Genesis of an indigenous social-ecological landscape in eastern Panama

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April 2015

A thesis submitted to McGill University in partial fulfillment of the requirements of the degree of a Master of Science

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ABSTRACT

In the face of global deforestation, and given the dependence of rural communities on forests for livelihoods, diverse and interconnected ecological and social drivers of land use change must be identified for successful conservation. The first chapter of this thesis focuses on land uses, analysing perceived influences on decision-making, and addressing historical factors and gendered perspectives as salient but poorly studied influences on the landscape. The case study was conducted in an indigenous communal land of eastern Panama that has experienced high deforestation since village settlement. We completed participatory mapping of lands, conducted semi-structured interviews and carried out participatory activities including wealth ranking, historical timeline creation and pebble scoring of historical land uses. Multivariate results derived from numerical ecology methods highlight the importance of historical factors like timing of settlement and place of origin on influencing the pasture-dominated communal landscape. We find gendered perspectives on landscape influences; men are more concerned with ecological influences and women with social-cultural. Traditional land use practices influence decision-making but ultimately decisions are guided by subsistence concerns. The second chapter provides a comparison of land uses and of the social-ecological factors that influence them in two communal lands that are similar in terms of known drivers of land use change but have differing land use trajectories. Spatial analysis of participatory maps using Geographic Information Systems (GIS) and remotely sensed Global Forest Watch (GFW) deforestation data illustrate the influence of topography as a key factor explaining differential forest cover. Additionally, qualitative analysis suggests the potential impact of historical factors on the landscape, including timber extraction, the presence of NGOs and scientific collaborators, and the strength of local leadership. We also compared GFW deforestation data to participatory data, to identify the usefulness of these new open source data as a local forest-monitoring tool. We find that, for applications on the ground, GFW data should be verified with local land users to ensure local relevance in areas with dynamic, complex mosaics of land uses. The research presented here illustrates the nexus of ecological and social influences on a landscape, as well as the potential for successful participatory engagement with locals and effective interdisciplinary science within a single study.

RÉSUMÉ

Étant donné la déforestation mondiale, et compte tenu de la dépendance des communautés rurales sur les forêts pour les moyens de subsistance, les facteurs interconnectés écologiques et sociaux de l'utilisation des terres doivent être identifiés pour une conservation efficace. Dans le premier chapitre de cette thèse, nous examinons les utilisations des terres, analysons les influences perçues sur la prise de décision, et étudions les facteurs historiques et les perspectives déterminées par le sexe, qui sont des influences sur le paysage importantes mais moins reconnues. Une étude de cas a été menée dans un territoire communautaire indigène du Panama de l'Est qui a connu une forte déforestation depuis la colonisation du village. Nous avons terminé la cartographie participative des terres, mené des entrevues semi-structurées et organisé des activités participatives telles que le classement de richesse, la création d'une chronologie historique, et la notation de l'utilisation des terres historique en utilisant des pierres. Les résultats multifactoriels issus de méthodes d'écologie numérique mettent en évidence l'importance des facteurs historiques sur le paysage communal où les pâturages dominent, tels que le lieu d'origine et le moment d'établissement des familles. Nous trouvons que les perspectives quant à les influences sur la terre sont déterminées en partie par le sexe; les hommes sont plus préoccupés par les influences écologiques sur le paysage, les femmes par les influences socio-culturelles. La prise de décision sur l'utilisation des terres est en partie influencée par les pratiques traditionnelles, mais surtout déterminée par les besoins de subsistance. Dans le deuxième chapitre, nous comparons dans deux terres communales l'utilisation des terres et les facteurs socio-écologiques qui l'influencent. Ces terres sont similaires en terme de moteurs connus de l'utilisation des terres, mais ont des trajectoires d'utilisation des terres différentes. L'analyse spatiale des cartes participatives utilisant des systèmes d'information géographique (SIG) et les données de déforestation du Global Forest Watch illustrent la topographie comme un facteur clé expliquant le couvert forestier différentiel. Aussi, l'analyse qualitative suggère que des facteurs historiques comme 1) l'extraction du bois, 2) la présence d'ONG et de collaborateurs scientifiques, et 3) les qualités des dirigeants locaux ont un impact potentiel sur l'utilisation des terres. Nous avons comparé les données de déforestation du GFW et les données participatives pour identifier l'utilité de ces nouvelles données open source en tant qu'outil de surveillance de forêt locale. Cette comparaison démontre que, pour les applications sur le terrain, les données du GFW doivent être vérifiées par les utilisateurs des terres locales. Ainsi la pertinence locale serait assurée dans les zones ayant des mosaïques complexes et dynamiques de l'utilisation des terres. La recherche présentée ici illustre le lien entre les influences écologiques et sociales sur un paysage, ainsi que le potentiel d'engagement participatif auprès des habitants et de la science interdisciplinaire au sein d'une seule étude.

RESUMEN

Frente a la deforestación mundial y, dada la dependencia de las comunidades rurales de los bosques para los medios de vida, diversos e interconectados factores ecológicos y sociales del uso de la tierra deben ser identificados para la conservación exitosa. El primer capítulo de esta tesis se centra en los usos del suelo, el análisis de las influencias percibidas en la toma de decisiones, y hacer frente a los factores históricos y los perspectivos de género como influencias más destacadas pero poco estudiadas sobre el paisaje. El estudio de caso se llevó a cabo en una tierra comunal indígena del este de Panamá, que ha experimentado una alta deforestación desde el asentamiento del pueblo. Completamos el mapeo participativo de las tierras, realizamos entrevistas semi-estructuradas y llevamos a cabo actividades participativas incluyendo la clasificación de la riqueza, la creación de una línea de tiempo histórica y la puntuación de los usos de la tierra históricos usando piedras. Los resultados multivariantes derivados de métodos de la ecología numérica ponen de relieve la importancia de los factores históricos como el momento del asentamiento y el lugar de origen como influencias sobre el paisaje comunal donde los pastos dominan. Encontramos que los perspectivos acerca de las influencias sobre la tierra son determinados en parte por el género; los hombres están más preocupados por las influencias ecológicas y las mujeres por las socio-culturales. Las prácticas tradicionales del uso del suelo influyen en la toma de decisiones, pero en última instancia, las decisiones se guían por las preocupaciones de subsistencia. El segundo capítulo se ofrece una comparación de los usos del suelo, y de los factores socio-ecológicos que influyen en ellos, en dos tierras comunales que son similares en términos de controladores conocidos del uso de la tierra, pero que tienen diferentes trayectorias del uso del suelo. El análisis espacial de los mapas participativos, utilizando Sistemas de Información Geográfica (SIG) y datos de deforestación del Global Forest Watch, ilustran la influencia de la topografía como factor clave que explica la cobertura forestal diferencial. Además, el análisis cualitativo sugiere el impacto potencial de factores históricos sobre el paisaje, como la extracción de madera histórica, la presencia de organizaciones no gubernamentales (ONG) y colaboradores científicos, y la fuerza del liderazgo local.

Comparamos los datos de deforestación del GFW con los datos participativos para identificar su utilidad como herramienta del monitoreo del bosque local. Los resultados ilustran que, para las aplicaciones en el terreno, los datos de GFW deben ser verificados con los usuarios de la tierra locales. Así se podría asegurar su relevancia local en zonas con complejos y dinámicos mosaicos de los usos del suelo. La investigación que aquí se presenta ilustra el nexo de las influencias ecológicas y sociales en un paisaje, así como el potencial de compromiso participativo con los lugareños y la ciencia interdisciplinaria eficaz en un solo estudio.

ACKNOWLEDGEMENTS

This research was funded by the Natural Sciences and Engineering Resource Council of Canada (NSERC) via an Alexander Graham Bell Canada Graduate Scholarship-Master's Program, as well as the *Fonds de recherche du Québec – Nature et technologies* (FQRNT) via a Master's research grant (*bourse de maîtrise en recherche*), and the Biology Department of McGill University for travel and research in Panama via Graduate Research Enhancement and Travel Awards. Travel to the International Alliance of Research Universities (IARU) Sustainability Science Congress in Copenhagen, 2014, where the first chapter of this research was presented as a poster, was made possible by the *Centre d'étude de la forêt* (CEF) travel grant and the McGill Biology Department Graduate Research Enhancement and Travel Awards. The broader project of Professor Catherine Potvin, within which my research is embedded, is funded by the Margaret A. Cargill Foundation.

I would like to personally thank Dr Potvin for her constant guidance throughout the research process, for establishing the relationship of collaboration between McGill, the Smithsonian Tropical Research Institute (STRI) and the indigenous Emberá of eastern Panama, and for being an inspirational role model as a trailblazing woman in interdisciplinary science. I would also like to thank Ana Spalding, Jeanine Rhemtulla and Lauren Chapman, members of my supervisory committee, for reviewing proposals and manuscripts, providing research advice in their respective fields and leading me to new insights. I am very grateful to Ignacia Holmes, Leidy Mancilla, Gerardo Vergara Asenjo, José Monteza and Javier Mateo Vega for their counsel and collaboration in all stages of the research. I would like to thank Mélanie Desrochers of CEF, Milton Solano of STRI, Pablo Arroyo of the McGill Geography Department and Carlos Gordon of Metromapas for their indispensable expertise in Geographic Information Systems, and Stéphane Daigle and Marc Mazerolle of CEF for their invaluable guidance with statistics and statistical software. I would also like to thank STRI for creating an environment that fosters scientific innovation and dialogue between international fellows and researchers. Finally, I would like to thank Claire Salisbury for her advice in the writing process, and Alex Tran for help with the graphic design of figures and posters and for his photography in the field.

The continued support, guidance and vision of Rodolfo Cunampio, second chief of the General Congress of the Upper Bayano, was foundational to this research from its onset through to its conclusion. Furthermore, the research could not have been realised without the field assistance, brainstorming sessions and friendship of Malala Cunampio, Raquel Cunampio and Mara Cunampio. Data collection in Piriatí and Ipetí would not have been possible without the knowledge of Bonarge Pacheco, Bolívar Jaripio, the team of local field technicians, Alfredo Garabato, Abdiel Omi, Ángel Ruiz and Jaime Caisamo, and the participation and interest of the community members of Piriatí-Emberá.

PREFACE & CONTRIBUTION OF AUTHORS

This research is presented as a manuscript-based thesis containing two manuscripts written for peer-reviewed publication. The manuscripts are connected by a linking statement and bookended by a general introduction and conclusion. The first manuscript is currently under review in Ecology & Society.

Brainstorming of research goals and methodology was a collaboration between myself, Malala, Raquel, Mara and Rodolfo Cunampio, and Dr Potvin. I am responsible for the organisation of fieldwork, and data collection, analysis and write-up, all with the aid of the aforementioned contributors. While data collection in Piriatí-Emberá was carried out by myself and Malala, Raquel and Mara Cunampio, data collection in Ipetí-Emberá was conducted by Ignacia Holmes, Petra Tschakert, Xoco Shinbrot and Julie Raynaud. Participatory mapping in 2012 in both communities was begun by co-author Gerardo Vergara Asenjo with the help of local technicians, which I then validated in Piriatí. Leidy Mancilla coordinated additional data collection in Piriatí and Ipetí with the help of José Monteza and current and past local leaders, namely Bonarge Pacheco, Bolívar Jaripio and Rodolfo Cunampio. The second chapter was in collaboration with Ignacia Holmes, a Ph.D. candidate in Dr Potvin's lab, who supplied the data from Ipetí and helped with the intellectual process, such as initial ideas for data analysis based on previous analyses on Ipetí conducted with Alex Hill. Co-author William N. Miller was responsible for data collection on historical timber extraction in the region, including interviews and archival research, as part of his internship under the supervision of Dr Potvin and myself for the Panama Field Study Semester in 2014.

Given the human-focused nature of the research process in terms of participatory methods, I provide here a brief self-description to shed light on my positionality. I am a multilingual Canadian woman of North Indian heritage, born in 1990. I was born and raised in suburban Montréal, but spent my high school years in the United Kingdom, after which I completed a *Diplôme d'études collégiales* (DEC) in Honours Science in Montréal. I completed a Bachelor of Science in Environment, with a minor in Hispanic Languages, at McGill University in 2009. I am generally interested in the nexus of environmental and social issues and the application of knowledge towards conservation goals.

GENERAL INTRODUCTION

This thesis adopts a broad, interdisciplinary science perspective to the study of indigenous landscapes. As such, the introduction presented below is a review of fields pertinent to the thesis, namely: global deforestation; ecosystem services and Indigenous Peoples; social-ecological systems; participatory research and past research on land use/land cover change.

Global deforestation

Global deforestation, defined as a permanent land use change (Houghton 2012), is occurring at an alarming rate. According to the World Wildlife Fund, over half of the world's forests had already disappeared fifteen years ago (WWF 1998). In its most recent assessment, the Food and Agriculture Organization estimated that over three per cent of the world's forests were lost between 1990 and 2010, with an annual rate of loss of 0.14% between 2005 and 2010 (FAO 2010). Documented drivers of deforestation include: extension of cropland; pasture conversion, especially in Latin America; peatland degradation; and timber extraction of both industrial and fuel wood (Houghton 2012). Shifting cultivation, also known as swidden or slash-and-burn agriculture, is the cyclical rotation of agricultural plots to allow for fallow regrowth and restoration of soil fertility (Lanly 1985; Sirén 2007). In that sense, traditional shifting cultivation, while removing forest cover temporarily, cannot be considered deforestation. However, one of the main drivers of deforestation is shifting agriculture that is no longer "traditional", where fallow does not grow back to forest given shortened fallow lengths following population pressure (Myers 1992; UNEP 1992; Bandy et al. 1993, as cited by O'Brien 2002; Tinker et al. 1996; Kotto-Same et al. 1997; Fischer & Vasseur 2000; Styger et al. 2007). Between 1850 and 1985, 28% of Latin America's forests were lost, 44% of which was due to conversion to pasture, 25% to cropland, 20% to land degradation and 10% to shifting cultivation (Houghton et al. 1991; see Geist & Lambin (2002) for a deeper discussion of drivers of tropical deforestation).

One of the consequences of deforestation is the loss of livelihoods of forest dwellers (Laurance 1999; Sunderlin et al. 2005; Larson & Petkova 2011; Shackleton et al. 2011). Forest dwellers are estimated to account for more than one billion extremely poor people around the world (World Bank 2004; Larson & Petkova 2011). Of these, the majority are rural and about one third, or 370 million, are Indigenous Peoples (IP; UNDESA 2009; Enns et al. 2014). Thus, an understanding of the causes and effects of deforestation must address the role that these forest dwellers play in land use change and its influences on their livelihoods.

Ecosystem services and Indigenous Peoples

The concept of ecosystem services articulates the values humans derive from the environment, and the consequences of human-induced changes to ecosystems on both the functioning of the Earth system and human well-being (Costanza et al. 1997; Nasi et al. 2002; Hooper et al. 2005; Carpenter et al. 2009). Ecosystem services have been categorised as provisioning, regulating, cultural and supporting, and occur at both local and global scales (MEA 2005a). It has been put forth that biodiversity supports these ecosystem services by enhancing ecosystem functioning (Chapin et al. 1999; Nasi et al. 2002; Hooper et al. 2005; Cardinale et al. 2012). For example, plant biodiversity is associated with protection from invasive plants and pathogens, greater carbon sequestration and improved nutrient cycling (Cardinale et al. 2012). Tropical forests in particular provide a multitude of ecosystem services. These include: biodiversity refuges; carbon sequestration and, therefore, climate change mitigation; evapotranspiration and absorption of solar radiation and, therefore, climate regulation; habitat for pollinators; nutrient cycling; protection from erosion; maintenance of hydrological systems and water quality; disease regulation; air filtration; seed dispersal; supply of timber and fuelwood; nutrition; shade and recreation (Ehrlich 1983; Myers 1997; Laurance 1999; Nasi et al. 2002; World Bank 2004; MEA 2005a; Foley et al. 2007; Lawrence et al. 2007). Moreover, for Indigenous Peoples, forests are not only dwellings but also house traditional medicine, culturally useful plants, hunting animals and spiritual refuges (Laurance 1999; Nasi et al. 2002; MEA 2005a; Larson & Petkova 2011). Thus tropical deforestation and subsequent biodiversity loss threaten the ability of forests to provide these intangible global services (Vitousek et al. 1997; Carpenter et al. 2009), but also to supply local services and therefore the livelihoods of indigenous forest dwellers (MEA 2005b).

Understanding the drivers of deforestation in indigenous areas, which has broader consequences on the Earth system, requires an understanding of land use decision-making by rural forest dwellers. Not only is decision-making influenced by the perceived services locals derive from their forests (Castillo et al. 2005), but subsequent land use changes feed back to influence the provision of these local and global ecosystem services (Nasi et al. 2002; Defries et al. 2004; Foley et al. 2007; Duguma & Hager 2011). Eastern Panama is part of one of the most biodiverse terrestrial ecoregions in the world, the Chocó-Darién moist forest (Olson et al. 2000). Indigenous frontier landscapes in eastern Panama are typified by mosaics of land uses and secondary forests (Wali 1993; St-Laurent et al. 2013; Vergara-Asenjo et al. 2015), which can have particular consequences for ecosystem service provision, for example in terms of biodiversity protection (Nakagawa et al. 2013). Indigenous Peoples have historically been engaged in conflict with entities that have invaded their territories: extractive industry but also small-scale colonist farmers in frontier zones like eastern Panama (Herlihy 1985; Wali 1989; Wali 1993; Horton 2006; St-Laurent et al. 2013). IP tend to practise traditional shifting cultivation, and have been doing so in Panama for thousands of years (McKay 1990, as cited by Fischer & Vasseur 2000). As indigenous groups have had to face encroachment, globalisation and modernisation, the scholarly discussion has expanded to include the dynamics of land use change in indigenous territories, as well as the need to protect and the ever-changing nature of indigenous knowledge. Concomitantly, finger pointing at shifting cultivation by local rural people as the principal cause of tropical deforestation has been questioned (Geist & Lambin 2002; Seidenberg et al. 2003; Ickowitz 2006; Makana & Thomas 2006; Sirén 2007; Mertz et al. 2008). Instead, in a movement away from simplification, there has increasingly been an appeal for local case studies embedded in larger social, economic and political systems and contexts to understand land use change (Lambin et al. 2001; Lambin et al. 2003; Chazdon et al. 2009; Rudel et al. 2009). A social-ecological approach that addresses this array of factors allows for the recognition of the feedback between environmental and human systems as ecosystem services are lost and actors respond (Carpenter et al. 2009).

Social-ecological systems

Ecology, an integrative science by definition, has developed a series of numerical, statistical tools to enable ecologists to deal with ecological complexity (see Borcard et al. 2011). The ecosystem approach of ecology means taking into account a range of factors that influence ecosystems. The study of deforestation and land use-land cover change (LUCC) focuses on the land resource, but the resource cannot be understood without consideration of the users as well. Thus a new frontier in ecological sciences is the social-ecological systems approach to land management that enables the inclusion of social factors into the study of ecosystems – *i.e.* the framing of land use change problems along cross-disciplinary systems thinking (Berkes et al. 2002; Berkes 2004). This movement has emerged with the recognition of the intricate and oftenunforeseen influence of humans on the environment, the inextricable nature of this interaction, and the concomitant emergence of cross-disciplinary fields like political ecology and ecological economics in the 1970s and 1980s (Berkes et al. 2002; Berkes 2004). The social-ecological system (SES) is a network of environmental and human subsystems that interact at multiple levels (Anderies et al. 2004). Berkes & Folke (1994) first defined "social/ecological systems" as consisting of five elements, later condensed to four (Berkes & Folke 1998): the ecosystem, people and technology, local knowledge and property rights institutions. The term social-ecological system was used to highlight this idea of the inseparability of humans and nature and to establish a framework for global, interdisciplinary case studies seeking to understand how social systems use ecological knowledge towards successful resource management, often in long-settled indigenous contexts. The framework has been articulated around the idea of the stability of social-ecological systems, expressed in terms of the system's resilience, *i.e.* the ability to withstand shock, and sustainability, *i.e.* the ability to meet both present and future needs (Berkes & Folke 1994; Berkes & Folke 1998; Berkes et al. 2002). Moreover, the authors point to the fact that this notion of an embedded and complex relationship between the ecological and social is one that is often consistent with the worldview of Indigenous Peoples, and that traditional knowledge is necessary to better understand the dynamics of such systems (Berkes & Folke 1998; Berkes et al. 2002; Berkes 2004; Folke et al. 2005). Additionally, the tools developed in numerical ecology that enable the study of complex systems (see Borcard et al. 2011), as well as the use of Geographic Information Systems (GIS), are amenable to the analysis of SES (Redman et al. 2004; Ostrom 2007).

In a series of papers building upon each other, Ostrom created a framework that is a tiered, diagnostic scheme for scholars to study the links and interactions in complex SES (Anderies et al. 2004; Ostrom 2007; Ostrom 2009; Ostrom & Cox 2010; McGinnis & Ostrom 2014). Formulated to help understand sustainable resource management, the framework divides the larger system into the resource system, resource unit, governance, and actor subsystems, which interact with the biophysical environment and the broader political, economic and social setting.

Recent studies of SES that have used Ostrom's framework were presented in a Special Issue of Ecology & Society. Frey & Rusch (2013) identified success factors in a literature review of common pool resource problems and used artificial neural networks as a quantitative model to estimate their interactions. The study by Baur & Binder (2013) used the SES framework modified for the Institutional Analysis and Development Framework to identify how socioeconomic changes have translated to governance changes in a Swiss common property meadows case. Nagendra & Ostrom (2014) identified how urbanisation and lake degradation led to differentially successful self-organisation and environmental management in communally managed lake systems in India. Risvell et al. (2014) studied the influence of decentralisation of protected areas on adaptive capacity in the reindeer industry. The advantage of common use of Ostrom's framework is in the ability to structurally organise case studies in mutually comprehensible ways that allow for meta-analyses and cumulative knowledge building. Its use also helps ensure that ecologists do not ignore social factors, given the interdisciplinary nature of such studies (Ostrom 2007; Ostrom 2009; Ostrom & Cox 2010; McGinnis & Ostrom 2014).

Past research and research objectives

Alongside such trends in academic thought, there has not ceased to be a chorus of voices calling for collaboration between Western science and traditional knowledge through participatory, place-based, problem-based approaches to forest and biodiversity conservation relevant to locals. Participatory research in land use and conservation studies has become a popular proposition over the past decades (Grove & Burch 1997; Potvin et al. 2006; Chazdon et al. 2009), extolled for its shared value for all co-researchers in its ability to both empower marginalised, often indigenous voices and access otherwise unrepresented knowledge of local landscapes (Smith 2003; Berkes 2004; Evans et al. 2006; Lilja & Bellon 2008; Bergold & Thomas 2012). Manifestations of participatory land use and management research over the years have included participatory rural appraisal (*e.g.* Zurayk et al. 2001), place-based learning communities (Davidson-Hunt & O'Flaherty 2007) and community-based resource management (see Berkes 2004).

In addition, forest conservation often requires the use of participatory methodology in order to creatively capture local knowledge of historical and current land uses (Geilfus 2002; Lilja & Bellon 2008). Participatory methods used in land use and conservation research have included scoring of land uses using local materials like pebbles or sticks (as used by Potvin et al. 2006; Duguma & Hager 2011); participatory mapping, where locals draw their own lands and/or sketch areas associated with particular values or characteristics to generate resource maps (see Herlihy 2003; Paulson 2003; Robiglio 2003; Smith 2003; Potvin et al. 2006; Kalibo & Medley 2007; Xu et al. 2009; Etongo & Glover 2012; Meyfroidt 2013); historical timelines (see Kalibo & Medley 2007); role-playing games (see Castella et al. 2005); and focus groups or workshops (see Dalle & Potvin 2004; Tschakert et al. 2007; see Geilfus (2002) for a comprehensive toolkit for participatory methods).

Drivers of deforestation and LUCC exemplify the importance of humans in ecological research and, therefore, the utility of an SES and participatory approach to their study. Land use decision-making and subsequent changes in land use are the types of interactions that explicitly link the ecological and the social (Redman et al. 2004). Of the studies suggested in the Human Dimensions Research agenda in 1992, LUCC has been investigated the most (Moran 2010). Case studies in Latin America illustrate the array of effects on LUCC spanning across different fields: the influence of physical geography (Nelson et al. 2001; Arroyo-Mora 2005; Ellis et al. 2010); household demographics and socioeconomics (Walker et al. 2000; Perz 2001; Abizaid & Coomes 2004; Carr 2005; Mena et al. 2006; Potvin et al. 2006; Tschakert et al. 2007; Gray et al. 2008; Ellis et al. 2010; Sydenstricker-Neto 2012); market influences (Simmons 1997; see Pacheco et al. 2010); property rights (Nelson et al. 2001; see Pacheco et al. 2010); and involvement in community organisations (Gray et al. 2008). LUCC studies have benefited from spatially explicit approaches that use GIS and Global Positioning Systems (GPS; *e.g.* Castella et al. 2005; Mena et al. 2006; Sloan 2008; Sydenstricker-Neto 2012). Remote satellite imaging has enabled the estimation of global deforestation rates and, more recently, the Global Forest Watch has released open source annual deforestation data from the past decade using Landsat imagery (Hansen et al. 2013). If accurate on the ground for locals, such a freely available database would benefit conservation research by supplying comparable global deforestation data derived from the same methods across countries. Moreover, it would facilitate conservation in action, such as measurement, reporting and verification (MRV) for forest monitoring.

The research presented here was carried out in the Bayano watershed of eastern Panama, an area characterised by a mosaic of land uses managed by indigenous Emberá-Wounaan and Kuna, and colonist peasant farmers (Wali 1989; St-Laurent et al. 2013). Previous research in the region has worked on best practices for reducing emissions from deforestation and forest degradation (REDD+; Holmes & Potvin 2014); participatory mapping of indigenous lands (Herlihy 2003; Vergara-Asenjo et al. 2015); Wounaan livelihood strategies (Runk et al. 2007); carbon consequences associated with different tree species and land management strategies (Kirby &

Potvin 2007; Tschakert et al. 2007); land use change in the context of Clean Development Mechanisms (Potvin et al. 2006); culturally important plants (Dalle & Potvin 2004); and differences in forest management between indigenous peoples and colonists (Simmons 1997). The overall objective of my thesis is to understand the legacy of ecological factors like topography and social factors like tradition and institutions on the genesis of an indigenous landscape. The research presented here builds on previous work as it answers directly the call for bottom-up studies with a problem-based definition, participatory approach and social-ecological (by definition, interdisciplinary) perspective to the study of land use change. Moreover, it establishes a spatially explicit comparative study, emphasises hitherto unstudied local perceptions of land use decision-making and compares local perceptions of land use to remotely sensed deforestation trends. It stems from the concern of local indigenous leaders in eastern Panama of forest loss in the communal lands. The following manuscripts first look at the community of Piriatí-Emberá as a case study to identify what factors are perceived to influence land-use decision-making and have ultimately led to a forest-poor landscape; and secondly to use Ostrom's framework to establish which ecological and social factors have led to differential land use outcomes in two seemingly homologous social-ecological systems, Piriatí-Emberá and the neighbouring Ipetí-Emberá.

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CHAPTER 1: GENESIS OF AN INDIGENOUS SOCIAL-ECOLOGICAL LANDSCAPE IN EASTERN PANAMA

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Keywords: Eastern Panama; history; indigenous; gender; livelihood strategy; participatory; perceptions; social-ecological landscape; subsistence; tradition

ABSTRACT

Land use change has a human dimension; however there is a paucity of knowledge on the interplay between ecological and social influences on the landscape. We conducted participatory land cover mapping in an indigenous territory of Panama to identify factors that influenced household land use decisions. The resultant map illustrated a mosaic of land cover dominated by pasture. Primary discourse on influences from 35 semi-structured interviews with landowners, women and youth, emphasised economic concerns, like subsistence, and social-cultural factors like reticence to abandon traditional agriculture. Multivariate analysis showed that historical factors have influenced the landscape: timing of family settlement helped determine the proportion of forest cover and place of origin the proportion of short fallow for agriculture. Gendered perspectives are informed by cultural norms and economic opportunities; women perceived more social-cultural and men more ecological influences on the land. Future communal reforestation plans would be well-informed by considerations of subsistence, traditional land uses, social organisation, and women's perspectives.

INTRODUCTION

Over one billion extremely poor people around the world, the majority of whom are rural dwellers, rely on forest resources for livelihoods (World Bank 2004). In Central America, where 45% of the total population is rural, deforestation rates are the highest in the world (FAO 2010). Land use decisions in rural Latin America are informed by bio-geophysical land characteristics (Nelson et al. 2001; Arroyo-Mora et al. 2005; Ellis et al. 2010), household demographics and socioeconomics (Walker et al. 2000; Perz 2001; Abizaid & Coomes 2004; Carr 2005; Chowdhury & Turner 2006; Mena et al. 2006; Potvin et al. 2006; Tschakert et al. 2007; Gray et al. 2008; Ellis et al. 2010; Sydenstricker-Neto 2012), ethnicity (Carr 2005; Chowdhury & Turner 2006), legal land title (Nelson et al. 2001; Carr 2005), public policies (Arroyo-Mora et al. 2005; Potvin et al. 2006) and market influences (Simmons 1997; Gray et al. 2008; see Pacheco et al. 2011). Identifying swidden agriculture as the principal cause of tropical deforestation has thus been questioned (Geist & Lambin 2002; Seidenberg et al. 2003; Ickowitz 2006; Makana & Thomas 2006; Sirén 2007; Mertz et al. 2008). Instead, local case studies considering ecological, social, economic and political systems are needed to understand complex inter-relationships driving land use change (Lambin et al. 2001; Lambin et al. 2003; Chazdon et al. 2009; Rudel et al. 2009).

More recently research is recognising the fact that landscapes are also a product of history (Rhemtulla & Mladenoff 2007; Gray et al. 2008; Moran 2010). For example, differential settlement histories between two groups of indigenous Asháninka in Peru partly explained market integration: the group more involved in the market had arrived later from an area of high colonisation (Peralta & Kainer 2008). Likewise, amongst the Venezuelan Barí, settlement patterns have influenced the landscape, with sedentarisation and market integration leading to deforestation (Behrens et al. 1994). In the Maya Biosphere Reserve, farmers with land in their previous settlements were those that practised more agricultural intensification after migration (Carr 2005).

Additionally, land use change studies must address the perceptions of indigenous resource users, which are influenced by their worldviews and inform decision-making (Vanclay 2003; Leonard et al. 2013; Meyfroidt 2013). These perceptions include the services forest dwellers consider to derive from their forests (Castillo et al. 2005). In a study of mangrove deforestation in Cameroon, for example, lack of perception of risk of flooding and deforestation meant that mangrove protection would be limited (Munji et al. 2014). Diverse perceptions of the causes of deforestation influenced degrees of interest in conservation in Los Tuxtlas, Mexico (Durand & Lazos 2008).

Gendered perspectives can also impact perceived influences on the landscape. Households' livelihood strategies can be determined by gender relations comprising consignment of women's duties to household chores, limited access of females to schooling and fewer opportunities for women to leave the home or migrate out of the community (Ellis 1998). Distinct livelihoods can entail different gendered relationships with the environment (Leach et al. 1995) and women and men can view the landscape differently depending upon the different values they derive from resources, determined in part by gendered divisions of labour (Etongo & Glover 2012).

Thus, land use changes result from explicitly linked ecological and social interactions (Redman et al. 2004). To consider diverse influences on land use decisions and contribute case study data to knowledge on global deforestation, we adopted a social-ecological approach to the study of land use change at the landscape level. Specifically, the objectives of our study were to (1) identify factors that have influenced past land use decisions leading to low forest cover at the landscape level in the indigenous Emberá community of Piriatí in eastern Panama; and (2) determine the influence of history and gendered perspectives on the landscape following the emergence of these factors during data collection.

In Panama, indigenous peoples have been practicing traditional shifting cultivation for thousands of years (McKay 1990, as cited by Fischer & Vasseur 2000). The landscape of eastern Panama, where this study occurred, was previously old growth forest or a highly advanced successional stage (Araúz et al. 1973; McKay 1984), but has come to be typified by mosaics of land uses and secondary forests (Wali 1993; St-Laurent et al. 2013; Vergara-Asenjo et al. 2015). This transition must be understood in the context of historical factors such as migration of Emberá, expansion of the Pan-American Highway, hydroelectric dam construction and small-scale colonist encroachment (Herlihy 1985; Wali 1989; Wali 1993; Horton 2006; St-Laurent et al. 2013). Amongst the Emberá of eastern Panama, men are traditionally responsible for hunting, physical tasks in agriculture, dealing with outsiders and handling money, while women take care of the household (Herlihy 1986; Kane 1986; Kane 1994). When men are those making land use decisions then, female perspectives can be excluded, with potential outcomes on the resultant landscape.

Our objective was developed jointly with indigenous community leaders who highlighted concern over deforestation in their lands and their desire to include reforestation in a future land use management plan. The participatory nature of the study reflects the call to engage stakeholders in research that is meaningful for locals and informed by local knowledge (Grove & Burch 1997; Scoones 1999; Smith 2003; Evans et al. 2006; Chazdon et al. 2009).

METHODS

Study site

The Piriatí-Emberá communal lands (*tierras colectivas*; hereafter Piriatí) comprise 3867 ha in the Alto Bayano watershed, approximately 100 km east of Panama City along the Pan-American Highway (Fig. 1.1). Piriatí was formed in the early 1970s following relocation of the Bayano River inhabitants after construction of a hydroelectric dam. Since then, the watershed has witnessed an influx of colonists from western provinces searching for land (Wali 1989; Wali 1993; St-Laurent et al. 2013). The eastern communal lands, known as Catrigandí, are an area outside the Piriatí village where Emberá live with latino farmers (*campesinos*). The village has 497 people, distributed among 117 families and 56 landowners who practise swidden agriculture and cattle ranching. The lands are communal, i.e. belonging to everyone in the community, but individual landowners manage each parcel. The communal lands were legally recognised by the Panamanian government in 2014.

Data collection

Participatory mapping of community lands

Participatory mapping communicates facets of the landscape that are of relevance and importance to local dwellers (Smith 2003). In 2012, a participatory map of land cover in Piriatí was begun following the method of Potvin et al. (2006). Forty-five landowners attended a workshop in which they discussed the appropriate land cover classes, including secondary forest, tall fallow, short fallow and pasture. They drew their parcels and associated land cover on a base map created from 2012 RapidEye® satellite images of the region (Vergara-Asenjo et al. 2015). We then validated this map in a participatory manner (see Appendix 1.1).

Household interviews

To quantify the relationship of land cover in the plot to (1) household-level demographic data and (2) factors perceived to influence land use decisions, aggregated at the landscape level, we carried out a participatory wealth ranking (see Appendix 1.1) and conducted 35 semi-structured interviews in 2013. Interviews were held individually with landowners who obtained land at the time of settlement (n=9), land inheritors (n=7), non-landowning or non-Emberá immigrants who came after the first waves of settlement (n=4), women (wives of landowners and inheritors; n=8) and youth (n=7). We asked questions about current and past land use and management practices, factors influencing land use/land cover, socioeconomic characteristics, land tenure, and means of subsistence. Interviews were coded in two iterations. Three canonical correspondence analyses (CCAs) were carried out to compare demographic characteristics of the household, perceived social influences and perceived ecological influences that emerged from the interviews to the landscape. Four linear discriminant analyses (LDA) were conducted to test which economic, social-cultural, political and ecological influences on land use decisions mentioned by interviewees (explanatory factors) could be used to discriminate among genders of interviewees, excluding youth (see Appendix 1.2). We then held a focus group discussion to discuss gendered differences in perceptions with 8 female participants who showed interest in the activity (see Appendix 1.1).

RESULTS

Participatory mapping of communal lands

There was a high concentration of pasture in Catrigandí and of fallow land on lands recently allotted to new families north of the community (Fig. 1.2). Forest was concentrated to the north, furthest from the Highway. Pasture accounted for 38% of the communal lands, while 48% was short and tall fallow and 11% was secondary forest, labelled as such because participatory mappers alleged that forest had already been selectively logged at the time of settlement. The proportion of pasture was highly variable across parcels, from 0-100%.

Household interviews

Demographic influences

In the CCA examining the relationship between household-level demographics and land cover in the plot, the cumulative proportion of variance in land cover explained by the two canonical axes was 86.7%; the first axis explained 47.9% (Fig. 1.3; see Appendix 1.2). The explanatory variable with the highest loading on the first canonical axis was *number of people living at home*, with an interset correlation coefficient of 0.5116, followed by *location* (0.4628). The highest negative loadings were the *number of people available to help* (-0.4517) and *wealth ranking* (-0.3703). On the second canonical axis *number of people living at home* (0.2162) and the *number of people available to help* (-0.3872) had the highest loadings. We found a greater percentage of pasture, used for livestock or rental to others, on plots of interviewees who were *wealthier* and had more *elders living at home*. Those plots with a greater percentage of short fallow, associated with agricultural land, had more *people living at home* and were *from the Darién*. Those plots with more tall fallow had a greater *number of people available to help*, and those with more secondary forest tended to be from *Site 2*.

Perceived influences

Thirty-three interviewees referenced the desire, necessity or advantages of reforestation within the community or communal lands; 28 explicitly expressed their own desire to reforest. The greatest proportion of interviewees referred to economic (versus social-cultural, political or ecological) factors that affect their land use decision-making or are perceived to influence others' decisions (*n*=33; 94%). Landowners (*n*=17; 100%) and women (*n*=8; 100%; Table 1.1) had the greatest proportion of interviewees who mentioned such factors. Of these, *potential income* (*n*=30; 86%), *subsistence* (*n*=29; 83%) and *availability of resources and labour* (*n*=29; 83%) were most mentioned. Economic influences explained forest cover in the communal lands partly through encouraging both felling and planting of trees such as *espavé* (*Anacardium excelsum*), *cocobolo* (*Dalbergia retusa*) and teak to sell to external buyers.

Historical timber extraction by outsiders and encroachment by colonist farmers have also contributed to lack of forest. *Campesinos* who rent or buy plots of communal land have felled the forest and/or put pasture in their parcels, and restricted access to seeds limits the ability to reforest harvestable wood. Meanwhile, limited land availability means forest reserves are left in parcels, in order to have land to cultivate in the future.

"For people there's no other option for sustenance, you know? To get their nourishment [cultivation] is the only form of work they have." - Youth

Economic factors also helped explain high pasture cover. Traditionally, livelihoods were subsistence-based, but now, as members of a market economy with the desire to buy goods and services, indigenous farmers seek ways to earn extra income. Given limited resources and labour, cattle ranching or renting land to cattle ranchers is seen as a less time-consuming, less physically demanding way to do so. However, some are deterred from pasture conversion due to the monetary investment and limited land availability, which would mean not having enough land for cultivation or for children.

"The only solution that will let me support my children or send them to university is to have a few more animals and in case of hardship I can sell and then use that to pay for school." - Landowner

A total of 20 (57%) interviewees referred to social-cultural factors affecting land uses, of which women had the greatest proportion (*n*=7; 88%; Table 1.2). *Tradition* was the factor most mentioned (*n*=10; 29%). Interviewees explicitly invoked tradition when explaining forest cover. Traditional uses justify reforestation of harvestable tree species, like *espavé* for the building of dugout canoes or *cocobolo* for artisanal activities. Presence of traditional medicine in forests discourages some landowners from deforesting. Traditional shifting cultivation accounts for forest presence, since it involves replanting seeds of naturally growing trees, fallowing land to enable tree regrowth, leaving trees, and planting trees as borders.

Social-cultural factors were also mentioned as influences on pasture levels. Weak internal laws (local, traditional rules) and lack of social organisation, due to perceived lack of communication and inclusion of people outside the community in communal activities, have encouraged the selling of land to c*ampesinos* who have converted land to pasture. Even so, there is a reticence to sell or rent land because it violates internal communal laws. Influenced by observing *campesinos* with pasture, some see it as a lucrative alternative to subsistence agriculture.

"*Even though you don't know how to read, you're working with cows so you have money…, [the campesino] told me." - Landowner*

Meanwhile, a total of 14 (40%) interviewees indicated political factors affecting land uses (Table 1.3). Of these, *public policies* was most mentioned, including land endowment, lack of support of indigenous populations and timber extraction by the government (*n*=11; 31%). The Agreement of Majecito, created in the early 1970s between the community members and the government, is one such public policy that establishes pasture as a legitimate use of communal land. Before the government granted legal land title, some sold the parcels they manage to colonist farmers who practise cattle ranching, for fear that the government could re-appropriate lands at any time.

A social CCA used interviewees' perceived economic, social-cultural and political influences on land uses and compared them to land cover in the interviewees' parcels (Fig. 1.4). The cumulative proportion of variance in land cover explained by the two canonical axes was 66.2% with the first axis explaining 35.9%. The explanatory variables with the highest loadings on the first axis were *presence of external organisations* (0.6638), *population increase* (0.4108), *availability of resources and labour* (-0.5034) and *lack of social organisation* (-0.3283). The highest loadings on the second axis were *population increase* (0.3162), *subsistence* (0.3118), *potential income* (-0.2528) and *local politicians* (-0.2145). We found a greater percentage of tall fallow in the plots of interviewees who referred more to the influence of *presence of external organisations* on land use. External organisations were mentioned in the context of non-governmental organisations (NGOs) that have introduced reforestation, such as the Global Brigades and Peace Corps. A greater percentage of secondary forest was found on plots of those who mentioned *population increase*. More short fallow for agriculture was found on plots of those who referred to *availability of resources and labour* and *proximity to outsiders*, and more pasture on those who referred to the influence of *local politicians*. In the last decade, a local politician has rented approximately 8 parcels of land and established cattle pastures that are managed by local landowners.

A total of 19 (54%) interviewees, the greatest proportion of whom were landowners (*n*=11; 65%), referred to ecological factors affecting land uses (Table 1.4). Of these, *soil characteristics* (*n*=5; 14%) and *distance from house to plot* (*n*=5; 14%) were most mentioned. Ecological considerations justified pasture conversion partly because elder landowners claimed that land in Piriatí is not as fertile as their place of origin (as cited by Wali 1993). Furthermore, crop disease of a yam species (*ñame; Dioscorea alata*) important as a cash crop (Herlihy 1986:245) and the invasion of the "Canal grass" (*paja canalera; Saccharum spontaneous*) have encouraged some landowners to opt out of cultivation and pursue cattle ranching. Distance to plot was invoked in the case of landowners who require pasture for horses that are used to get to remote plots. *Topography* was invoked by a landowner who was unable to have cattle on hilly terrain, and restoration of the *natural beauty/state* as a motivator for future reforestation.

In the CCA comparing the ecological influences on land uses mentioned by interviewees to land cover in the parcel (Fig. 1.5), the cumulative proportion of variance in land cover explained by the two canonical axes was the second highest of the three CCAs at 83.9%; the first axis explained 55.0%. The explanatory variables with the highest loading on the first axis were *distance to plot* (0.3959), *soil characteristics* (-0.4643) and *topography* (-0.3541). On the second axis, the highest loadings were *crop disease* (0.2797), *distance to plot* (-0.4396) and *effect on river* (-0.3042). Plots with a greater percentage of pasture tended to belong to interviewees who suggested the influence of *crop disease*, while plots with a greater percentage of tall fallow to those who referred to *distance to plot.* Those plots with more short fallow tended to belong to those who mentioned *topography* and *natural beauty/state*.

The economic LDA showed that mention of *off-farm employment* was a significant predictor of female interviewees, while *presence of external organisations* and *markets* were most significant predictors of males (Table 1.5). Jacknife cross-validated classification showed that 60.7% of women and men were classified correctly. The social-cultural LDA, also with 60.7% correct classification, showed that *population* and *social organisation* were significant predictors of females, and the influence of *outsiders'* (colonists') *worldviews* was a predictor of males. From the political LDA, *property title* was a significant predictor of females and *public policies* best predicted males, with 71.4% correct classification. The ecological LDA showed *effect on animals* as a predictor of females and *natural beauty/state*, *effect on river*, *heat/shade* and *topography* as the most significant predictors of males, with 64.3% correct classification.

DISCUSSION

Demographics and history

The pasture-dominated landscape in Piriatí can be seen as a product of a complex web of social-ecological factors informing individual household decisions, as suggested by the considerable variation in proportion of pasture across individual parcels. The CCA lets us draw a series of patterns in demographic influences on the landscape. The positive relationship of wealth and number of elders with the proportion of pasture in a plot supports the hypothesis that households further in their life cycle have the resources to invest in cattle ranching (Perz 2001; Walker et al. 2002). Households with no elders in Piriatí tended to be younger, formed by children after they married and established their own nuclear families. Meanwhile, the association of number of people at home with proportion of short fallow suggests that households use agriculture as a livelihood strategy shaped by the presence of more dependents. Increased household size has encouraged deforestation in rural Latin America by necessitating conversion to cropland for consumption or sale of surplus (Carr 2005; Mena et al. 2006). In a study of land use/land cover change in Mexico, population pressure was associated with the presence of pasture and agriculture, possibly for household consumption (Ellis et al. 2010).

The analysis also illustrates the legacy of settlement history on the communal lands. A group of Emberá first settled in the Bayano from the Darién province following expansion of the Pan-American Highway into eastern Panama in the 1950s (Araúz et al. 1973; Pastor 1985) in order to have better access to urban markets and open areas for agriculture (Herlihy 1986:93; Wali 1993). The current inhabitants of Piriatí settled along the Bayano River, where they practised swidden agriculture. After a resettlement operation following dam construction, the Emberá eventually settled in two communities in the Bayano, including Piriatí (Wali 1989; Wali 1993). Nevertheless, insecurity over land rights meant that the resettled Emberá did not engage in intensive agriculture (Wali 1989). They initially practised minimal cattle ranching due to lack of experience with the practice (Wali 1993).

Our analysis shows that the original households in Piriatí, not concentrated in a specific area, tended to have more customary land use, i.e. more forest and less pasture on their lands, than those of the more recent settlers. As Emberá along the Bayano were deciding where to resettle, the leader of the Piriatí group is said to have sought out Emberá who wanted to create a new community based on shared traditional values. These original households tend to have traditional houses and participate more in communal activities. Furthermore, those who originally came from the Darién province tended to have more short fallow than those who were not from that province, which can be explained by their greater engagement in traditional agricultural activities as opposed to cattle ranching. The Darién province, not entirely traversed by the Highway, includes two Emberá-Wounaan indigenous reserves (*comarcas*). Therefore communities in Darién are more isolated from latino influences. Thus degree of adherence to traditional worldviews and agriculture based on landowners' history apparently resulted in differential land use practices. In light of the community's objective of reforestation, organizing a more unified community that engages in traditional, communal activities can perhaps reinforce forest conservation.

Tradition and subsistence

Rural livelihood strategies constitute bundles of activities that enable survival and security, including subsistence or commercial agriculture, hunting and gathering, timber harvesting, selling of arts and crafts, day labour and city jobs (de Sherbinin et al. 2008). Once in the market, indigenous peoples become increasingly reliant on market products (Godoy 2001). Livelihood strategies are then negotiated to incorporate these new needs. For example, natural resources like timber and non-timber forest products provide an avenue for income generation in rural Latin America, becoming a form of insurance or "livelihood buffer" for well-being (de Sherbinin et al. 2008). Livelihood profiles can be highly heterogeneous between and within indigenous villages, however. Among the Tawahka Sumu in Honduras, those who generated the most income from forest products were also those least financially dependent upon forest goods, given diversified income sources (McSweeney 2002).

Livelihood strategies respond to environmental, socioeconomic and political circumstances (Nygren 2000). They form as a result of coping behaviour, risk management and market opportunities, negotiated by social institutions like kin networks and gender norms (Ellis 1998). The influence of social-cultural institutions in light of externally imposed factors has been found in numerous indigenous settings. In southwest China, forest restoration was enabled by the renegotiation of belief in sacred forests, following government policies like sedentarisation of slash-and-burn cultivation (Liu et al. 2000, as cited by Xu et al. 2009). Increased prices of agroforest tea encouraged indigenous Akha farmers in China to use social institutions like ecological knowledge to network with the tea industry (Ahmed et al. 2010). The livelihoods of the indigenous Wounaan of eastern Panama, a neighbouring indigenous group with whom there is some intermarriage (Herlihy 1986), display a similar proclivity for cultural values, which encourage traditional basket weaving but also non-traditional shrimping in tune with norms of independence (Runk et al. 2007).

Interview results show that both traditional agriculture and the forest are constitutive of Emberá identity much in the same way. Despite the ubiquitous emphasis on economic factors, community members often said conversion to pasture would result in lack of land for traditional subsistence agriculture, illustrating the importance of cultural worldviews on the landscape.

"Well, I plan on continuing to work the land [after putting pasture], because it's my everyday sustenance, no? Until I get pains in my body." - Landowner

Moreover, there was a steady allusion to the role of tradition even when not explicitly articulated. Often community members explained their decisions by stating, "*This is what we do*" or, "*This is what we have always done*". The importance of tradition on the landscape was especially evident in the difficulty some landowners had in accounting for forest reserves in their parcels. This struggle to justify a practice elders claim was traditionally carried out to ensure sustainability of the forest and its cultural resources, as well as to preserve land for future cultivation, suggests the understated role of tradition in guiding land use decisions, albeit at times through convention more than active decision-making.

Ultimately, however, the interviewees' focus on income, subsistence and resources, and the prevalence of pasture in Piriatí suggest that social-cultural concerns have become secondary to economic concerns in the negotiation of livelihood strategies and, therefore, in the genesis of the landscape. Indeed, the context in which institutions like internal laws were mentioned was largely one of ineffectiveness; social institutions have not been harnessed to ensure livelihoods like in other documented indigenous circumstances. Cattle raising or selling of agricultural surplus, both drivers of deforestation in Piriatí, are largely justified as the optimal livelihood strategy that enables subsistence. In the Bayano, indigenous and colonist communities both displayed similar patterns of timber extraction based on proximity to market, despite ethnic differences (Simmons 1997). In the context of limited resources and exclusionary public policies like granting of private land title for productive use, historical natural resource exploitation (Wali 1993) and urban rather than rural economic growth and investment (Runk 2012), community members perceive little practicality of long-term cultural preservation at the expense of immediate survival. Therefore any future reforestation plan must necessarily value subsistence needs in order to be relevant to villagers' concerns.

Gendered perspectives

Our LDA shows that in Piriatí, women appear to be more aware of the internal social-cultural factors that shape land uses than men, who are more aware of external and ecological constraints. Our focus group discussion led us to the insights that this gendered divide can be explained by: women's greater social role within the community; women's decreased participation in cultivation due to new technologies and economic opportunities in timber extraction; and women's less frequent interaction with outsiders compared to men due to cultural norms.

Men in Piriatí make land use decisions, which can be informed by women's judgement. Women were often unable to describe in detail their land use and management practices. They help with sowing and harvesting but not land clearing, and sometimes cook for the men who are working (as occurred traditionally; see Araúz et al. 1973; Herlihy 1986; Kane 1986). Likewise, in Bolivia, there was a subtle gendered subdivision of tasks within particular shared activities (Paulson 2003) and, in Guatemala, women are not responsible for the most important household decisions (Taylor et al. 2006). This limited involvement of women in cultivation may entail less ecological knowledge and therefore less awareness of ecological influences on land use decisions. In general, women are also more engaged in community groups, perhaps entailing a more acute awareness of the social and traditional aspects of community life. The social role of women helps explain why, in Mexico, women were more concerned with the effects of pollution, while men were more concerned with the threat of deforestation. Specifically, women were the ones looking after sick children (Arizpe et al. 1996). Men in Piriatí alluded more to the influence of external organisations on the presence of forest through reforestation, suggesting that they are more aware of the ecological rather than social effect of such organisations.

Additionally, gendered labour divisions are subject to change over time. Women spend less time in the fields than previously, in part due to an increased emphasis on timber extraction rather than agriculture, which yields slower financial returns. Timber extraction is a male enterprise, as it requires camping away from the community for weeks at a time. Women have not become caretakers of farms following men's shift to income-generating labour, as has occurred in other circumstances (see Razavi 2003), due to a sense of decreased value of farming in general. Rather, increased timber extraction has heightened women's role in the social domain as housekeepers and thereby influenced women's livelihoods and perceived influences on the land, reflecting the co-production of land use and livelihood (see McCusker & Carr 2006).

"With agriculture it's not the same because you can go yourself, take your kids, leave them in a ranchito there. You're helping. But there [in timber extraction] it's another method. It's different." - Woman

Furthermore, broader economic changes including new technology such as machine huskers, vendors who come to the community and stores that sell goods have all led to a decreased need to work the lands or fish, a previously important subsistence activity (Herlihy 1986). Similarly, Emberá women in the Darién spend decreasing amounts of time on the land, due to the presence of stores that limit the need for household gardens and sugarcane production; less fishing and gathering associated with diminished resources; and an increasing view of the forest as an unsuitable place for women (Colin 2013). The result is continued consignment of women's roles in the household and less interaction with the land than men. Araúz et al. (1973) argued that Emberá women's household responsibility gave them power to help with household decisions and therefore an advantage in the home and society. Gendered social roles therefore influence who has the power to make decisions, and the gendered perspectives of land use decision-makers can shape the subsequent landscape.

Women's lower interaction with outsiders perhaps explains why they referred more to internal social influences, like social organisation and population increase, while more men referred to the external influence of outsiders, external markets and public policies on land use decisions. Emberá men increasingly engage with the outside world as leaders who represent both households and communities (Kane 1986; Kane 1994). Meanwhile, women say they are discouraged from leaving the community, as the city is considered dangerous and there is a fear that women will marry non-indigenous men. Therefore, as suggested by Vergara & Barton (2013) amongst the Mapuche of Chile, women are more familiar than men with communal matters having stayed in the community. In Sri Lanka, women's greater involvement in the community compared to men has allegedly translated to greater traditional knowledge, which women then apply to their subsistence activities, contributing to the sustainability of the local system (Wickramasinghe 2004). Thus men and women's relative degrees of interaction with the external world form part of the context that influences interaction with the land. Men are more aware of the influences of external agents in decision-making because they have the power and knowledge, as defined by local gender norms, that come with the role of dealing with external agents.

Subsistence needs guide land use decisions and justify conversion to pasture because it is the men who, informed by ecological and economic concerns, are making the decisions in a context where men have the power and knowledge to decide. Future reforestation could therefore benefit from the inclusion of female perspectives that include social-cultural considerations, given that social organisation and tradition may discourage pasture conversion.

CONCLUSION

A social-ecological perspective that considers local context avoids generalised prescriptions of deforestation that are not relevant on the ground (Ostrom & Cox 2010). In Piriatí the landscape is a result of individual household land use decisions that are constrained by ecological characteristics of the land like crop disease, household level socio-economics like wealth, the social-cultural context of the community like weak internal laws, and broader political and economic circumstances like government policies and resource availability. Decisions are largely informed by subsistence concerns, accounting for the dominance of pasture, but are also influenced by traditional norms and settlement history, leading to mosaics of land cover across the landscape. Meanwhile, gendered perspectives mediate the awareness of influences on the landscape and interaction with the land. Any future communal reforestation efforts must address these diverse concerns in order to be effective.

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APPENDIX 1.1

Supplementary information on methods used.

Participatory methods

The project objectives were conceived in collaboration with the village chief and the three co-authors (MC, RBC and MBC) who are Piriatí community members. Each step of the research process entailed dialogue and consultation with these collaborators and key informants, and brainstorming sessions were held together prior to all data collection to decide upon culturally appropriate methods. At least one of these co-authors was present during each stage of data collection.

Participatory mapping

In 2013, a digitised version of the map was presented to interviewees and annotated for corrections. We held a focus group meeting with four key informants chosen by a traditional authority in which any further errors were addressed, and the map was re-digitised. Short fallow is cleared land (1-4 years old) used for agriculture, while tall fallow is fallow that is ≥5 years old. After 2-3 years of cultivation, landowners clear a new hectare of land and leave the previous patch in fallow to regenerate. Secondary forest is considered land that has been un-cleared since settlement, but selective logging still occurs in both tall fallow and secondary forest. Parcels of land are rectangular and perpendicular to the highway, unlike the traditional land structure (Herlihy 1986), due to the nature of allotment at the time of settlement. A government engineer assigned each two-hundred metre stretch of land along the highway, from the highway to the northern border, to a single landowner.

Participatory wealth ranking

In order to quantify if there is a relationship between household wealth and land cover at the level of the individual parcel, we ranked each household in the community according to perceived wealth. To do this we held a focus group meeting in 2013 with two village authorities and three key informants to create a participatory wealth map of the community (Geilfus 2002). A leading traditional authority chose these key informants based on their knowledge of the community's household level socio-economics. Focus group members decided to choose four levels of wealth from 1 (poorest) to 4 (wealthiest). Each household was colour-coded according to its perceived wealth, using whether the household owns land, livestock and household electronics; its relative income; and whether the house has walls, floors and a tin roof as proxies for wealth, as used by Tschakert et al. in Ipetí (2007).

Focus group discussion

The leading traditional authority personally selected several of the female participants for the gender focus group based on their knowledge and participation in community congresses. The focus group was held in the communal house and was also open to any women who wished to join. Discussion centred on gendered divisions of labour and changes in divisions over time.

Interviews

We recorded all interviews for which consent to record was given (32 of 35). Ethics approval was obtained from the Instituto Nacional de Cultura (INAC) in Panama and the McGill Research Ethics Board. We used a purposive sampling strategy, selecting interviewees who were available and who fit into our target interview groups with the help of a leading traditional authority. Interviewees were categorised based on the recommendations of the traditional authority and local co-authors, in order to ensure a range of generations and stakeholders in a future land use management plan was interviewed. We ensured that each wealth ranking was represented. Youth were characterised as ≤26 years of age, unmarried and non-landowners. Landowners are those who were given their land to manage at the time of settlement, whereas land inheritors are the sons of these original settlers, who now own and manage their parental lands. While women can be landowners when the male household head has passed away and land has not been allotted to male inheritors, they are not generally landowners or the ones who manage the land in Piriatí (similar to traditional modes of inheritance, see Herlihy 1986:192). In two cases where the interviewed woman was a landowner by virtue of being widowed, her son was responsible for land management. Three women belonged to the same households as landowners/inheritors. Eight women were interviewed, chosen based on their availability, in order to maintain roughly equal numbers of interviewees in each category. There was a geographical division between two parts of the community, drawn due to the asserted difference in worldviews between community members; the community leaders claim that those in "Site 1" are generally those who participate less in communal activities than those in "Site 2", who tend to have concrete houses (*i.e.* more wealth) and pasture, and who settled in the community after the first wave in the early 1970s. Thus we stratified the interviewees of the community *a priori* according to their location: 16 interviewees in "Site 1" and 15 in "Site 2". Four interviewees (3 landowners (one female) and 1 woman) live in Catrigandí. We chose to interview people in Catrigandí in order to capture any variation in perceived influences on land uses between community and non-community members. Approximately one third of all households in the village were surveyed (26 out of 88). We terminated sampling when novel information from interviews was saturated. These interviews were held in Spanish and Emberá and lasted from 30 minutes to 2 hours. The lead author (DS) led all interviews with the assistance and translation, as necessary, of some of the co-authors (MC, RBC or MBC). All three of these co-authors were present during the first interview, after which we held a discussion of appropriate questions and addressed any ambiguities, in order to refine the interviews (Table A1.1.1).

Table A1.1.1. Examples of questions asked during semi-structured interviews.

Subject	Questions
Origin	Where are your parents from?
	When did you come to Piriatí? Why?
	How many people are in your family?
	How many children are there in your family?
	How old is the eldest person in your house?
Tenure history	When did you obtain your land?
	From whom did you obtain your land?
	When did the previous owner receive the land?
	How was the land when you obtained it?
Land uses	When did you cut your forest?
	When did you establish pasture?
	How many cows do you have?
	What type of pasture do you have?
	Do you have a small-scale plantation?
	Was there a government programme or NGO that encouraged you to plant a particular crop?
	How much money did they give you? Did you like the project?
	Do you share cows with another landowner?
	Can we reconstruct the history of the forest in your plot? How, when and why has it changed?
Land management	Why did you establish pasture?
	Can you explain how you manage your land? Do you burn your land?
	How many times per year?
	For how long do you leave burned land in fallow?
	Can you explain to me the burning cycle?
	Can you explain the rotation between fallow and cultivated land? Why do you burn?
	Do you produce for sale or self-consumption or both?
	What do you plant?
	Do you fell wood?

	Do you rent out a part of your land? Have you sold part of your land? Do you have any problems with neighbours or colonist farmers?
Subsistence	What do members of your family do? What do you do? How many people in your family help with cultivation? Do you receive social benefits?
Future land uses	How do you want your lands to be in the future? Do you want to see more pasture, more forest, more cultivated land? Why? Where would you like to see more of this? Why? Would you like to reforest your lands? Why?

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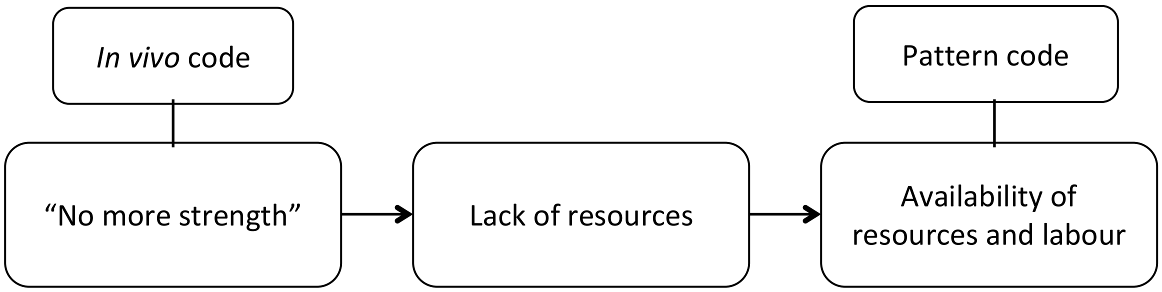
APPENDIX 1.2

Supplementary information on analysis of interviews.

All interviews for which audio recordings were made were transcribed verbatim in Microsoft Word. Preliminary codes related to factors that influence land uses were created from three interviews and used as a point of departure to code the remaining interviews during the first round of coding. The codes used were a combination of *a priori* codes generated from background literature and *a posteriori* codes generated from the interview data themselves (Saldaña 2009). The first iteration of coding involved holistic coding, where sets of data were coded as a whole to be divided into more specific codes later, and *in vivo* coding, where direct quotes from the interview transcripts were used as codes (Fig. A1.2.1). An example of an *in vivo* code created is "no more strength" (used in the context of interviewees choosing not to clear forest for cultivation because of lack of energy to work the land). Codes were then grouped into broader categories derived from the research questions. For example, "no more strength" was put under the category of "reasons for having remaining forest" within the subcategory of "lack of resources". The second round of coding constituted pattern coding, where codes were grouped and renamed as more intangible explanatory codes (Saldaña 2009). For example, "no more strength" and the subcategory of "lack of resources" were then grouped with related codes under the more inclusive category of "availability of resources and labour" as a factor influencing land uses (*i.e.* it was pattern coded as "availability of resources and labour"). Each code was assigned to an inclusive category and new categories were created if there were codes that could not be subsumed under a pre-existing category. It was then noted which interviewees referred to each of these inclusive categories. This process was repeated to ensure consistency. All coding was carried out on open source TAMS Analyzer software (version 4.45b7ahL).

Fig. A1.2.1. Flow diagram illustrating an example of the process of first- and second-round coding to derive factors that influence the landscape.



Canonical correspondence analyses (CCA) (Borcard et al. 2011) were carried out to compare household-level land cover data as a dependent variable from the participatory map to the demographic characteristics of the interviewees, as well as to the social and ecological factors that emerged from interviews as influences on land uses. Three separate CCAs were carried out in RStudio (version 0.98.484): one for demographic characteristics; one for social factors influencing land uses; and one for ecological factors influencing land uses. Canonical correspondence analysis is a weighted redundancy analysis (RDA) that extends regression analysis to multivariate response data by combining multiple linear regression and principal component analysis (PCA) using a matrix of response variables and a matrix of explanatory variables. The analysis produces two canonical axes that represent linear combinations of the explanatory matrix variables, with vectors that visually represent the degree to which the explanatory variables account for the variation in the response matrix (Borcard et al. 2011). The response matrix of the canonical correspondence analyses in this study consisted of the per cent land cover values for each household for which data were available, and the explanatory matrices consisted of demographic characteristics and binary values of social and ecological influences on land uses (Table A1.2.1).

Only data from those interviewees for whom land cover data were available were used in the CCAs. All the interviewees with parcels to the north of the village had to be removed from the analysis due to the inability of the community members to accurately distinguish between the different parcels in this region. Therefore per cent land cover values of these parcels could not be determined. This ambiguity was due to the large number of parcels in a small area and extensive cloud cover preventing referral to the satellite image of the area. Immigrants without land were excluded from analysis and those with land were grouped with landowners. Land inheritors were also grouped with landowners, since they manage their parcels. Youth and women were excluded from the demographic analysis, as they are not the ones who manage the parcels and determine land uses. Any interviewees for whom there were no demographic data for a particular category were removed from the analysis, due to the inability of CCA to manage empty cells. Thus, the interviewees living in Catrigandí, for whom wealth rankings were unavailable, were not included in the demographic CCA. As a result, all landowners with mapped parcels and complete demographic data were included in the demographic CCA (*n*=10); while all interviewees with mapped parcels were included in the social CCA and in the ecological CCA (*n*=20).

Stepwise LDAs were not carried out as they did not make a significant difference to correlations.

Table A1.2.1. Possible inputs used for non-numerical variables in canonical correspondence analysis.

Category	Possible CCA Input
Wealth ranking	1 (poorest) - 4 (wealthiest)
Location	0 (“Site 1”) or 1 (“Site 0”)
Education	0 (none) - 13 (Bachelor’s)
Place of origin	0 (not Darién province) or 1 (Darién province)
Encroaching frontier settlement, *e.g.*	0 (not mentioned) or 1 (mentioned)

LITERATURE CITED

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TABLES AND FIGURES

Table 1.1. Economic factors that influence land use decisions mentioned by interviewees. †Total number of landowner respondents *n*=17; ‡Total number of female respondents *n*=8 §Total number of youth respondents *n*=7. “Total” is the percentage of respondents in each category that referred to economic factors as influences.

Factor	% Landowners†	% Women‡	% Youth§
Resources and labour	100	100	14
Natural resource use by outsiders	53	38	0
Encroaching frontier settlement	12	13	0
Lack of off-farm employment	0	13	0
Subsistence	94	88	57
Potential income	100	88	57
Presence of external markets	12	0	0
Tourism	0	0	0
Off-farm economies	6	13	0
Presence of external organisations	29	0	14
Total	**100**	**100**	**71**

Table 1.2. Social-cultural factors that influence land use decisions mentioned by interviewees. †Total number of landowner respondents *n*=17; ‡Total number of female respondents *n*=8; §Total number of youth respondents *n*=7. "Total" is the percentage of respondents in each category that referred to social-cultural factors as influences.

Factor	% Landowners†	% Women‡	% Youth§
Proximity to outsiders	6	0	0
Influence of outsider's worldview	29	13	0
Population increase	0	38	14
Lack of social organisation	6	50	0
Tradition	29	38	14
Internal laws	24	25	0
Total	**59**	**88**	**14**

Table 1.3. Political factors that influence land use decisions mentioned by interviewees. [†]Total number of landowner respondents n=17; [‡]Total number of female respondents n=8; [§]Total number of youth respondents n=7. "Total" is the percentage of respondents in each category that referred to political factors as influences.

Factor	% Landowners[†]	% Women[‡]	% Youth[§]
Public policies	53	25	0
Lack of property title	12	50	0
Local politicians	6	0	0
Total	**53**	**50**	**0**

Table 1.4 Ecological factors that influence land use decisions mentioned by interviewees. †Total number of landowner respondents *n*=17; ‡Total number of female respondents *n*=8; §Total number of youth respondents *n*=7. "Total" is the percentage of respondents in each category that referred to ecological factors as influences.

Factors	% Landowners†	% Women‡	% Youth§
Crop diseases	12	13	0
Soil characteristics	18	13	0
Invasive species	12	0	0
Topography	6	0	0
Effect on river	12	0	14
Effect on animals	0	13	0
Distance to plot	12	13	14
Heat/Shade	6	0	14
Natural beauty/state	18	0	0
Total	**65**	**50**	**14**

Table 1.5 Correlations of influences on land uses with discriminant functions. Separate linear discriminant analyses were conducted for economic, for social-cultural, for political and for ecological factors, with female and male interviewees as groups. The most significant predictors are shown.

Explanatory Factor	Correlation
Off-farm employment	-0.483
Presence of external organisations	0.487
Presence of external markets	0.290
Population	-0.750
Social organisation	-0.727
Outsiders' worldview	0.250
Property title	-0.730
Public policies	0.370
Effect on animals	-0.662
Natural beauty/state	0.476
Effect on river	0.381
Heat/Shade	0.381
Topography	0.264

Figure 1.1 Map of the location of the indigenous community of Piriatí-Emberá in eastern Panama.

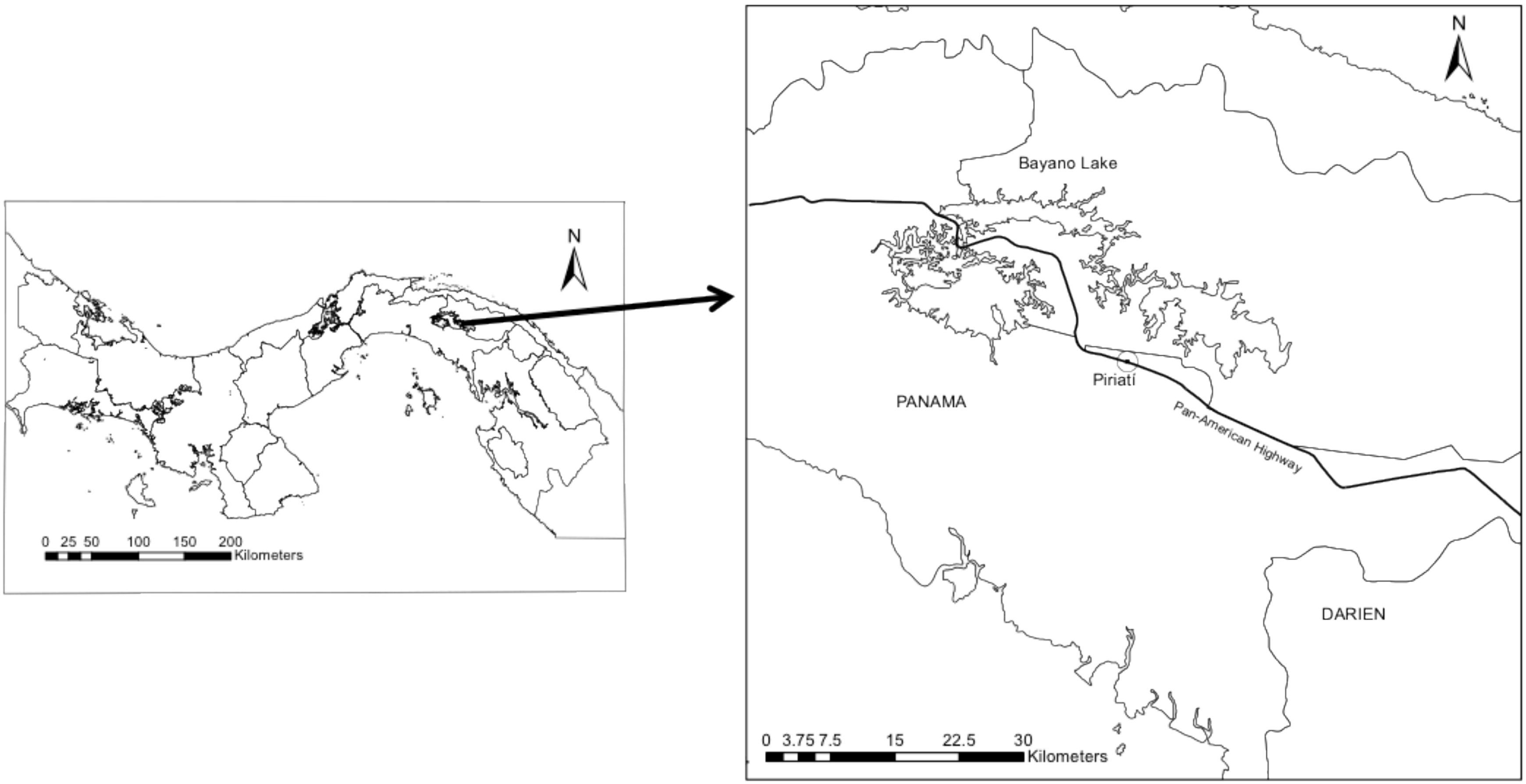


Figure 1.2. Participatory map of the community land (*tierras colectivas*) of Piriatí-Emberá.

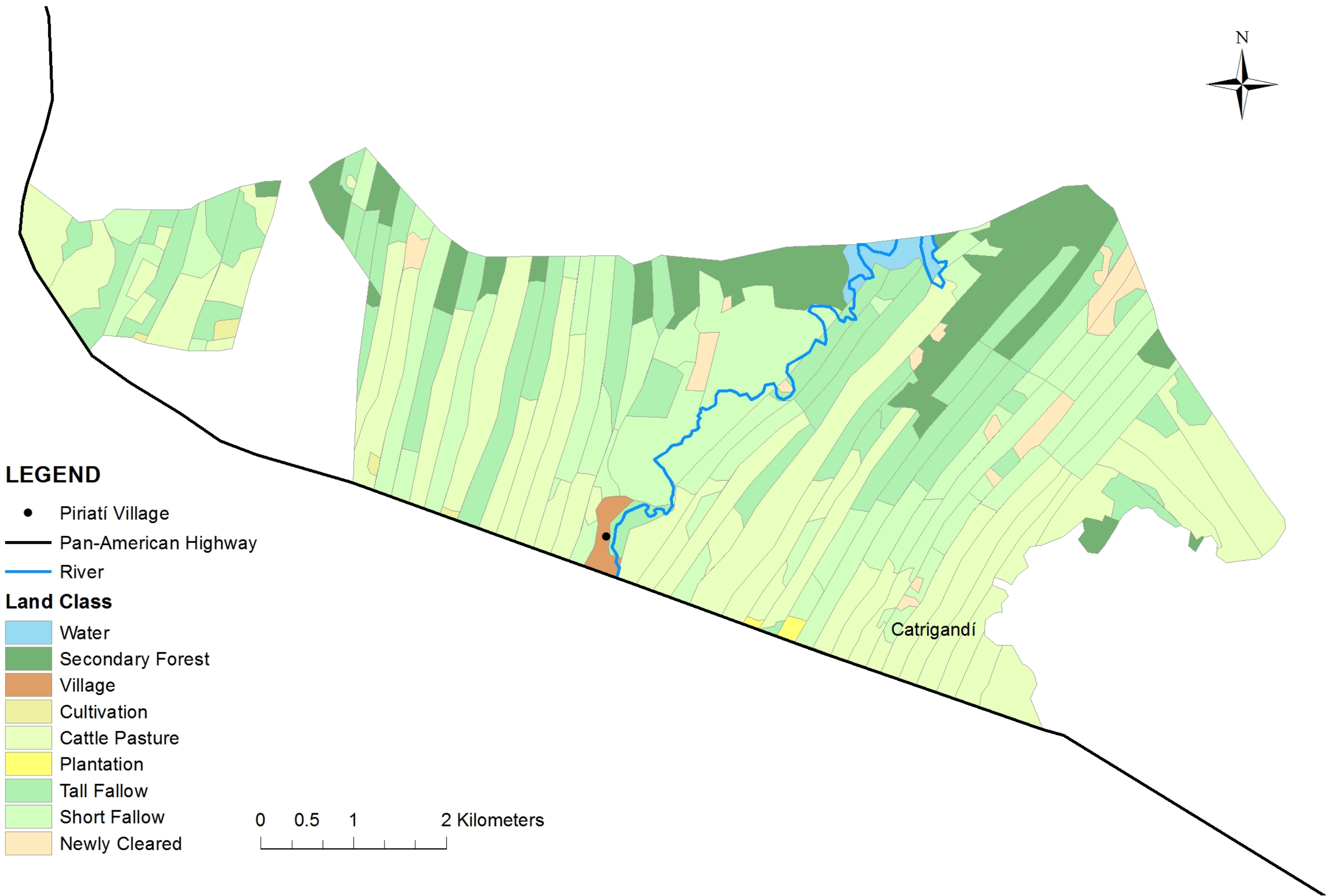


Figure 1.3. Biplot of canonical correspondence analysis between land cover and demographic characteristics at the household level. The axes are linear combinations of the demographic explanatory variables in italics (e.g., # *elders*). The relationship between the explanatory variables and the axis can be estimated by drawing a perpendicular line from the tip of the vector to each axis. The relative importance of the explanatory variables on the canonical axes can be estimated by the length and position of the vectors. The bold arrows position the land cover dependent variables (e.g. % pasture) on the 2D space to help visualise the degree to which the explanatory variables explain the variation in the dependent variables. *Origin* represents whether the interviewee's family is originally from the Darién province (value of 1; otherwise value of 0). *Location* represents whether the interviewee lives closer to the Highway (*Site 1*; value of 0) or further (*Site 2*; value of 1). *Number of help* represents the number of people available to help work the land.

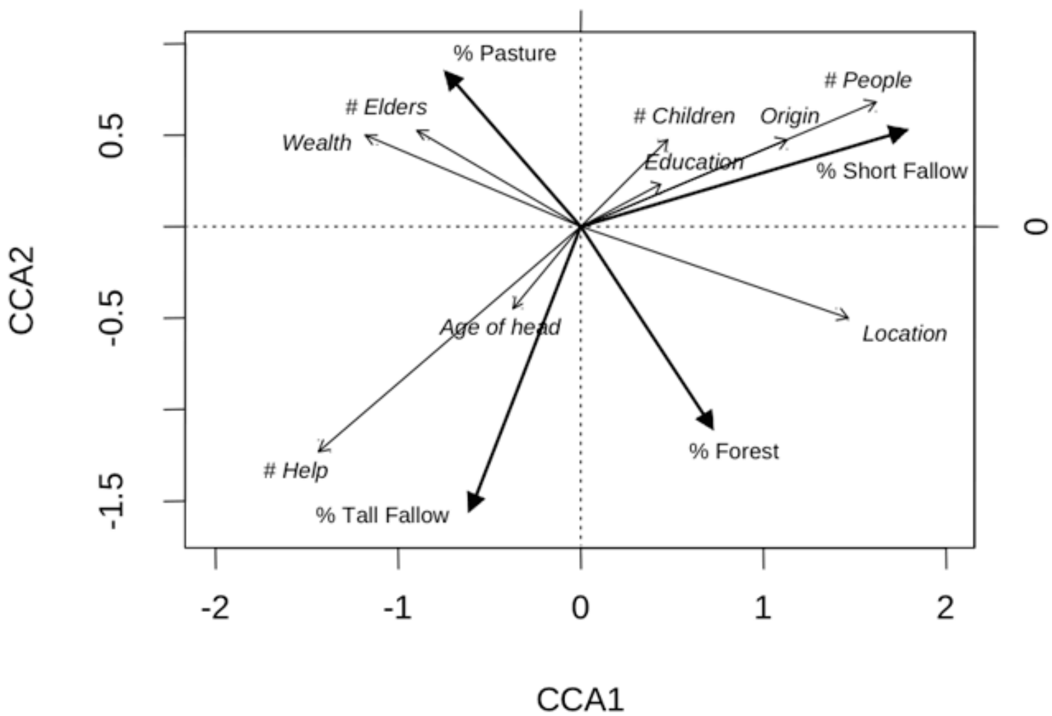


Figure 1.4. Biplot of canonical correspondence analysis between land cover (dependent variables) and social-cultural, economic and political influences on land use (explanatory variables) mentioned by interviewees. Influences are in italics, while per cent land cover is represented by bold arrows. a = Availability of resources and labour; b = natural resource use by outsiders; c = encroaching frontier settlement; d = off-farm employment opportunities; e = population increase; f = potential income; g = presence of external markets; h = proximity to outsiders; i = influence of outsiders' worldview; j = subsistence; k = lack of social organisation; l = presence of external organisations; m = tradition; n = internal laws; o = public policies; p = lack of property title; q = local politicians.

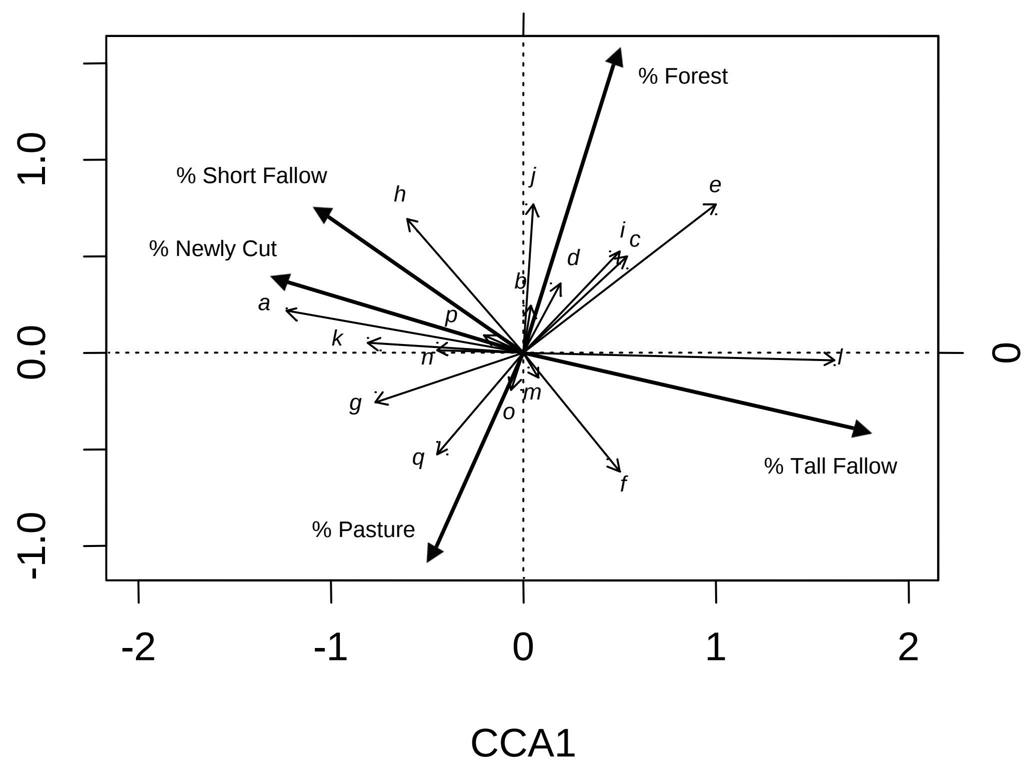
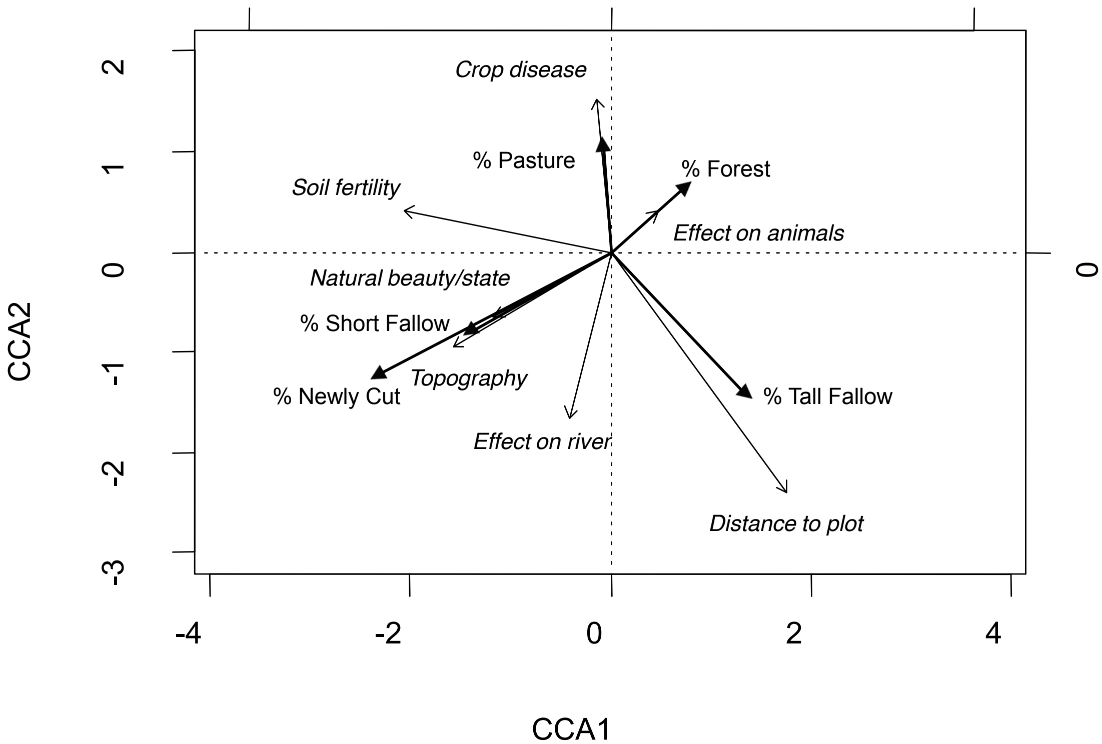


Figure 1.5. Biplot of canonical correspondence analysis between land cover and ecological perceptions of influences on land use mentioned by interviewees. Ecological explanatory variables are in italics, while per cent land cover dependent variables is represented by bold arrows. *Soil characteristics* includes the soil fertility and water content of the soil.



CHAPTER 2 PREFACE

Moving now from a single snapshot case study, this second chapter allows us to establish whether factors perceived to influence land uses translate at a larger scale to explain divergent landscapes in two otherwise comparable social-ecological systems. Our case study is therefore expanded to include the neighbouring Ipetí-Emberá. This chapter builds on the first by using a framework that can open the door for longitudinal comparative studies between the two communities, namely the framework for analysing the sustainability of social-ecological systems of Ostrom (2009). It also addresses more explicitly the spatial and locational factors that influence the landscape, as well as adding a temporal dimension by looking at historical land uses and deforestation. Additionally, this next chapter compares recently shared, remotely sensed Global Forest Watch deforestation data with participatory mapping data, to evaluate their usefulness in local forest monitoring and therefore management.

CHAPTER 2: A COMPARISON OF INFLUENCES ON THE LANDSCAPE OF TWO SOCIAL-ECOLOGICAL SYSTEMS

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Keywords: Deforestation; demographics; eastern Panama; Global Forest Watch; history; indigenous; non-governmental organisations; participatory; social-ecological systems; topography

ABSTRACT

Given high rates of tropical deforestation in areas inhabited by rural forest dwellers, forest conservation requires local spatially explicit case studies that elucidate the ecological and social influences on deforestation. This study focussed on two indigenous communal lands of eastern Panama that share a settlement history, size and location but differ in terms of land uses. To identify drivers of the disparate landscapes, we conducted spatial analysis using ArcGIS and multivariate statistics from numerical ecology on land use data from participatory maps, deforestation data from the Global Forest Watch (GFW), and household level demographic and socio-economic data from semi-structured interviews and surveys. Results illustrate that topography is a key constraining variable on land uses and helps explain divergent deforestation, where flat land is more conducive to forest clearing for activities like cattle ranching and agriculture. To reconstruct the influence of history on the landscapes we conducted interviews with key informants and participatory pebble scoring of historical land uses, and created a participatory historical timeline. Results illustrate that historical human land use activity can also leave its imprint on current landscapes. Historical events like governmental timber extraction in the region pre-settlement, guided by topography constraints, may have led to degraded forests susceptible to clearing. Additionally, our comparison suggests that forest conservation can be encouraged by the promotion of conservation-oriented institutions through collaboration between outside and local institutions in scientific projects. We also compared deforestation according to

participatory mapping to remotely sensed GFW data on deforestation, with the aim of identifying the usefulness of these new open source data as a local forest-monitoring tool. We found that for applications on the ground GFW deforestation data should be verified with local land users to ensure local relevance in areas with dynamic, complex mosaics of land uses. Our findings support the claim that an accurate understanding of deforestation must address local spatial and contextual factors like physical geography and history to better inform forest conservation science.

INTRODUCTION

Global deforestation has become a well-documented phenomenon, with 13 million hectares of forest estimated to have been lost yearly between 2000 and 2010 worldwide (FAO 2010). In Central America and the Caribbean, satellite imagery and literature analysis show that 1.4% of forest cover was lost between 2000 and 2005 (Asner et al. 2009). According to national reports and remote sensing, Panama had 44% forest cover in 2010 and, between 2005 and 2010, lost 0.36% of its land cover annually to deforestation (FAO 2010). These forests are also home to local people; in Latin America and the Caribbean, about 40 million Indigenous Peoples live in forests (World Bank 2004) and Indigenous Peoples in Latin America own almost half of all global community-owned forests (van Dam 2011). A 'conversion of land use and its effects' model in the neotropics predicted that Central America, including Panama, would be a hotspot of deforestation in 2010. The model characterised eastern Panama, home to the indigenous Emberá-Wounaan, as mostly forest with scattered forest loss to pasture and cropland (Wassenaar et al. 2007). In spite of this trend of deforestation, the conventional view of indigenous communities as forest stewards was recently supported in Panama; Vergara & Potvin (2014) showed that indigenous territories, including claimed lands without legal title, had significantly higher per cent forest cover than non-protected public and private lands in 2008.

Global landscapes are formed from a composite of local changes in land use (Lambin et al. 2003). They consist of complex social-ecological systems in which particular land uses emerge from an array of environmental and human interactions within particular contexts. Thus case studies that consider fine-grained nuances on land use change are necessary for the development of generalised knowledge on deforested landscapes (Lambin et al. 2001; Chazdon et al. 2009; Ellis et al. 2010). Furthermore, there is a need to relate ecological and social factors to the landscape in a spatially explicit manner (Field et al. 2003; Pijanowski et al. 2009; Shkaruba &

Kireyeu 2013). Ostrom's framework for analysing the sustainability of social-ecological systems (SES; Ostrom 2009) provides a useful theoretical structure for identifying this diversity of characteristics that can distinguish between social-ecological systems and therefore help diagnose forest-poor landscapes. The aim of the framework is to allow for replicable research (Cox 2011); case studies that use the same vocabulary allow for more comparable studies across disciplines (Ostrom 2009; McGinnis & Ostrom 2014).

Measurement, reporting and verification (MRV) of forest cover is a necessary step to inform any effective management strategies, but MRV capabilities are lacking in most tropical countries (Angelsen 2009). The current range of remotely sensed forest cover databases with disparate methodologies means that each comes with its own set of limitations, often leading to incomparable datasets (McCallum et al. 2006; Herold et al. 2008). However, the World Resources Institute recently made public an open-source remotely sensed dataset on global forest cover under its project name the Global Forest Watch (GFW). The aim of GFW is to create a global database for forest monitoring and improved forest management (Hansen et al. 2013; GFW 2014). The advantages of use of GFW data for conservation research are manifold: they are comprehensive, freely accessible, annual, derived from uniform methods, and therefore comparable across countries. In Panama there are no time series land use maps that allow us to precisely evaluate historical land use trends. While the accuracy of participatory mapping in the country has been confirmed (Vergara-Asenjo et al. 2015), this comparison was not drawn with GFW data. Moreover it used expensive remotely sensed images for which time series are not readily available. Therefore, if valid at a local scale, GFW data are an invaluable resource to inform forest management. However, to our knowledge, the relevance of GFW data in local forest monitoring applications is just beginning to be verified on the ground.

Moving to a local scale then, this paper adopts a spatially explicit approach to understanding factors that influence differences in forest cover in two seemingly analogous social-ecological systems. Despite sharing the same ecoregion, recent settlement history in a frontier zone, cultural background, bounded property system and distance to market, two neighbouring indigenous territories, namely Piriatí- and Ipetí-Emberá in the Chocó-Darién moist forest of eastern Panama, have disparate landscapes. While Ipetí maintains forest, deforestation is a focal concern of local leaders in Piriatí. Thus the comparison provides a unique opportunity to identify broader implications of the social-ecological factors that drive deforestation. We hypothesised that differences in forest cover could be in part explained by topographical variations between the lands. The objectives of this paper were therefore to 1) determine, using Ostrom's framework, which ecological, locational, social and historical factors can lead to divergent land use outcomes, and 2) to establish the accuracy of deforestation according to the GFW open source data at the local scale relative to perceived deforestation according to participatory mapping. The comparison therefore enables the identification of the usefulness of GFW at the scale of local land use decision-making.

METHODS

Study sites

This study focussed on two indigenous communal lands of eastern Panama that share a settlement history, size and location but differ in terms of land uses. These communal lands (*tierras colectivas*) are those of Piriatí- and Ipetí-Emberá. They are located in the Bayano watershed of Panama province, ~100 and ~120 km east of Panama City, respectively (Fig. 2.1). Piriatí's lands comprise 3867 ha, while Ipetí's 3145 ha. Both communities were formed following the displacement of inhabitants along the Bayano River due to the construction of a hydroelectric dam in the early 1970s (Wali 1989; Wali 1993). Until 2014, both Piriatí and Ipetí lacked legally recognised land title, after which Piriatí was granted communal land rights. The communities consist in their majority of indigenous Emberá, originally from the Darién province that shares an eastern border with Colombia. Shifting cultivation and cattle ranching are practised on plots of land managed by individual households.

Comparison of land uses between the communal lands

The first step in our analysis was to establish how similar or dissimilar the communal lands are in terms of recent land use. To do so we conducted a linear discriminant analysis (LDA) on RStudio (version 0.98.484) using per cent forest, tall fallow, cropland and pasture cover at the level of the individual plot in both communities as explanatory variables (n_{Piriati}=47; n_{Ipeti}=73). Individual plots were coded as 1 if they pertained to Piriatí and 2 for Ipetí. Land use cover came from 2012 participatory maps of Piriatí (see Chapter 1) and Ipetí (Vergara-Asenjo et al. 2015). All households for which land use cover data were available were used. In Piriatí there was a high concentration of many small plots in lands recently allotted to new families; these were excluded from the LDA due to participants in mapping being unable to distinguish between the plots. The LDA biplot was produced in JMP 11.0.0.

In addition, in order to reconstruct how and why land use has changed since resettlement in Piriatí and to compare changes to those in Ipetí, we conducted a participatory pebble scoring activity in 2013. We modelled the activity after the methods of Geilfus (2002) and a similar process carried out in Ipetí by Potvin et al. (2006). The deputy chief selected 8-12 participants with knowledge of the communal lands, including middle-aged to elderly men and women. Participants were asked to divide 20 pebbles between each land use category for each decade from the 1970s until the 2010s to represent the composition of the communal lands over time. In order to further reconstruct the history of the communities, we created a participatory timeline of the major events that had occurred in Piriatí since re-settlement, following methods outlined in Geilfus (2002; see Appendix 2.1 for details). To better understand the legacy of historical timber extraction by the government on differential forest cover in the two lands, we also interviewed key informants in both communities ($n_{\text{Piriatí}}$=5; $n_{\text{Ipetí}}$=2). In addition we conducted an archival search of historical timber extraction in the region and unstructured interviews with 12 key informants employed in governmental logging, using a snowball sampling approach.

Identification of social-ecological factors influencing land uses

Once we established whether land uses differ between the lands, our next step was to determine which social-ecological factors help explain differential land uses. We used per cent forest, tall fallow, cropland and pasture cover at the level of the individual plot as dependent variables and 16 ecological and 12 social explanatory variables chosen based on their potential to be different between the communities, using Ostrom's framework for analysing social-ecological systems (SES; Ostrom 2009). This framework enables the identification of which features of comparable SES should be included in an analysis of divergent land use outcomes, by dividing the SES into eight first-tier variables that are each comprised of second-tier variables (Table 2.1). As a preliminary screening test, we used correlations to identify the explanatory variables that were most correlated to land uses. When explanatory variables were categorical we screened using a canonical correspondence analysis (CCA; detailed explanation of the explanatory variables and their sources in Table 2.2).

The screening allowed us to reduce the number of explanatory variables to 10. Those explanatory variables were then put into an LDA in RStudio to establish which of these social-ecological variables discriminated between the two communities, after standardising and centring the variables ($n_{\text{Piriatí}}$=9; $n_{\text{Ipetí}}$=19). We also compared population between the two communities using population data per decade from 1980 to 2010 from the Contraloría General de la República de Panamá (Contraloría 2014).

Comparison of GFW deforestation in the communal lands

Our next step was to establish whether deforestation rates differ between the two communal lands. Annual deforestation was estimated from data made available by Global Forest Watch (GFW) between 2004 to 2012 using ArcGIS 10.1 (see Appendix 2.2 for more details on spatial methods). GFW uses Landsat imagery at 30 m resolution, where trees are vegetation of greater than 5 meters in height, and deforestation is a stand-replacement disturbance or total loss of tree cover in a pixel (Hansen et al. 2013).

To visually compare deforestation according to remote sensing to deforestation perceived by community members, we laid the GFW data over a map of deforestation calculated from participatory maps of Ipetí created in 2004 (Potvin et al. 2006) and 2012 (Vergara-Asenjo et al. 2015). Historical participatory maps were only available for Ipetí. To better understand the discrepancies between GFW and participatory deforestation, in 2014 local GPS (Global Positioning System) technicians ground-truthed 17 sites that were a) deforested according to GFW but not according to participatory mapping; b) patches > 1.5 ha and c) either forest (*n*=10) or tall fallow (*n*=7) according to 2012 mapping. These sites were chosen because they were relatively homogeneous patches of deforestation according to GFW, and therefore deforestation (or lack thereof) would be evident on the ground (see Appendix 2.2 for details).

To further compare GFW data to participatory data, we examined if the social-ecological factors related to participatory land uses were congruent with those related to remotely sensed deforestation. We compared per cent deforestation between 2004 and 2012 according to GFW to 12 numerical household level characteristics at the level of the individual plot using a principal components analysis (PCA) in JMP 11.0.0, after thinning the variables by removing those factors strongly correlated to each other but not to per cent deforestation ($n_{\text{Piriatí}}$=9; $n_{\text{Ipetí}}$=18). The factors found to be most associated with deforestation were then used in an LDA in RStudio to identify which of these factors are most different between the two communal lands ($n_{\text{Piriatí}}$=9; $n_{\text{Ipetí}}$=19) and, therefore, could explain differential deforestation.

RESULTS

Comparison of land uses between both communal lands

The 2012 participatory maps of Piriatí and Ipetí showed 10.7% and 42.5% forest cover, respectively. The linear discriminant analysis (LDA), conducted to establish whether the two lands are different in terms of land uses, found that land uses at the level of the individual plot allowed discrimination between the two communal lands with 74.0% correct classification. Forest cover was the most significant predictor of community grouping followed by pasture, with correlations to the discriminant function of 0.911 and -0.720 respectively, which compares to 0.0762 and 0.454 for tall fallow and cropland (Fig. 2.2). Results from the participatory pebble activity suggest that both Piriatí and Ipetí had similar levels of forest at the time of settlement until the 1980s. The perception of participants was that Piriatí experienced a greater decline in forest after this point (Fig. 2.3).

To shed light on the differences in forest cover we researched timber harvesting in the region. Interviewees from the community reported the presence of a logging court in the early 1970s where the villagers first settled in the western communal lands of Piriatí, known as Partí. The court belonged to what became known as the governmental Corporation for the Integrated Development of the Bayano (hereafter the Bayano Corporation). The camp allegedly employed 20-100 workers who logged downriver and upriver (southward) until the terrain became too hilly. Villagers decided to relocate to the current village site of Piriatí, at the time primary forest, due to the presence of peasant (*campesino*) farmers on Partí lands. At this point the Bayano Corporation agreed to clear the new community lands for the villagers. Once they returned to the new village to settle, community members observed a cut path from Partí leading to a courtyard of abandoned *espavé* (*Anacardium excelsum)* logs, suggesting that the Corporation had since engaged in selective logging. Indeed participants in pebble scoring in Piriatí emphasised that forest had always been secondary due to timber extraction by the Bayano Corporation pre-settlement. Meanwhile, villagers stated that the Corporation did not extract timber south of the Pan-American Highway due to its hilly terrain. Instead the operation moved eastward towards Ipetí, where timber extraction was also limited as the Corporation arrived post-settlement and extraction was possible only in flat lands. In the early 1980s, one independent logging operation was given a 2000-hectare concession for three years in Piriatí, but by this point the Corporation had already extracted the valuable timber. Two teams of two locals were contracted by the group to harvest 300 trees per year, with additional pay for every extra tree harvested. An estimated 4200 trees were cut over the three years in Piriatí in the post-Corporation period. These claims were supported by interviews with former employees involved in timber extraction, who stated that the Corporation had been harvesting *cativo* (*Prioira copaifera*) and *espavé* along the Bayano River between approximately 1967 and 1973. After clear-cutting the reservoir and selling valuable timber species to fund dam construction, the Corporation began to log selectively eastward. Selective logging in Piriatí was of fine wood like Spanish cedar (*Cedrela odorata*), *cedro espino* (*Pachira quinata*), mahogany (*Swietenia macrophylla*) and oak (*Tabebuia pentaphylla*) and, less preferentially, *espavé*. There was at least one other logging camp in the eastern lands of Piriatí and logging occurred both east and west of these communal lands. South of the Highway extraction was limited due to lack of valuable species. These interviewees further alleged that timber extraction was boosted by construction of the Bayano Bridge in the mid-1970s. Archival research further supports findings of timber extraction in the communal lands. A documentary from the time explicitly states that extraction was occurring in Piriatí (GECU 1974). In eastern Panama bulldozers clearing logging roads, trucks and felled trees were observed east of the communal lands in the early to mid-1970s (Webb 2008). Selective logging in eastern Panama in the mid-1970s was reportedly vital to funding the Bayano Corporation (Corporación Bayano 1982). A study by an international organisation, contracted to inform a management plan for the watershed, reported that the Corporation was still harvesting wood in the Bayano watershed between 1980 and 1989 (Louis Berger 1999). By the mid-1980s, thirty-nine independent logging operations with concessions of over 100 000 ha were reportedly running in eastern Panama (Rojas 1985).

Identification of social-ecological factors influencing land uses

Which social-ecological factors are related to communal land uses?

Having established that the communal lands do differ in terms of land uses and historical timber harvesting, we found that number of people and children at home, elevation, slope and distance to highway were the continuous factors most correlated to land uses in both lands (Table 2.3).

Land and livestock ownership and education level of household head were the categorical explanatory factors most related to land uses in both lands (Fig. 2.4).

The correlation analysis between continuous social-ecological factors and land uses in both lands showed that those households that had more people tended to have more cropland in their plots; those that had more children at home tended to have less pasture, when using a moderate correlation of >0.400 (Table 2.3). Those household plots that had a higher elevation, slope and distance to highway tended to have more forest and less pasture, when using a stronger correlation (0.600) (Table 2.3). However, the positive relationship of the nearest distance to highway on forest cover, only strong in Ipetí (0.581), is likely in fact representative of the effect of topography. In Piriatí alone, where the lands are relatively flat (Fig. 2.5) and individual plots are arranged perpendicular to the highway, land uses were *not* strongly correlated to nearest distance to highway (0.368, 0.167, -0.313 and -0.087 for per cent forest, tall fallow, cropland and pasture, respectively). Additionally, in Ipetí, nearest distance of plot to highway was positively correlated to average elevation (0.774) unlike in Piriatí (-0.017).

A comparison of average elevation (Fig. 2.5) and slope (Fig. 2.6) across land uses between the two communal lands further showed that Piriatí has a relatively flat topography and that in Ipetí forest tended to be located in areas of high elevation and slope. While distance of a plot to the village was not strongly related to its land use composition - *i.e.* its amount of forest - a comparison of the average distance to village of each land use class showed how forest was, on average, located furthest from the village (Fig. 2.7). Similarly, forest tended to be located furthest from the Highway in both communal lands.

The two canonical axes of the canonical correspondence analysis (CCA) between the categorical explanatory variables and the per cent land use response variables explained a cumulative proportion of variance of 95.1%; the first axis explained 60.8% (Fig. 2.4). The axes are linear combinations of the explanatory variables. The vectors illustrate the degree to which the explanatory variables account for the variation in the response matrix (Borcard et al. 2011). Those who own land tended to have a greater percentage of tall fallow than those who have either sold or rented their plot of land. Those who own their own livestock and have a greater education tended to have more forest.

Which social-ecological factors related to communal land uses differ between the two communities?

Of the factors we found to be related to land uses in the previous steps, the number of people at home, land ownership and topography were the factors that could help explain the observed differences in communal land uses. The LDA between the two lands, with 60.7% correct classification, showed that number of people per household was the most significant, although only a moderately strong, predictor of membership to Piriatí. Elevation, slope and ownership of land were the most significant predictors of membership to Ipetí (Table 2.4). That is, Piriatí had more people per household, and Ipetí had a greater elevation, slope and proportion of landowners who still own their land. It should be noted that the inability to include newly allotted lands in Piriatí in the analysis entailed the exclusion of some relatively young households, likely with fewer people at home. While number of people at home differed between the communities, population rate change per decade between 1980 and 2010 was not significantly different; $t(2)=0.667$, $p=0.574$.

Comparison of GFW deforestation in the communal lands

Congruent with the perception of landowners, the two communal lands differed significantly in recent deforestation rates ($t(8)=2.60$, $p=0.0316$; Table 2.5; Fig. 2.8). According to the GFW data, 237 ha of communal land were deforested between 2004 and 2012 in Ipetí, and 535 ha in Piriatí. Meanwhile, the participatory maps of 2004 and 2012 in Ipetí suggest a loss of 299 ha of both forest and tall fallow. Despite similar estimates of the amount of deforestation, the two methods were incongruent in terms of the precise location of deforestation in the territories. Roughly one third (74.8 ha) of the total area of deforestation according to GFW data fell within the deforested areas according to the participatory maps (Fig. 2.9). Those areas that were considered deforested according to GFW but not participatory mapping tended to be perceived as forested areas by community members (~1/2; 71.8 ha), while one third corresponded to tall fallow (52.7 ha), and one sixth to pastured lands (24.2 ha).

Ground-truthing by local technicians in 2014 was used to verify land uses. The data show that 12 of 17 sites that were considered deforested by GFW between 2004 and 2012 were either forest or tall fallow in 2014 and, therefore, are unlikely to have been non-forested in 2012. Indeed, 8 of these 12 points were also forest or tall fallow in the recent past, according to local technicians, suggesting they are unlikely to have been deforested in 2012 and then reforested by 2014. Four of these 17 sites were deforested between 2004 and 2007 and so could theoretically have been deforested and then reforested by 2012, but not considered deforested by a comparison of the 2004 and 2012 participatory maps. Out of the five points that could have been correctly classified as deforested by GFW (*i.e.* that were not forest or tall fallow in 2014), four had either forest or tall fallow in the hectare surrounding the GPS point visited and three out of the five were forest or tall fallow in the recent past. Of all the points visited, 14 were characterised by mixed land uses in the immediate vicinity or surrounding hectare.

The PCA comparing per cent deforestation between 2004 and 2012 according to GFW and household level characteristics at the level of the individual plot in both lands showed that ownership of livestock, plot size, minimum distance to village, year of arrival, level of education of household head, maximum elevation and maximum slope were the variables most associated with per cent deforestation. Number of people at home was unrelated to deforestation (Fig. 2.10). Consistent with the findings of the land use comparison, the LDA comparing these factors showed that, with 77.8% correct classification, slope and elevation were the most significant predictors of membership to Ipetí (Table 2.6). The analyses together therefore suggest that topography explains both current land uses and differential loss of forest cover in the communal lands (see Table 2.7 for a summary of the differences between the communities that can explain divergent forest cover, according to Ostrom's framework (Ostrom 2009)).

DISCUSSION

Topography

The case studies we used of two similar communities with contrasting landscapes in eastern Panama enabled the identification of salient ecological and social influences on rural deforestation. As hypothesised, the difference in forest cover between the two communal lands was explained in part by topographical variations. Flat land is more conducive to forest clearing for activities like cattle ranching and agriculture. Likewise, six per cent of the cases examined in a meta-analysis identified topography and slope as "predisposing" explanatory factors of deforestation in Latin America. Land characteristics such as these corresponded to deforestation via enabling shifting cultivation, frontier colonisation and conversion to pasture (Geist & Lambin 2002). In an analysis of forest cover change in the Chorotega region of Costa Rica, secondary forest tended to be in areas of high slope and low soil depth and fertility, where pasture establishment would not be viable (Arroyo-Mora et al. 2005). Elevation and slope were most significantly related to deforestation in a study of LUCC in an indigenous coffee-growing region in Mexico; pasture and agricultural lands tended to be located in areas of lower elevation (Ellis et al. 2010).

In both communal lands forest tended to be located in areas more remote from the villages and the Highway, congruent with a previous report that forests were in hilly areas in Ipetí (Kirby & Potvin 2007). Deforestation rates according to GFW have also decreased in both communal lands in recent years; according to community members in Piriatí, this is because remaining forests are in inaccessible areas. Similarly, in indigenous Mexico parcels of land further from the road were not actively used, *i.e.* were in fallow (Ellis et al. 2010). This latter finding conforms to the expected outcome of tropical deforestation - that rates will decrease as remaining forest becomes less accessible (Myers 1993 and Rudel & Roper 1997, as cited by Geist & Lambin 2002). While landowners leave forest in parts of their parcels that are most remote, the distance to their plot does not seem to influence the overall proportion of forest they retain. The consideration of the path network that connects plots and likely influences accessibility across the communal lands - more so than the linear nearest distance to the village - would perhaps alter this finding. Mapped path networks can be incorporated into land use research, as was done in a study of the effect of factors like land uses on the spatial distribution of plant species in an indigenous Kuna community of eastern Panama (Dalle et al. 2002).

Historical context and the governance system

Beyond biophysical influences, historical human land use activity can leave its imprint on current landscapes (Rhemtulla & Mladenoff 2007; Gray et al. 2008; Sloan 2008; Rhemtulla et al. 2009; Moran 2010). In the communal lands, a combination of three historical events can help explain differences in forest cover: 1) the decisions of local leaders to distribute unused lands, taken based on population pressure and subsistence needs, 2) pasture conversion on rented lands by a local politician exerting political power, and 3) timber extraction by the national government pre-settlement, shaped by topography constraints. Firstly, participants in the pebble scoring activity in Piriatí alleged that the drop in forest cover in the 1990s was partly due to the allotment of previously ownerless lands by local leaders to new, landless families. These new landowners immediately began deforesting to cultivate for subsistence and sale of surplus. A similar transition has been anticipated in Ipetí (Potvin et al. 2006). Secondly, the further decrease in forest cover in the 2000s in Piriatí, and the subsequent high proportion of pasture, was attributed to a regional politician renting multiple parcels of land and converting forest and fallow to pasture for cattle ranching. The finding that there are fewer landowners in Piriatí who still own their land, and the negative relationship of land ownership to proportion of pasture both support this claim. The result is a comparable situation to that observed among indigenous coffee-growers in Mexico: few landowners own the majority of pasture and local community members who have sold or rented lands look after these landowners' cattle (Ellis et al. 2010).

Finally, the influence of history on the landscape in eastern Panama is exemplified in the engagement of the Bayano Corporation in timber extraction during the time of hydroelectric dam construction in the 1970s. Inheriting already degraded forests in Piriatí may have incentivised forest clearing compared to Ipetí, where forests were reportedly pristine at the time of establishment (Potvin et al. 2006). Forty per cent of the Latin American cases in a meta-analysis of tropical deforestation showed that commercial timber extraction, including selective logging, combined with proximate drivers like shifting cultivation resulted in deforestation (Geist & Lambin 2001). In the Brazilian Amazon, areas that were within 5-25 km of a main road and that underwent selective logging were up to four times more likely to be deforested in the subsequent four years than unlogged areas (Asner et al. 2006). Logging can leave forests vulnerable to droughts and forest fires (Asner et al. 2006; Matricardi et al. 2010) but subsequent forest clearing may also be motivated by the loss of perceived value of forests through depletion of culturally valuable tree species, as purportedly occurred in Piriatí (see Chapter 1). Thus, a review of the history of the region illustrates the potential influence on land uses of constraints imposed by physical geography, subsistence needs and the political environment - *i.e.* actions by actors at different spatial and power scales - all forming the context around which deforestation has occurred.

Landscapes can also be shaped by non-governmental organisations (NGOs) that, in their ability to change resource use patterns, can alter human-environment relationships (Bebbington 2004). Either by reinforcing community forest governance or by directly engaging in forest conservation activities, NGOs can be involved in the discouragement of deforestation (Wright & Andersson 2012). For example, in the Maya Biosphere Reserve of Guatemala, contact with an environmental NGO was deemed a potentially negative influence on the decision to clear forest, although no relationship was found (Carr 2005). Involvement in community organisations was associated with a greater area under cultivation in a study across five indigenous populations in the Ecuadorian Amazon (Gray et al. 2008).

In eastern Panama, collaboration between outside and local institutions in carbon projects and, later, agroforestry may help explain differences in forest cover. The local registered NGO of Ipetí has been involved in a series of projects with external donors and collaborators, including co-author CP since 1996 (see timeline (Fig. 2.3)). Scientific collaboration with Ipetí was begun at a time of strong local leadership with an apparent motivation to ameliorate the quality of life of the community members. The strength and presence of the local NGO set the foundation for these projects and suggest the presence of strong conservation-oriented institutions, *i.e.* norms and leadership, which may have incited the relative decrease in deforestation compared to Piriatí. Indeed, community members in Piriatí, where there is no such active NGO, previously alleged that weak internal laws and lack of social organisation in the community were factors that have led to forest loss in their lands (see Chapter 1). Participants in pebble scoring in Piriatí anticipated that the arrival of external NGOs in the next decade would entail shifts from land devoted to tall fallow to agroforestry. Prior relationships inform the places that NGOs seek to establish projects (Bebbington 2004) and subsequent collaboration with external NGOs in Ipetí was enabled by this initial scientific relationship. Thus the continued presence of such scientific projects has likely perpetuated Ipetí's culture of conservation and harnessing of external resources for conservation purposes. A comparison of two communities in the Los Tuxtlas Biosphere Reserve in Mexico showed that the community that had contact with outside NGOs and government agencies took greater responsibility for deforestation and demonstrated more concern about conservation (Durand & Lazos 2008). In an analysis of the effect of NGOs on deforestation in 200 rural communities in Bolivia, the presence of more NGOs that were viewed as "important" was associated with lower rates of deforestation, but not to the presence of community forest institutions. The result suggests that NGOs do prevent deforestation in the country but not via enhancing community's forest governance capacity through the creation of institutions (Wright & Andersson 2012). Meanwhile, the case study presented here suggests that the symbiotic promotion of attitudes favouring conservation by pre-existing local NGOs and subsequent scientific collaboration may ultimately influence forest cover.

Global Forest Watch versus perceived forest loss

Constant monitoring of forest resources is valuable for effective resource management: for example, rapid detection of land use change via satellite databases was key to limiting deforestation in the Brazilian Amazon (Assunçao et al. 2013). However, global datasets on forest cover must reflect local level deforestation in order to be relevant in local monitoring and forest management. We found that for applications on the ground GFW deforestation data should be verified with local land users to ensure local relevance, especially in areas with dynamic, complex mosaics of land uses. Ground-truthing showed that part of the discrepancy between GFW and participatory mapping could be explained by the mosaic nature of indigenous lands, but also by local perceptions of what constitutes forest cover. GFW's definition of forest is not perfectly compatible with that of locals, where trees in the Bayano watershed are on average 17 metres in height (Vergara G., pers. comm.). Inclusion of perceived tall fallow loss increased the spatial overlap of GFW and perceived deforestation, suggesting the fine line between what is considered forest and what is considered tall fallow for community members. Nevertheless GFW deforestation data can be useful in identifying areas in need of conservation; both GFW and participatory data were consistent in their demonstration of how forest loss is minimal in areas of high elevation and slope, and how topography best explains differences in land uses between the two lands.

Likewise, studies have shown that the accuracy of global satellite-based land cover change datasets tends to diminish at local scales and in areas of mosaic land uses (McCallum et al. 2006; Herold et al. 2008; Cabral et al. 2010). In Angola, an increase in cropland and bare soil was detected by imagery at 30 m resolution but not by global maps at 1 km resolution. Land use changes detected by global maps were more accurate in Guinea-Bissau than in Angola, where the landscape is more mountainous and patchy (Cabral et al. 2010). A comparison of four global land use datasets showed decreased compatibility between them when compared at the continental scale of Europe, which the authors characterised as "heterogeneous and anthropogenic" (McCallum et al. 2006). A similar study comparing four global datasets at 1 km resolution showed that datasets were less accurate spatially and in terms of land classification in heterogeneous areas of mixed, mosaic vegetation (Herold et al. 2008). This study presented here confirms that forest monitoring can be well informed by locally derived data.

CONCLUSION

This case study was initiated due to local indigenous leaders' concern over forest loss in their communal lands relative to the lands of their neighbours. Results suggest that differential deforestation is an outcome of contextual factors like physical geography and history. Landscapes can be shaped by topographical constraints and subsistence needs but also by historical factors, like past land use activities of powerful external agents; long-term collaboration with NGOs and scientists; and their feedback with local conservation-oriented institutions. A spatially-explicit analysis that examines both ecological and social factors is therefore imperative to the study of potential influences on land uses. Verification of Global Forest Watch deforestation data at the local scale suggests that the data are useful in diagnosing regions in which forest loss is occurring. However, results support previous findings on the limitations of global remotely sensed data on deforestation at the local scale, in areas of dynamic, mosaic land uses. Global forest monitoring can therefore be supplemented with local studies to inform local forest management practices, with future research to scale up the verification of global data to a more regional scale.

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APPENDIX 2.1

Supplementary information on participatory timeline methods.

To help identify the influence of history on the landscape, in 2013 the deputy chief in Piriatí chose 12-16 male and female community members across a range of ages to participate in a workshop, which was also made open to anyone willing to participate. Participants met in the communal meeting area of the village and were separated into four working groups according to gender and age. Each group generated its own timeline and presented it to the group, followed by a group discussion. The individual events were then compiled to create a comprehensive timeline based on events found in multiple timelines and/or events considered important by participants. Information gathered from documents of the on-going relationship between the Smithsonian Tropical Research Institute, McGill and Ipetí, and discussions with a key informant enabled the addition of equivalent events in Ipetí to the timeline. Ethical certificates were obtained from the McGill University Research Ethics Board and the Instituto Nacional de Cultura (INAC) in Panama.

APPENDIX 2.2

Supplemental information on spatial analysis methods, operated with ESRI ArcGIS 10.1.

Elevation, slope and nearest distance calculations

The Digital Elevation Model (Digital Elevation Database SRTM 90m v4.1) was downloaded from the CGIAR Consortium for Spatial Information website (http://www.cgiar-csi.org/data/srtm-90m-digital-elevation-database-v4-1), which was clipped to the polygons of the communal lands using the Clip Raster tool. The Project Raster tool was used to convert to WGS 1984 UTM Zone 17N. The slope (per cent rise) was generated using Spatial Analyst, and the Zonal Statistics as Table tool was used to calculate the average slope and elevation per land use class. To obtain the elevation at the level of the pixel and compare maximum, minimum and average elevation at the level of each household parcel, the DEM was converted from raster to polygon. It was then spatially joined to the participatory map file and the Zonal Statistics as Table tool was used to obtain elevation values per household. To obtain the slope at the level of the pixel, the Raster Calculator tool was used to obtain integer values of slope. Then the Raster to Polygon tool was used to enable a Spatial Join to the participatory map, and slope values per household were obtained using the Zonal Statistics as Table tool. To calculate the nearest distance of each land use patch to the river, village and highway, we used the Near (Proximity) tool. Village, highway and river shapefiles were obtained from participatory maps of 2012, with the exception of the rivers to the east and west of the Piriatí communal lands, which we sketched using the World Imagery Basemap.

Global Forest Watch calculations

Global Forest Watch data for Panama were obtained from the website www.globalforestwatch.org (Hansen et al. 2013). This raster contains all pixels that were deforested between 2001 and 2012, with the pixel value being the year the forest loss occurred. We used the Identity tool to identify GFW deforestation features in the participatory maps, and convert the data to the WGS 1984 UTM Zone 17N coordinate system. We then added an area field and calculated the area of each land use patch in the participatory maps, using Calculate Geometry, and summarised the total area of each patch according to landowner. We used the Dissolve tool to remove the divisions of land uses within a single landowner, added an area field and calculated the total area of the parcel per landowner using Calculate Geometry. We then spatially joined the participatory map's attribute table to the GFW deforestation table to obtain the total area deforested per landowner. The Multipart to Singlepart tool was used to re-separate land use patches within each landowner's parcel, and then we added the field "Patch No.". We then calculated the area of each patch using Calculate Geometry, and exported the table as a database file. We then used the Identity tool to identify GFW deforestation features in the multipart file and added the field "Patch No_Code", which combined the patch number with the GFW gridcode (*i.e.* year of deforestation). An area field was added and the geometry was calculated and summarised per patch number to obtain area deforested per land use patch per owner. The table was exported as a database file and joined to "Patch No_Code". An area field was added and the field calculator was used to calculate the per cent deforestation per land use patch. This was done for both communal lands.

Comparing GFW deforestation to participatory mapping deforestation

GFW deforestation data was clipped to the Ipetí participatory map shapefile, and the Select Attributes tool was used to select for deforestation on or after 2005 (gridcode ≥ 5). The participatory maps of 2004 and 2012 were both converted from polygon to raster, with land use as the value field. To generate a column of land use change, we reclassified the 2004 map, where we multiplied by a value of 10 to the gridcode representing the land use class (1 = forest; 2 = tall fallow; 3 = short fallow; 4 = plantation; 5 = pasture; therefore 1 became 10, etc.). We then used the Raster Calculator to add these new values to the comparable land use gridcode values for 2012. Thus, a value of 14 meant that the patch was forest (1) in 2004 and plantation (4) in 2012.

Therefore, gridcodes of 12, 13, 14 and 15 represented deforestation, and so we converted from raster back to polygon, and selected for deforestation by attribute (12 or 13 or 14 or 15 or 23 or 24 or 25 to include loss of tall fallow as deforestation).

To remove patches of deforestation deemed unable to be perceived by landowners (corresponding to single pixels of deforestation data), GFW deforestation data were dissolved based on location, then re-separated using the Multipart to Singlepart tool. We then added an area field, selected by attribute for area < 0.1 ha. Patches of deforestation <0.1 ha were excluded from the analysis, as this was the minimum scale at which change in land use was perceived in participatory mapping. Thus single pixels of deforestation (0.09 ha) were excluded. We switched the selection and extracted the file as a new shapefile of GFW deforestation to generate the final map comparing deforestation according to different sources. To identify the smallest area of change perceived by participants in mapping, we dissolved the participatory deforestation in Ipetí between 2004 and 2012 according to geographic location, then used the Multipart to Singlepart tool to separate the isolated patches of deforestation. We then added an area field and the minimum change perceived by mappers was 0.1 ha. (The smallest patches drawn by owners in the 2012 participatory map were at least 0.0275 ha.)

In order to generate a map of areas considered deforested by GFW but not by the participatory maps, we used the Identity tool with the shapefile of GFW and participatory deforestation between 2004 and 2012 as the input and the identity feature as the 2012 participatory map. We then removed the patches deforested according to the participatory map by selecting from the GFW data by location the patches that contain data within participatory deforestation patches. We then switched the selection in the attribute table to select the GFW patches that are outside patches deforested according to participatory mapping and exported the shapefile. We added the area field and summarised to calculate the total area per land use class for which the two data sources were incompatible.

Selection of ground-truthing sites

In order to select sites for ground technicians to visit, we dissolved the land use field of the shapefile containing non-overlapping deforestation from both sources. We then selected by attribute for patches <1.5 ha and where the land use in 2012 was forest or tall fallow. This was done in order to visit sites that are relatively homogeneous patches of deforestation according to

GFW, so that deforestation (or lack thereof) would be evident on the ground. Sites considered forested by participatory mapping were chosen since ground-truthers would not be able to confirm deforestation, but only reject it. We then used the Feature to Point tool and added the XY coordinates and joined the data to the original participatory map shapefile to obtain landowner data and facilitate ground-truthing for technicians.

GFW's reforestation data were not included as they are not annual data, but rather represent overall reforestation between 2001 and 2012.

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TABLES AND FIGURES

Table 2.1. First- and second-tier variables of a social-ecological system (SES). Source: McGinnis & Ostrom 2014.

First-tier variables	Second-tier variables
Social, economic, and political settings (S)	S1 – Economic development
	S2 – Demographic trends
	S3 – Political stability
	S4 – Other governance systems
	S5 – Markets
	S6 – Media organizations
	S7 – Technology
Resource systems (RS)	RS1 – Sector (e.g., water, forests, pasture, fish)
	RS2 – Clarity of system boundaries
	RS3 – Size of resource system
	RS4 – Human-constructed facilities
	RS5 – Productivity of system
	RS6 – Equilibrium properties
	RS7 – Predictability of system dynamics
	RS8 – Storage characteristics
	RS9 – Location
Governance systems (GS)	GS1 – Government organizations
	GS2 – Nongovernment organizations
	GS3 – Network structure
	GS4 – Property-rights systems
	GS5 – Operational-choice rules
	GS6 – Collective-choice rules
	GS7 – Constitutional-choice rules
	GS8 – Monitoring and sanctioning rules

Resource units (RU)	RU1 – Resource unit mobility RU2 – Growth or replacement rate RU3 – Interaction among resource units RU4 – Economic value RU5 – Number of units RU6 – Distinctive characteristics RU7 – Spatial and temporal distribution
Actors (A)	A1 – Number of relevant actors A2 – Socioeconomic attributes A3 – History or past experiences A4 – Location A5 – Leadership/entrepreneurship A6 – Norms (trust-reciprocity)/social capital A7 – Knowledge of SES/mental models A8 – Importance of resource (dependence) A9 – Technologies available
Action situations: Interactions (I) → Outcomes (O)	I1 – Harvesting I2 – Information sharing I3 – Deliberation processes I4 – Conflicts I5 – Investment activities I6 – Lobbying activities I7 – Self-organizing activities I8 – Networking activities I9 – Monitoring activities I10 – Evaluative activities O1 – Social performance measures (e.g., efficiency, equity, accountability, sustainability) O2 – Ecological performance measures (e.g., overharvested, resilience, biodiversity, sustainability) O3 – Externalities to other SESs

Related ecosystems (ECO)	ECO1 – Climate patterns ECO2 – Pollution patterns ECO3 – Flows into and out of focal SES

Table 2.2. Social-ecological factors statistically compared to land uses at the level of the individual plot in Piriatí- and Ipetí-Emberá. Households for which both factors and plot-level land use data were available were analysed, accounting for different sample sizes.

Type of factor	Factor	Sample size	Source	Statistical Test
Continuous ecological factors	Maximum, minimum and average distance to highway	$n_{\text{Piriatí}}$=47; n_{Ipeti}=73	Nearest distance of each land use polygon to highway from 2012 participatory maps in ArcGIS 10.1	Correlation
	Maximum, minimum and average distance to river		Same	Same
	Maximum, minimum and average distance to village		Same	Same
	Maximum, minimum and average elevation		Digital Elevation Model (SRTM 90m) downloaded from the CGIAR Consortium for Spatial Information website. Average per land use class extracted using zonal statistics in ArcGIS 10.1	Same
	Maximum, minimum and average slope		Same	Same
	Plot size		2012 participatory maps	Same

Continuous social factors	Number of people available to help	$n_{\text{Piriatí}}$=13; $n_{\text{Ipetí}}$=17	Piriati: 35 semi-structured interviews with household heads, wives of household heads, land inheritors and youth conducted in 2013 (see Chapter 1); Ipeti: 36 household surveys in 2009 (Raynaud & Shinbrot 2009) as a follow-up to surveys by (Tschakert et al. 2007).	Correlation
	Year of household establishment		Same	Same
	Number of people at home		Same	Same
	Number of children at home		Same	Same
	Number of elders at home		Same	Same
	Age of eldest		Same	Same
Categorical social factors	Whether livestock owned (Y or N)	$n_{\text{Piriatí}}$=8; $n_{\text{Ipetí}}$=18	Same	Canonical correspondence analysis
	Whether land owned (Y or N)		Same	Same
	Education level of household head (none, primary, secondary or post-secondary)		Same	Same
	Place of origin of household head (community, the Bayano watershed or the Darién province/Colombia)		Same	Same

Table 2.3. Continuous explanatory factors correlated (>0.400, in bold) to per cent land uses at the level of the individual plot in communal lands of both Ipetí- and Piriatí-Emberá.

Factor	% Forest	% Tall Fallow	% Cropland	% Pasture
Maximum elevation	**0.694**	-0.062	-0.315	**-0.419**
Minimum elevation	**0.619**	-0.138	-0.326	**-0.407**
Average elevation	**0.702**	-0.072	-0.336	**-0.436**
Maximum slope	**0.670**	-0.053	-0.339	-0.381
Average slope	**0.649**	-0.017	-0.371	**-0.415**
Maximum distance to highway	**0.574**	-0.031	-0.387	-0.393
Minimum distance to highway	**0.687**	0.085	**-0.418**	**-0.484**
Average distance to highway	**0.671**	0.065	**-0.434**	**-0.465**
# People at home	-0.321	0.007	**0.511**	-0.238
# Children at home	0.050	0.334	0.167	**-0.458**

Table 2.4. Correlations of explanatory factors (that were found to be related to land use in previous analyses) to the discriminant function (those most correlated in bold).

Factor	Correlation
# People at home	**-0.438**
# Children at home	-0.186
Livestock	0.345
Land	**0.401**
Education	-0.081
Maximum elevation	**0.860**
Minimum elevation	**0.680**
Average elevation	**0.826**
Maximum slope	**0.888**
Average slope	**0.812**

Table 2.5. Per cent deforestation in the communal lands of Piriatí- and Ipetí-Emberá between 2004 and 2012 according to Global Forest Watch data (Source: Hansen/UMD/Google/USGS/NASA).

Year	Piriatí	Ipetí
2004	0.236	0.083
2005	1.241	0.469
2006	2.357	0.759
2007	1.744	0.786
2008	3.247	2.310
2009	1.399	1.309
2010	0.568	0.313
2011	1.090	0.960
2012	0.216	0.505
2004-2012	14.455	9.545

Table 2.6. Correlations of explanatory factors (that were found to be related to per cent deforestation according to Global Forest Watch data in previous analysis) to the discriminant function (>0.400 in bold).

Factor	Correlation
Plot size	-0.104
Livestock	0.303
Minimum distance to village	-0.078
Education	-0.037
Year of arrival	-0.385
Maximum elevation	**0.683**
Maximum slope	**0.707**

Table 2.7. Investigated factors using Ostrom's framework for analysing the sustainability of social-ecological systems (Ostrom 2009; McGinnis & Ostrom 2014). These factors were chosen due to the potential for being significantly different between the two systems. The codes are those given by Ostrom to distinguish each variable and the category in which it falls.

Category	Variable (Code)	Results
Resource System	Storage characteristics (RS8)	The communal land that has more forest is located on steeper, higher land
Resource Units	Spatial and temporal distribution (RU7)	The proportion of the household's land devoted to forest is positively correlated to its elevation and slope; in both lands, forest is located furthest from the village and Pan-American Highway; both lands began with a similar amount of forest cover
Actors	Number of relevant actors (A1)	There is no difference in population growth between the two communities
	Socioeconomic attributes (A2)	The communal land with more forest has fewer people per household surveyed; number of people at home is positively correlated to proportion of the household's land that is cropland; number of children at home is negatively correlated to proportion of pasture. However all these correlations are mild.
	History or past experiences (A3)	The communal land with more forest has experienced a lower rate of deforestation, specifically post-1990s; forest in the less forested communal land was considered secondary at the time of settlement due to governmental timber extraction
	Location (A4)	There appears to be no effect of distance to village or river on plot-level land use proportions in both lands; the positive correlation between distance to highway and forest cover in the more forested land likely reflects the influence of topography
Governance System	Government (GS1) and non-governmental organisations (NGOs; GS2)	The more forested communal land has an active local NGO and has been involved in scientific projects since 1996; there is a small-scale reforestation initiative by an international NGO in the less forested land since 2009 (see Fig. 2.3)

Figure 2.1. Location of the two communal lands studied, Piriatí- and Ipetí-Emberá, off of the Pan-American Highway in eastern Panama.

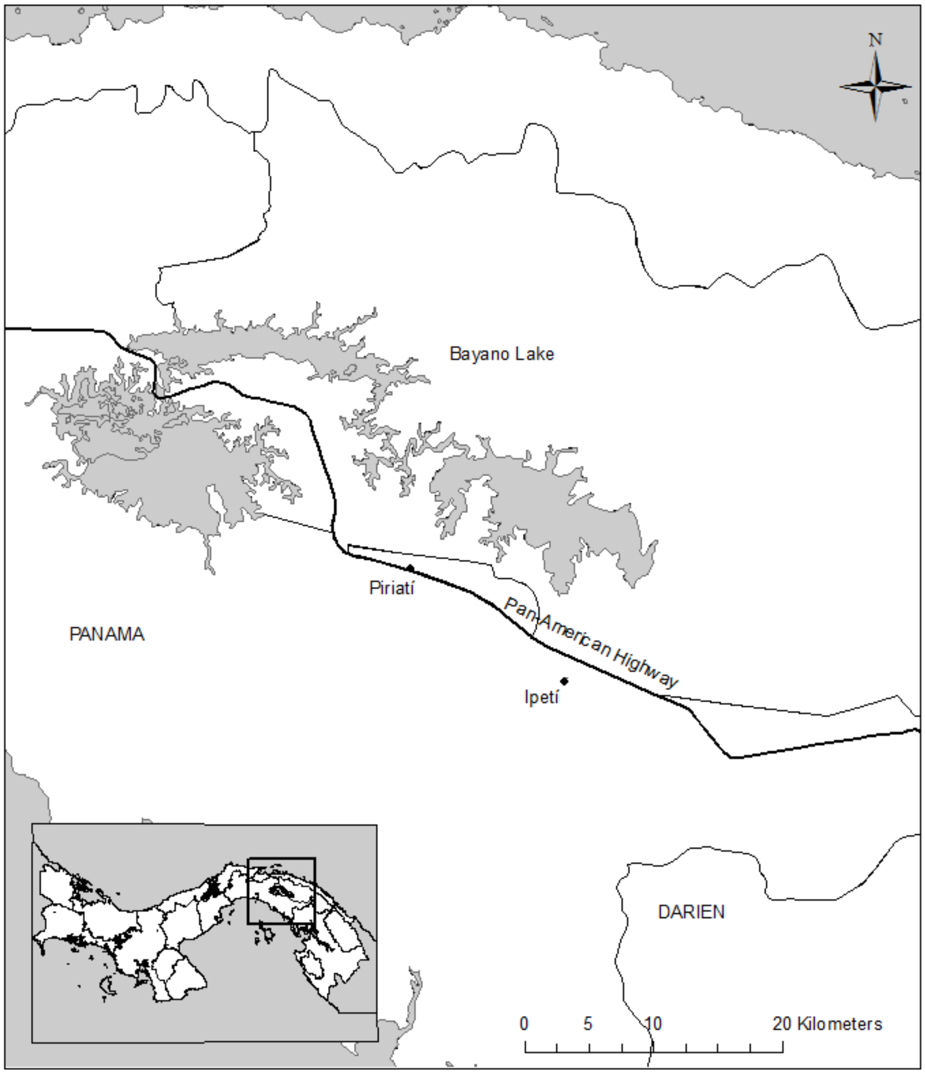


Figure 2.2. Linear discriminant analysis illustrating the coefficients of per cent land uses at the individual plot level that maximise discrimination of the communal lands of Piriatí (1) and Ipetí (2). Each point represents each row of data. The circle is the 95% confidence interval for the mean of each communal land. The more similar the lands, the greater the overlap between the circles.

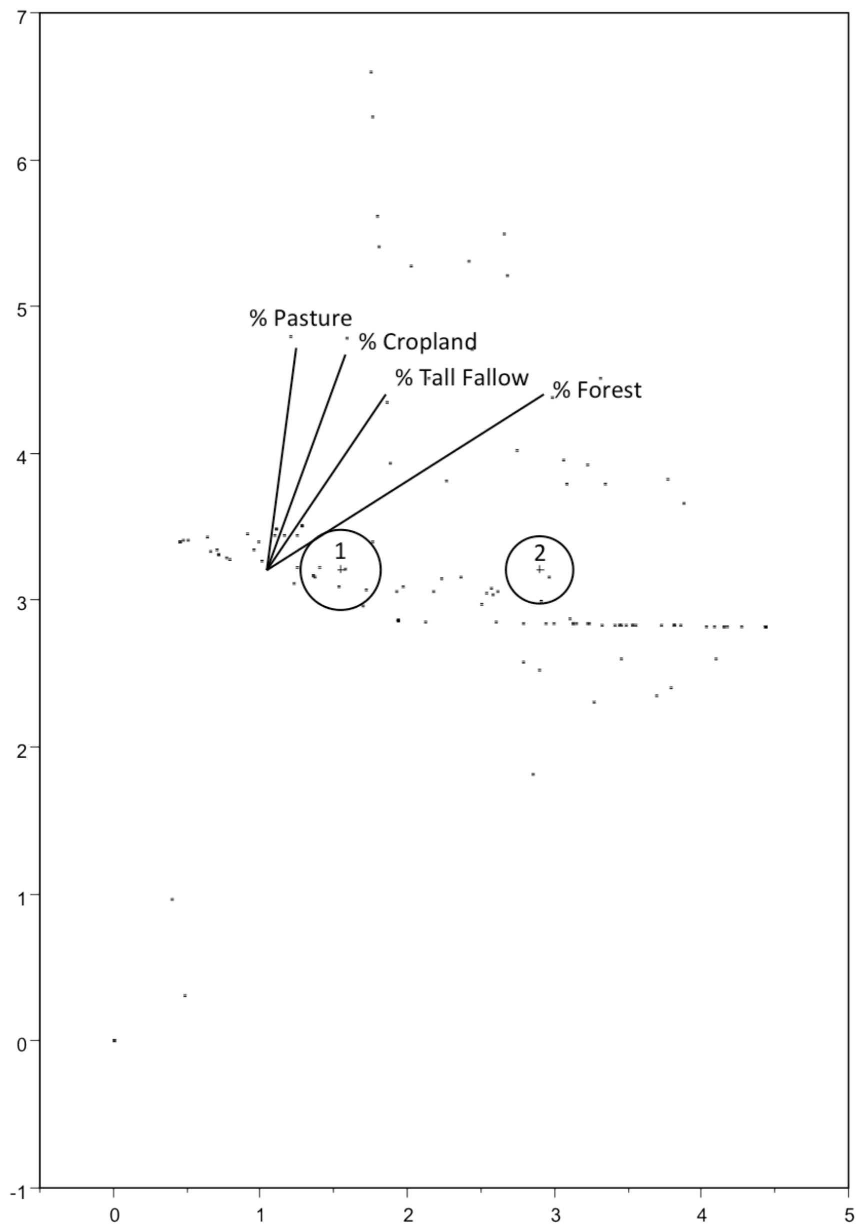


Figure 2.3. Perceived per cent forest cover according to participatory pebble scoring (see arrow; Ipeti's data from Potvin et al. 2006), combined with the participatory historical timeline of Piriatí- and Ipetí-Emberá. Forest includes agroforestry in Ipetí, as agroforestry was not used as a separate category in Piriatí.

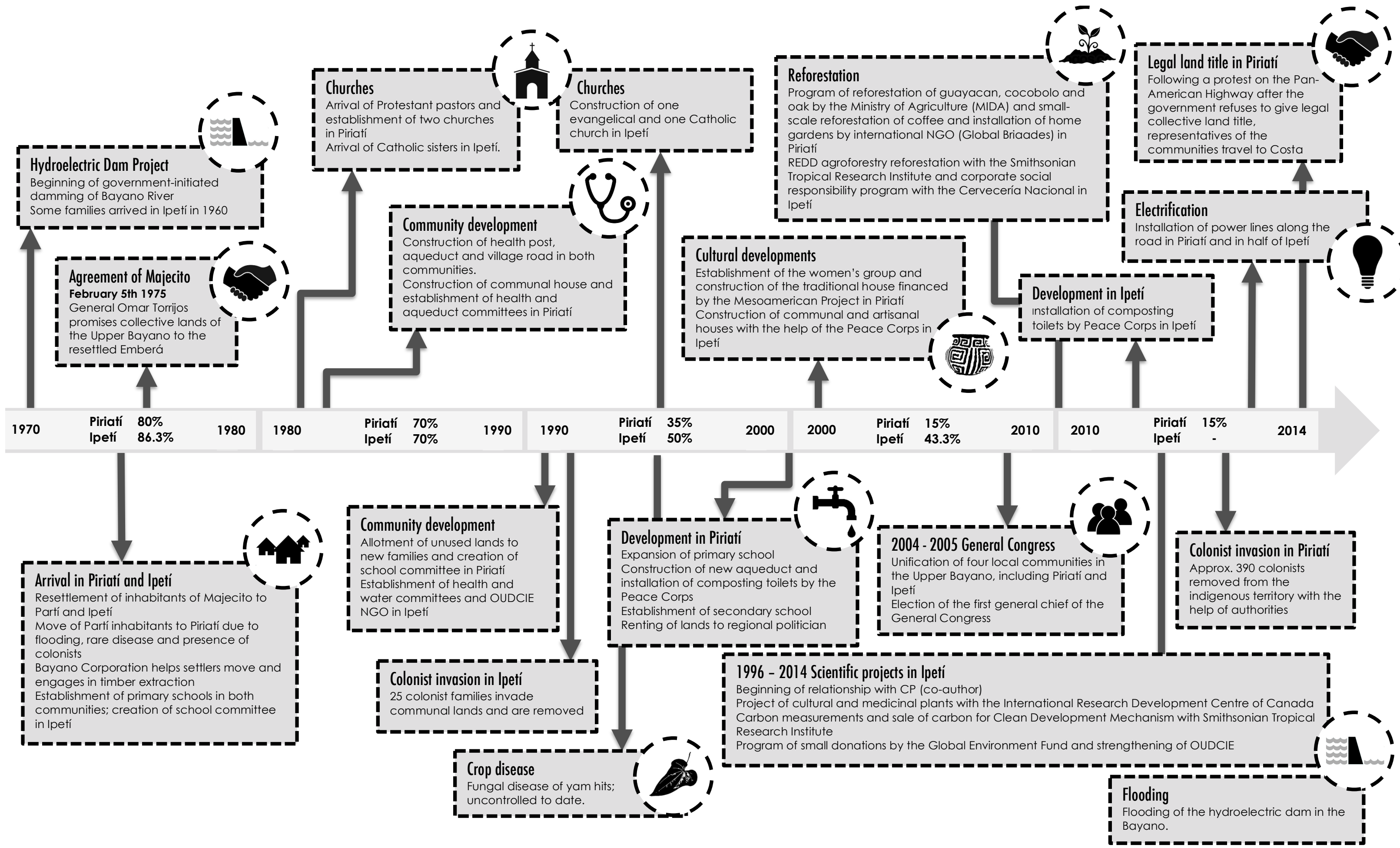


Figure 2.4. Biplot of canonical correspondence analysis (CCA) between categorical explanatory factors and per cent land uses at the level of the individual plot in Piriatí- and Ipetí-Emberá. The plot illustrates the degree to which the explanatory factors explain the variation in land uses. A perpendicular line from the tip of the vector to each axis shows its relative importance on the canonical axes, which are linear combinations of the explanatory variables. Explanatory variables are in italics, while per cent land uses are in bold. The dots represent the "site" (household) scores of each row of data (Piriatí is represented by white circles; Ipetí by black circles).

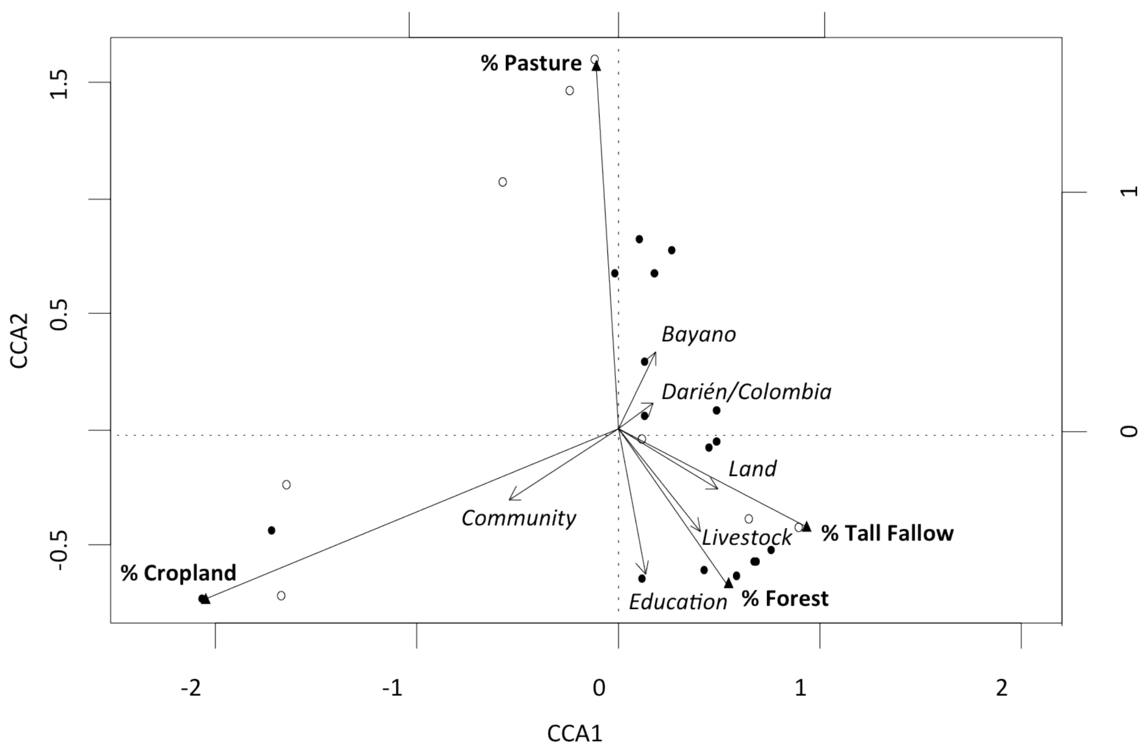


Figure 2.5. Average elevation and total area per land use class in the communal lands of Piriatí- and Ipetí-Emberá. Error bars represent standard deviation.

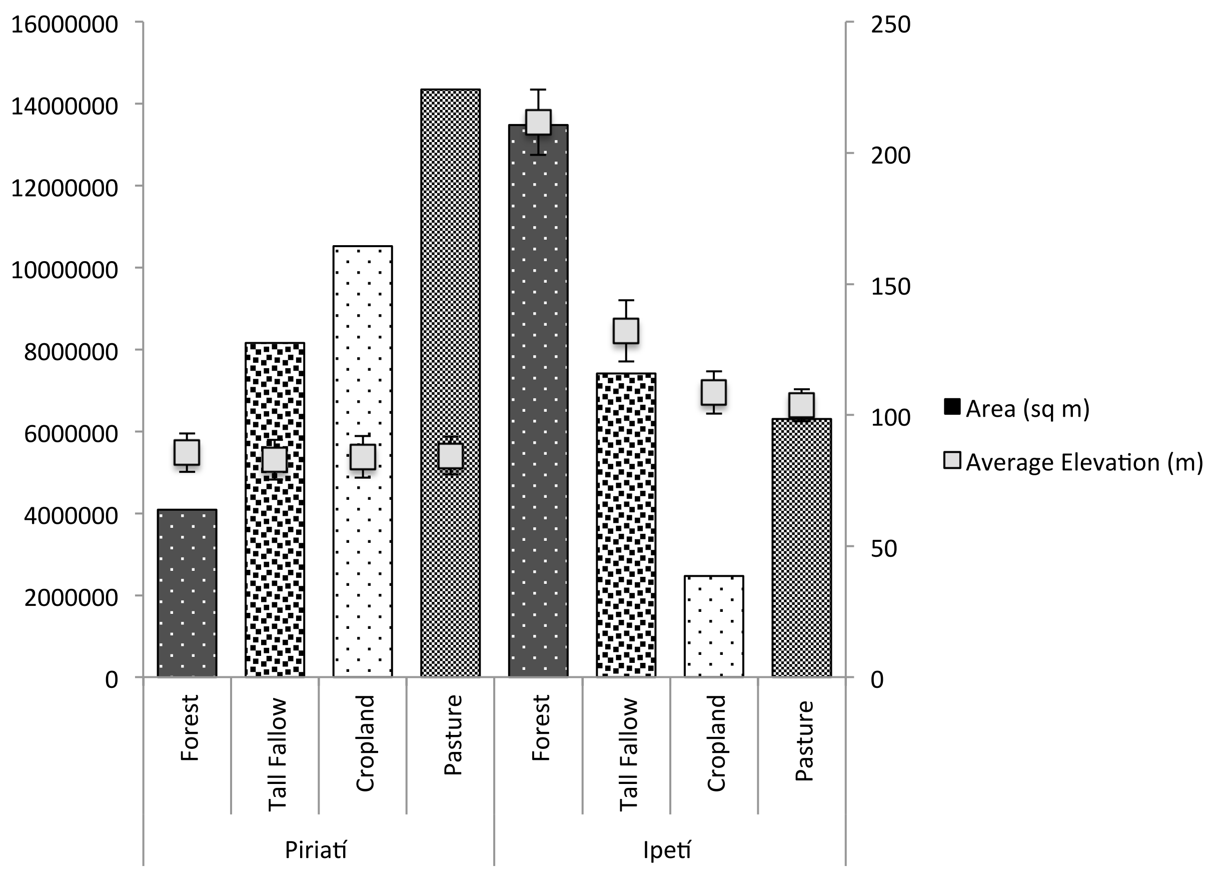


Figure 2.6. Average slope and total area per land use class in the communal lands of Piriatí- and Ipetí-Emberá. Error bars represent standard deviation.

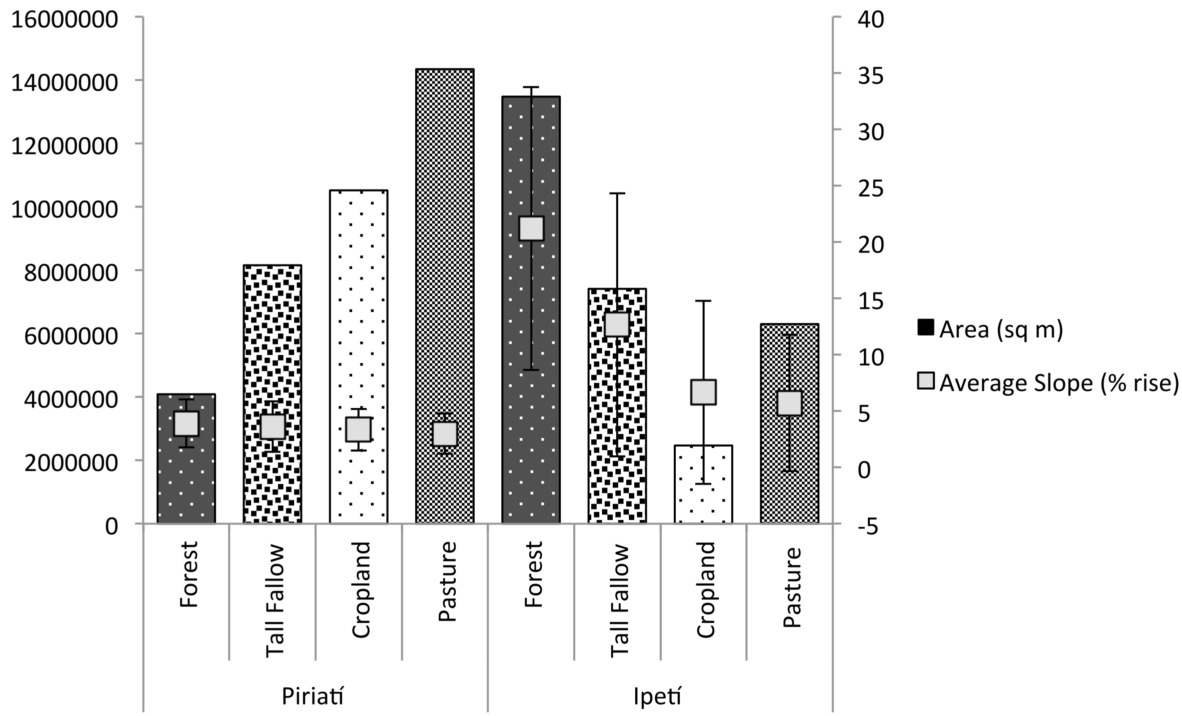


Figure 2.7. Average distance of each land use type to village, river and highway in Piriatí- and Ipetí-Emberá. Forest is, on average, furthest from the highway and the village.

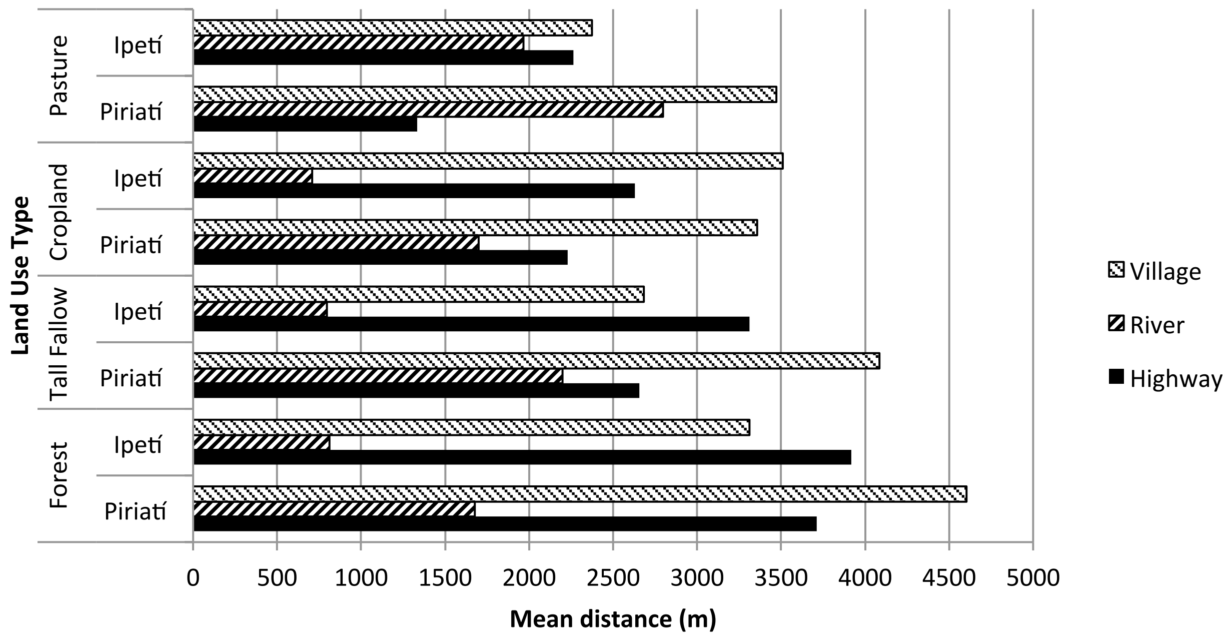


Figure 2.8. Map of Piriatí- and Ipetí-Emberá overlaid with deforestation data from the Global Forest Watch (Source: Hansen/UMD/Google/USGS/NASA).

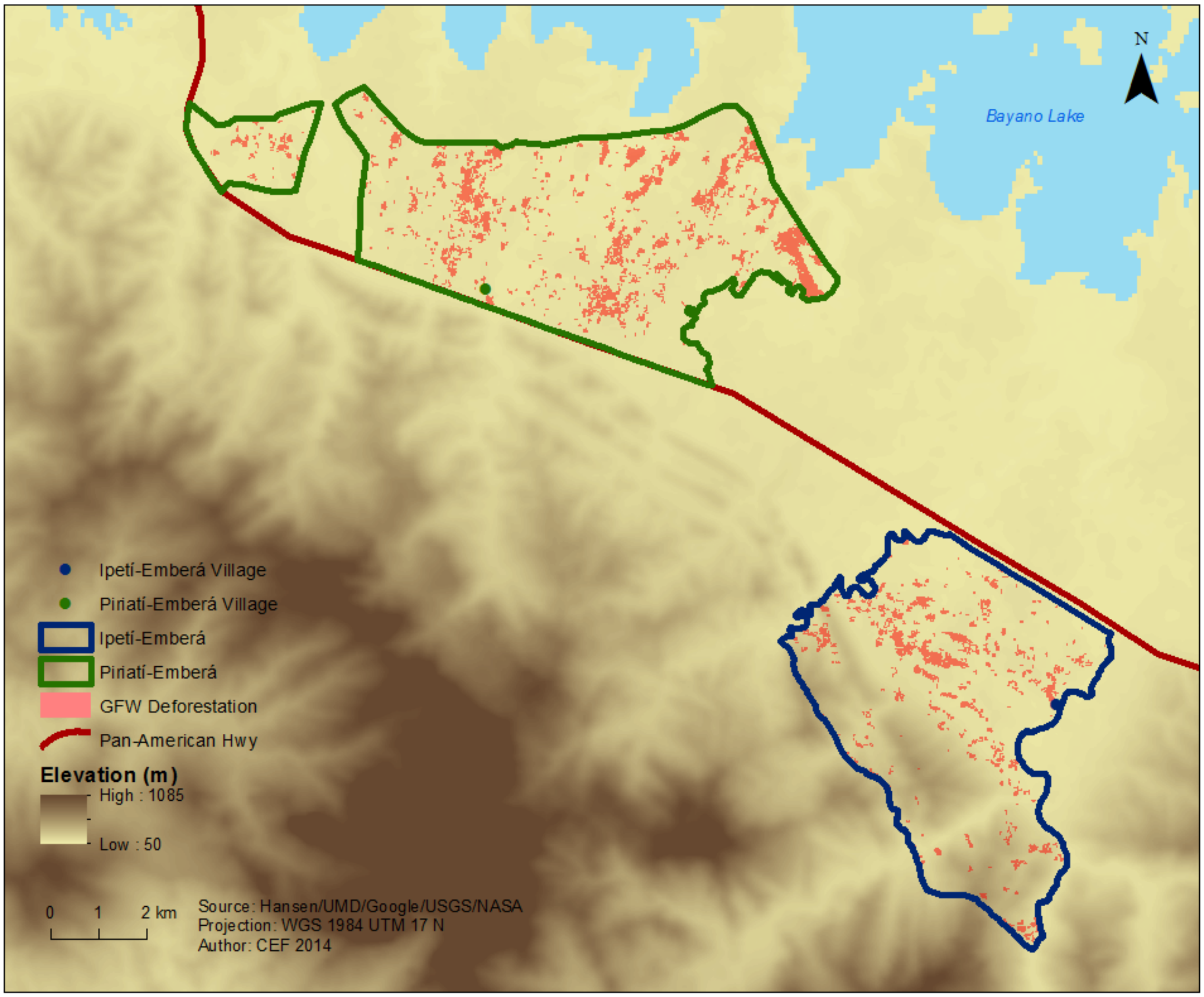


Figure 2.9. Visual comparison of deforestation in the communal lands of Ipetí-Emberá according to Global Forest Watch satellite data (Source: Hansen/UMD/Google/USGS/ NASA) and participatory mapping (2004 - Potvin et al. (2006); 2012 – Vergara-Asenjo et al. 2015).

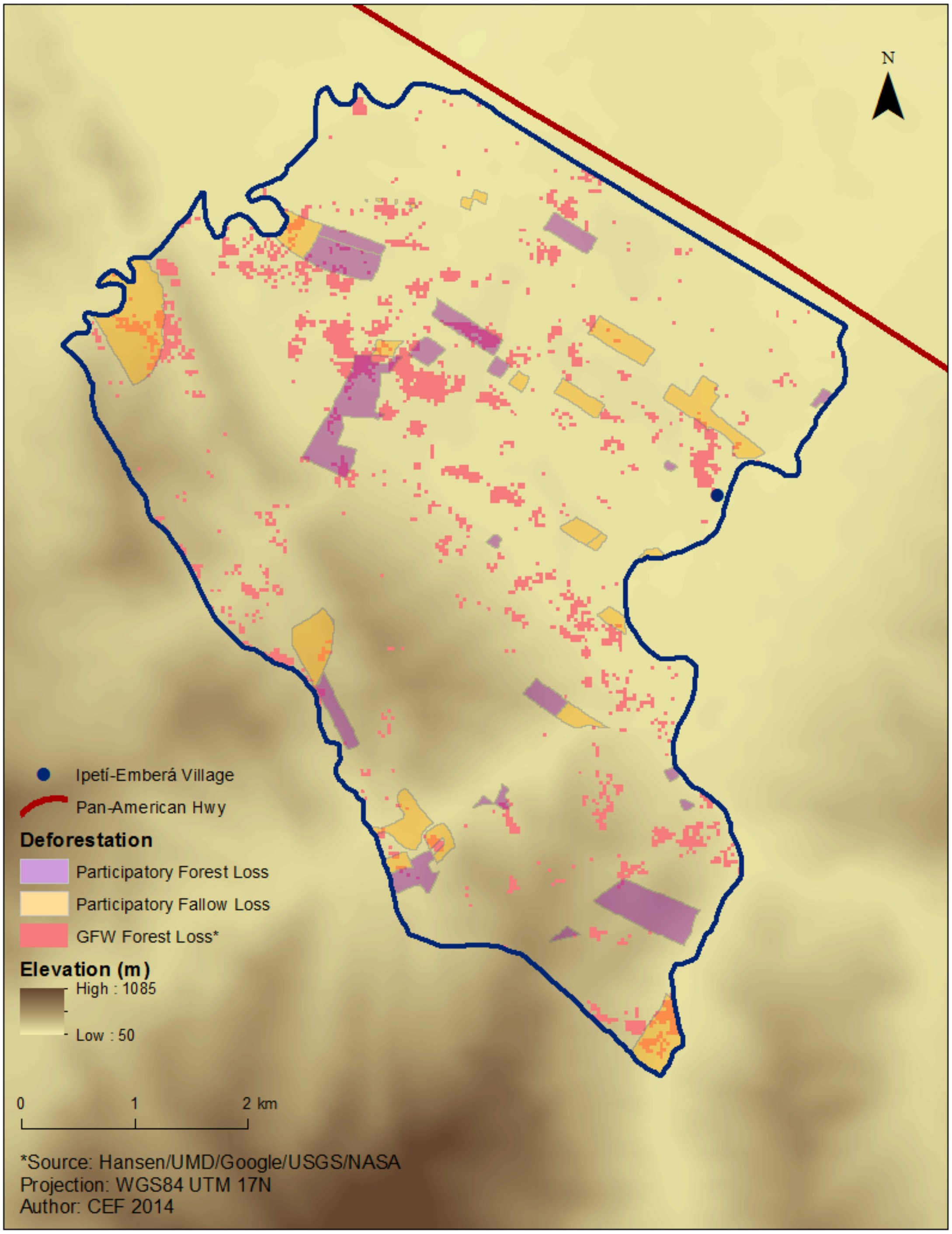
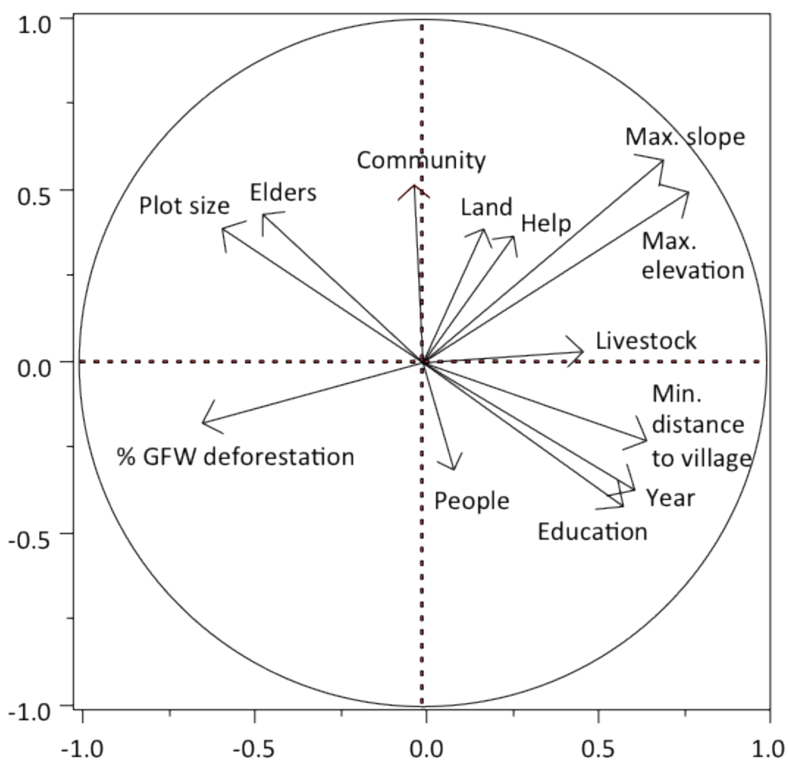


Figure 2.10. Biplot of principal components analysis (PCA) between social-ecological factors at the household level and per cent deforestation in Ipetí-Emberá according to the Global Forest Watch (Source: Hansen/UMD/Google/USGS/NASA) at the level of the plot. Factors that are more associated with each other are represented by arrows that are more parallel; negative associations are represented by arrows in opposite directions. Origins in the community and ownership of livestock and land were binary factors, while education of household hold was ordinal according to whether none, primary, secondary or tertiary.



GENERAL CONCLUSION

Summary

Participatory mapping and comparison of land use trajectories with remotely sensed data illustrate the importance of viewing indigenous landscapes as mosaics of dynamic land uses that cannot be sweepingly classified in static land use patches. The complex nature of land uses means that global datasets on forest cover should be validated locally to assist local forest management. The comparison of land uses between communal lands and to social-ecological variables demonstrates how landscapes are shaped by an intersection of natural features and social influences. Topography is a critical constraint on land uses when lands are not flat, and considerations of crop disease, soil fertility and water content, invasive species and distances for landowners to travel also influence decision-making. However household demographics, concerns of subsistence, tradition and convention, and historical factors also play into the factors that determine land uses. Historical influences can include past timber extraction, settlement and land use patterns, collaboration with NGOs and scientists, and the strength and priorities of community institutions and leadership. Moreover, power and gender dynamics influence the structure of landscapes, in a context where powerful external actors and local male decision-makers exert control over local land uses. The study also emphasises the importance of considering the perceptions of local landowners, which necessarily affect decision-making. For example, land cover classification by locals, particularly of fallows and forest, represents a gradient that does not necessarily reflect standard definitions of land cover based on global numerical cut-offs like tree height. According to community members, the worldview of the Emberá is that forest has always existed, and so to imagine that it could be irretrievably lost and the consequences of such an occurrence is inconceivable. Village settlement, pasture conversion, day labour, European schooling and Christian religions are all relatively recent phenomena, with unpredicted outcomes at the landscape scale. Thus the social-ecological approach adopted in this study enables the recognition of a range of influences on the genesis of an indigenous frontier landscape, in order to truly diagnose causes of low forest cover.

Convention on Biological Diversity Targets

In May 2013, Piriatí hosted a three-day workshop attended by over 200 community members on the creation of an integrated development plan for indigenous territories in Panama, organised by the United Nations. A main theme in the workshop was the need to procure legal land title to enable the protection of natural resources, including forests, but also to ensure indigenous participation and to find a balance between development and preserving tradition. The need for a reforestation programme to protect the ecosystem services forests provide was also insisted upon. Piriatí is not alone in this vision. The Convention on Biological Diversity (CBD), an outcome of the 1992 Earth Summit, held its latest Conference of the Parties in 2014 (CBD 2014). As a result of the conference, the Aichi Biodiversity Targets of the 2011-2020 Strategic Plan were devised to achieve the vision of a world in which biodiversity is maintained, in order to safeguard benefits to ecosystem functioning and human well-being. The targets address clearly the need to minimise deforestation as part of the goal to reduce pressure on biodiversity (Target 5); the influence of biodiversity on ecosystem services and livelihoods of indigenous peoples (Target 14); and the need for participation of indigenous peoples and inclusion of traditional knowledge, practices and values in biodiversity protection (Target 18). The CBD lists a series of guiding questions to help set national targets to achieve these goals. These include identifying who are the stakeholders impacted by habitat protection measures, which stresses threaten the services ecosystems provide, what are the costs and benefits of protection, and whether indigenous peoples' traditional knowledge and use of resources is incorporated in protection efforts. The CBD considers the elucidation of trends in land use change in indigenous territories as an indicator of national achievement of Target 18 (CBD 2014). The research presented here helps answer the guiding questions by identifying causes of forest loss, and also shedding light on the ecological, social and economic trade-offs of land use management as perceived by indigenous forest dwellers. Further, this study provides a backdrop against which to judge future trends in land use change in indigenous territories in Panama.

Future research

The high rate of deforestation in Panama and in Piriatí means that a business-as-usual land use trend will not be sustainable. Future research directions, in keeping with the interdisciplinary tradition of this study, could include:

- a participatory approach to the documentation of ecological and ethnobotanical knowledge among men and women of all age groups. This could be done through social-ecological hotspots mapping exercises of areas that are both ecologically and socially valuable, in terms of the ecosystem services they provide. Factors that influence the value of land uses could be decided upon in an initial workshop. The mapping could include transect walks with key informants and field tests of ecological indicators like soil fertility, tree species and cover, shade provision, presence of plant disease, etc. in order to identify hotspots following GIS analysis (as used by Alessa et al. 2008; and Duguma & Hager 2011). Such research can set precedence for identifying areas in need of conservation, in response to the guiding questions for Aichi Target 14 (CBD 2014). Part of the field visits can also include a mapping with GPS of the path network used within the communal lands, to better understand patterns of resource use and the influence of physical geography and distances on land uses (as used by Dalle et al. 2002).

- Restoration of ecologically and culturally important tree species can then be begun in areas based on data collected, with the aim of supporting biodiversity and cultural diversity conservation. For example, reforestation could occur in sites deemed potential hotspots, such as along river edges to restore riparian zones. These areas are ecologically important in prevention of soil erosion and maintenance of water quality and flow (see Jones et al. 2010) and socially important for community members in terms of maintaining rivers that are sites of bathing, fishing and recreation. Given the importance of both subsistence and tradition on land use decision-making, fruit tree species, commercial species like coffee and artisanal species like cocobolo (*Dalbergia retusa*) could be planted in hotspots like river edges, by fences around pastures or along commonly used paths that have been mapped. Reforestation could be followed by re-visiting sites in hotspots mapping to re-evaluate the factors measured and their hotspot status, to gauge the effectiveness of reforestation. This research would entail using influences on land use decision-making derived from Chapter 1, and further participatory methods assessing local values and broader ecological services to inform local conservation.
- In order to further the analysis of Chapter 2, future research could involve recording which households are or have been involved in reforestation and agroforestry projects with NGOs or community organisations, and comparing this involvement to land uses at the individual plot level using methods in numerical ecology. A Venn diagram of community organisations and their relative importance in Ipetí could be produced, as we did in Piriatí (following Geilfus (2002)). This can help better understand the influence of involvement in organisations on the landscape and the differences in forest cover between

the two lands, and therefore help disentangle the individual effects of qualitative factors like institutions from quantifiable factors like topography.

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