e-16	15534	15766	-1.7196	0.0018833
	Number of unmatched obs.	36008	Distance_to_River	1919	3171	56.522	< 2.22e-16	3142.6	3327.6	-6.2301	< 2.22e-16
			Elevation	274.09	316.6	-61.059	< 2.22e-16	315.95	309.78	4.7612	< 2.22e-16
			Soil_type	0.43644	0.40586	6.164	0.0064235	0.40538	0.39857	1.3868	0.013384
Park and Reserve Buffer Zone			Conflict	1.0911	1.0502	14.233	< 1.8111e-11	1.051	1.061	-4.5346	< 7.8604e-14
	Original number of obs.	100000	Deforested 01-06	0	0.018338	Inf.	<2.22e-16	0.017854	0.029074	-8.4728	< 2.22e-16
	Original number of treated obs.	88729	Distance to Deforestation	1361.5	5997.3	-220	< 2.22e-16	5887.4	6156	-3.0904	< 7.5842e-08
	Matched number of obs.	59537	Distance_to_Highway	6463.8	11750	-88.232	< 2.22e-16	11615	11744	-1.1308	0.050925
	Number of unmatched obs.	40463	Distance_to_River	2015.6	3410.8	-61.398	< 2.22e-16	3374.6	3652.8	-8.8726	< 2.22e-16
			Elevation	276.82	279.1	-3.1451	0.13688	278.83	284.35	-8.3719	< 2.22e-16
			Soil_type	0.37599	0.42638	-10.402	< 9.7459e-07	0.42726	0.40185	5.1372	< 2.22e-16
Ecotourism Concessions	Original number of obs.	200000	Conflict	1.0013	1.0039	-7.3503	0.00057915	1.0035	1	5.904	< 1.9124e-09
	Original number of treated obs.	99470	Deforested 01-06	0	0.018527	Inf.	<2.22e-16	0.017273	0.059539	-32.439	<2.22e-16
	Matched number of obs.	11470	Distance to Deforestation	1280.7	6373.6	-254.43	<2.22e-16	6185.8	4816.6	15.362	<2.22e-16
	Number of unmatched obs.	188530	Distance_to_Highway	6613.7	11943	-85.74	<2.22e-16	11686	6755.7	43.346	<2.22e-16
			Distance_to_River	1905.3	3497.3	-71.396	<2.22e-16	3449.8	2959	15.473	<2.22e-16
			Elevation	273.46	282.92	-13.765	< 4.601e-11	282.27	288.57	-9.5695	< 2.216e-13
			Soil_type	0.41373	0.43677	-4.6769	0.024905	0.43868	0.72373	-57.441	<2.22e-16
Conservation Concessions	Original number of obs.	100000	Conflict	1.0046	1.006	-2.1329	0.32607	1.0053	1.0011	5.8105	<2.22e-16
	Original number of treated obs.	92413	Deforested 01-06	0	0.017523	Inf.	<2.22e-16	0.017189	0.033925	-12.876	<2.22e-16
	Matched number of obs.	28681	Distance to Deforestation	1267.5	7298	-289.94	<2.22e-16	7265.9	7104.6	1.5664	0.064462
	Number of unmatched obs.	71319	Distance_to_Highway	6615.7	13302	-109.58	<2.22e-16	13261	13546	-2.2337	0.010374
			Distance_to_River	1992.9	3427.1	-61.476	<2.22e-16	3379	3710.2	-10.532	<2.22e-16
			Elevation	273.06	286.16	-18.939	<2.22e-16	285.92	285.87	0.080525	0.92258
			Soil_type	0.41457	0.40677	1.5824	0.46469	0.40996	0.42328	-2.708	0.0011831
Park & National Reserve	Original number of obs.	100000	Conflict	1.0017	1.0041	-5.5339	0.0099015	1.004	1.0006	5.381	<2.22e-16
	Original number of treated obs.	93889	Deforested 01-06	0	0.01748	In.f	<2.22e-16	0.01743	0.0036768	10.509	<2.22e-16
	Matched number of obs.	42972	Distance to Deforestation	1363.1	6271.9	-226.81	<2.22e-16	6125.3	7401.3	-14.442	<2.22e-16
	Number of unmatched obs.	57028	Distance_to_Highway	6362.8	12261	-97.971	<2.22e-16	12080	12273	-1.6893	0.011009
			Distance_to_River	1998.7	3423.9	-59.928	<2.22e-16	3376.7	3491	-3.6709	<1.4058e-07
			Elevation	271.97	279.02	-10.545	<6.318e-07	278.57	278.15	0.63694	<2.22e-16
			Soil_type	0.4102	0.4462	-7.3164	0.00054352	0.44655	0.42253	4.8308	<1.3363e-12
Brazil Nut Concessions	Original number of obs.	100000	Conflict	1.0014	1.0188	-46.854	<2.22e-16	1.019	1.0044	10.703	<2.22e-16
	Original number of treated obs.	90813	Deforested 01-06	0	0.017927	Inf.	<2.22e-16	0.017491	0.023218	-4.3683	<7.9775e-16
	Matched number of obs.	51340	Distance to Deforestation	1322.7	6334.2	-235.38	<2.22e-16	6262.4	4830.4	16.305	<2.22e-16
	Number of unmatched obs.	48660	Distance_to_Highway	6662.2	13632	-112.12	<2.22e-16	13580	16979	-26.064	<2.22e-16
			Distance_to_River	2021.5	3814.8	-77.464	<2.22e-16	3759	4054	-8.3004	<2.22e-16
			Elevation	272.8	282.29	-13.561	<5.0507e-10	282.02	281.63	0.62232	0.30475
			Soil_type	0.40065	0.39515	1.1215	0.60626	0.3972	0.33007	13.717	<2.22e-16
Conservation vs. Non-Conservation	Original number of obs.	100000	Conflict	1.1652	1.0744	24.433	<2.22e-16	1.0752	1.0831	-3.0038	<8.2752e-07
	Original number of treated obs.	58070	Deforested 01-06	0	0.012946	In.f	<2.22e-16	0.013001	0.0098751	2.7595	<8.3261e-07
	Matched number of obs.	56303	Distance to Deforestation	1212.7	9791.8	-436.6	<2.22e-16	9592.3	9226	3.0187	<3.607e-07
	Number of unmatched obs.	43697	Distance_to_Highway	6560.9	17240	-179.83	<2.22e-16	17006	16645	2.5746	<1.5717e-05
			Distance_to_River	2059.2	3306.4	-55.364	<2.22e-16	3290	3160.4	4.0563	<4.4791e-12
			Elevation	272.3	305.86	-50.382	<2.22e-16	305.13	301.14	3.3698	<5.57312e-09
			Soil_type	0.43028	0.36741	12.695	<2.9339e-07	0.36611	0.35674	0.077423	0.8965
Conservation vs. Conservation in Conflict	Original number of obs.	100000	Deforested 01-06	0	0.0047295	Inf.	<2.22e-16	0.0046783	0.0033574	1.9357	0.045491
	Original number of treated obs.	18243	Distance to Deforestation	1289.5	14406	-633.55	<2.22e-16	14394	14813	-2.935	0.0060098
	Matched number of obs.	18213	Distance_to_Highway	7651.6	24536	-304.02	<2.22e-16	24517	24378	0.99668	0.34789
	Number of unmatched obs.	81787	Distance_to_River	1937.7	3006.2	-52.511	<2.22e-16	3029.6	2840.6	5.9432	<6.3932e-09
			Elevation	269.03	336.07	-122.46	<2.22e-16	333.98	332.23	1.1211	0.27848
			Soil_type	0.5634	0.27595	57.923	<2.22e-16	0.27316	0.28086	-1.7293	0.10214

Appendix 3. Classified Land-Cover Maps of MdD 2001-2006-2011

Figure 1. 2001 classified land-cover map of study area. This map was produced from NASA's Landsat sensor ETM+ & TM. (Path/row 2/69). Overall accuracy is 87.7%, kappa .86.

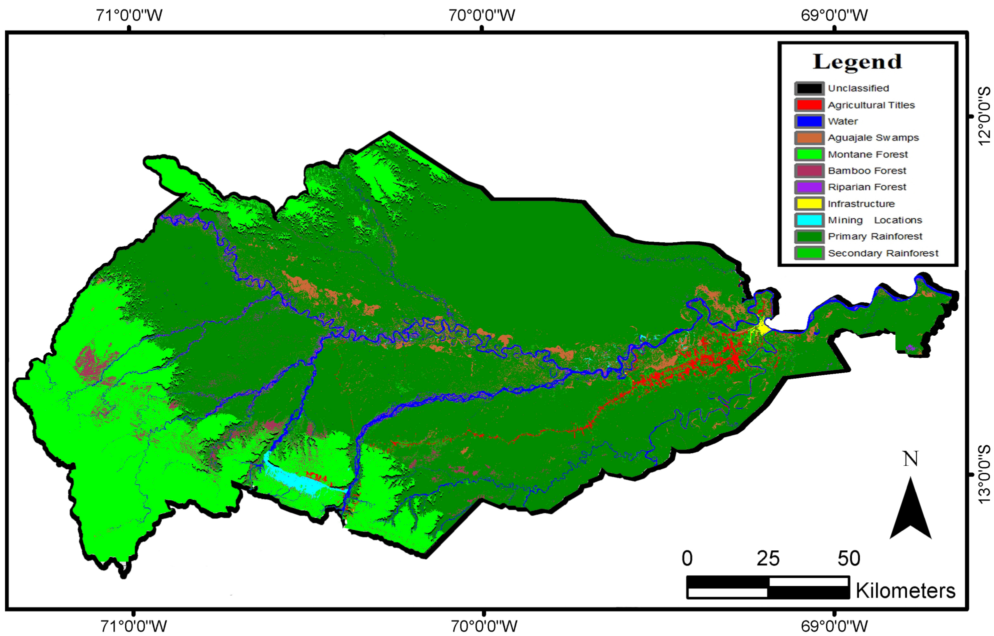


Figure 2. 2006 classified land-cover map of study area. This map was produced from NASA's Landsat sensor TM. (Path/row 3/68). Overall accuracy is 86.5%, kappa 85.1.

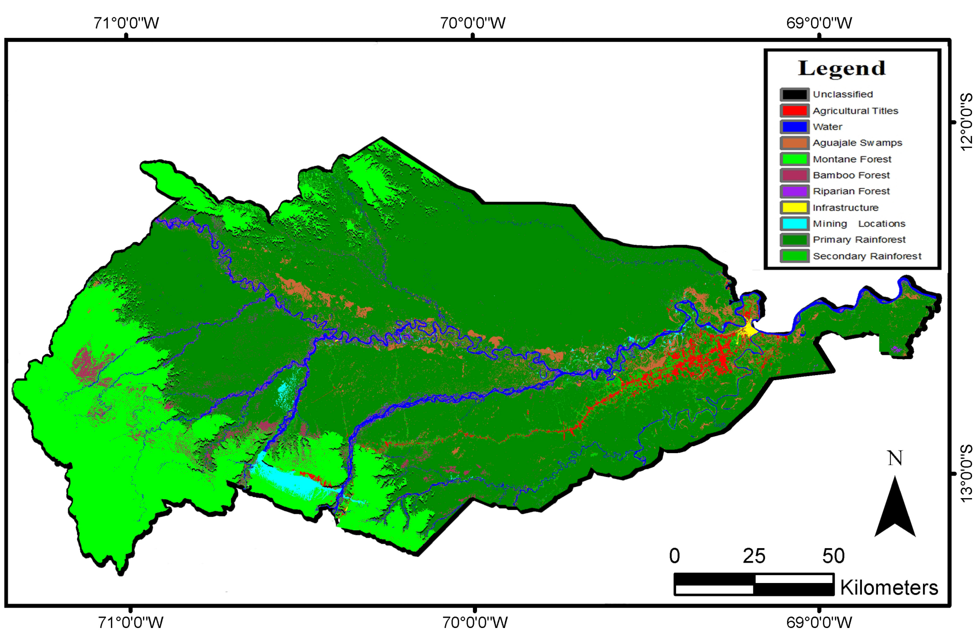
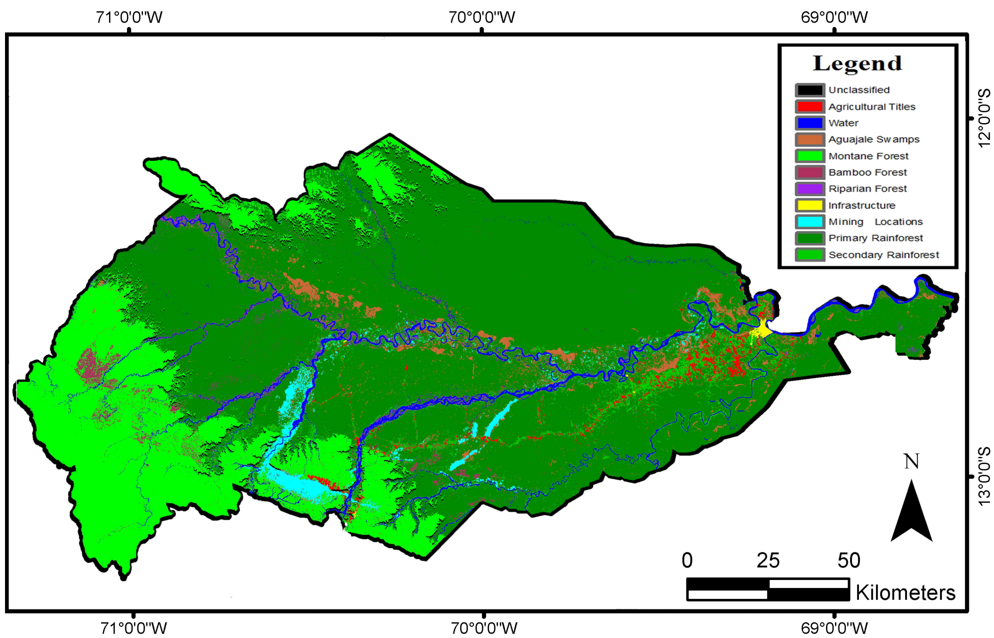


Figure 3. 2011 classified land-cover map of study area. This map was produced from NASA's Landsat sensor TM (Path/row 3/69). Overall accuracy is 86.1%, kappa 84.6.



Appendix 4. Confusion Matrices for MdD 2001-2006-2011 Land-Cover Classifications

2001 Confusion Matrix.
Overall Accuracy: 87.72% & **Kappa** = 0.863

Land Cover Types	**Ground Verification Points**											
	Agriculture	Aguajales	Bamboo	Montane	Riparian	Primary	Secondary	Mining	Infrastructure	Water	**Total**	**User Accuracy**
Unclassified	0	0	0	2	0	0	0	0	0	0	2	
Agriculture	54	0	0	0	0	0	3	0	13	0	70	77.1%
Aguajales	0	54	0	0	5	0	0	0	0	0	59	91.5%
Bamboo	0	0	51	0	0	0	0	0	0	0	51	100.0%
Montane	0	0	0	57	0	0	0	1	0	0	58	98.3%
Riparian	0	0	0	0	49	0	1	0	0	0	50	98.0%
Primary	0	6	3	1	3	59	14	0	0	0	86	68.6%
Secondary	6	0	6	0	1	1	42	0	0	0	56	75.0%
Mining	0	0	0	0	1	0	0	29	0	2	32	90.6%
Infrastructure	0	0	0	0	0	0	0	0	47	0	47	100.0%
Agua	0	0	0	0	1	0	0	0	0	58	59	98.3%
Total	60	60	60	60	60	60	60	30	60	60	570	
Producer Accuracy	90.0%	90.0%	85.0%	95.0%	81.7%	98.3%	70.0%	96.7%	78.3%	96.7%		

Figure 4. Confusion matrix for 2001 classified land-cover map. Confusion matrix land-cover abbreviations are: Agriculture (Agricultural Titles); Aguajales (Aguajale Swamps); Bamboo (Bamboo Forests); Montane (Montane Forest); Primary (Primary Forest); Secondary (Secondary Forest); Mining (Mining Locations); Infrastructure (Infrastructure); Water (Water).

2006 Confusion Matrix.
Overall Accuracy: 86.5% & **Kappa** = 0.8501

Land Cover Types	**Ground Verification Points**											
	Agriculture	Aguajales	Montane	Bamboo	Primary	Riparian	Secondary	Infrastructure	Water	Mining	**Total**	**User Accuracy**
Unclassified	0	0	0	0	0	0	0	2	0	0	2	
Agriculture	45	0	0	0	0	0	0	8	0	0	53	84.9%
Aguajales	0	54	0	0	3	6	1	0	3	0	67	80.6%
Montane	0	0	60	0	0	0	0	0	0	0	60	100.0%
Bamboo	0	0	0	47	0	0	1	0	0	1	49	95.9%
Primary	0	6	0	5	55	5	6	0	0	2	79	69.6%
Riparian	0	0	0	0	0	48	0	0	0	0	48	100.0%
Secondary	13	0	0	8	2	0	52	0	0	0	75	69.3%
Infrastructure	2	0	0	0	0	0	0	50	0	0	52	96.2%
Water	0	0	0	0	0	1	0	0	55	4	60	91.7%
Mining	0	0	0	0	0	0	0	0	2	53	55	96.4%
Total	60	60	60	60	60	60	60	60	60	60	600	
Producer Accuracy	75.0%	90.0%	100.0%	78.3%	91.7%	80.0%	86.7%	83.3%	91.7%	88.3%		

Figure 5. Confusion matrix for 2006 classified land-cover map. Confusion matrix land-cover abbreviations are: Agriculture (Agricultural Titles); Aguajales (Aguajale Swamps); Bamboo

(Bamboo Forests); Montane (Montane Forest); Primary (Primary Forest); Secondary (Secondary Forest); Mining (Mining Locations); Infrastructure (Infrastructure); Water (Water).

2011 Confusion Matrix.
Overall Accuracy: 86.17% & **Kappa** = 0.8464

Land Cover Types	**Ground Verification Points**											
	Agriculture	Aguajales	Bamboo	Montane	Primary	Secondary	Infrastructure	Water	Riparian	Mining	**Total**	**User Accuracy**
Unclassified	0	0	0	0	0	0	2	0	0	0	2	
Agriculture	48	0	0	0	0	0	9	0	0	2	59	81.4%
Aguajales	0	54	0	0	2	0	0	2	7	0	65	83.1%
Bamboo	0	0	53	0	0	2	0	0	0	0	55	96.4%
Montane	0	0	0	60	0	0	0	0	0	0	60	100.0%
Primary	1	6	2	0	52	1	0	0	8	0	70	74.3%
Secondary	7	0	5	0	6	57	0	0	2	1	78	73.1%
Infrastructure	2	0	0	0	0	0	49	0	0	0	51	96.1%
Water	2	0	0	0	0	0	0	58	0	14	74	78.4%
Riparian	0	0	0	0	0	0	0	0	43	0	43	100.0%
Mining	0	0	0	0	0	0	0	0	0	43	43	100.0%
Total	60	60	60	60	60	60	60	60	60	60	600	
Producer Accuracy	80.0%	90.0%	88.3%	100.0%	86.7%	95.0%	81.7%	96.7%	71.7%	71.7%		

Figure 6. Confusion matrix for 2011 classified land-cover map. Confusion matrix land-cover abbreviations are: Agriculture (Agricultural Titles); Aguajales (Aguajale Swamps); Bamboo (Bamboo Forests); Montane (Montane Forest); Primary (Primary Forest); Secondary (Secondary Forest); Mining (Mining Locations); Infrastructure (Infrastructure); Water (Water).

Appendix 5. Field Surveys Used in the MAT Corridor (In Spanish)

Farmer Survey Instrument (2013)

Preguntas Para Los Agricultores
Borrador 2

Prácticas actuales

1. ¿Cuál es su principal actividad económica? Es decir, ¿cómo se gana la vida?
   _______ Agricultura
   _______ Minería
   _______ Otro. ¿Cuál es? _____________

2. ¿Cuántos años tiene? ____________

3. ¿Cuál es el nivel más alto de educación que ha alcanzado? Seleccione uno.
   _______ Primaria
   _______ Secundaria
   _______ Educación superior

4. ¿Cuántas hectáreas tiene esta parcela de tierra? _______

5. En este momento, ¿cuántas hectáreas de esta parcela se utiliza para cultivos permanentes, cultivos anuales, bosques y pastos?
   _______ Cultivos permanentes
   _______ Cultivos anuales
   _______ Bosques
   _______ Pastos
   _______ ¿Algo más? ______________

6. ¿Qué porcentaje de sus terrenos cultivados anteriormente retornan a ser bosques frente a convertirse en pasto?
   _______ Bosques
   _______ Pasto
   _______ Otro

7. Indique el porcentaje de los productos producidos en esta granja o rancho que son para la venta comercial. Igualmente, indique el porcentaje que son para el mantenimiento personal o subsistencia.

_______ Venta comercial
_______ Subsistencia
_______ Otro
_______ No sé

5. En los últimos cinco años, ¿cuántas hectáreas de bosque fueron retirados en esta parcela cada año?
_______ Este año
_______ El año pasado
_______ Hace dos años
_______ Hace tres años
_______ Hace cuatro años
_______ Hace cinco años

Prácticas Futuras

1. Suponga que de aquí hasta dentro de veinte años los precios relativos de los cultivos no cambian y usted sigue cultivando esta tierra. ¿Cómo se imagina que su propiedad se verá en términos de porcentaje de pasto, bosque primario, bosque secundario, y los cultivos?
   _______ Pasto
   _______ Bosque primario
   _______ Bosque secundario
   _______ Cultivos

2. Suponga que los precios de sus cultivos se duplicaran. ¿Incrementaría el área total de su tierra dedicado a la cultivación?
   a. Sí / No
   b. Si sí, ¿cuántas hectáreas aumentaría (no incluyendo el área que actualmente cultiva)? ___________________

3. Suponga que los precios del ganado se duplicaran. ¿Incrementaría el área total de su tierra dedicado a la pastura?
   a. Sí / No
   b. Si sí, ¿cuántas hectáreas aumentaría (no incluyendo el área que actualmente usa para la pastura)? _________________

4. Imagínese que tiene una oportunidad de ganarse la vida con un trabajo a tiempo completo relacionado a la conservación. Por ejemplo, un trabajo en piscicultura o en el ecoturismo. Si este trabajo relacionado a la conservación le compensara con un ingreso comparable a lo que

actualmente tiene como agricultor o ranchero, ¿tomaría este nuevo trabajo o seguiría trabajando en su trabajo actual?

_______ Trabajaría en agricultura o ganadería
_______ Trabajaría en conservación
_______ No sé

a. Si indicó que tomaría el trabajo en conservación, continuaría de todas maneras la actividad agrícola o ganadera en su tierra a la misma escala? O sea, si usted no tiene el tiempo para cultivar su tierra, podría arrendar su tierra, emplear a personas para trabajar su tierra, etc. y así podría continuar la actividad agrícola o ganadera.
    i. Sí / No

5. Si se le ofreciera pagos anuales de $72.54 Soles por hectárea/año por más de veinte años para conservar los bosques existentes en sus tierras, aceptaría las pagos?
    a. Sí / No
    b. ¿Por qué sí o por qué no aceptaría usted estos pagos?

____

____

6. Si se le ofreciera pagos anuales de $145.09 Soles por hectárea/año por más de veinte años para conservar los bosques existentes en sus tierras, aceptaría los pagos?
    a. Sí / No
    b. ¿Por qué sí o por qué no aceptaría usted estos pagos?

____

____

7. Si se le ofreciera asistencia técnica y fertilizantes para mejorar el rendimiento de los cultivos anuales con la condición de que usted conserve sus bosques restantes, ¿aceptaría usted esta ayuda con la condición de conservar sus bosques restantes?
    a. Sí / No

Miner Survey Instrument (2013)

Preguntas Para Los Mineros

Numero de Identidad:________________

Fecha:____________________

Lugar:_________________

Objetivo: Comprender las prácticas *actuales* del uso de la tierra y también la demográfica de los mineros.

1. ¿Cuántos años ha vivido en Madre de Dios? ________

2. ¿Cuántos años tiene? ________

3. ¿Cuántos años ha estado trabajando en la minería? ________

4. ¿Cuál es el nivel más alto de educación que ha alcanzado? Seleccione uno:
   ___ Primaria
   ___ Secundaria
   ___Educación superior

5. Si el precio del oro permanece en o cerca del precio actual, ¿continuaría trabajando en la minería?
   a. Sí / No
   b. Si sí, ¿por cuántos años? ________

6. ¿Trabaja con otras personas (o sea, puede ser jefe de un grupo o simplemente una persona en el grupo), o trabaja por su cuenta? Seleccione uno:
   ___ Trabajo con otras personas
   ___ Trabajo por mi cuenta

*Si trabaja con otras personas, continúe a la pregunta 7. Si no, prosiga a la 10.

7. ¿Es dueño de su propia operación minera o trabaja para otra persona? Seleccione una de las siguientes opciones:
   ___ Soy dueño de una operación minera
   ___ Trabajo para otra persona
   ___ Hago los dos

8. ¿Cuántas personas hay en su grupo? ________

9. ¿Cuánto gana en promedio por mes su grupo o su operación minera? ________

10. ¿Cuánto gana usted en promedio por mes, como individuo, de su trabajo en la minería? ________

Objetivo: Comprender las prácticas futuras del uso de la tierra por los mineros.

1. Suponga que ya no puede trabajar en la minería por razones de regulaciones del gobierno o porque los precios del oro están ya muy bajos. ¿Qué haría usted? Seleccione una de las opciones siguientes:
   ___ Me quedaría en Madre de Dios
   ___ Me iría de Madre de Dios
   ___ No sé lo que haría.

*Si respondió que se "quedaría," continúe a la pregunta 2. Si no, sigua a la 3.

2. ¿Qué haría si se quedara en Madre de Dios? Seleccione una de las opciones siguientes:
   ___ Intentar de establecer un rancho o predio agrícola en mi tierra propia.
   ___ Trabajar la tierra de otra manera
   ___ Buscar un empleo rural y local
   ___ Buscar un empleo en la ciudad
   ___ Ninguna de las anteriores.

3. Suponga que el precio del oro se duplicara durante el año que viene. O sea, a partir de este mes hasta un año de ahora. ¿Cambiaría la manera en que trabaja en la minería haciendo lo siguiente? Seleccione todas las opciones que correspondan:
   ___ Trabajaría más horas.
   ___ Emplearía trabajadores.
   ___ Trabajaría más terreno por mes.
   ___ Ninguna de las anteriores.

4. Otra vez, suponga que el precio del oro se duplicara durante el año que viene. ¿Conoce a personas que viven afuera de Madre de Dios y que vendrían a trabajar en las minas a causa de este incremento de precio? Es decir, no vendrían a trabajar en la minería en Madre de Dios si los precios se quedaran iguales.
   a. Sí / No
   b. Si sí, ¿cuántas personas? ________

5. Suponga que pudiera ganar la mitad de su ingreso anual actual por medio de un empleo local en piscicultura o en ecoturismo. ¿Continuaría trabajando en la minería o escogería trabajar en el otro empleo local? Seleccione uno:
    ___ Continuar trabajando en la minería
    ___ Trabajar en el otro empleo local

6. Suponga que pudiera ganar su ingreso anual actual por medio de un empleo local en piscicultura o en ecoturismo. ¿Continuaría trabajando en la minería o escogería trabajar en el otro empleo local? Seleccione uno:
    ___ Continuar trabajando en la minería
    ___ Trabajar en el otro empleo local