Understanding Governance Dynamics in a Social-Ecological System: Chitwan Community Forests and the Invasive Mile-a-Minute Weed

by

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ABSTRACT

Employing an interdisciplinary approach with a grounding in new institutional economics, this dissertation investigates how institutions, as shared rules, norms, and strategies, mediate social-ecological outcomes in a system exposed to a novel threat in the form of a rapidly growing and especially destructive invasive plant, *Mikania micrantha* (Mikania). I explore whether and how communities (largely part of community forest user groups in the buffer zone of Chitwan National Park in Chitwan, Nepal) collectively act in the face of Mikania invasion. Collective action is vital to successful natural resource governance in a variety of contexts and systems globally. Understanding collective action and the role of institutions is especially important in the face of continued and amplifying global environmental changes impacting social-ecological systems, such as climate change and invasive species. Contributing to efforts to bolster knowledge of the role of collective action and institutions in social-ecological systems, this research first establishes that community forest governance and institutional arrangements are heterogeneous. I subsequently utilize content and institutional analyses to identify and address themes and norms related to Mikania management. The content analysis contributes an empirical study of the influence of trust in collective natural resource management efforts. Using two complementary econometric analyses of survey data from 1235 households, I additionally assess equity in access to community forest resources, an understudied area in the institutional literature, and the factors affecting collective action related to Mikania removal. Finally, an agent-based model of institutional change facilitates the comparison of two perspectives, rational choice and cultural diffusion, of how shared norms and strategies for Mikania management change

over time, providing insight into institutional change generally. Results highlight the importance of trust and understanding the de facto, or on-the-ground institutions; the influence of perception on collective action; that integrating equity into institutional analyses may strengthen sustainable resource management efforts; and that rational choice is an unlikely mechanism of institutional change. The mixed-methods approach contributes to a more comprehensive understanding of the role of institutions and collective action in invasive species management and broadly to the scientific understanding of the role of institutions in mediating global environmental changes.

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CHAPTER 1

INTRODUCTION

Over the past decade, terms such as social-ecological, coupled human-natural, and human-environment systems have become increasingly popular in scientific research stemming from a wide variety of disciplines (Berkes, Colding, & Folke, 2008). Similar terminology has been in use for much longer than the previous decade, but the recent surge in social-ecological systems research (as such systems are referred to throughout this dissertation) is recognition of the frequent separation of humans and the environment in past research and an acknowledgement of the importance of studying humans as a part of the environment, where each component influences the other. It is now common, and somewhat expected, to study environmental issues from a human-environment perspective. Social-ecological systems research can be accomplished by multi-disciplinary teams, with scientists each contributing their expertise from a traditional social or natural science discipline. This research can also be accomplished by scientists trained in an interdisciplinary manner, with blended knowledge from natural and/or social science fields. This dissertation is an example of the latter, written by a scholar trained in the interdisciplinary field of environmental social science. While traditional disciplines remain vital to science, interdisciplinary scholarship has been steadily increasing and has the opportunity to provide unique insights (Van Noorden, 2015), especially with regard to scientific understanding of social-ecological systems which are inherently interdisciplinary. This dissertation explores a specific social-ecological system located in Nepal, but uses a combination of qualitative and quantitative methods to explore the

broader implications of the findings and advance the interdisciplinary field of environmental governance more generally.

Study Site and Problem Overview

Chitwan, Nepal is a rapidly urbanizing region adjacent to the internationally important Chitwan National Park located in Nepal's southern Terai region (figures 1.1, 1.2, 1.3 and 1.4). Locally governed community forests were formally established around the park (known as the buffer zone community forests, as they are in the buffer zone around the national park) in the mid-1990s in order to provide residents opportunities to collect forest products and timber in forests that were largely self-governed (Acharya, 2002; Baral & Subedi, 2000; Jones, 2007). The establishment of community forests aided in reducing illegal harvesting of resources and was intended to support sustainable resource management to bolster local agricultural livelihoods. A more detailed examination of the creation of community forests in Nepal and the buffer zone community forests is presented in chapters 2 and 3.

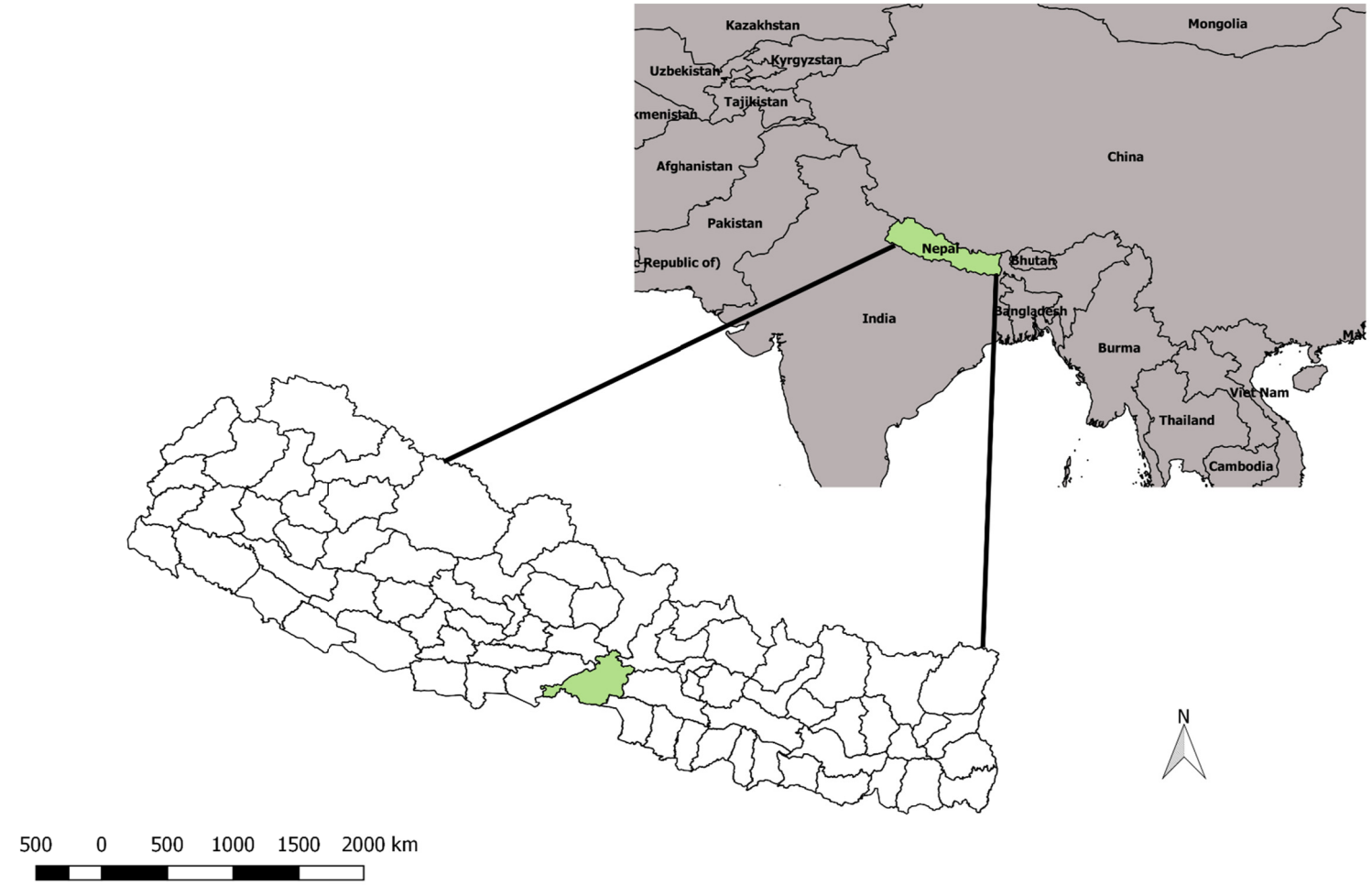


Figure 1.1. Geographic location of Nepal and Chitwan within Nepal.

Figure 1.2 Map of study site. Location of Chitwan, Chitwan National Park, and the buffer zone community forests within Nepal. Note that Chitwan National Park and the buffer zone overlap Chitwan.

Figure 1.3. This map is located at the entrance of Chitwan National Park. Note the location of the park between two prominent rivers, the Narayani in the north and the Rapti in the south.

Figure 1.4. Views of Chitwan during fieldwork in 2014, ranging from forests, to rivers, to households.

In the past, increasing population pressure has affected the community forests, but a newer social-ecological threat looms with the invasion of the "mile-a-minute weed," *Mikania micrantha* (Mikania) (Rai, Sandilya, & Subedi, 2012; Sapkota, 2009). Mikania

is a creeping vine native to South America that favors humid, warm environments, such as the sub-tropical Terai region of Chitwan in southern Nepal (Barreto & Evans, 1995). As its moniker indicates, Mikania is rapidly growing and problematic for several reasons, ranging from its ability to quickly kill trees and cover grasses, to the implications this has for biodiversity and degradation of community forest resources. The detrimental effects of Mikania on the biodiversity of the Chitwan region have been well established. These include significantly harming the vulnerable (Lahkar, Talukdar, & Sarma, 2011) one-horned rhinoceros' food and habitat sources (Murphy et al., 2013); Mikania's impact on the one-horned rhino is second only to poaching (Ram, 2008) (figure 1.5). Research on human factors influencing Mikania's spread has focused on resource harvesting and collection activities (such as gathering and transporting grasses and fodder). These activities correspond to an increased risk of spreading Mikania (Murphy et al., 2013). Annual burning activities, related to traditional agricultural practices, in and around Chitwan National Park additionally pose a high risk of increasing the spread of Mikania and burning contributes more significantly to spreading Mikania than resource collection activities. Mikania is an important issue as it has invaded the buffer zone community forests (Clark et al. 2016) and is a threat to livelihoods in Chitwan (chapters 2 and 3 will elaborate on this issue).

Figure 1.5. Tribute to one of Chitwan National Park's most prominent animals, the previously endangered (now vulnerable) one-horned rhinoceros. Rhinos are commonly sighted in the park.

A Note about Political Conditions in Nepal

Nepal recently faced the conclusion of a ten-year civil war in 2006. The war was an escalation of conflict between Maoist groups (labeled People's War by the Maoist fighters) and the government (at the time a monarchy), and the impacts of the conflict are ongoing in many respects. A formal democracy was established in 2006 with the election of a Constituent Assembly to draft the new constitution. However, the First Constituent Assembly failed in their task and the Second Constituent Assembly only very recently (September 20, 2015) promulgated the new Constitution of Nepal. The new constitution immediately garnered protests from human rights organizations regarding citizenship clauses that were perceived as unfair and discriminatory towards certain ethnic groups and women.

The civil war impacted community forestry in multiple ways, including soldiers from both sides exploiting forests as hiding places in preparation for combat (Karna, Shivakoti, & Webb, 2010). Interestingly, Karna et al.'s (2010) study of seven community forests with similar governance structures found the armed conflict did not erode the ecological condition of the community forests. Additionally, in community forests where the members rated themselves as facing severe armed conflict, characteristics like trust and reciprocity were improved, though more research is necessary to fully understand this outcome. Although this dissertation does not focus on the impacts of the civil war on community forestry or interpersonal relationships in Chitwan, it is important to remember the political context of the country and future work may more explicitly address this element.

Background on Mikania

Mikania is a vine that both grows and reproduces rapidly (figure 1.6). It is native to South America and was most likely intentionally transferred to India and the Pacific Islands around the 1940s for use as a cover crop for airfields (IUCN, 2005) and was also utilized by soldiers in India during World War II as a type of camouflage (IUCN, 2005). From its initial introduction, Mikania quickly spread to warm, humid places in Asia (including parts of China, India, and Nepal) and North America (including parts of the southeastern United States). In addition to Mikania, there are several other invasive plant species in Nepal harming the buffer zone community forests' productivity and potentially the livelihoods of communities that rely on the buffer zone (Rai et al., 2012). This dissertation will focus only on *Mikania micrantha*. More information on Mikania cover in the buffer zone community forests is provided in chapter 2.

Figure 1.6. *Mikania micrantha* in Chitwan (climbing the tree near the front center and several in the background).

Yang et al. (2005) noted that Mikania is one of the top 100 invasive plant threats in the world. As it is a creeping vine, it climbs small trees and covers grasses, often depriving them of sunlight and smothering them to death (Siwakoti, 2008). Dazhi et al. (1999) suggested that Mikania is a heliophylic species, meaning that it is adapted to and thrives in sunlight. Considering this, Mikania often covers and inhibits the growth of other plants in its search for sunlight, but although it dislikes deep shade, it can tolerate shaded areas such as those found on forest floors (Kuo, 2003). Mikania growth introduces a variety of ecological changes that impact the abilities of native plant and microbial systems to thrive. Ecosystems that are partially invaded by Mikania have served as experimental systems to researchers seeking to understand its effects. Li et al. (2006) discovered areas of a forest ecosystem in Shenzhen, China invaded by Mikania

had a significantly increased aerobic soil microbial community and different microbial phospholipid fatty acid profiles and enzyme activity compared to areas where Mikania was absent. It was concluded that it is important to consider the influence of Mikania on the soil system when removing it.

Mikania primarily reproduces sexually via seed dispersal, with one plant able to disperse up to 40,000 seeds per year, but also reproduces vegetatively where parts of the stem placed in moist soil will result in a new plant. This has important implications for its spread in Chitwan, as resource collection activities have resulted in people accidentally transporting pieces of Mikania plants. These pieces are often deposited as people are walking with large bundles of grasses or fodder and the plant may reproduce even in the absence of a seed. Mikania has been found to have difficulty reproducing when seeds are buried deeper than 1.5 centimeters in either clay or sandy soils (Yang et al., 2005).

There are several ways to remove Mikania ranging from pulling or cutting the plant, to burning, chemical herbicides, and a predatory rust fungus (Ellison, Evans, & Ineson, 2004). These methods are examined in more detail in the following chapters. The removal of Mikania around Chitwan National Park has been explored by Sandilya (2011). It was concluded that Mikania can be successfully managed through repeated cycles of manual cutting. However, this study was limited as it was conducted in only one buffer zone community forest, it was not long term, and as such there is no evidence this will work in the long run for Mikania management. Additionally, this study did not distribute this information to community members to sustain the cutting necessary to mitigate Mikania. Currently, the removal method thought to be most successful in Chitwan is mechanical removal, bagging the removed Mikania, and burning the bags.

A Foundation in New Institutional Economics

As people make decisions about how to interact in settings involving choices with others, they form norms, rules, and shared values that guide their decision making processes. These sets of rules, norms, and values are jointly defined as institutions (Ostrom, 2005). Social-ecological systems are recognized as places where people and the environment reciprocally influence each other; studying a system holistically enables researchers to better understand outcomes from changes in the system (Berkes, Colding, & Folke, 2003). New institutional economics recognizes information constraints, the costs of interactions, and the limits of the rational, self-interested actor as portrayed in classical economics (Menard & Shirley, 2008). This dissertation research combines this institutional lens with social-ecological modeling to better understand how institutions influence the management of an invasive plant. Each component of the proposed research is situated, at least partially, in the frameworks and theories of new institutional economics. As such, it seems important to provide a brief overview of the field of new institutional economics.

New institutional economics (NIE) was established in 1975 and its body of research incorporates a wide variety of topics dealing with rules ranging from federal prisons to fisheries. Institutions include both formal rules, such as regulations and laws, and informal rules and norms that are often unwritten, such as social norms.[1] The field has expanded both classical economics and earlier institutional studies to focus on the

[1] Although not discussed in detail here, it should be noted Ostrom (2005) advocated for the use of institutional grammar over terms like "formal" or "informal." The institutional grammar tools allow for a precise analysis that may be more easily replicated by scholars less familiar with institutional analysis. For a detailed discussion of institutional grammar and the attribute, deontic, aim, condition, or else (ADICO) syntax, refer to Crawford and Ostrom, chapter 5 in Ostrom (2005).

social norms aspect of the effects of institutions in the world. The field of new institutional economics is largely based on classical economic theory with one major modification (Coase, 1984). The assumption that people are rational and utility maximizing was eventually modified to recognize that people are boundedly rational, or rational within cognitive limitations and information asymmetries (Coase, 1984; Ostrom, 2005). The scholarship of Douglas North is foundational in NIE theory and North (1990) was one of the first works to clearly articulate the difference between organizations and institutions in the scholarly literature, noting that organizations are groups of people with a common purpose and can range from political bodies to corporations. Distinctly, institutions are the "rules of the game" that shape human decision making. While research studying institutions is often conducted by economists or political scientists, Nee and Swedberg (2005) and Moe (2005), are examples supporting that NIE and institutions have been explored from an array of alternative perspectives. NIE complements disciplines including political science, political economy, psychology, sociology, economic sociology and other interdisciplinary scholarship. For instance, Moe (2005) discussed the role of power in NIE and Nee and Swedberg (2005) propose to restart the conversation between NIE and sociology. Ostrom (2008) acknowledges that the study of institutions from a variety of disciplines offers fresh insights and is important for growth of the field.

Ostrom, with the contributions of many other scholars, developed the institutional analysis and development (IAD) framework in an effort to systematically analyze institutions in any scientific study, regardless of geographic location or content (natural resources, technology, etc.) (Ostrom, 2005). The framework has been widely applied and

it has been used extensively to explore natural resource management. The focal point of the IAD framework is the action arena, where participants involved in a specific action situation interact. Exogenous biophysical variables, community attributes, and rules (along with norms and strategies) influence the participants and the outcomes of action situations (see chapters 2 and 3 for use of the IAD). The IAD framework has been utilized to explore the governance of a variety of common pool resources (e.g. Andersson, 2006; Ostrom, 1995, 2010b) and scholars utilizing the framework for institutional analysis typically focus on portions in detail rather than assessing the framework in its entirety.

Social-Ecological Systems, New Institutional Economics, and Research Gaps

Common pool resources are non-excludable, meaning it is very difficult to prevent their usage, and rivalrous/subtractable, meaning usage reduces the availability and supply for others. In the case of common pool resource management, collective action (voluntary action to achieve a common goal) and successful governance have been important areas of study. Ostrom's (1990) seminal book Governing the Commons presented a set of institutional principles that were found to be vital to successful governance of common pool resources, ranging from the importance of well-defined boundaries to graduated sanctions for breaking established management or use rules. These principles were later adapted more generally to address resilience and robustness of social-ecological systems (Anderies et al., 2004).

Institutions play an important role in mediating the relationship between communities and the environment in social-ecological systems (Agrawal & Chhatre, 2006; Berkes et al., 2003; Ostrom, 2005). This dissertation will explore how institutions

impact the sustainability of a social-ecological system by increasing researchers' understanding of how institutions influence Mikania management. Informed by both social and ecological data, this research contributes to addressing the often missing link between institutions and the biophysical world (Ostrom, 2005). While the literature on managing invasive species in a social-ecological systems framework is growing, studies seeking to understand both the social and ecological impacts and outcomes of invasive species are needed (Schuettler, Rozzi, & Jax, 2011), and institutional components of invasive plant management have rarely been considered.

In community forestry globally, decentralization and the transfer of forest use and management rights to local communities from state or federal control has often been disappointing and incomplete. Community forestry in practice frequently seems to produce greater ecological compared to social and economic benefits (Charnley & Poe, 2007; Nightingale, 2005; Thoms, 2008; Tinker, 1994). More research is needed to bridge the gap between community forestry in theory and practice. Particularly, further empirical work is necessary to either support or reject hypotheses related to whether (1) use rights of forests are actually transferred to local communities, (2) whether there are truly social and economic benefits related to community forestry, and (3) a more detailed understanding of community forestry outcomes (Charnley & Poe, 2007). Embracing a mixed methods approach, this study contributes to the need to better understand the outcomes of community forestry in the context of Mikania in Chitwan.

The impacts of Mikania on biodiversity in Chitwan have been explored (Murphy et al. 2013), but less is understood regarding: (1) the role that Mikania plays in affecting the everyday lives of the community forest residents, (2) how governance relationships in

the region operate, (3) the influences on collective action for managing Mikania, (4) how norms and strategies for Mikania management change over time and how this influences Mikania spread in the community forests, and (5) the broader lessons from Mikania and Chitwan that will contribute to scientific understanding of the role of institutions in mediating social-ecological challenges (figure 1.7).

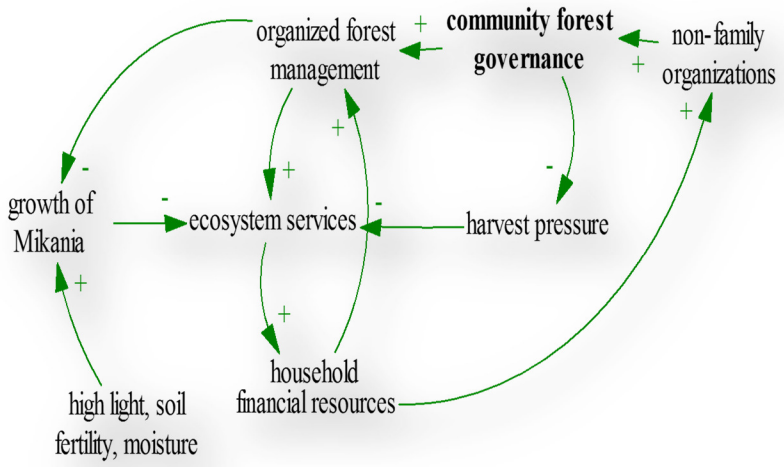


Figure 1.7. Systems diagram of the Chitwan social-ecological system, adapted from Yabiku, Hall, An, York, and Ghimire (2012). This dissertation will focus on understanding how governance relationships fit into the dynamics of the system.

Broader Implications: People and Mikania

The rapid spread of Mikania has tangible consequences for community forests and the remainder of the ecosystem, including diminishing biodiversity and damaging resources vital to the vulnerable one-horned rhinoceros. The forests along the urban-rural gradient in Chitwan provide communities with often indispensable timber, fuel wood, fodder, and thatch resources. The fieldwork conducted for this dissertation revealed that Mikania is perceived as impacting resource collectors' daily time budgets, increasing the time it takes to gather grasses and fodder from the community forests and exposing people, particularly women, to greater risk of encountering wildlife, such as tigers and

rhinos (figure 1.8). Thus, this research additionally seeks to provide information relevant to improving human welfare via a better understanding of factors impacting the spread of Mikania and roadblocks to successful management. I hope the models and approach developed in this research will eventually provide an additional source of information for stakeholders to use in evaluating risk management strategies related to improving human welfare and protecting wildlife habitat impacted by Mikania.

Figure 1.8. A group of women after collection of grasses and fodder from their community forest in Chitwan. Mikania is entangled in the grasses the middle woman had collected. Women reported having to spend increased amounts of time collecting grasses necessary for their livestock and having to venture farther into the forest, amplifying their vulnerability to wildlife attacks (primarily from rhinos, tigers, and wild boar).

Research Questions and Format of the Dissertation

This dissertation will investigate the following questions in an article dissertation format, with each chapter contributing to a more complete understanding of the social-ecological elements of Mikania management. Although each chapter is intended to be a

standalone piece, together they tell the complex story of the role of institutions in Chitwan community forests and are meant to be read in order. The overarching question that this dissertation investigates is: How do institutions mediate outcomes in social-ecological systems facing rapid changes? Specifically: How do institutions mediate Mikania management and outcomes in Chitwan community forests? The following questions guide this dissertation and aid in addressing the principal question in more detail.

1. Based upon the de jure, or formal, institutional arrangements, what actors should be involved in Mikania management and what does Mikania management resemble de facto, or on-the-ground? How do norms alter the de jure institutional arrangements and influence community forests' collective Mikania management activities? What lessons can be learned from this case study of Mikania management to inform the role of institutions in mediating collective action problems involving social-ecological challenges?
2. Who has access to community forest resources? What factors influence community forest membership?
3. What factors are affecting collective action related to Mikania? How does perception of Mikania as a problem at multiple levels influence collective action?
4. How do empirically observed and theoretically hypothesized management norms and strategies in Chitwan impact patterns of Mikania distribution? How does the adoption of norms and strategies change over time and which theory of institutional change, rational choice or cultural diffusion, better fits empirical observations in the system? What are the implications for managing social-

ecological challenges in the future, including when current institutions do not fit new social-ecological challenges?

Figure 1.9 summarizes the methodological framework that will be utilized to address these research questions.

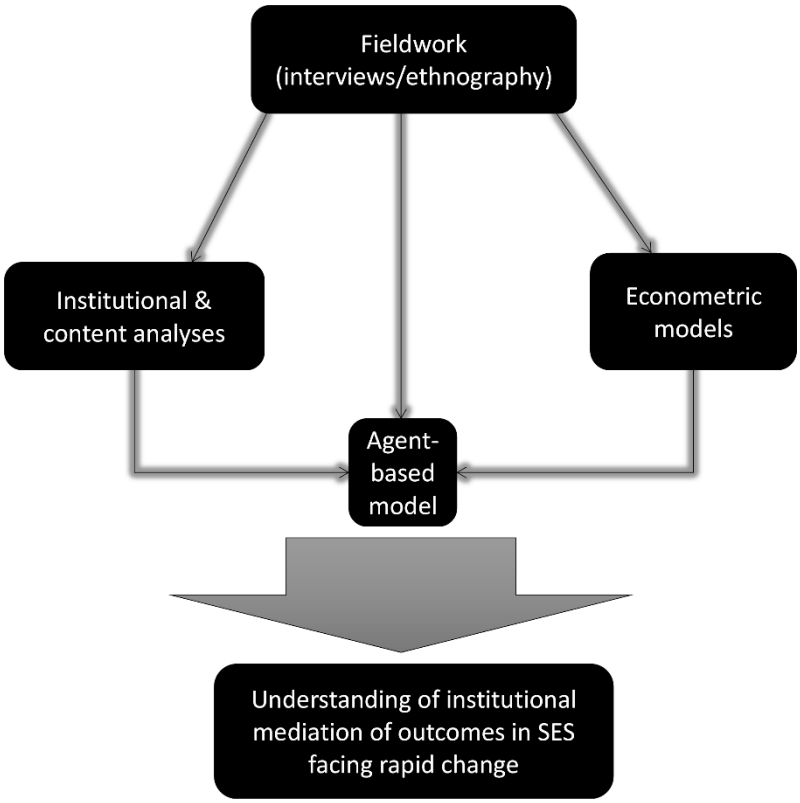


Figure 1.9. Methodological framework and main contribution of this dissertation.

First, chapter 2 establishes that community forest governance in the buffer zone is heterogeneous and subsequently utilizes content and institutional analyses to identify and explore themes and norms in relationships relevant to Mikania management.

The institutional literature, and arguably studies of sustainable resource management, has seldom considered equity in past research. Chapter 3 contributes to this important and growing area of institutional research via a statistical analysis of the factors that influence access to community forest resources in Chitwan.

Collective action has played a vital role in managing common pool resources in numerous global contexts (Ostrom, 2005). Thus, in a statistical analysis complementary to chapter 3, chapter 4 explores the factors affecting collective action related to Mikania removal in depth, using both household survey data and more nuanced qualitative interview data.

Chapter 5 presents an agent-based model (Grimm et al., 2006) to explore two theoretical perspectives of how institutions change over time, with the goals of understanding patterns of institutional change and Mikania distribution and exploring competing theories of institutional change.

The mixed-methods qualitative and quantitative approach outlined here facilitates a thorough exploration of the overarching question regarding the role of institutions in mediating outcomes in a social-ecological system facing rapid changes.

A Description of the Data Used in this Dissertation

This dissertation assesses and is informed by a range of data types, including interview, participant observation, survey, and ecological data. Here I provide an overview of each data source; the data employed in each chapter are also explained briefly in the chapter's respective methods section.

Ethics note.

This project, and all of the data collected, has been granted Institutional Review Board Human Subjects approval by Arizona State University (approval can be viewed in Appendix A). The names of the five community forests explored as case studies in this dissertation are and will remain anonymous. As the communities are small, identifying

them would increase the possibility of linking interviewee comments and concerns with individuals or households.

Case study interviews and participant observation.

There are 21 buffer zone community forests included in the household survey and ecological datasets. Five of these 21 community forests were selected for detailed qualitative fieldwork in summer 2014. The five community forests were selected to represent the diversity of financial and social resources (like partnerships with other government agencies or non-governmental organizations (NGOs) that provide services including toilets and wells) historically available within the 21 communities. Financial and social resources influence the ability of a community forest governance committee[2] to govern its forest resources and members, so I refer to levels of these resources and others collectively as the governance capacity of a community forest. Using historic data on each community forest's income and resources from previous projects in the buffer zone, five community forest case studies were selected, with historic governance capacities ranging from high to very low.

Interviews were conducted in Nepali in the interviewees' homes and surrounding forests with the translation assistance and guidance of Rajendra Ghimire from the Institute for Social and Environmental Research-Nepal (ISER-N). In addition to interviewing governance committee and regular user group members in each community forest, officials at two NGOs, Chitwan National Park, and the buffer zone committee

[2] Each community forest in the buffer zone has a locally elected governance committee that is responsible for administrative activities related to the forest user groups, such as collecting fees for resource collection (if present), hiring and overseeing guards for the forest, administering related educational programs, and generally enforcing and monitoring the rules outlined in the specific community forest's management plan (see chapter 2).

were interviewed. In total, 29 interviews with 87 people were conducted. Detailed information on the interviewees can be found in Appendix B.

Participant observation was conducted in each of the five case studies in order to better understand activities such as fodder/grass/thatch collection, forest cleaning, livestock care, farming, and household chores such as well water collection.

Household and community forest management surveys.

The survey data analyzed in this dissertation was collected by ISER-N as part of the Chitwan National Science Foundation Coupled Natural Human systems project (http://www.nsf.gov/awardsearch/showAward?AWD_ID=1211498). The household survey included 1235 households in the catchment areas of the 21 buffer zone community forests. A catchment area includes all of the households eligible for membership in a given community forest which are determined by the district government in conjunction with village development committees (local level governance) and community forest governance committees. Thus, the survey included both non-members and members, allowing assessment of a model of the factors influencing membership (which is the subject of chapter 3). The survey included demographic information and sections on household farming, livestock and fish farming, household relationship to community forest governance, household relationship to invasive species (including Mikania), ownership of household items, and household consumption. The survey was conducted in 2014 and the response rate for the survey was 98.6%. Variables used in each of the analyses are described in their respective chapters. The community forest management survey was conducted with one member of each of the 21 community forest governance committees and included sections on general background information, local plant species

and their uses, governance committee activities, rules and enforcement, user groups, and perceptions of community forest issues. The survey was conducted in 2014 and the response rate was 100%.

Ecological survey.

Plot-level ecological data from the 21 community forests were collected over three years (2013-2015; one set of data from each community forest). The dataset includes over 2000 plots total and information on percent Mikania cover, common plant species (including other invasives), forest type, and evidence of disturbance (including fire). The ecological data generally inform the understanding of the extent and location of Mikania throughout Chitwan as well as the creation of the agent-based model presented in chapter 5.

The goal of employing this variety of data is to add depth to the analyses presented in this dissertation and to increase the accuracy of investigating the overarching research question, which I hope the reader will keep in mind: How do institutions mediate outcomes in a social-ecological system facing rapid changes?

CHAPTER 2

DE JURE VERSUS DE FACTO INSTITUTIONS: TRUST, INFORMATION, AND COLLECTIVE EFFORTS TO MANAGE THE INVASIVE MILE-A-MINUTE WEED (MIKANIA MICRANTHA)

Chapter Overview

Differences in governance relationships and community efforts to remove an exotic, rapidly spreading invasive plant, the-mile-a-minute weed (*Mikania micrantha*), are explored in five case study community forests in the subtropical region of Chitwan, Nepal. An institutional analysis informs an examination of the de jure (formal) versus de facto (on-the-ground) institutions and actor relationships relevant to Mikania removal efforts. Contrary to the expectations set by the de jure situation, governance relationships and norms related to Mikania management are heterogeneous across community forests. Content analysis of interview data illuminate reoccurring themes and their implications for social and ecological outcomes in the communities. Complex governance relationships and regular discussion of distrust of government and non-government officials help explain collective action efforts and management decisions. The content analysis suggests that Mikania is impacting people's daily lives but the perceived degree of severity and the response to the disruption varies substantially and is heavily affected by other problems experienced by community forest members. The results indicate that understanding how the de facto, or on-the-ground, situation differs from the de jure institutions may be vital in structuring successful efforts to manage invasive species and understanding collective action problems related to other social-ecological threats. Data-informed propositions about common pool resource management and invasive species are

presented. This study contributes to a better scientific understanding of how institutions mediate social-ecological challenges influencing common pool resources more broadly.

Chitwan National Park, Buffer Zone Community Forests, and the Mile-a-Minute Weed

Chitwan is a rapidly urbanizing district in Nepal's subtropical Terai region containing the internationally-important Chitwan National Park. Chitwan National Park was founded as Nepal's first national park in 1973 (Straede & Helles, 2000) and is home to high-profile species such as the Bengal tiger and one-horned rhinoceros. The park's area is approximately 932 square kilometers (Nepal & Weber, 1994) and in 1996 a formally recognized buffer zone of approximately 750 square kilometers surrounding the park was created (Straede & Treue, 2006). The purpose of establishing the buffer zone was to decrease the impact of human activity on the park ecosystem by creating rules on resource collection and use for people who live in these areas (Nepal & Weber, 1994). Human impacts on the park are substantial: it is heavily visited, having hosted 115,181 visitors in fiscal year 2009-2010 (Pandit, Dhakal, & Polyakov, 2015). Furthermore, the buffer zone area saw a net decrease of 62 square kilometers of forest and a net increase of 67 square kilometers of agricultural land between 1978 and 1999 (Baidya, Bhuju, & Kandel, 2010).

Community forestry is a type of decentralized, local forest resource governance system. Community forest user groups were formally established in Nepal in 1993 through the Forest Act and were designed to address the challenges of people, natural resources, and protected areas (Iversen et al., 2006; also see Gilmour, 2003 for an overview of community forestry and associated policies in Nepal). In the mid-1990s, Chitwan gained its first formally-recognized community forests, most in the buffer zone.

These community forests provided residents opportunities to collect forest products and timber in forests that are largely self-governed. The community forestry program also intended to reduce people's reliance on often illegally harvested forest resources within the national park, while simultaneously supporting livelihoods through sustainable management of the buffer zone forests. However, novel social-ecological changes such as increasing rates of urbanization and biological invasions now threaten the success of the community forestry program in increasing and maintaining forest health. This research explores how institutions influence community forest members' collective efforts to manage a rapidly spreading invasive plant, known informally as the mile-a-minute weed (*Mikania micrantha*: hereafter referred to as Mikania), that is disrupting social-ecological processes in this region. Institutions are defined in this research as the shared rules, norms, and strategies that shape human decision making and are inherently intertwined in efforts to govern common pool resources, such as community forests (Ostrom, 2005).

This research addresses a gap in analyses of community forestry outcomes (Charnley & Poe, 2007; Lachapelle, Smith, & McCool, 2004) by elucidating the impacts of governance relationships, or their absence, on collective action in a common pool resource facing social-ecological changes. Thus, this study contributes to social scientific understanding of the relationship between institutional diversity and management efforts and illuminates the importance of learning the on-the-ground conditions, as opposed to solely studying the formal situation. This research has practical significance as the findings can improve collective natural resources management, leading to enhanced efforts to mitigate the negative impacts of invasive species on ecologically significant

species, such as the Bengal tiger and one-horned rhinoceros, and socially and economically important protected areas.

Mikania micrantha invasion as a social-ecological challenge.

Mikania micrantha is a fast-growing plant native to South America that favors humid, warm (tropical and subtropical) environments (figure 2.1). Mikania is believed to have been intentionally transferred to India and the Pacific Islands around the 1940s for use as a cover crop for airfields (IUCN, 2005). Since then it has negatively impacted agricultural and forest resources in parts of India, China, and Nepal, among other regions. Mikania spreads rapidly across landscapes through both vegetative growth from dropped stems and wind-borne seeds; it is fire-adapted and contains allelopathic compounds in its roots that inhibit growth of other plants. Household resource collection activities often result in unintentional exacerbation of Mikania. Mikania is often entangled in collected grasses and grows where pieces are dropped along resource collection routes. For these reasons, it has proved to be extremely difficult to eradicate. In Chitwan, Mikania was present in 20 percent of Chitwan National Park in 2010 (Khadka, 2010) but the buffer zone community forests have been invaded to differing degrees of severity (Clark et al., 2016). Recent work has shown that Mikania invasion causes significant ecological harm to local resources, including food and habitat for the vulnerable one-horned rhinoceros (Murphy et al., 2013; Ram, 2008). By covering and killing vegetation, Mikania further represents a threat to the livelihoods of Chitwan households dependent on collecting grasses and fodder (Rai & Scarborough, 2014). Many invasive plants globally have become useful to local communities after their invasion. Unfortunately, Mikania is not a

viable substitute for the grasses it covers, which are often used as livestock feed by many Chitwan households, as Mikania is indigestible to livestock.

Figure 2.1. *Mikania micrantha* climbing a tree in Chitwan.

Efforts to manage Mikania in the buffer zone community forests have been largely unsuccessful. “Mikania management” refers to efforts by actors to address the Mikania invasion, primarily involving different removal attempts and discussion of or planning for such efforts. Removal attempts often include pulling, cutting, or burning the plant. To strengthen Mikania management, researchers and stakeholders first need a clear understanding of the governance relationships across the buffer zone community forests. Without information about the actors involved in Mikania management efforts on-the-ground, stakeholders will continue to lack the information necessary to successfully design or influence collective Mikania management efforts in Chitwan and elsewhere.

Definitions and research questions.

The term de jure (“by law”) is used to reflect the actors theoretically involved in Mikania management in the buffer zone, or the situation as it formally exists via laws, policies, and records. The term de facto (“in fact”) is used to reflect the actors truly

involved in Mikania management, explored in my fieldwork. To understand the de facto situation, case studies in five community forests are employed to explore the connections between the perceived effects of Mikania on livelihoods, the diversity in current Mikania management practices, and the relationship between these factors and existing institutions and governance relationships. The term "governance relationship" refers to interactions between different actors (including government agencies at different levels, non-governmental organizations, community forest governance officials, and local community members) involved in a collective issue that results in the creation or reinforcement of institutions (Hufty, 2011).

In general, little is understood about the role that Mikania plays in affecting the everyday lives of the buffer zone community forest residents, how the buffer zone community forest members interact with other actors regarding Mikania management, and the role of institutions in mediating threats to social-ecological systems. To address these scientific and management gaps, I focus on the following:

1. Based upon the de jure institutional arrangements, what actors should be involved in Mikania management and what does Mikania management resemble de facto, or on-the-ground?
2. How do norms alter the de jure institutional arrangements and influence community forests' collective Mikania management activities?
3. What lessons can be learned from this case study of Mikania management to inform the role of institutions in mediating collective action problems involving social-ecological challenges?

Community forestry and institutional heterogeneity.

Recent research from around the globe has focused on the various factors that lead to successful community forestry outcomes, including common property management, power, and accountability (Agrawal & Chhatre, 2006; Behera & Engel, 2006). Despite this prior work in Nepal (Ojha, 2006; Ojha, Cameron, & Kumar, 2009; Pokharel, 1997; Poteete & Ostrom, 2004; Varughese & Ostrom, 2001), little is known about how different governance relationships between community forestry groups may mediate social-ecological challenges like invasive species management or what this means for how institutional analysis may be most effectively conducted (i.e. exploring the on-the-ground situation versus the formal situation)

Community forestry often introduces decentralized, democratic governance where people within a given community contribute to decision making processes (Lachapelle, Smith, & McCool, 2004). However, heterogeneity exists among these institutions; some community forests target specific groups (including women or disadvantaged caste and ethnic groups) in an effort to correct long-enduring discrimination, inequality, and injustice, and there are substantial differences in community forest management practices or goals. Different institutional arrangements within Nepal appear to reflect underlying heterogeneity of the communities including the variation in biophysical condition of the forest (forest degradation/forest health), dominant labor occupation (community dependence on the forest resources and employment opportunities in nearby markets), and community dynamics and population size (Acharya, 2002).

Institutional heterogeneity related to governance practices and management norms often exists within community forests in the same geographic region. Heterogeneity in

caste, education, gender, and other factors influence which households benefit the most from community forestry and who participates in collective resource management (Adhikari, 2005). Contrary to previous studies, richer households with land holdings, livestock, and more monetary resources are sometimes more dependent on community forest resources than poorer households, and thus are in a better position to benefit from intermediate forest products (Adhikari, 2005; Gilmour, Malla, & Nurse, 2004). The very poorest households often have few land holdings and work for others as wage laborers.

The role of heterogeneity in collective management of common pool resources has been hotly debated in the literature (Varughese & Ostrom, 2001). Heterogeneity here refers to differences that might impact the success of reaching a collective goal. Kant (2000) defined this heterogeneity in three levels: (1) if there are social, cultural, and economic differences between people living in the same area using the same resources, there are likely to be (2) different preferences for using the resources and (3) different preferences for the ways in which resources are managed. Thus, heterogeneity theoretically can pose difficulties in successful collective action to manage a common pool resource (Ostrom, 2005). Ostrom (2005) argues that the focus on heterogeneity has been misplaced; instead the focus should be on the factors affecting differences in heterogeneity, such as the governance relationships, and interactions between factors.

Chitwan community forests formally have homogeneous structures: to become recognized as community forests by the government, a community forest governance committee must create management and governance plans that are reviewed by the district forest office or, if the community forest borders the national park (as in all of the case studies), the plans are reviewed by the park office. These two offices have similar

requirements, and thus these two organizations have created formally homogenous structures in the community forests in this area. Local community forest members are part of a community forest user group and each community forest has a locally elected governance committee. Committees typically consist of ten to fifteen members each. Households are eligible to join an established community forest user group based on their location within a community forest's catchment area. These catchment areas are administrative boundaries that are determined by district and local level government (the latter known as the village development committee). The community forest governance committees are responsible for carrying out rules and policies outlined in their own forest management plans. These plans can be altered by the governance committees, but they are largely similar across community forests and include policies such as fees (if any) for grass and fodder collection; membership fee structures; rules for collection of resources such as fuelwood and timber (which is typically prohibited due to the general scarcity of harvest-ready trees); and possible sanctions for violating resource collection or use rules. Community forest members are informed of their committee's policies when they join and are responsible for upholding the policies outlined in the management plan as well as informal norms such as aiding in activities like annual forest cleaning where trash is collected. Based on my 2014 fieldwork and 2015 household survey data, membership of eligible households in the buffer zone community forests ranges from 38 percent in forests near urban areas to 93 percent elsewhere; over 80 percent of buffer zone households engage in some form of agriculture and thus many rely on the forest resources.

Formal rules (de jure) versus rules in use (de facto).

It is important to understand institutions as they exist formally, but entirely different and equally essential to understand how they operate in practice, the "rules in use" (Ostrom, Gardner, & Walker, 1994; Ostrom, 2005, p.186). Formally, as defined in forest management plans, the buffer zone community forest rules are very similar due to the aforementioned management plan procedures. Figure 2.2 details the actors that theoretically, de jure, would be involved in some aspect of Mikania management based on forestry acts or Nepal's government structures that have established these actors. This analysis will explore the ways in which the de facto situation, the way institutions are operationalized, differs from the de jure situation depicted in figure 2.2 and why this matters. Ultimately, this research contributes three propositions based on the finding that the situations differ significantly – connecting governance relationships, common pool resources, and invasive plants – which lend insight into the role of institutions in mediating social-ecological challenges more generally.

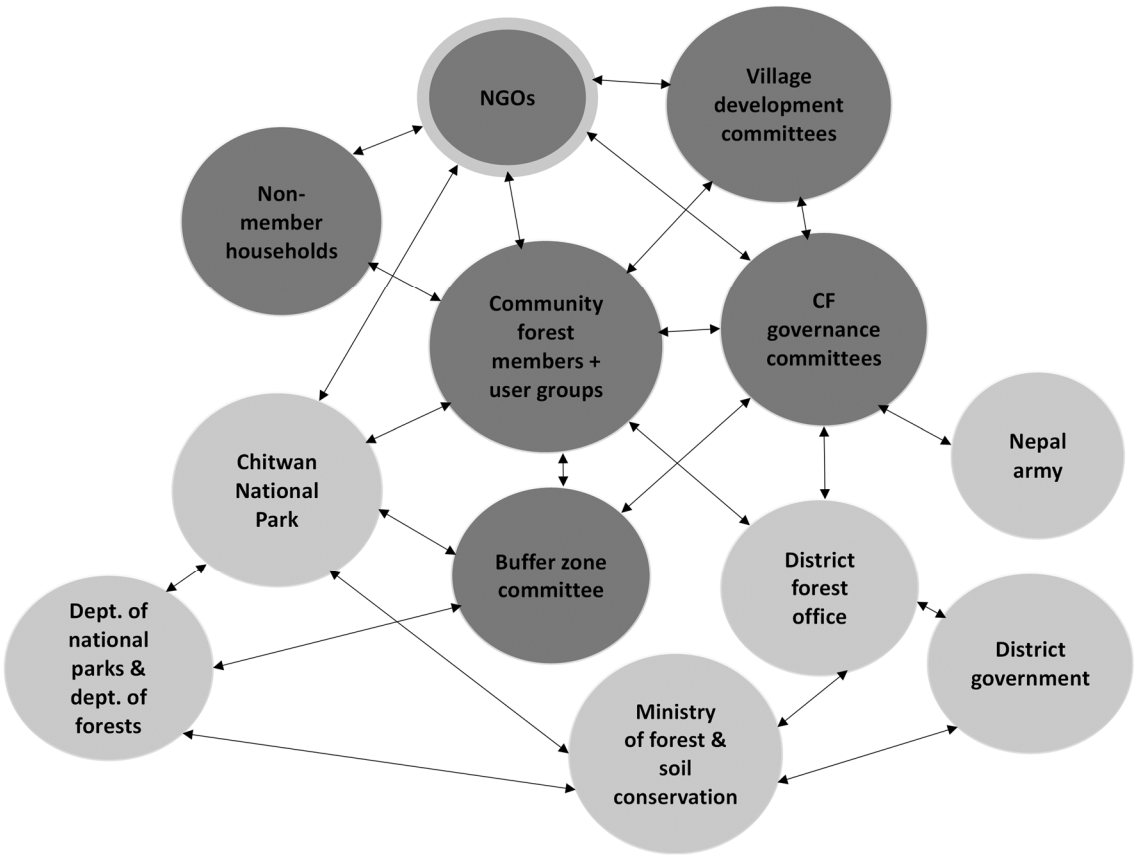


Figure 2.2. Governance relationships involved in Mikania management in the buffer zone community forests in the de jure situation. Darker grey circles are local level actors, while lighter grey circles represent district or national level actors (non-governmental organizations—NGOs—are both).

Case studies.

Using data from five case study community forests, the relationship between governance, institutions, and invasive species management is explored. This research investigates the role of institutions as mediators of shocks and disruptive events that threaten community sustainability (Leach, Scoones, & Stirling, 2010). In Chitwan, these disruptions take the form of invasive plants as a threat to the social-ecological system. Institutions evolve over time and adapt to the social, political, economic, and ecological context in which they are embedded. When there are slow or gradual changes in this context, there is time and flexibility for institutions and relationships to successfully

adapt. Abrupt shocks, such as rapidly spreading invasive species, challenge these relationships and their sustainability (Young et al., 2006).

Distinct from much community forestry literature, the focus is not on understanding collective action to establish community forestry programs (Varughese & Ostrom, 2001; Poteete & Ostrom, 2004), but rather on collectively acting to manage the forest in the face of potentially catastrophic social-ecological challenges like Mikania. An understanding of collective action on-the-ground is important for confronting common pool resource threats (Ostrom, 2005).

Methods

Case study selection and fieldwork.

Five community forests were selected for household and management committee interviews from a group of 11 buffer zone community forests where ecological data, including Mikania distribution, was collected in 2013. To select case studies, first, a preliminary "governance capacity" index (high, medium, or low) based upon historical data related to community forest income (government funds and money community forest governance committees raised via selling resources such as gravel or tourist entry fees) and the community forest's age (time since establishment) was created. The stratification process ensured cases included a mixture of historically high, medium, and low governance capacities. After classifying all community forests, a random number generator was used to assign numbers to each case. The community forests corresponding to the two largest values in the high and low categories, and the largest value in the medium category, were selected. This methodology was adopted to reduce any personal biases (such as personal experience or learned information about specific communities)

in selecting the cases and to increase the likelihood of variation in governance capacities. The five community forests in this research are identified by pseudonyms (the names of rivers in Nepal) because some of the information discussed is sensitive to these small communities.

In total I conducted 29 semi-structured, small-group interviews with 87 interviewees between May and July 2014. This method is the most appropriate way to understand the rules in use, as I was able to collect richer, more nuanced information than with other methods such as surveys. Five interviews were conducted in each community forest, which each included between two and ten participants. The remaining interviews took place in Chitwan National Park, two non-governmental organizations, and the buffer zone committee office. All interviews were between one and two hours in length. These interviews included questions covering interactions with a variety of individuals and organizations, Mikania management, and perceptions of Mikania; the semi-structured nature also allowed participants to discuss emergent topics (Bernard, 2011). Before interviewing, the protocol was translated to Nepali by a native Nepali speaker and tested with several community forestry members at the Institute for Social and Economic Research-Nepal (ISER-N) in Chitwan. Some concepts, such as "invasive species," do not directly translate or have a meaning in Nepali. As such, translations were made to best approximate the intended meaning in English. Fieldwork additionally consisted of participant observation (of activities such as fodder collection) between and during interviews to more fully understand the contexts of the responses.

Types of interviewees and interview structure.

To explore governance relationships, I interviewed community forest members, the five governance committee presidents, Chitwan National Park officials, buffer zone committee officials, and officials from two non-governmental organizations. Figure 2.2 presented the de jure conceptual representation of the actors. The buffer-zone community forests are connected to the buffer zone committee, which generally acts as a mediator between the community forest governance committees and the national park. Most of the community forests in Chitwan are registered with either the district forest or Chitwan National Park; all of the case study forests except one were registered with Chitwan National Park (the remaining community forest was restricting resource collection due to poor forest health and intended to register with the park in the future).

While interviews with community forest members usually focused on one individual or household, they almost always became group events where neighbors' opinions were provided. The interviewee composition was representative of the ethnic composition and educational status of each of the community forests. It is possible that higher caste Hindus were underrepresented in the interviews and females were overrepresented. Young women (18-21 years) who were less likely to participate in an interview with males or older females present were under-represented; additionally, there were fewer young men, as many were working overseas. Both farmers and non-farmers were interviewed, but it was very difficult to find people that did not farm in some capacity. Interviews were also conducted with two non-governmental organizations consisting of representatives from NGO A and NGO B (pseudonyms), both working in Chitwan and with some of the case study community forests. These non-governmental

organizations are both conservation oriented and provide services to local households, such as wildlife and plant identification classes and habitat management/restoration information (for example, wetland management). Each non-governmental organization has worked with some local households on invasive plant management.

Content analysis.

Content analysis, also sometimes referred to as theme analysis, is a systematic text analysis method common in anthropology that is applicable in any research with text data. Content analysis can be both deductive, where the analyst begins with a hypothesis or an idea from the literature that they seek to assess, or inductive where codes stem from fieldwork and intimate knowledge of the data (Bernard, 2011). Content analysis can be quantitative or qualitative in nature. In this analysis, it is both. Some of the codes are quantitatively presented as percentages while others are discussed qualitatively in the context of participant observation notes or an entire interview. The codebook was developed according to best practices established by MacQueen et al. (1998). Two independent coders went through the codes together and calculated inter-rater reliability for each code in five interviews. In order to resolve codes where an initial Kappa (the standard inter-rater reliability statistic of agreement) of 0.7 or greater was not reached, coders discussed the codes for clarification and re-coded (MacQueen et al., 1998).

Institutional analysis.

Content and institutional analyses are natural complements for qualitative data that explores governance relationships, as themes can be interpreted in the context of governance relationships. There are a wide variety of approaches to institutional analysis, but in many cases the institutional analysis and development framework provides a

background to the interpretation of existing strategies, norms, and rules (Ostrom, 2011). Here, I focus on the actors and the action situation within the Institutional Analysis and Development (IAD) framework (figure 2.3) to explore linkages between governance relationships. There are a variety of actors interacting with community forest groups in some manner. The linkages between these actors, including the frequency and strength of the relationships, are distinct in the five case studies. Coding the interview data for the presence of these relationships aided in clarifying them, but initial diagrams of governance relationships and norms of interactions were created during fieldwork for each case. The institutional analysis examines the text and participant observation notes for the existing relationships between the participants theoretically involved in the action arena focused on Mikania management presented in figures 2.2 and 2.3. These relationships impact how information about Mikania is communicated and will be discussed qualitatively in the context of the information from the content analysis. Future research will elaborate on other areas of the framework in figure 2.3, including linking biophysical conditions of the forests to the action situation and related outcomes.

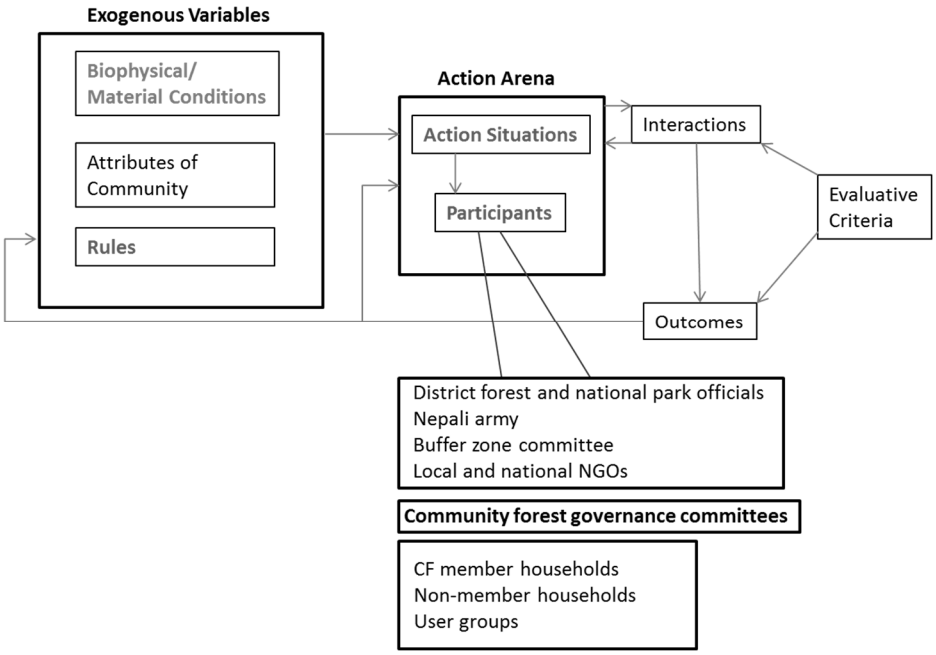


Figure 2.3. The Institutional Analysis and Development Framework, adapted from Ostrom et al. (1994)

Results

Community forests are heterogeneous.

Based on the similarity of most community forest management plans, I anticipated that the community forests would be similar in multiple aspects. In actuality, heterogeneity in governance is the norm and the de facto governance relationships (figure 2.4) differ from the de jure situation (figure 2.2) across the five community forests. There is variation in the concern about Mikania, perceived extent and spread of Mikania within the forests, the physical methods used to manage Mikania, and organization of community members involved in management. Variation also exists in the major problems identified by each case study: invasive species, human-wildlife conflict, flooding, forest degradation, and pollution. There is substantial variation in community forest collaboration with outside entities, specifically non-governmental organizations

and the national park. Next, I elaborate on these variations and then expand upon the importance and impact of this heterogeneity.

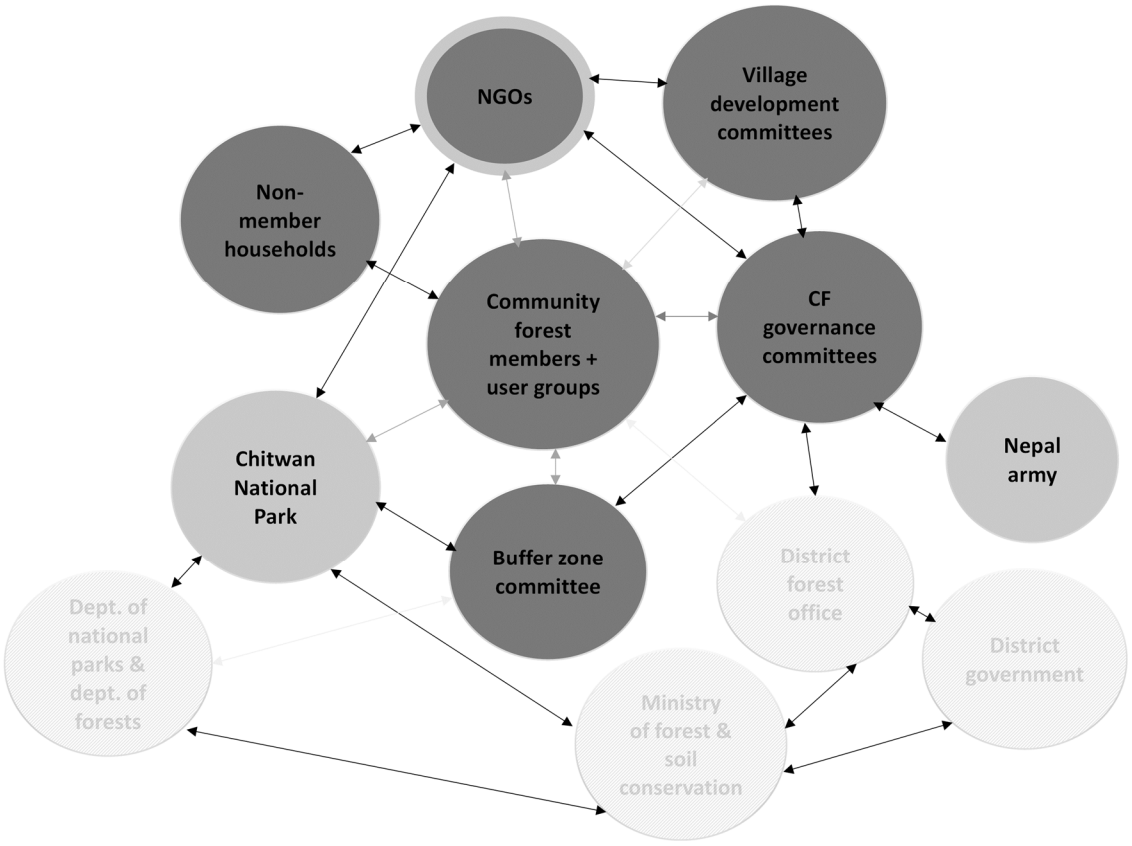


Figure 2.4. Governance relationships involved in Mikania management in the buffer zone community forests in the de facto situation. Faded circles and lines (the lightest grey) represent actors and relationships formally present that do not exist, or are significantly weaker, in practice.

Perceptions of Mikania and impact on daily lives.

Most interviewees in all five community forests believed that Mikania was increasing in abundance, while some thought Mikania presence in their forest was the same when compared to the previous year (figure 2.5). Interviewees in Trishuli, Koshi, and Gandaki (particularly women, who are responsible for most resource collection) expressed that Mikania was impacting how they allotted their daily time, by making collection of forest resources such as grasses and fodder increasingly difficult.

Interviewees in all five community forests articulated that increasing Mikania abundance limits food sources for wildlife, resulting in additional large fauna (e.g. tigers, rhinos, wild boar) leaving the forest in search of food.

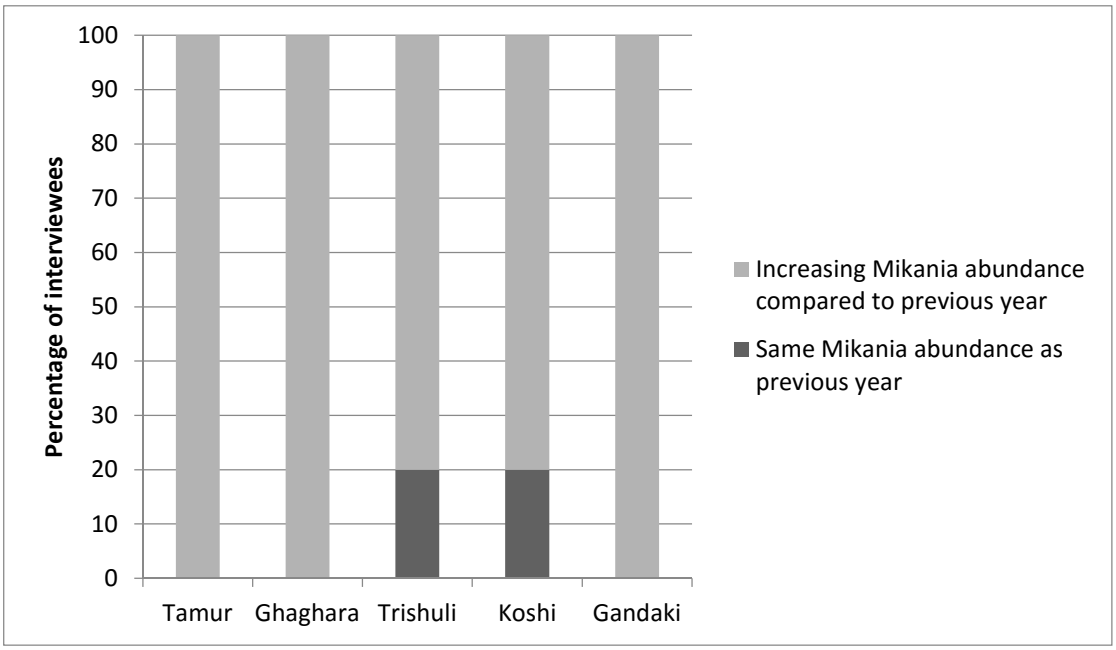


Figure 2.5. Perceptions of change in Mikania abundance over the past year, by community forest.

Major problems identified in the community forests.

There was substantial variation in the problems discussed by interviewees (table 2.1). All interviewees were asked about flooding, issues experienced with wildlife (crop destruction, attacks, or related), invasive species, and the condition of community forest resources. Industrial pollution was mentioned without prompting in Gandaki; in this case three interviewees discussed an industrial factory that had discharged an unknown substance onto their field.

Table 2.1. Major problems identified in each community forest

	Tamur	Ghaghara	Trishuli	Koshi	Gandaki
Flooding	✓	✓	✓	✓	
Wildlife: Rhinos	✓	✓	✓	✓	
Wildlife: Elephants	✓	✓			
Wildlife: Tigers		✓			
Wildlife: Deer and boar	✓	✓	✓	✓	✓
Mikania		✓	✓		
Stressed/Limited CF resources				✓	
Industrial pollution					✓

Interviewees from all community forests discussed a lack of forest resources in some capacity, but in Koshi resource collection was prohibited (except for one collection day per month) due to forest health and wildlife conflict (rhino attacks). In Koshi, the Nepal Army was stationed at entrances and within the forest in an attempt to prevent and protect people from rhino attacks (the Nepal Army only provides guards to the community forests in severe cases where the governance committee has requested them through the buffer zone committee, who then contacts the national park where a request is typically placed with the district level government). Mikania as a problem was discussed by interviewees from every community forest, but only in Ghaghara and Trishuli was it perceived as a top problem. In these communities Mikania was identified as directly affecting livelihoods by increasing the time and distance to collect forest products.

Mikania.

All of the case study communities discussed invasive plant species and Mikania within their forests, but there was variation in the level of concern. As noted, Ghaghara and Trishuli were the most concerned about Mikania. Interviewees discussed its impact on the time it took to collect grasses, as well as an increase in the distance ventured into

the forest to collect grasses not engulfed by Mikania. There was also variation in removal methods (table 2.2). Interviewees in Trishuli and Gandaki discussed burning for Mikania management, as well as to promote grassland growth (note in Trishuli and Gandaki the governance committee presidents denied burning; it can be a contentious topic as burning is prohibited in many community forests). Cutting and pulling was mentioned in all communities. Pesticide use was only discussed in Tamur and Gandaki. Only one interviewee (in Koshi) reported seeing Mikania on their farmland, which was very near the community forest fence. Other interviewees strictly reported finding it in the forest and along the forest fence. One interviewee (the governance committee president of Ghaghara) reported a group he organizes to remove Mikania by uprooting it from within the forest and throwing it all into the nearby river.

Table 2.2. Presence of Mikania and removal methods

	Tamur	Ghaghara	Trishuli	Koshi	Gandaki
Mikania (presence)	✓	✓	✓	✓	✓
Burning			✓		✓
Cutting	✓	✓	✓	✓	✓
Pulling	✓	✓	✓	✓	✓
Pesticides	✓				✓

Understanding governance relationships.

The de facto governance relationships (figure 2.4) are distinct from the de jure situation (figure 2.2). I find that community forest members are largely isolated in managing Mikania. First, governance relationships are discussed generally. Then, interactions explicitly involving Mikania management and the implications of general relationships for Mikania management outcomes are considered. All community forest members interviewed reported some level of interaction with the buffer zone committee, and many reported indirectly conveying concerns to the national park through the buffer

zone committee members. The community forest governance committee in each forest communicates with the national park and buffer zone committee about a variety of issues relevant to the community forests. Several key differences between the cases are emphasized.

Key differences in governance relationships.

First, collaboration and interaction with non-governmental organizations is distinct in each case (non-governmental organization connections include all non-governmental organizations working with the community forests, not only ones related to invasive plants). For instance, in Trishuli, non-governmental organizations are highly integrated, interacting with the governance committee, community forest members, and village development committees (local level government). They provide resources such as toilets and wells, and in some cases skills-based trainings. Gandaki presents the opposite case, as they have little to no integration with non-governmental organizations.

Second, the strength of the relationships between different actors and community forest members differs. For instance, community forest members in each case have either direct or indirect connections with the national park. However, the level of trust in the national park is very different in each case (figure 2.6). In particular, members of Tamur, Trishuli, and Koshi reported low levels of trust in the national park. Trishuli members expressed concern that park officials were corrupt and sequestering monetary resources that could be shared with the buffer zone forests. Ghaghara members expressed lack of trust in their governance committee's ability to follow through with promises, as well as distrust in park officials.

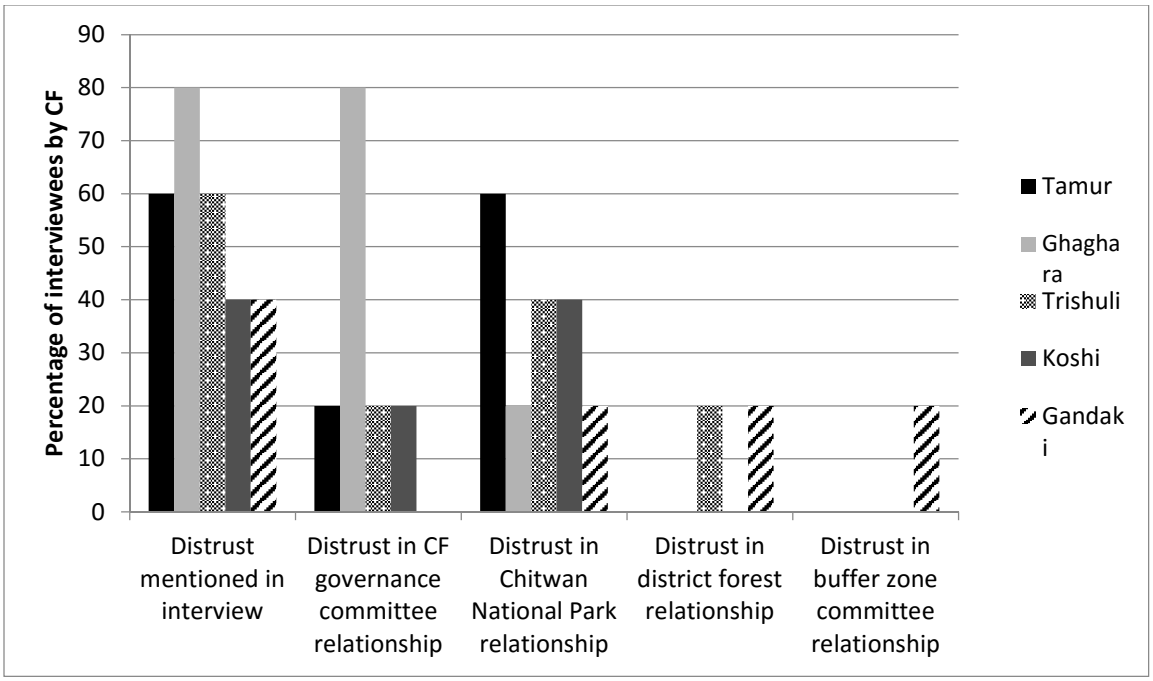


Figure 2.6. Percentages of interviewees expressing distrust by community forest.

Finally, Gandaki is the only case study with significant ties to the district forest. They are not registered with the district forest, but because of their proximity to a highway and the district forest office, the district forest office occasionally communicates with the governance committee members.

Governance relationships affect information and management decisions.

Characteristics of governance relationships are impacting management. First, members in each case are making Mikania management decisions without consulting their governance committees or other actors, limiting the information available regarding the best ways to successfully remove Mikania. In some cases, community members are engaging in removal practices (such as burning) that increase its dispersal (Murphy et al., 2013). The content analysis revealed that community forests with increased numbers of negative interactions (e.g., a community forest member's request to Chitwan National Park for monetary compensation due to wildlife injury being ignored) are more likely to

have members that report distrust and less likely to seek information about management from outside sources. Second, in cases where Mikania is affecting time budgets and daily lives, people expressed that they lacked resources or relationships that could improve the management situation. Additionally, interviews revealed that there were conflicting perspectives between actors contributing to distrust and information availability. For example, a non-governmental organization (NGO) expressed the opinion that Mikania was not increasing and largely failed to consider community forest members' opinions regarding Mikania spread and management; this lack of communication negatively impacted the relationship between the community forest and NGO. Currently, community forest interviewees report no interactions with the NGO as a result.

Collective action and governance capacity.

Collective efforts to manage invasive species exist in each of the community forests, but to differing degrees. The income of the community forests affects their governance capacity; this amount differs substantially based upon political connections, as well as differing resources and income streams. The buffer zone community forests registered with the national park receive annual funds distributed through the buffer zone committee to individual governance committees; the total amount of money available is impacted by political conditions, which have dramatically changed in recent years (see Karna, Shivakoti, & Webb, 2010). Some governance committees supplement this income with tourist entry fees or selling resources like gravel, but their ability to engage in such activities is limited by the condition of the forest and their available resources, resulting in differential income opportunity, and thus governance capacity, across community forests.

In Tamur and Ghaghara there were organized efforts to cut and pull Mikania within the forest directly following monsoon season for at least the past five years. Trishuli had "jungle cleaning" groups where specific plants were removed and the forest was cleaned of trash, but they were not centrally organized and were not necessarily targeting Mikania. Koshi and Gandaki did not participate in collective efforts to remove Mikania in the past year. Koshi members previously attempted to cut and pull Mikania, but because forest access is currently restricted there, they are no longer able to organize. Gandaki members reported that their community forest governance committee paid individuals to pull Mikania along the fence, but most community members did not know this. Gandaki also hired people to burn Mikania (this was denied by the governance committee president), but there were fewer voluntary efforts.

Collective action was not tightly linked to historical governance capacity, as defined by income and how long the community forest officially existed. Governance capacity has changed in some of the case studies based on income and resources reported from the community forest governance committee presidents and field observations. Collective action related to Mikania removal was assessed as either high, medium, or low based on interviewee reports of and/or participation in such efforts (table 2.3).

Table 2.3. The relationship between governance capacity and collective action.

	Tamur	Ghaghara	Trishuli	Koshi	Gandaki
Collective action observed in 2014	High	High	Medium	Low	Low
Governance capacity observed in 2014	High	Medium	Low	Low	High
Governance capacity assessed from historical data (1995-2009)	Medium	Low	Low	High	High

Discussion

Overall, the methodological approach provided insight into how unanticipated levels of institutional heterogeneity between community forests impact the management of a common pool resource invaded by Mikania. In figure 2.2, I outlined governance relationships in Chitwan community forests de jure, as they formally exist according to official agencies, laws, and policies. However, as the analysis detailed, these relationships look different on-the-ground. Figure 2.4 represents the de facto situation, with the relationships as they exist in practice. This study discovered that formal relationships were often absent in practice, in part due to practical restrictions like distance (such as the lack of communication between most of the community forests and the district forest office), but also because of broken or absent trust between actors. These absent or weakened relationships effectively isolated Chitwan community forest group members in their Mikania management efforts. The diversity of management behaviors across community forests is significant because it suggests that the community forest system in Chitwan has not implemented a consistent, effective, and unified strategy to address Mikania.

Ostrom (2005) argued that institutional scholars need to understand better the factors that influence institutional heterogeneity, i.e., in this case, why are there differences in norms and strategies surrounding Mikania management efforts? The analysis of the governance relationships in Chitwan revealed that these relationships influence such differences. Research exploring de jure institutions has made critical and important contributions, but it is also important to understand de facto institutions. Indeed, I argue that investigating both the de jure and de facto situations can create a

richer understanding of a given case, leading to more effective solutions in natural resource management that are able to target management weaknesses as they exist in practice. Understanding the de facto institutions is important because in natural resource management efforts, particularly top-down efforts or those implemented by outside actors like NGOs, false assumptions are frequently made about resource users, information, and relationships that exist (Blaikie, 2006; Leach, Mearns, & Scoones, 1999).

It is likely that understanding the reasons for specific management decisions and the relationships between actors will improve efforts to manage Mikania, as understanding these relationships is the first step towards strengthening them. Here I present three propositions for addressing common pool resource management, with particular relevance to invasive plant species that have proven difficult to remove, an increasingly relevant issue globally (Chornesky et al., 2005). The first two focus on the importance of access to information and how institutions impact this access, while the third focuses on connections to the natural resource of interest. These propositions are informed by my case studies, but I posit that they provide transferable insight (see Lincoln & Guba, 1985) to research with other communities facing related social-ecological challenges.

Propositions: managing invasive plants in the context of common pool resource.

1. Communities that have more trust-based interaction with non-government organizations and local government actors will have increased access to resource management information, which is likely to increase management success.

This study found that communities that interacted more frequently with non-government organizations and government actors reported greater access to information on a variety of topics, including farming, construction, and education opportunities. In particular, communities with ties to NGO B had increased access to information about best practices for Mikania management and the management activities in which other communities had engaged. Communities that did not interact with these external organizations, either because they were too far away from them or they did not trust them (figure 2.6), lacked this information. In essence, these differences in relationships between community forest members and non-governmental organizations produce information asymmetries related to Mikania management and often leave community forest members isolated, with fewer management options and frustrating, unsuccessful removal attempts.

Connections to non-governmental organizations and other actors are often considered part of social capital (McCarthy, 2014); these networks provide improved access to information (Matsaganis & Wilkin, 2015). Thus, strengthening the networks of relationships between non-governmental organizations and communities managing an invasive plant is likely to provide information benefits. While increased knowledge does not always lead to increased efforts to implement this knowledge (Finger, 1994), communities with knowledge about best practices for invasive plant removal and information regarding others' efforts begin with an advantage over communities missing this information. Further, in communities that are already actively attempting to manage an invasive plant, new information may be implemented sooner. For instance, community

forest members noted they welcomed and needed new Mikania removal information because their current efforts often resulted in the plant growing back.

Due to Nepal's political conditions (currently a very new democracy) and limited resources in mid-level government agencies, it is unlikely that all of the management-relevant relationships absent in the de facto situation could be quickly built or repaired. Thus, to manage Mikania, community forest members need to bolster bottom up collective action. While current district and national level government actors lack resources to significantly aid Mikania management, a combination of bottom up collective action and improved community relationships with actors such as the national park or district forest office could increase the success of bottom up management efforts. Improving the frequency and quality of relationships between community members, non-governmental organizations, and government actors is demanding in practice and these relationships depend on the historical and cultural context of the corresponding community (Bebbington, 2004). In the context of Chitwan, overcoming distrust could begin with an effort from the national park and the non-governmental organizations in the area to increase the accessibility of their information and services (Agrawal & Gupta, 2005).

2. If resource users are struggling to manage common pool resource threats (like invasive species), an absence of valuable management information due to lack of trust between resource users and actors at different scales is potentially a contributing factor and a useful diagnostic starting point.

When resource users are struggling to confront threats to their common pool resource, where can stakeholders begin to address the issue? First, stakeholders, including

the case study community forest governance committees, may confirm that the threat to the resource is an important issue to the local resource users. In this case, Mikania is perceived as increasing in all of the community forest groups (figure 2.5) and that it is viewed as a major problem in some cases (table 2.1).

The interviews indicated that the initiative to collectively manage Mikania was present, but that community members' current efforts had largely been frustrating and unsuccessful, as Mikania typically returned. Additionally, distrust inhibited access to relevant management information and resources (figure 2.6). This analysis highlighted the importance of understanding the on-the-ground situation, as opposed to exclusively studying the de jure situation, as many of the relationships present in the de jure situation were absent or weakened in part due to trust issues.

The idea that trust matters is intuitive in common pool resource management, but there is a dearth of empirical and systematic studies of trust in the common pool resource literature (Ostrom, 2010); this systematic analysis of interview data lends scientific support to the importance of unpacking trust in common pool resource management. Community forest members' lack of trust between the national park and/or their governance committees resulted in isolation, where members managed Mikania alone or opted out of management entirely. The precise definition of trust is contentious in literature from a variety of scholarly fields (Heemskerk, Duijves, & Pinas, 2015). Here, trust refers to whether a partner organization or individual can be depended upon, whether they respect the interests of others, and if they are competent in acting upon their agreements (Dirks, 1999; Heemskerk et al., 2015). It is difficult to quantify and when resource users and managers hold different levels of power, distrust among actors can

result when power is abused (Dhiaulhaq, De Bruyn, & Gritten, 2015). Trust has been found to be central in natural resource management contexts generally, but is not as frequently explored in the context of common pool resources. For example, along with boundary spanning leadership (leadership that connects actors at different levels and of different types), trust has been shown to be vital in successful water management (Edelenbos & van Meerkerk, 2015). There are numerous studies exploring techniques to build trust. Berkes (2009) discussed the importance of trust in implementing successful co-management of natural resources and elaborated the vital role that bridging organizations play in cultivating trust between stakeholders. It has also been found that strong leaders can be instrumental in building trust (Folke et al., 2005), social learning processes can build trust in the context of natural hazards planning (Henly-Shepard, Gray, & Cox, 2015), and the participation of stakeholders can improve public trust in natural resource management (Reed, 2008). In order to strengthen the fairness and effectiveness of natural resources management, it is important both for governments to reach out to local resource users to nurture trust and for local resource users to reciprocate efforts to become trustworthy (Heemskerk, Duijves, & Pinas, 2015).

There are fewer examples exploring what happens when trust is entirely lacking in governance relationships and how this influences the social-ecological system. One notable example is Heemskerk et al. (2015), who found that distrust among actors was detrimental in the management of mineral resources in Suriname, where distrust actively impacted natural resource policies and outcomes. Distrust is not only important in shaping policy perceptions but also prohibits communication and information flow

among resource users, inhibiting effective natural resource management (Bodin, Crona, & Ernstson, 2006).

Trust is important in shaping institutions on-the-ground, including how institutions are upheld and interpreted. An essential finding is that trust is sometimes deficient between community forest members and their own governance committees (figure 2.6). This is important because these committees are not typically viewed as "outsiders," imposing rules and practices that are viewed as insensitive towards the community they are intended to serve. Instead these management committees have in the past been viewed as working for households and integral to sustainable resource governance. This distrust could in part be a reflection of the lack of ethnic diversity in management committees (committee members primarily belong to the higher socio-economic status Brahmin/Chhetri ethnicity, whereas communities are more diverse). This study cannot discern the precise factors promoting distrust between members and governance committees, but it is an important area for future research. Davenport et al. (2006) studied natural resource management and trust in communities located near the Midewin Tallgrass National Prairie in Illinois, United States and detailed the critical importance of trust between the local community and the Forest Service (responsible for the prairie's administration) in effective management. Although the local communities were not utilizing the prairie for resource extraction, but recreation, the study underscores the importance of identifying and encouraging trust between resource users and local resource managers for sustainable management.

In Chitwan, where distrust is present, information availability was impacted (figure 2.4). When trust was lacking between the community forest members and either

their governance committee or the national park, the relationship between the community forest members and other actors suffered. Members reported less communication with participants they did not trust, which impacted Mikania management information. Well defined institutions in the forms of norms and cognitive structures can strengthen and engender interpersonal trust, as well as trust among different actors and organizations (Fuglsang & Jagd, 2015).

Importantly, both propositions 1 and 2 argue that institutional norms and relationships are influencing information, and that information matters for successful common pool resource management. By articulating differences in governance relationships and management norms, the reasons for differences in information access become clearer and can be addressed to improve management efforts.

3. Specific to community forests: Community forests that provide more resources to members will exhibit greater potential to collectively manage invasive plants and resources due to greater buy-in/reliance on forest resources

The relationship between governance capacity and collective action is not entirely clear from the literature. Collective action has played a vital role common pool resource management in numerous global contexts (Agrawal, 2001; Agrawal, 2003; Ostrom, 2005, p.200) and this research supports that people are more likely to engage in collective action for Mikania management when they are more reliant on the community forest resources. Monetary and social resources have a positive relationship with governance capacity, and as this capacity increases, people may have greater access to a collectively managed resource and incentive to organize to manage it (Coaffee & Healey, 2003).

Governance capacity and collective action for Mikania management were closely linked in Tamur and Koshi, moderately linked in Ghaghara and Trishuli, and not closely linked in Gandaki (table 2.3). Supporting this proposition, in Koshi, the condition of the forest is very poor, the community forest governance committee has little resources, and the members are forced to rely less on these resources. In turn, members reported being less invested in maintaining the forest and organizing collective action for Mikania management. In Tamur, the condition of the forest is much better, the community forest governance committee has more income, and the members have greater access to fodder collection and timber resources. These members reported annual instances of collective action to both clean the community forest of trash and manage Mikania. Gandaki, the urban community in this study, represents a caveat to part of the proposition. This community forest has a high governance capacity, but a very low level of collective action for Mikania management. This deviation is likely due in part to Gandaki's urban location; it has very close proximity to a city and a highway. Thus, despite the community forest governance committee's capacity to maintain the community forest and provide members with access to these resources, the members are less dependent on forest resources as they have a variety of livelihood opportunities available in the nearby city.

The perception that Mikania is increasing in all cases (figure 2.5), combined with identification of Mikania as a major problem in two cases (table 2.1), is an indication that people are frustrated by its impact on their forest resources. Women in particular identified having their daily time budgets altered, amplified vulnerability to wildlife attacks, and worrying about resource availability due to increasing Mikania. External

factors related to the differential income potential available to each community forest governance committee influence a committee's ability to enhance governance capacity, including reducing potential social programs. Committees with fewer monetary resources could begin to enhance the quality of the resource, and the value members receive from membership, by seeking and sharing information on Mikania management best practices. Members that are more reliant on the resources and best able to utilize them are the most likely to participate in collective action to maintain them (Lise, 2000). Thus, this may increase collective action potential, reduce Mikania, and simultaneously have benefits for women.

Through elucidation of the de facto institutions involved in collective efforts to manage Mikania, these propositions are a useful starting point for understanding how institutions mediate collective action problems involving social-ecological challenges such as invasive species. Understanding institutions is vital to successful common pool resource management (Becker & Ostrom, 1995; Ostrom et al., 1994; Tang, 1991) and can potentially aid community members and other stakeholders in designing systems to address issues that prohibit successful management such as lack of trust and information barriers.

Conclusion

While institutional research has stressed that there are no one-size-fits-all solutions (Ostrom, 2007), the approach presented here can be employed to understand de facto governance relationships in any region to inform resource management plans that address the idiosyncrasies of a given situation, such as varying levels of trust and the community of interest's goals. The propositions presented in this chapter provide

stakeholders a generalizable starting point for addressing institutions and relationships that impact invasive plant management and common pool resource management generally.

This study contributes knowledge relevant to the Chitwan case study participants, as well contributing more broadly to an understanding of the complexities involved in managing invasive plants and other disruptive events that threaten social-ecological systems, an increasingly important issue globally (Chornesky et al., 2005). It is my hope that in the context of Chitwan, this detailed understanding of governance relationships and norms related to management as they actually exist on-the-ground will support successful efforts to manage Mikania and other invasive plants. The key recommendations from this study related to institutional design are to foster norms of trust between actors and to implement well-defined management rules. The former has the potential to improve the flow of information pertinent to management decisions (Levin & Cross, 2004), while the latter has been shown to improve resource management in many cases (Anderies, Janssen, & Ostrom, 2004). One potential way to advance trust and strengthen relationships between resource users and other actors in this case study and beyond is for government actors to address problems viewed as critical by resource users (e.g. in Chitwan, wildlife attacks and flooding). Addressing issues that immediately threaten resource users' daily experiences may augment community trust in government actors and bolster community efforts to manage invasive species, through freed time and expanded information access, improving the quality of their lives in multiple ways.

CHAPTER 3

MOVING TOWARD SUSTAINABILITY: INTEGRATING INTER- AND INTRA-GENERATIONAL EQUITY INTO INSTITUTIONAL ANALYSIS

Chapter Overview

Sustainability is often conceptualized as including equity in addition to environment and economy. However, this chapter argues that despite the institutional literature's numerous contributions to sustainability research, institutional literature has typically failed to consider equity. A statistical model integrating equity in terms of income, wealth, and ethnic and caste access to natural resources is presented. The model is operationalized using a case study of community forestry in Chitwan, Nepal focusing on household access to forest resources through membership in a community forest user group. A first step in understanding equity for sustainable resource management is an assessment of who has rights to access. Although an important first step, often in community forestry work there is a presumption of membership for a local population without empirical examination of who is excluded. Membership in Chitwan is influenced by the degree of reliance on the forest resources, income, and ethnicity. These findings are explored in the context of livelihood transitions and the historic role of ethnicity in Nepal and the rationale for integrating equity into institutional studies more frequently is addressed.

Introduction

Over the past four decades, scholars of the Ostrom Workshop in Political Theory and Policy Analysis developed and utilized the institutional analysis and development (IAD) framework (Ostrom et al., 1994) to understand governance of the world around us,

but the IAD framework has not been operationalized to fully capture the breadth of sustainability (Cole et al., 2014). Sustainability has been defined in myriad ways, but often has been conceptualized with the "triple bottom line diagram," where the intersection of environment, economy, and equity is characterized as achieving sustainability (Hansmann et al., 2012). Although the institutional literature has made significant contributions to scientific understanding of the environment and economy, scholars frequently fail to incorporate or consider the third component of sustainability, equity (Barnaud & Van Paassen, 2013). In this chapter, the attributes of the community are unpacked to explore equity in community forestry membership within a case study of 21 forests in Chitwan, Nepal. Then, a richer conceptualization and integration of equity within the IAD framework is presented.

Community forestry is a type of locally governed, decentralized forest governance. There can be numerous social benefits to community forest membership (Adhikari et al., 2007), but the primary benefit is arguably increased access to natural resources, including non-timber forest products and, to a lesser extent, timber. The relationship between household wealth or income and natural resource use is diverse; even within small, rural communities there may be differences in resource use among households within the same income level, and poorer households do not always extract the most natural resources (Cavendish, 2000). However, often as household wealth and income increase, reliance on and benefit from natural resources decreases relative to lower income households (Turner et al., 2007). The relationship between household socioeconomic status and environmental degradation is complex and in some cases reinvestment and intensification of agriculture by higher income households may lead to

increased resource extraction (Scherr, 2000). Both in urbanizing regions (such as parts of Chitwan) and more isolated rural communities, markets for products and labor are critical to understanding natural resource governance; yet global labor markets and flows of remittances are often overlooked. This research explicitly explores the impact of globalization through labor markets that allow Chitwan residents to work abroad and send remittances, changing household structures, livelihood strategies, and natural resource use. This critical teleconnection affects and connects the developing world to wider economic and employment opportunities, and in turn influences the ability of communities to sustainably manage natural resources for future generations.

In Nepal, the 1993 Community Forestry Act granted communities use and management rights of forests, while the national government retained official ownership of the land. The government designated areas with land available for community management, such as those adjacent to Chitwan National Park, known as the buffer zone, and communities organized and registered with the government prior to gaining official recognition and access to the land and forestry resources. All of the case study forests presented here fall within or very near the buffer zone of Chitwan National Park; the national park oversees management plans, fiscal accounts, and forestry conditions. The community forests in the study were officially recognized by the national government five years ago, on average, but there is variability and some of the forests were established in the mid-1990s. Households do not live within the community forests, but rather live nearby; eligible member households live within a catchment area, designated by the local level of government, called the village development committee. These catchment area boundaries were established by the (primarily district level) government

in order to limit harvesting pressure on any particular forest, fitting one of Ostrom's (2005) Design Principles establishing clear boundaries for user groups. Each community forest in Chitwan is governed by a community forest governance committee, elected by its members who establish management plans. Governance committees enforce the management plans including rules regarding resource collection and use and they collect any fees or fines. They additionally provide some welfare programs such as extra fuelwood and other resources for impoverished households, and provide various economic development, educational, and environmental programs for the benefit of the community and forest. To become a member of a community forest, households pay a membership fee (typically a one-time fee); some community forests also require other fees, or purchase of tickets, for collection of resources like grasses, thatch, and firewood. A few of the community forests offer timber sales to member households, but these sales are typically irregular for most Chitwan community forests due to the ecological conditions (i.e. there are not many mature, harvest-ready trees). Community forestry in Nepal has been widely hailed as a global model because of the locally created management plans, with their associated rules and boundaries, graduated sanctions, and nested governance structure which has reduced forest degradation while promoting development within the community (see Gilmour (2003) for an overview of community forestry in Nepal more generally). This success mirrors many of the design principles for successful common pool resource management (Ostrom, 2005), but less attention has been paid to issues associated with intra- and inter-generational equity.

When intra-generational equity, or equity within a single generation, is examined as an important issue, there are sometimes cases where tension exists in management of

resources for biodiversity or economic development. In some cases, there has been evidence that better management of natural resources increases the ability of elites to capture rents, which may enhance the economy in the aggregate and the resource base, but increases inequity (Persha & Andersson, 2014). Studies of intra-generational equity within community forestry largely focus on community members, but here equity is examined starting with a more fundamental question: who has access to community forest resources in Chitwan via household membership?

This work builds upon the extensive literature of new institutional scholarship examining community forestry governance and common pool resource management (see Ostrom, 2005). Within this literature, there is a recognition that the first step in understanding equity for sustainable resource management is an assessment of who has rights to access (Ostrom, 2005), yet there is a dearth of literature that actually examines this question empirically. In this chapter, a multi-level model is developed to explore who has access to natural resources by unpacking the factors that influence community forest membership in Chitwan.

The Action Arena, the gray area in figure 3.1, of the IAD framework is relatively well studied and understood (Ostrom, 2005), but there is a need to better understand how community attributes (such as sociodemographics and livelihoods) affect membership and heterogeneity among resource users (Varughese & Ostrom, 2001). This concern is extended to examine how heterogeneity of members may be related to inequity and intra-generational sustainability; intra-generational sustainability is a first step towards ensuring there are resources available to future generations (inter-generational sustainability). The model presented in this chapter is a contribution towards this goal.

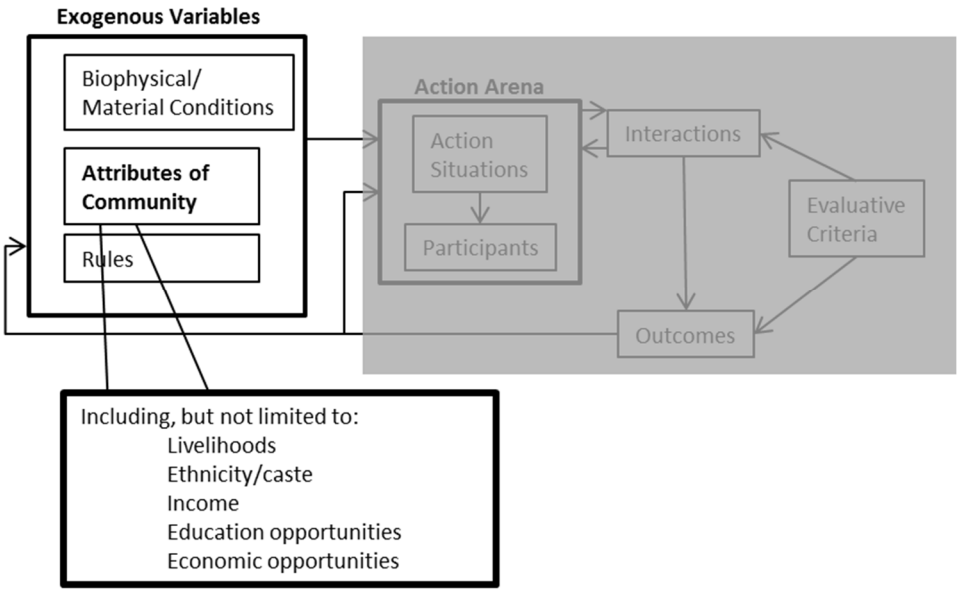


Figure 3.1. Unpacking Attributes of Community in the IAD framework

Sustainability, community forestry, and equity.

Community forestry research has examined sustainable common pool resource management (Charnley & Poe, 2007); this work reinforces the Design Principles that Elinor Ostrom (2005; 1990) developed. Community forestry includes diverse programs that incorporate local governance and management of forest resources. The Nepalese community forestry program has been hailed as one of the world's most successful (Acharya, 2002) and by many measures has achieved its initial goals of providing community access to resources while simultaneously reducing forest degradation through overharvesting (Bhattarai & Ojha, 2001). The community forestry program in Nepal has provided natural resources that are indispensable to a predominantly agricultural workforce (Baral & Subedi, 2000; Rai & Scarborough, 2014). In this sense, the economic and ecological aspects of community forestry, two elements of sustainability, have been widely considered. However, it is not clear whether the third aspect of sustainability, equity, has been achieved; partially this is due to more limited scholarly activity

(Agarwal, 2013). Thus to achieve sustainability, researchers and practitioners need to understand how community forestry has impacted not only rural development and forest conditions, but also equitability of resource distribution and access.

Understanding who has access to natural resources is an important issue globally, but it is particularly vital in the context of developing countries. Historical and social processes have ensured that specific ethnic groups in developing countries are disproportionately disadvantaged in educational and economic opportunities. In Nepal, historical displacement of indigenous groups and a caste system shaped the social structure and unequal relationships between ethnic groups that persist in many present situations (Jha, 2014).

Income inequality is another important indicator of inequality, which is frequently measured with the Gini coefficient, a measure of statistical dispersion producing a ratio that was developed to assess national income inequality (Deininger & Squire, 1996). The ratio ranges from 0 to 1, with 1 representing complete inequality (for example, all income is controlled by one person) and 0 representing a completely equal distribution of income (Kennedy et al., 1996). One critique of the Gini coefficient is that it is an oversimplified and relative measure, which is often incorrectly used and misinterpreted (Cobham & Sumner, 2013). Thus, it is important to keep in mind that the Gini coefficient does not provide information on absolute changes in income, as may be of interest for economic development, so it should be used in tandem with other measures, including qualitative context. Within Nepal, it has been used to assess income inequality between community forest member households in Nepal (Sharma, 2009).

Community forest membership is often an important indicator of the resources eligible households have access to, yet few previous studies have explicitly considered how community forest membership mediates access to natural resources important to agricultural households. Coulibaly-Lingani et al. (2011) explored factors that influenced established community forest members' access to forest products in Burkina Faso and Maskey et al. (2006) examined aspects that motivated the level of participation in community forest management decisions. Because much of the research on community forestry bounds the study with members, it is unclear what factors influence the decision to become a member in contexts where households must register and pay a fee to join. How access to common pool resources is determined represents both a key to sustainably managing the resource, and to preventing over-harvesting (Ostrom, 1990), but also an important determination of sustainability writ large if exclusion is exacerbating inequity within the community. Thus, this study presents an opportunity to begin with a fundamental examination of who joins and who is excluded from a community-managed common-pool resource critical to livelihoods within a developing country context.

Case study.

In the western Chitwan case study, 34 percent of the survey sample consisted of nonmember households. The survey sample is described in detail in the methods section. A household may be a nonmember by purposeful choice, or through a barrier it cannot overcome. In Chitwan, all of the community forests have some sort of barrier to entry; these are rules regarding where a household is located, as well as fees. The fees vary across the forest, although very few nonmembers (three percent) cited fees as being problematic. Rather the most common reasons nonmember households cited for not

joining include distance to the forest (i.e. a household is too far away from the resource for it to be practical, which is by far the most common reason for nonmembership) and disagreement with a community forest governance committee's policies. The goal is to better understand additional household attributes that may drive the decision to join a community forest or not.

Model Development

Household level.

Technology: ownership of dairy animals and use of firewood.

It is likely that a household's reliance on natural resources, which they expect will be available via obtaining community forest membership, will increase the likelihood of becoming a community forest member. Agricultural households are more likely to need access to forest resources than non-agricultural households (Adhikari et al., 2004). Specifically, households that own dairy animals (such as buffalo, cows, sheep, and goats) need access to grasses and fodder to care for these animals. Without membership, agricultural households have limited legal access to forest resources such as grasses and fodder; the only remaining access to these products is to purchase on the market, gather along the roads or small public areas such as schoolyards, or own extensive lands to provide fodder (which is very uncommon). While agricultural households without farmland rely on access to forest grasses and fodder, they do not rely on these forests to the same extent for fuel wood and timber resources. Many of the Chitwan buffer zone community forests provide limited timber resources to members, often due to lack of timber ready for harvest. Buffer zone households have other ways of accessing and collecting fuel wood for cooking and heating. Thus, while this resource is important to

consider and could be a significant influence on membership in other regions, this research does hypothesize that a household's use of fuel wood will be an important indicator of community forestry membership in Chitwan because most community forests limit access to fuelwood for members due to dearth of supply.

Dairy animals are coded as a continuous variable representing the number of dairy animals the household owns. Firewood usage is a binary variable that is coded 1 if the household uses firewood for cooking, and 0 otherwise.

Income.

The literature contains mixed evidence regarding the influence of household income on use of community forest resources. For instance, lower income households might be less able to join a community forest if the fees are too high and lower income groups have been found to receive fewer benefits from community forestry in many instances (Adhikari, 2005). Higher income households are often better positioned to take advantage of intermediate forest resources (Acharya, 2005) while very high-income households may not need forest products and may opt not to become members.

Income was measured as total household income from all sources in the past year, including wages, salaries, pensions, income from selling crops, animals, or goods, income from renting houses, land or equipment, business income, or income from gifts or other payments. This was coded as an ordinal variable representing seven income categories.

Ethnicity/caste.

Nepal has a complex social structure with castes and ethnicity historically playing a role in access to resources and livelihood strategies (Pokharel, 2011). Since the mid-20th

century, Chitwan has been the site of extensive internal migration within Nepal; minority households from the Hills have moved to access land and economic opportunities (Shrestha, 1989). In Nepal, the Brahmin and Chhetri are religious castes of higher status, the Newar is a middle caste associated with trade and shop-keeping, the Hill Janajati and Terai Janajati are indigenous groups with a historically lower socioeconomic status, and Dalit are a religious caste with historically lower socioeconomic status (Stash & Hannum, 2001). Minority households are classified into four dummy variables, with the non-minority ethnicity (Brahmin/Chhetri) serving as the reference case. The variables represent the Hill Janajati (indigenous ethnicity historically from the mountains and hills in Nepal), Dalit, Newar, and Terai Janajati (indigenous ethnicity from the Terai, which includes Chitwan). In many cases, minority access to locally governed natural resources is underrepresented (Gilmour et al., 2004). I anticipate that minority households may be underrepresented in community forest memberships.

Receipt of remittances from household members abroad.

Both migration into the region and the temporary absence of individuals working abroad are very common in Chitwan (Bohra & Massey, 2009). Households that are receiving remittances from family members abroad tend to have higher incomes than strictly agricultural households. Increased income combined with increasing market access in Chitwan provides some households the opportunity to begin to shift their dependence on agriculture and the need to harvest their own natural resources (Acharya, 2011). Thus, remittances may reduce the need to access natural resources and decrease the likelihood of joining a community forest. Household remittances were coded as the number of household members currently away who sent remittances in the past year

(information regarding the total amount of income received exclusively from remittances was unavailable; future work will seek to assess the impact of remittances in distinct ways, including collecting the total monetary value of remittances received).

Household size.

Most of the households in Chitwan are agricultural (over 80 percent). It follows that households with more individuals require increased natural resources to support their lifestyle. It is anticipated that larger households will have a higher rate of community forest membership in an effort to access these resources. Household size is coded as the number of household members.

Household distance from community forest center.

In the Chitwan household survey, 179 nonmember households (51 percent) identified distance to the forest as a barrier to membership. Previous studies have found that distance to other natural resources influences access and usage, especially when human-wildlife or armed conflicts are present (Stites et al., 2010). Here, it is proposed that distance to the community forest will influence a household's ability to regularly access the forest resources, and thus the likelihood they will join. Distance was calculated as the kilometers between the interviewed household and the center of the nearest community forest.

Community level.

Gini coefficient.

At the community forest level, community forests with higher levels of income inequality may have lower membership rates. The Gini coefficient is employed to assess the level of income inequality within 21 community forests in Chitwan and explore

whether potential income heterogeneity between the community forests impacts membership decisions.

Methods

The analysis utilizes a sub-set of a 2014 survey consisting of 1041 households in the catchment area of 21 community forests located in the buffer zone in Chitwan (194 households surveyed outside the community forest catchment area were excluded, because these households were ineligible for community forest membership based on their location). The survey was implemented in 2014 with a response rate of 98.6 percent. Using this robust dataset, a multilevel model is developed to explore the factors influencing community forest membership, as a lens to examine equity in access to forest resources. Multilevel models are useful for accounting for group effects in a dataset (Steele 2008). Not accounting for group effects in grouped data will likely violate the assumption of independence in an ordinary least squares (OLS) regression. While there are ways of accounting for group effects in OLS regression, such as using dummy variables to represent groups, such approaches risk over fitting the model when there are a large number of groups (Steele, 2008). Here, the data are structured in terms of households (level 1) within community forest catchment areas (level 2).

As the dependent variable (membership) is binary, a binary logistic model is fitted. Member and nonmember households are present across the 21 community forest catchment areas. Table 3.1 presents this breakdown in detail. Overall, about two-thirds (690/1041) of eligible households have joined a community forest, but this varies from a low of 38 percent to a high of 93 percent.

Table 3.1. Membership dependent variable categories by community forest

Community forest	Non-member HHs	Member HHs	Total
1	18	33	51
2	5	39	44
3	11	35	46
4	27	34	61
5	15	34	49
6	14	34	48
7	16	33	49
8	22	28	50
9	10	39	49
10	15	35	50
11	33	31	64
12	20	32	52
13	3	38	41
14	36	22	58
15	13	34	47
16	12	27	39
17	12	33	45
18	14	33	47
19	10	33	43
20	36	28	64
21	9	35	44
Total	**351**	**690**	**1041**

The independent variables included in the specification are presented in table 3.2, with descriptive statistics following in table 3.3. The model was implemented in R (version 3.1.2) using the lme4 package (version 1.1-9).

Table 3.2. Multilevel membership model variables

Variable	Type	Description
Dairy_animals	Continuous	Number of dairy animals owned by a household
Ethnicity_2	Binary	Ethnicity of the head of household; coded 1 if Hill Janajati
Ethnicity_3	Binary	Ethnicity of the head of household; coded 1 if Dalit
Ethnicity_4	Binary	Ethnicity of the head of household; coded 1 if Newar
Ethnicity_5	Binary	Ethnicity of the head of household; coded 1 if Terai Janajati
Use_firewood	Binary	Household use of firewood; coded 1 if the household uses firewood
HH_size	Continuous	Number of individuals in a household
HH_remittances	Continuous	Number of individuals abroad sending remittances to a household
Income	Categorical	Household income, categorized into seven ascending categories based on survey
HH_dist_CF	Continuous	The distance (in kilometers) of a household from the center of the closest community forest
CF_gini	Continuous	The Gini index of a community forest, based on household income

Table 3.3. Descriptive statistics of multilevel membership model variables

	CF_mem	Dairy_ani	E_2	E_3	E_4	E_5	firewd	HH_size	remit	income	CF_gini
Mean	0.663	3.072	0.159	0.127	0.037	0.170	0.740	5.281	0.586	3.384	0.469
Standard error	0.015	0.098	0.011	0.010	0.006	0.012	0.014	0.069	0.024	0.079	0.001
Median	1	2	0	0	0	0	1	5	0	2	0.476
Mode	1	0	0	0	0	0	1	4	0	1	0.425
Standard deviation	0.473	3.155	0.366	0.333	0.188	0.376	0.439	2.240	0.766	2.541	0.036
Sample variance	0.224	9.954	0.134	0.111	0.035	0.141	0.193	5.019	0.587	6.458	0.001
Kurtosis	-1.53	5.516	1.474	3.052	22.55	1.098	-0.81	2.561	2.660	-1.54	-1.06
Skewness	-0.69	1.599	1.863	2.246	4.950	1.759	-1.09	1.281	1.450	0.440	0.345
Range	1	29	1	1	1	1	1	15	5	6	0.108
Minimum	0	0	0	0	0	0	0	1	0	1	0.425
Maximum	1	29	1	1	1	1	1	16	5	7	0.533
Sum	690	3197	166	132	38	177	770	5497	610	3523	488.7
Count	1041	1041	1041	1041	1041	1041	1041	1041	1041	1041	1041

Results

The model revealed that ownership of dairy animals and household size are positively associated with being a community forest member and that belonging to the Hill Janajati or Dalit ethnicities, income, and a household's distance to the closest community forest are negatively associated with being a community forest member (table 3.4). These results are consistent with previous literature and the hypotheses discussed. Belonging to the Terai Janajati minority ethnicity, household use of firewood, a household's receipt of remittances from household members abroad, and a community forest-level measure of income inequality are not significantly correlated with community forest membership. Table 3.5 presents regression results for eight model specifications, each including one independent variable to assess its relationship with membership alone. Each of the variables alone has the same sign and significance as in the final model version with all variables included. This indicates there is not strong colinearity between the independent variables. Potential reasons for these findings are discussed next.

Table 3.4. Multilevel membership model regression results

Level 1 (HH)	Estimate	Standard error
Intercept	1.07566	2.09252
Dairy_animals	0.16319***	0.02898
Ethnicity_2 (Hill Janajati)	-1.04440***	0.23224
Ethnicity_3 (Dalit)	-0.71965***	0.25293
Ethnicity_4(Newar)	-0.15315	0.39821
Ethnicity_5 (Terai Janajati)	-0.38262	0.25627
Use_firewood	-0.05036	0.18111
HH_size	0.08630***	0.03735
HH_remittances	0.03512	0.10683
Income	-0.06680**	0.03179
HH_dist_CF	-0.51833***	0.13358
Level 2 (CF)		
CF_gini	0.48778	4.07159

$p < 0.001$ '***' $p < 0.01$ '**'; N = 1041 HH, 21 CFs

Table 3.5. Relationship of each independent variable with membership

Model		Estimate (Standard error)
Model 1 (dairy_animals)		0.18057***(0.02766)
Model 2 (ethnicity)	ethnicity_2	-0.8821*** (0.2022)
	ethnicity_3	-0.6733*** (0.2283)
	ethnicity_4	-0.2593 (0.3781)
	ethnicity_5	-0.2726 (0.2389)
Model 3 (use_firewood)		0.0062 (0.1657)
Model 4 (HH_size)		0.12309***(0.0329)
Model 5 (HH_remittances)		0.13980 (0.0916)
Model 6 (income)		-0.002151* (0.0271)
Model 7 (HH_dist_CF)		-0.4080*** (0.1123)
Model 8 (CF_gini)		3.766 (3.829)

$p < 0.001$ '***' $p < 0.01$ '**'; N = 1041 HH, 21 CFs

Discussion

The results highlight two important themes that influence access to natural resources: social structure and livelihood transitions. These concepts, the role of household distance from a community forest, and the potential role of community forest-level income inequality are unpacked in order to understand these indicators of access to resources and equity in locally governed common pool resource systems.

Social structure matters.

There is local debate regarding how caste and demographics affect community forest membership, which largely centers on whether lower castes, many of which are indigenous groups, were stripped of access via formalization of the community forests and creation of local user groups to manage these forests. The evidence is decidedly mixed depending on where the research is done and how the lower castes and socioeconomic classes are defined, yet it clearly remains a concern within the nation via policies that implement ethnicity quotas in community forest management.

In this case it does appear that Brahmin/Chhetri are more likely to be members of a community forest than Dalit; additionally, all of the community forest presidents are

also Brahmin/Chhetri, which echoes prior work such as Yadav et al. (2015). But the survey data demonstrate that the fees set in Chitwan forests are not cost prohibitive, with only three percent of nonmembers reporting that high fees were a reason for not joining, indicating that there are more complex reasons for these decisions. Thus, a significantly lower likelihood of membership among lower caste groups, like the Hill Janajati and Dalit in this analysis, may be more reflective of social differences as opposed to income. It is possible the relatively high number of non-members expressing concern about forest policies, which are largely written by higher caste Brahmin and Chhetri management committees, may indicate the tension between the ethnic and caste groups. Nepal has changed numerous institutions regarding castes (Lawoti, 2007), but these structures have evolved over centuries, so it may take time for differences in access to be understood and recognized, but more importantly for their influence on access and economic opportunity to decline.

Unpacking the influence of ethnicity in Chitwan.

The historic roots of the caste system and the migration of indigenous ethnicities continue to influence community forest membership today. Members of the Terai indigenous population, which is from Chitwan and nearby districts in southern Nepal, are just as likely to be a community forest member as a Brahmin/Chhetri individual. This is likely influenced by a unique feature of the Chitwan region; in comparison to the remainder of Nepal, there is substantially more government oversight of community forests due to their proximity to the jewel of Chitwan National Park. Government oversight in the Terai includes recent policy efforts to increase the participation of the indigenous Terai Janajati population in Chitwan community forests. Community forest

governance committees in the Terai region were encouraged to provide membership/fill quotas related to this indigenous group. In contrast, the indigenous population that emigrated to Chitwan from the hills, the Hill Janajati, is significantly less likely to be a member than the Brahmin/Chhetri and similar policy efforts do not exist in the Terai region for this indigenous group.

Livelihood transitions: the shift from agriculture.

The negative correlation of income with community forest membership indicates that the model may have captured some households shifting out of agriculture. Although households with higher income are often better positioned to take advantage of intermediate forest products, like fuel wood for stoves, provided by many community forests (Acharya, 2005), some higher income households in Chitwan are receiving income from non-agricultural sources and this correlation indicates that they may have become less dependent on forest resources. One of the most common sources of non-agricultural income in Chitwan is the receipt of remittances from family members working abroad. Although receipt of remittances is not significant in the model, this is an important area for future research and further ethnographic work may aid scientific understanding of the relationship between remittances, livelihoods, and community forestry. It appears that the more critical element in determining membership is overall income level, which is likely related to other sources of non-agricultural income. For instance, the increasing urbanization of the region has afforded some households opportunities to work in industries such as tourism and hospitality, facilitated by a household's proximity to the highway and the nearest city (Narayangarh). Future

modeling efforts will incorporate related variables to assess their possible influence and better understand the linkage between household income and community forestry.

The ownership of dairy animals is one of the most direct linkages between households and natural resource use, as they require grasses and fodder for feeding and bedding. These resources are sometimes obtained from an individual's farmland, but farmland is typically utilized for other crops for both subsistence and market. Households with dairy animals are reinforcing resource ties to the community forests, while some of those with alternative livelihood options appear to be transitioning away from agriculture.

Relatedly, this analysis found that the farther from the nearest community forest a household is located, the less likely they are to become a member. This could be an indicator that distance is a physical barrier to access to community forest membership, but typically in Chitwan households farther from the community forests are non-agricultural and dependent on some of the alternative income sources mentioned above, such as tourism, hospitality, or other market opportunities. It may be the case that distance to these opportunities for member households limits access to other resources and livelihood strategies, which is an important area for further study.

The potential importance of community forest-level income inequality.

Populations eligible for community forest membership with higher levels of income inequality are theoretically more likely to have lower membership rates (Adhikari, 2004; Bhattarai & Ojha, 2001), but in this case there are two factors that limit the effects of income inequality on membership. First, there is very little variation in the level of income inequality among the 21 community forests. Second, as noted earlier 97 percent of nonmember households indicated that fees were not an obstacle to

membership. Similar to the impact of household level income on membership, the fact that membership fees were not identified as an issue for low income households indicates that even with an increase in community forest-level income inequality, there may not be a significant difference in Chitwan community forest membership. Importantly, these relationships between income, income inequality, and membership may not hold if community forest membership fees are increased enough that they become burdensome to lower income households in the future. As the prior results regarding ethnicity make clear, it may be important for researchers to investigate how community-level ethnic heterogeneity affects membership. The results indicate that the relationships between sociodemographics and equity in terms of community forest access are complex.

Implications of incorporating equity in institutional analysis.

Incorporating equity and considerations of resource access within Ostrom's body of work in a more explicit manner extends the IAD framework in a manner, it appears, she would have strongly supported. Increasing equal access to resources strengthens natural resource management efforts (e.g. some development work notes that inequality in access to natural resources is a catalyst for violence and other issues (Jensen & Halle, 2013)). Including equity in institutional analysis will not necessarily alter the theoretical findings about common pool resource management, but rather it will allow researchers to address and unpack community attributes within the IAD framework, a social component of resource access that is important ethically and may strengthen efforts to sustainably manage natural resources.

Sustainable resource management can be achieved under circumstances of inequality (if sustainability is defined solely in economic and ecological terms) (Baland et

al., 2007), but equality in resource access is (beyond the ethical importance of ensuring people have equal access to resources) likely to strengthen successful resource management. This idea is supported in the Chitwan case through a study of the factors influencing collective action (see chapter 4). The collective action study finds that members with resource access are more likely to participate in managing and caring for the community forest resources. A small portion of institutional literature has considered equity (e.g. Clement, 2009), but incorporating equity, including discussions of how it is defined, is a gap the institutional literature can continue to address in future studies. It is possible that extending equity considerations of IAD research will facilitate sustainable management in all three aspects, economic, environmental, and equity. This usage of the IAD framework to explore equity has the potential to aid researchers in systematically understanding under what conditions equity contributes to sustainable resource management and the institutions that engender equity.

Conclusions

In this chapter, community forest membership was analyzed as a starting point for investigating natural resource access, with the recognition that this is but one aspect of access. Future research may examine elite capture, or the control of resources primarily by elite groups (Persha & Andersson, 2014), in more detail. In the case of Chitwan, this research supported that certain minority ethnic groups are as likely as elite groups to have access to community forest resources via membership. In Chitwan, it is known that most community forests are led by elites. Thus, while these results support equitable access for some indigenous groups, it is unclear how they translate to tangible resource collection or perhaps more importantly to forest policies that affect the overall economic development

trajectory of the community. While these findings are situated in Chitwan community forests in the Chitwan National Park buffer zone, they point towards the importance of studying and understanding membership decisions in natural resource user groups as a way to explore equality in access to natural resources throughout the world.

Studies informed by institutional perspectives and theory consistently consider economic and environmental components of natural resource governance, but institutional studies explicitly incorporating equity are infrequent. Examining the attributes of a community within the IAD framework will naturally aid in revealing characteristics where inequalities have manifested within a system (figure 3.1). Coupling a more detailed understanding of community attributes (and revealed inequalities) with an understanding of biophysical conditions and rules will position researchers to holistically understand the sustainability of a system, which is ultimately necessary to maintain and design sustainable social-ecological systems (Ostrom, 2009; Ostrom, 2007).

CHAPTER 4

HOW DOES PERCEPTION AT MULTIPLE LEVELS INFLUENCE COLLECTIVE ACTION IN THE COMMONS? THE CASE OF MIKANIA MICRANTHA IN CHITWAN, NEPAL

Chapter Overview

Collective action has played a vital role in managing common pool resources in numerous global contexts. This article explores the factors affecting collective action related to the removal of the mile-a-minute weed (*Mikania micrantha*), an invasive plant, in community forests in the buffer zone region around Chitwan National Park in Chitwan, Nepal. Few studies have combined larger sample size quantitative data with greater generalizability and nuanced, case study-based qualitative data to explore what factors influence collective action or focused on how perception of the issue at multiple levels affects outcomes. This research employs household and community forest management survey data from 21 community forests in and near the buffer zone of Chitwan National Park in Nepal in an econometric analysis, which aims to investigate what influences local people's participation in Mikania removal and contextualizes the findings with rich case-study interview data. The model finds that reliance on community forest resources and perception of the issue are influential factors in participation in Mikania removal efforts. The implications of these findings are discussed in the context of increasing the effectiveness of Mikania removal efforts and influencing collective action in relation to other global human-environment issues.

Introduction

In contrast to popular imagery of mountainous terrains, Nepal, at roughly the size of the U.S. state of West Virginia, is one of the most diverse countries (both geographically and culturally) in the world. Historically, Nepal has often been isolated from outside influence due to the surrounding terrain along borders shared by China and India and is one of very few nations in the region never colonized by the British Empire (Bohara et al., 2006). Geographically, the country consists of three distinct horizontally divided regions: the mountains in the north, the sub-tropical Terai in the south, and the mid-hills in between. The sundry rivers, mountains, forests, and other features made travelling between these regions prohibitively difficult in the past and often demanding in the present. As a result, the Nepali people have developed many different sub-cultures and ways to interact with the environment. The varied climates of each region shape this biodiverse nation and house numerous endangered plant and animal species (Nepal & Weber, 1993). For over two decades, community forestry has been an integral part of improving and maintaining the ecological conditions of the forests in the mid-hills and Terai that are home to many of these plants and animals (Acharya, 2002; Adhikari et al., 2007). Recently, community forest user groups in the Terai have confronted managing their forests located around the border of Chitwan National Park in the face of a rapidly spreading invasive plant species, known informally as the mile-a-minute weed and scientifically as *Mikania micrantha* (hereafter referred to as Mikania).

As a type of forest governance, community forestry attempts to decentralize forest resource management from national level government by transferring most use and management rights to local forest user groups (Barsimantov, 2010; Lama & Buchy,

2002). It has been argued that decentralizing resource management may lead to increased possibilities for collective action to manage resources more sustainably. In Nepal, community forestry appeared in 1978 when the national government issued the first set of regulations intended to legitimize this form of governance (The Panchayat Forest and Panchayat Protected Forest Rules and Regulations of 1978). With promulgation of the Forest Management Act (1993), management rights were formally transferred to local user groups. Although there have been setbacks (particularly during political turmoil in the early 2000's (see Gilmour, 2003)), the community forestry program in Nepal has been considered one of the most successful in the world, particularly in the middle hills region (Nagendra, 2002; Timsina, 2003). However, the success of community forestry in the southern Terai is more debatable. When community forestry was implemented in the Terai, some of the forests were retained by the national government to be protected as national forests. A portion of the remainder of the unprotected forests was given to local communities to manage. However, the condition of the forests transferred to community forest user groups to manage was significantly poorer than that of the forests that remained under national protection. Protected forest lands have been found to have a higher level of biodiversity and plant mass (Nagendra, 2002). Despite this difference in condition, the initial historic conditions of the forest given to local user groups must be taken into account when evaluating the success of community forestry in the Terai. Overall, the community forestry program can be considered successful in the Terai on the basis of forest health, as there is evidence that resource conditions have improved in many cases (Nagendra, 2002), but its outcomes related to equity and relinquishing of technocratic control by the national government are more debatable (Nightingale, 2005;

Ojha, 2006; Tinker, 1994). Given this tension in the literature, there is much room to contribute to understanding the outcomes of community forestry in the Terai and what influences those outcomes, especially in the context of recent attempts to manage Mikania to reduce its impact on forest resources.

The contribution in this analysis is to combine independent, representative data sources from community forest management committees and households living in the areas served by the community forests. The multilevel approach spans both community forest and household levels to examine how an ecological, and potentially economic, shock to this social-ecological system impacts multiple stakeholders and the potential for collective action to respond to this shock.

Mikania micrantha.

Mikania is a vine species that both grows and reproduces rapidly. Mikania is native to South America and is believed to have been intentionally transferred to India and the Pacific Islands around the 1940s for use as a cover crop for airfields (IUCN, 2005). It was additionally utilized by soldiers in India during World War II as a type of camouflage (IUCN, 2005) and has since spread to warm, humid places in Asia (including parts of China, India, and Nepal) and elsewhere globally. Yang et al. (2005) noted that Mikania is one of the top 100 invasive plant threats in the world. As it is a creeping vine, it climbs small trees and covers grasses, often depriving them of sunlight and smothering them to death (Siwakoti, 2008). Mikania primarily reproduces via seed dispersal, with one plant able to disperse up to 40,000 seeds per year, but also reproduces through vegetatively (Yang et al., 2005).

There are a variety of removal methods for Mikania including mechanical removal and pulling, uprooting, cutting, burning, chemical herbicides, and the use of a predatory rust fungi (Ellison et al., 2007). The success of these methods depends on both the biology of Mikania and the social context. For example, burning can further aid seed dispersal (Murphy et al., 2013) and the plant can reproduce vegetatively, an asexual process where the plant can reproduce when a stem is placed in moist soil. Regarding the social context, people's commitment to regular removal using known best practices impacts its spread.

In addition to the negative impact Mikania has had on Chitwan animals and plants (Ram, 2008), Mikania also appears to be an important social issue. In consideration of the impacts of Mikania on rural livelihoods in Chitwan, household surveys have provided evidence that Mikania disproportionately affects forest-dependent households (Rai & Rai, 2013). The longer it remains in the forest, the greater the perceived social impacts become and in absence of a plan to successfully remove it, households feel they have been forced to find uses for it (Rai & Rai, 2013), despite the fact that Mikania is not useful to most households (Rai & Scarborough, 2014). In the past five years there has been news coverage from high profile media on the Mikania issue, primarily focusing on its impact on the vulnerable (previously endangered) one horned rhinoceros' habitat. In 2010, the BBC published a short report containing excerpts of an interview with the then chief warden of Chitwan National Park, exploring the impact of Mikania on the park's ecosystems (Khadka, 2010); this included the fact that Mikania had spread to cover over 20 percent of the park. Mikania has become a relatively well known issue in the region

and successfully managing Mikania to reduce or remove its presence has the potential to improve conditions for both humans and the remainder of the environment.

Mikania as a collective action problem.

The case of Mikania removal presents a social dilemma, a situation where acting in the benefit of the group puts an individual at a disadvantage unless everyone acts in the interest of the group; i.e. an individual return is always greater than an individual's share of a group return. Such dilemmas present a collective action problem, where collective action could lead to the best outcome for the group, but not the best outcome for an individual (unless everyone chooses the action most individually advantageous, causing everyone involved to lose as the tragedy of the commons plays out) (Ostrom 2005, p. 37). A large and diverse body of literature explores the situations and reasons individuals choose to act in the interest of the group when a rational actor would act in their own self-interest (Vanni 2014). Removing Mikania takes an investment of time and physical and mental effort, whereas opting to ignore the plant's presence and collect resources not impacted by it (i.e., free riding off of someone else's efforts to manage it) reduces the personal costs involved with collecting forest resources.

The model presented in this article focuses on understanding what factors may impact local people's participation in collective action, and is informed by previous analyses but expands these with an additional focus on perception of the situation at multiple levels (household and community forest) and a comparative analysis exploring the influence of space via size-varying neighborhoods. This study assesses the following questions: What factors are affecting collective action regarding Mikania removal in Chitwan community forests? What role does perception of Mikania as a threat at both the

household and community forest governance levels play in the decision to participate in its removal?

What is collective action? Many definitions with common ground.

Collective action as a concept has been adopted by a wide variety of social science disciplines, ranging from psychology to political science, to research and explain actions taken by a group to achieve a specific outcome. As such, collective action as a whole has been defined and redefined numerous times, but Meinzen-Dick et al. (2004) find that common ground can be found among most definitions. Collective action at its core includes a group of people acting voluntarily in the name of a common purpose or shared interest to achieve a desired outcome. People do not always have to act simultaneously in a group to engage in collective action; sometimes a representative of a group may act on the group's behalf. Further, collective action can occur at multiple scales and include both top-down or bottom-up actions, with Davies et al. (2004) labeling the former "coordination" and the latter "cooperation." In the context of commons research, collective action has been found to be of vital importance in successful governance of common pool resource systems around the globe (Ostrom et al., 1994; Vanni, 2014).

What influences collective action?

A variety of factors have been found to influence collective action in common pool resource management situations, including governance structure, group size, distance from nearest market, resource scarcity, age, income, land holding, distance from the relevant resource, caste, gender, and education (Adhikari, 2005; Araral, 2009). Despite this work, the role that informal institutions (such as social norms) play in

community forestry outcomes remains poorly understood (Lachapelle et al., 2004) and the factors influencing collective action are incredibly complex, requiring further investigation (Araral, 2009).

The role of heterogeneity in collective action is not always clear or straightforward (Varughese & Ostrom, 2001). Heterogeneity in this context relates to variation that could influence a group's ability to achieve a commonly held goal. It is therefore possible that variation in formal and informal institutions could pose a challenge to successfully engaging group members in collective action to manage common pool resources (Kant, 2000; Ostrom, 2005). Variation in local institutions related to sociodemographics, like caste, ethnicity, race, or gender, influences community forestry operations including who benefits from or participates in collective resource management (Adhikari, 2005). Some scholars assert that sociodemographic heterogeneity undermines collective action, but there are few empirical studies that assess how variation affects the individual decision to collectively act (Ostrom 2005). This study posits that exploring this variation, shifting focus from the obstacles heterogeneity poses, can lead to important insights in what factors may influence collective action. The multilevel modeling approach presented here promotes exploration of heterogeneity in a variety of factors, including caste, household income, and perception of the issue, and provides an understanding of their significance in the Mikania collective action problem.

Previous econometric analyses have used collective action as a dependent variable, but usually as an assessment of free riding in a collective action problem rather than directly estimating household or individual participation in a specific collective action (outside of participation in small-scale resource management programs like

forestry or irrigation (e.g. Chun, 2014; Coulibaly-Lingani, 2011)). Araral (2009) used a binary variable to represent irrigation systems that were under government control or fully managed by local users, finding that collective action was impacted by governance structure, as well as resource scarcity, resource user group size, and farm size. There is a need for further research in this area to understand if similar factors influence collective action in other systems. Few empirical quantitative analyses of collective action have been conducted, partially due to lack of data, and interactions between group heterogeneity and size have been paid little attention in the past (Poteete & Ostrom, 2004). The majority of commons research has been qualitative work, but there are calls to conduct more systematic, comparative, and quantitative research (Agrawal & Chhatre, 2006). Such studies would complement existing qualitative studies, provide a different prospective, and increase the replicability of research.

Space and collective action: The role of neighborhoods.

Previous work exploring space has most often conceptualized space in terms of place, region, or networks (e.g. Bosco, 2001; Hedström, 1994; Miller, 1992; Murdoch & Marsden, 1995; Paasi, 2002); such work has largely concluded that space seems to play an important role in the formation of collective action for political and other purposes and that the role of space in collective action requires further investigation (Newman, 2008). Within the realm of space, neighborhoods are highly influential on many different social dynamics (Leventhal & Brooks-Gunn, 2000; Lochner et al., 2003; Sampson et al., 2002). The term "neighborhood" has been defined and redefined many times, but a key component of most definitions is that neighborhoods are nested units within larger communities; the way these units are defined varies from administrative boundaries (such

as census blocks in the U.S. census) to local networks (Sampson et al., 2002). Despite the potential importance of the role of neighborhoods in influencing participation in collective action and the particular significance of neighborhood social groups in Nepal, to my knowledge such research linking collective action and neighborhoods has seldom been conducted.

Combining qualitative and quantitative data.

It has been argued that research related to collective action must move towards a diagnostic approach where local context is taken into account in exploring institutional and governance arrangements in social-ecological systems and acknowledge that there is decisively not a single, optimal set of rules and norms (Araral, 2009; Ostrom, 2007). To accomplish this, research is needed that carefully combines in-depth qualitative, contextual knowledge to inform and aid in interpretation of quantitative (e.g., statistical) analyses (Agrawal & Chhatre, 2006).

Collective action has been assessed at the association/resource group level by multiple studies, but multilevel models of collective action incorporating household data are less common (Tesfaye et al., 2012), and even lesser are models considering the influences of various visible or invisible neighborhoods. By using both household and community forest level data (see methods section), this study provides a more nuanced picture of factors influencing collective action. This study builds on previous analyses about the factors influencing collective action and explores additional factors related to perception of the situation, in this case whether Mikania is viewed as harmful. It is important to understand the factors that impact collective action in a variety of contexts to

discern patterns as many pressing global environmental problems are also collective action problems (Esty & Moffa, 2012; Ostrom, 2010).

Model Development: Variables that may Influence Participation in Mikania Removal

Household level variables.

Participation in collective removal of Mikania growing in or near a community forest.

The dependent variable in the model concerns whether a household participates in Mikania removal either with a group or both individually and with a group. In the study site, each community forest is governed by a locally elected governance committee. No organized effort to remove Mikania has been implemented by the community forest governance committees in this study; some committees have paid individuals or rarely have paid specific user groups within their community forest to remove Mikania. As such, almost all group removal efforts are coordinated by households (both community forest members and non-members) living in the area. In interviews with individuals from five case studies from 21 Chitwan community forests (case studies were selected to capture the range of resources available in each group, including monetary), it was found that household members participating in Mikania removal self-organized annual efforts with their neighbors. The survey question (see the methods for survey information) captured all such self-organized group removal efforts. A unique dependent variable conceptualization in an econometric model of collective action is presented here. Other such models have assessed free riding (monetary and labor) in collective resource

management (Araral, 2009; Ito, 2012) whereas this research explicitly models who is engaging in collective Mikania removal (i.e. who is not free riding).

Community forest membership.

Most households in the buffer zone region of Chitwan National Park using forest resources are members of an established community forest user group. However, there are households in the buffer zone that utilize forest resources yet are not community forest members; two-thirds of the survey sample (690/1041) are community forest members. There are several reasons households are not members, including (from most to least common): living too far from the forest, disagreement with management policies, ineligibility for membership (due to living outside the community forest ward, which is the administrative boundary containing all households eligible for membership), and fees being too high (fewer than three percent of respondents report that fees are a barrier to entry). The household survey dataset analyzed here includes both buffer zone community forest members and non-members, in an effort to accurately assess the factors influencing collective action among all the households in the region, whether they are community forest members or otherwise. Previous work has discovered that community forest members tend to be more reliant on forest resources than non-members (see chapter 3) and I hypothesize that households that are more reliant on natural resources from the forests are more likely to participate in collective action; thus, I anticipate that community forest membership will be an important predictor of participation in Mikania removal efforts. Other variables included represent different dimensions of reliance on forest resources.

Ethnicity/caste and income.

Caste plays a complex role in community forestry outcomes in Nepal. In general, several studies have found that traditionally disadvantaged indigenous ethnic groups in Nepal are less likely to receive benefits from community forestry operations (Adhikari et al., 2004; Gilmour et al., 2004). However, this relationship is not always straightforward, as there are policies regarding ethnicity and caste that influence regions in Nepal, benefiting certain groups (Nightingale, 2011). In the case of collective action problems, indigenous groups often lead and participate in efforts to collectively solve them, but may not receive the same benefits as other privileged groups (Graner, 1997). Given this uncertainty in the literature, caste is included to explore potential differences in caste composition among the 21 community forests to understand if they influence participation in Mikania removal efforts.

In many social science applications, the influence of income is well understood. However, there is no consensus on the impact of household income on reliance on natural resources. Some studies have found that households with lower levels of income are more dependent on natural resources and receive more absolute benefits from the resources (Shackleton & Shackleton, 2006; Turner et al., 2007). Others have discovered that higher income households are better positioned to take advantage of intermediate forest resources (Acharya, 2005).

Household size.

A larger household size could either be prohibitive in deciding to remove Mikania, due to the effort required to shift time away from other important household activities, or helpful in that more household members are available to distribute the labor

involved in Mikania removal. It is logical that as household size increases, people already reliant on natural resources would tend to maintain or increase their resource use (Adhikari, Di Falco, & Lovett, 2004). However, household size may also be irrelevant as small households dependent on natural resources may be just as likely to engage in resource management and Mikania removal as large households using forest resources.

Farming activity.

This variable is coded one if a household farms any amount of land, and zero otherwise. Over 80 percent of households in Chitwan farm in some capacity. Farming households in general are especially reliant on natural resources from community forests to maintain farm animals and crops. Over 80 percent of Chitwan households rely on farming for a portion of their food and income, so although this is an indicator of reliance on forest resources, it is possible there may not be enough variation in the case study to accurately discern its impact.

Household distance to community forest.

A household's distance to the nearest community forest was the most frequently cited barrier to entry by survey respondents. Households that are farther from community forests are less able to access the resources they may need. As distance from the resource influences access to the resources (chapter 3), and a household's ability to utilize them, it is likely households that are farther from the resource will be less able to participate in Mikania removal.

Household perception of Mikania as harmful to households and forests.

Individual level perception of collective action problems can alter whether an individual is interested in participating in collective action to solve an issue. In a study of

participatory forest management in Ethiopia, perception of planting success rates (seedling survival) was found to strongly influence intentions and attitudes towards participating in collective tree planting efforts (Tesfaye et al., 2012). Similarly, individual perception of risk has been found to influence willingness to engage in collective action to solve climate change and other environmental problems in other case studies (Lubell, 2002; Lubell et al., 2007; Stoutenborough et al., 2015), with higher perceived individual risk correlated with a greater potential of participating in collective action.

Community forest level variables.

Community forest age and income.

This model explores the influence of a variable of the total income per capita of each community forest governance committee (CF_income in table 4.1). This information is recorded in Nepal rupees from community forest management survey responses and then divided by 1,000,000 to ensure the variable is on a similar scale compared to the other variable ranges (the exchange rate of rupees to dollars is small: 1,000,000 rupees is approximately 15,000 USD as of this writing). Like household income, the impact of community forest management-level income is unclear. Increased income should allow for community forest governance committees to provide their members with more resources and attract members (Graner, 1997), but how such income is invested is not always clear to members. A second variable measuring the number of years since a community forest was established is included to detect the impact of the maturity of the community forest governance on collective action. Earlier founded community forests are likely to possess increased social capital including monetary resources and connections with non-government organizations and other community

forest governance committees. The resources available to members can influence their investment in the resource and age influences governance structure (Araral 2009).

Community forest governance committee perception of Mikania as harmful.

Qualitative findings support that perception of issues by different actors within polycentric governance systems can influence actions among other actors (Ostrom, 2010). In this case, I believe the perception of Mikania as harmful to local households by members of community forest management will impact the household decision to remove Mikania.

Space conceptualized via neighborhood size.

Space often plays a key role in social-ecological outcomes (Alessa et al., 2008; Walker et al., 2004). As few previous studies have explored the potential impact of neighborhoods on collective action, it is hypothesized here that incorporating space, via neighborhoods at various sizes, into this analysis may change the interpretation of the results and that varying neighborhood sizes may have different impacts on a household's participation in collective action (i.e. it is hypothesized that some relationships in the presented model may change as neighborhood size increases).

Methods

In order to assess the factors influencing collective action, a multilevel/hierarchical analysis of survey data is conducted and the results are interpreted in the context of rich, qualitative case study interview data. First the results of the model without space are presented and then a comparative analysis incorporating space is shown. Agrawal and Chhatre (2006) have called for more studies of common pool resources that combine statistical analysis with rich contextual data. The qualitative data

consists of 29 semi-structured interviews conducted in 2014 in five case study community forests. Survey data from 1041 households in 21 Chitwan buffer zone community forests and survey data from members of the governance committees of all 21 community forests are utilized in the analysis (table 4.1). The dependent variable is not continuous and ordinary least squares (OLS) regression with discrete dependent variables (in contrast to continuous) produces biased estimators. Thus, the multilevel model is binary logistic, as it allows for analysis with discrete dependent variables (Williams, 2006).

Table 4.1 Variable explanations and summary statistics

Variable	Explanation	Type	Mean	S.D.	Min	Max	Sum
participateCA	Household participation in Mikania removal in a group or as a group and an individual.	Dependent variable; Dichotomous; 1 = yes, 0 = no	0.348	0.47	0	1	363
CFmember	Is the household a community forest member?	Dichotomous; 1 = member, 0 = non-member	0.662	0.47	0	1	690
ethnicity/caste	Caste of interviewee or head of household.	Expanded dummy variable with Bramin as the reference level (ethnicities 2-5 in order*)	0.159	0.36	0	1	166
			0.126	0.33	0	1	132
			0.036	0.18	0	1	38
			0.170	0.37	0	1	177
income	Household income past year.	Categorical; coded 1 to 7 from under 10,000 rupees to more than 500,000 rupees	4.163	1.42	1	7	
HH_size	Number of people in a household.	Continuous	5.280	2.24	1	16	
HH_dist_CF	Distance from house to nearest community forest in km.	Continuous	1.644	1.06	0.04	5.2	
farm	Does the household farm?	Dichotomous; yes = 1; no = 0	0.810	0.39	0	1	
perceive threat	Does the household perceive Mikania as harmful?	Dichotomous; yes = 1; no = 0	0.886	0.31	0	1	
CF_income	Total income received by governance committee in past year, divided by total member households; in Nepal rupees, divided by 1,000,000.	Continuous	1.396	1.87	0.002	6.7	
CF_age	Years since community forest was established to present.	Continuous	20.86	6.84	6	35	
CF perceive threat	Does governance committee perceive Mikania as harmful to local households?	Dichotomous; yes = 1; no = 0	0.749	0.43	0	1	

*ethnicities- 2: Hill Janajati, 3: Dalit, 4: Newar, 5: Terai Janajati (all ethnicities are coded in reference to the Bramin/Chhetri group).

Model specification.

Building off of factors found to be significant in impacting collective action and including new variables, the model specification is below.

$$participateCA_{ij} = \beta_0 + \beta_1 CFmember_{ij} + \beta_2 ethnicity_{ij} + \beta_3 income_{ij} + \beta_4 HHsize_{ij} + \beta_5 HHdistCF_{ij} + \beta_6 farm_{ij} + \beta_7 perceiveMikaniaThreat_{ij} + \beta_8 CFage_j + \beta_9 CFincome_j + \beta_{10} CFperceiveThreat_j + u_{0j}$$

The above specification is a random effects hierarchical linear model for every individual *i* in community forest *j* where u_{0j} represents these random effects at community forest users group level. Because the dependent variable is dichotomous, a logistic model where the dependent variable represents the log odds ratio (or logit) is appropriate and estimated (Snijders & Berkhof, 2008). In any type of logistic regression, the primary assumptions involve sample size, outliers, and multicolinearity (Menard, 2002). Sample sizes for logistic regression should take into consideration the number of predictors used; small samples with a large number of predictors can produce problems (sample N = 1041 households, 21 community forests). Outliers and multicolinearity were checked for in each independent variable; extreme outliers were not present and issues with correlation between independent variables are discussed below. Analyses were conducted in R (version 3.1.2) using the lme4 package (version 1.1-9).

Using eigenvectors to explore the impact of space.

In order to understand how spatial association among nearby households may influence the chosen factors' capability to explain collective action, the comparative spatial models employ eigenvectors as spatial filters. Eigenvectors are non-zero vectors and the incorporation of eigenvector values in regression models to explore spatial impacts has been established in geographical analysis (An et al., 2016; Y. Chun &

Griffith, 2011; Griffith, 2000). Eigenvectors were calculated for a set of predetermined neighborhood sizes according to latitude and longitude coordinates collected from each survey respondent's household location. These coordinates allowed for mapping of households into neighborhoods and eigenvectors were accordingly calculated for the 10, 20, 30, 40, and 50 nearest neighbors for each household. One hundred eigenvectors were calculated for each household at each neighborhood size. The top ten eigenvectors (i.e., the ones with the highest eigenvalues) at each neighborhood size in five models (one for each neighborhood size) were used as a comparative analysis with respect to the model without spatial filtering. The full details of the eigenvalue calculation can be viewed at http://complexities.org/Photo&PDF/CNH_Eigvec_Instructions.pdf.

Results

Belonging to a community forest and perceiving Mikania as a threat are significantly positively associated with participating in Mikania removal at the household level and being Newar decreases the likelihood of participating in Mikania removal (table 4.2). In Chitwan, being Newar is relatively rare as the Newar are an indigenous group that has been historically present further north, in the valley just outside of Kathmandu. The Newar have a higher average socio-economic status compared to other indigenous groups in Nepal and traditionally have held professions outside of agriculture and are thus likely less reliant on forest resources. Additionally, at the community forest level, the governance committee's perception of Mikania as harmful is significantly negatively correlated with a household's decision to participate in Mikania removal. Household income, belonging to several indigenous groups or being Dalit, household size, household distance to the forest, and farming were not significant influences on Mikania removal in

the final non-spatial model. However, alone, household distance to the forest and farming were both significant influences on participation in Mikania removal (table 4.3). These variables are correlated with being a community forest member and the moderate multicolinearity renders them insignificant in the final model including all variables.

Table 4.2. Model results with all variables (no spatial filtering)

Level 1 (HH)	Estimate (standard error)
Intercept	-1.385059** (0.614937)
CF_member	0.813201*** (0.164079)
ethnicity_2 (Hill Janajati)	-0.004459 (0.212095)
ethnicity_3 (Dalit)	0.172931 (0.231685)
ethnicity_4 (Newar)	-0.993093** (0.475196)
ethnicity_5 (Terai Janajati)	0.062026 (0.242313)
income	0.029869 (0.050848)
HH_size	0.017616 (0.032006)
HH_dist_CF	-0.144327 (0.116428)
farm	0.232520 (0.199788)
perceive_mikania_threat	0.861755*** (0.255881)
Level 2 (CF)	
CF_AGE	-0.012219 (0.017111)
CFincome	-0.057189 (0.075865)
CF_perceive_threat	-0.597360* (0.318123)

p<0.0001 ***, p<0.01 **, p<0.05*; N = 1041 HH, 21 CF

Table 4.3. Model results with single variable estimates

Model (predictor)	Estimate (Standard error)
Model 1 (CF member)	0.8793*** (0.1574)
Model 2 (ethnicity)	ethnicity_2: -0.1353 (0.2027); ethnicity_3: 0.0788 (0.2233); ethnicity_4: -1.0785** (0.4660); ethnicity_5: 0.1383 (0.2353)
Model 3 (income)	0.0415 (0.0478)
Model 4 (HH size)	0.0477 (0.0300)
Model 5 (HH distance forest)	-0.1800* (0.1042)
Model 6 (farm)	0.4904*** (0.1877)
Model 7 (perceive Mikania threat)	0.8775*** (0.2494)
Model 8 (CF income)	-0.0320 (0.0709)
Model 9 (CF age)	-0.0191 (0.0183)
Model 10 (CF perceive threat)	-0.2793*(0.3014)

p<0.0001 ***, p<0.01 **, p<0.05*; N = 1041 HH, 21 CF

When spatial filtering is incorporated into the model, the majority of the results hold at the smaller spatial scales, but some relationships change as the neighborhood size increases (table 4.4). The implications of the findings are discussed next.

Table 4.4. Results of spatial filtering models

Model →	**No spatial**	**NBH 10**	**HBH 20**	**NBH 30**	**NBH 40**	**NBH 50**
Level 1(HH)						
Intercept	-1.385059**	-1.8627**	-1.6117**	-1.76583**	-1.5442**	-1.5526**
	(0.614937)	(0.79675)	(0.614022)	(0.555294)	(0.565005)	(0.571927)
CF_member	0.813201***	0.80440***	0.77331***	0.81208***	0.8146***	0.8332***
	(0.164079)	(0.16825)	(0.165543)	(0.164652)	(0.164825)	(0.165212)
ethnicity_2 (Hill	-0.004459	-0.02685	-0.029390	-0.101710	-0.075044	-0.077877
Janajati)	(0.212095)	(0.21929)	(0.2136)	(0.211223)	(0.211663)	(0.211145)
ethnicity_3 (Dalit)	0.172931	0.30331	0.175541	0.174156	0.253085	0.327081
	(0.231685)	(0.25158)	(0.234244)	(0.232780)	(0.234320)	(0.238692)
ethnicity_4 (Newar)	-0.993093**	-0.90141**	-0.93893**	-0.94097**	-0.9165**	-0.8664**
	(0.475196)	(0.48807)	(0.478861)	(0.482376)	(0.478808)	(0.482824)
ethnicity_5 (Terai	0.062026	0.10685	0.216007	0.305682	0.273732	0.271159
Janajati)	(0.242313)	(0.2712)	(0.232012)	(0.23917)	(0.240665)	(0.237680)
income	0.029869	0.02750	0.026267	0.014879	0.017177	0.018064
	(0.050848)	(0.05165)	(0.050938)	(0.051204)	(0.051276)	(0.051340)
HH_size	0.017616	0.01910	0.021240	0.020089	0.018595	0.018612
	(0.032006)	(0.03259)	(0.032479)	(0.032338)	(0.032309)	(0.032252)
HH_dist_CF	-0.144327	**-0.37557****	-0.152223	-0.240010	**-0.3104****	-0.241587
	(0.116428)	**(0.16224)**	(0.138599)	(0.139012)	**(0.144388)**	(0.150712)
farm	0.232520	0.21845	0.249721	0.220717	0.251899	0.254372
	(0.199788)	(0.20421)	(0.201226)	(0.203623)	(0.202856)	(0.202335)
perceive_mikania_threat	0.861755***	0.87822***	0.85084***	0.82325***	0.8135***	0.8223***
	(0.255881)	(0.26066)	(0.256024)	(0.257383)	(0.257638)	(0.258346)
Level 2 (CF)						
CF_AGE	-0.012219	0.02428	-0.001696	0.006029	0.004768	0.005126
	(0.017111)	(0.02931)	(0.015828)	(0.015092)	(0.015155)	(0.015207)
CFincome	-0.057189	0.14540	-0.007164	**-0.4018*****	**-0.372*****	**-0.3969*****
	(0.075865)	(0.13262)	(0.088989)	**(0.107376)**	**(0.102935)**	**(0.104871)**
CF_perceive_threat	-0.597360*	-0.87605**	-0.726559*	**0.354947**	**0.159632**	**0.008384**
	(0.318123)	(0.42155)	(0.295239)	**(0.306564)**	**(0.279693)**	**(0.289957)**
Eigenvectors						
Eigen1		-5.04185	-2.168690	-6.949163	4.525912	49.8083***
		(14.18957)	(3.217738)	(3.566353)	(5.697266)	(14.365982)
Eigen2		9.80318	3.712529	-19.542***	-25.92***	110.795***
		(14.86248)	(3.677870)	(5.004745)	(6.252023)	(28.413786)
Eigen3		-5.19743	-9.14711**	15.7656***	24.922***	-3.354607
		(3.80379)	(3.774720)	(4.411047)	(6.817462)	(5.874289)
Eigen4		-4.15245	2.106211	31.4282**	37.171***	7.884616
		(3.83952)	(4.729554)	(13.538901)	(9.308714)	(6.584032)
Eigen5		-1.16079	-0.174514	43.4101***	-2.745146	-14.663***
		(3.95069)	(4.179696)	(16.038039)	(5.358389)	(4.656964)
Eigen6		12.85628**	-6.995553	6.209407	-39.54***	-13.005***
		(6.34740)	(4.172717)	(4.717159)	(14.82324)	(4.252553)
Eigen7		10.06661**	-23.02401	-13.774***	10.067689	1.858194
		(4.52989)	(12.4325)	(4.989631)	(6.254897)	(5.419257)
Eigen8		12.89399**	-20.35677	28.1619***	-15.22334	8.2293***
		(5.87581)	(16.96564)	(8.254470)	(9.217449)	(3.910026)
Eigen9		-3.91785	-4.677092	-6.072814	-6.495850	-12.446***
		(5.11391)	(5.970647)	(3.486686)	(7.688246)	(4.502668)
Eigen10		-1.34642	-2.108502	-5.291565	2.440397	-9.018***
		(4.33239)	(10.12355)	(4.414548)	(2.515810)	(4.367460)

p<0.0000 ***, p<0.01 **, p<0.05*; N = 1041 HH, 21 CF; Standard error in parentheses
Values that have changed in significance are bolded and NBH = neighborhood

Discussion

Here, the results are first considered without spatial filtering and later discussed in the context of the impact of the spatial filters.

Perceptions of collective action problems influence participation.

The model supports that household perception of Mikania presence as harmful is significantly positively correlated with a household's participation in Mikania removal. This indicates that people need to perceive the situation as personally harmful before working to collectively solve it or cease free riding off of others efforts (Lubell, 2002); this insight has important implications for other collective action problems. This analysis is not the first to suggest the importance of individual, community, or household perception of issues in solving collective action problems, but this quantitative, multilevel exploration in the context of an increasingly important global human-environment issue, the spread of invasive species, is an important contribution and confirms the need for further study in this area.

Reliance on natural resources is an important indicator of engaging in collective action.

This analysis supports the hypothesis that households more dependent on community forest resources are more likely to engage in Mikania removal, as belonging to a community forest was significantly correlated with participating in Mikania removal; community forest membership is an important indicator of having a personal stake in community forest resources. Another measure of reliance on community forest resources, farming, was significantly correlated with participating in Mikania removal on its own, but was highly correlated with being a community forest member and thus insignificant

when all variables were included (see tables 4.2 and 4.3). The correlation between resource dependence via farming and membership aligns with expectations, as although a few Chitwan residents in need of forest resources are prohibited from joining a community forest (see "community forest membership" section for a discussion of barriers to entry), most that are dependent on forest resources are members (whether or not all members receive the same benefits is contested, see Bhattarai & Ojha, 2001). The relationship between reliance on forest resources and participation in Mikania removal is linked to the perception of the problem as harmful or benign because people with no stake in the impacted resource (those who do not need to use it) are unlikely to perceive Mikania as an issue that impacts them and needs to be addressed; there is little perceived risk in their choice to ignore Mikania.

Unpacking the influence of perception at the community forest level.

The finding that perception of Mikania as harmful by a community forest governance committee is significantly negatively correlated with a household's participation in Mikania removal may seem counterintuitive at first. It appears logical to make the connection that perception of Mikania as harmful at the community forest governance committee level might foster a setting where more individual households are aware of Mikania as harmful and choose to participate in removal efforts. Awareness of a problem does not always lead to action (e.g., Kollmuss & Agyeman, 2002), and in this case, governance committees that perceive Mikania as harmful do not always share this information with their members. In the fieldwork conducted in 2014 in five case-study community forests, interviewees reported distrust in their community forest governance committees and officials from the nearby Chitwan National Park. With this

contextualized knowledge, it makes sense that even if governance committee members were diligent in informing community forest members of their perceptions of the Mikania issue, members are unlikely to trust all of the information they receive from their governance committees and may perceive issues differently. Further, research has learned that perceptions of collective action problems among actors in polycentric governance systems can influence collective actions taken by actors at different levels (Andersson & Ostrom, 2008; Ostrom, 2010). Another possibility is that the forest governance committee's perceptions are a consequence of their member's lack of action. In other words, governance committees may perceive Mikania as a significant threat to their forests when they realize that their own members are not engaging in any efforts to stop the spread of Mikania. This analysis is unable to discern the mechanism that differentially links members' and governance committees' perceptions to households' Mikania removal, but the multilevel approach highlights the importance of measuring perceptions at these two different levels: as these results show, it is unwise to assume that perceptions of governance actors is identical to and is merely a reflection of members' perceptions.

Top-down versus bottom-up approaches to solving collective action problems.

In this case, the model supports that perception of Mikania as harmful by individual households is vital to participation in efforts to prevent and reduce the spread of Mikania. This linkage between the perception of an issue as personally harmful (personal risk) and engaging in collective action in an effort to solve it is highly relevant to other critical global environmental issues, such as mitigating or adapting to climate change (Lubell et al., 2007). Even in cases where Mikania is not viewed as harmful by

the community forest governance committee, households that view Mikania as personally harmful are more likely to participate in removal efforts. In the case of collective action, problems where households or individuals do not rely on or buy into the impacted resource or system, top-down perception of the situation may be important. For example, in the case of climate change, even in cases where bottom-up collective action has been absent, strong action from government in a top-down approach can have success; many studies have found support for a blended top-down and bottom-up approach to solving collective action problems (Anderson & Grewell, 1999; Ansari et al., 2013; Fujisawa et al., 2015; Green et al., 2014; Pahl-Wostl, 2009).

According to the survey data, 35 percent of the surveyed households are participating in Mikania removal efforts. The initiative for engaging in collective action to remove Mikania exists in Chitwan but the methods people choose to remove Mikania often unfortunately work against their goals, spreading the plant and its seeds further. It is possible that the nature of the human-environment problem determines what type of collective action will be proficient in solving it. For example, some problems may be most effectively solved with collective action initiated from the top down, while others will have better results organizing from the bottom up. However, it may also be the case that most collective action problems can be solved with a bottom-up approach if the people involved are given access to the appropriate tools, knowledge, and resources; most research on the commons supports the assertion that individuals can self-organize to solve a wide variety of human-environment issues (Ito, 2012; Meinzen-Dick et al., 2000; Tang, 1992). For instance, if a local non-government organization provided information on the best practices for Mikania removal to every household in Chitwan, it is possible

the collective action efforts of the community would be far more effective in preventing the spread of Mikania than they are at present.

Incorporating spatial filtering: The role of neighborhoods.

Overall, the addition of spatial filtering did not have a large impact on the factors influencing collective action at smaller neighborhood sizes, but some of the relationships in the model changed at larger spatial scales (table 4.4). It is important to keep in mind that the survey data utilized in the analysis represents a subset of the households within a given community forest. Therefore, the spatial influences in the analysis are likely to be amplified in the actual neighborhoods containing more households. Based on fieldwork in Chitwan, the smaller neighborhood scale (10 or 20 households in the analysis) is the most accurate representation of how people regularly interact and define their neighbors. Because the spatial filtering via inclusion of the eigenvectors largely significantly impacts the model results at the larger neighborhood sizes, space is more influential as neighborhood size increases. Two collective action relationships that space appears to influence are interpreted: community forest level income and the perception of Mikania as a threat by a community forest governance committee (both community forest level variables in the analysis).

Community forest level income.

The model results indicated that spatial influences operate at the larger neighborhood sizes on community forest level income (the total income available to each community forest governance committee; see table 4.1). With the addition of spatial filtering, community forest level income changes from insignificant to significant and negative at neighborhood sizes 30, 40, and 50 (indicating the higher the community

forest's income, the less likely a household will participate in Mikania management). In chapter 3 it was discovered that household income was negatively correlated with membership; households with higher incomes were less likely to be community forest members. The relationship between income and membership appears to be capturing a livelihood transition in Chitwan, where people with higher incomes have begun to transition away from dependence on the forest resources to other, non-agricultural livelihoods. Similar to the household level relationship between income and membership, the influence of space (especially in terms of larger neighborhoods where households may be more representative of aggregate community forest characteristics) on the relationship between income and collective action is intuitive, as the model results support that collective action is influenced by community forest membership. Households in wealthier community forests that provide a wider variety of resources to their members (such as non-agricultural, skills based trainings and workshops) may be less likely to participate in collective action because they may be shifting away from dependence on the community forest resources. As mentioned above, a neighborhood of 50 (or 40 or 30) selected households may represent a much larger actual neighborhood, even exceeding the size of a community forest user group. This might imply that the spatial spill-over effect operates across several community forest groups, e.g., some community forest groups have similar incomes. Capturing this kind of spatial spill-over effect is important not only for statistical reasons (e.g., an insignificant coefficient becomes significant or vice visa), but also for theoretical and practical reasons: This kind of spatial spill-over effect only exists on some variables, which might indicate that collective action may be affected by factors operating at more than one spatial scale or neighborhood size. Hence

there should not exist one-size-fits-all solutions when considering management interventions.

Perception of Mikania as a threat at the community forest level.

Spatial filtering additionally impacts the relationship between collective action and the perception of Mikania as a threat by community forest governance committees. Perception at the community forest level shifts from significantly influencing collective action at the smaller neighborhood scale, to being insignificant at larger neighborhood sizes (30, 40, and 50 households); in other words, this relationship breaks down at larger spatial scales. Numerous households belonging to Chitwan community forests report distrusting either their governance committee members or Chitwan National Park officials and such households are often spatially close (i.e. neighbors) and share their immediate neighbors' or family members' opinions (chapter 2). This results in heterogeneous clusters of opinions within a given community forest user group. When these heterogeneous clusters are grouped together in a larger spatial unit, the relationship between perception and household participation in collective action breaks down.

As space appears to alter some factors' influences on collective action at larger neighborhood sizes, i.e., sizes that are more representative of the community forest spatial extent, there are important implications for local stakeholders interested in encouraging or influencing Mikania management efforts. For instance, if community forest governance committee members wish to improve the reception of their opinions regarding Mikania and management options in areas where household distrust is present, the analysis indicates engagement at the sub-community forest level is important to overcome these issues. Opinions of community forest governance committees are

clustered and influential in collective action decisions at smaller neighborhoods, of which there are many in a given community forest area. Targeting efforts to disseminate information about Mikania management at a smaller scale may improve trust and have a greater impact than attempting to blanket all households in the community forest with the same information simultaneously.

The comparative analysis incorporating spatial filtering is one way to examine the influence of space on collective action and is a point of departure for future efforts. There are many potential ways to strengthen or expand this analysis in future work, including exploring different conceptualizations of neighborhoods and investigating other ways of defining space, such as through different network analyses.

Conclusions

Understanding what influences collective action in the management of natural resources is broadly important, with the potential to unlock insights to aid groups in overcoming barriers to taking collective action at multiple scales to solve a host of global human-environment issues. A more detailed understanding of the factors influencing collective action, using an approach that values both quantitative and qualitative information, is the first stage in handling problems that have the potential to be addressed with collective action. This analysis also supports the importance of studying the precursors of collective action at multiple scales, including both actors at the individual or household level as well as the larger governance institutions in which they are embedded.

Agrawal (2001, 2014) notes that the search for general principles to govern the commons and common pool resources, that apply in all cases, is often fruitless and time

consuming and argues researchers should instead focus on comparative analyses and statistical interpretations of data to achieve an "empirically relevant theory of the commons" (Agrawal, 2001, p.1649). I believe statistical analyses, large sample size comparative studies, and consideration of neighborhood impact can contribute to both of these ideas. Statistical analyses can assist researchers in identifying overarching patterns in collective action as they accumulate over time, while they simultaneously provide insight into unique systems and local problems (Gibson et al., 2005; Pagdee et al., 2006). Using a statistical model, this research was able to compare collective action across 21 community forests, contextualize the findings with qualitative data, and explore how these findings fit into a larger discussion regarding the importance of rigorously understanding what influences collective action.

Certain types of human-environment problems are suited to be effectively solved with different types of collective action (i.e. top-down versus bottom-up), and although solutions will be context and community specific (Ostrom, 2007; Ostrom et al., 1999; Taylor & Van Grieken, 2015), general patterns that emerge in factors that influence collective action resulting from empirical statistical studies and large sample size comparative studies can promote research able to identify commonalities. This more general understanding of what impacts collective action from a rigorous perspective can contribute to influencing situations and designing institutions to encourage collective action at different levels, such as households, neighborhoods, or entire community forest user groups. In other words, if researchers understand what is likely to motivate collective action in different global contexts, they can empower communities with this information to aid them in building strong, effective collective action movements to solve

critical issues as the community perceives them. If individuals must perceive environmental issues as posing personal risk to attempt to solve them (Lubell, 2002; Lubell et al., 2007; Stoutenborough et al., 2015), researchers need to fully understand when and why people perceive some human-environment issues as personally risky while others are interpreted through a distant, detached, or indifferent perspective. Information gained from a greater number of rigorous studies investigating perception of collective action problems as personally harmful or benign to individuals at multiple levels will aid researchers in understanding (1) if perception is universally important in all collective action problems and (2) the differences between individuals who perceive these problems as posing personal risk. This work contributes to an empirical understanding of how these variables catalyze effective collective action.

CHAPTER 5

EXPLORING INSTITUTIONAL CHANGE THROUGH RATIONAL CHOICE AND CULTURAL DIFFUSION PERSPECTIVES

Chapter Overview

There are multiple theories regarding how institutions change over time, but institutional change is often difficult to study and understand in practice. Agent-based modeling, also called individual-based modeling, is known as a technique to explore emergent phenomena resulting from the micro level activities and interactions between heterogeneous agents and between agents and the environment. Such models allow researchers to investigate theories which may otherwise be difficult to examine. This study presents a theoretically driven agent-based model to explore two perspectives on institutional change, rational choice and cultural diffusion, in a rapidly changing social-ecological system in Chitwan, Nepal. The Chitwan region is urbanizing and facing a threat associated with the spread of an invasive plant, *Mikania micrantha* (Mikania). This chapter focuses on understanding how shared norms and strategies for Mikania management may change over time with each perspective of institutional change and the resulting impacts on the spread of Mikania. Understanding shared norms and strategies (often referred to as types of 'informal' institutions) is critical to understanding natural resource management outcomes. The model results are largely intuitive and consistent with previous studies. It is found that rational choice is an unlikely candidate for institutional change in Chitwan and that the social learning and imitation mechanism modeled in the cultural diffusion perspective better replicates empirical patterns. Although the focus here is on invasive species, the approach is applicable to many other

sites with implications for understanding institutional change in any social-ecological system confronting global environmental changes. Ultimately, this study advances the understanding of how adopted norms and strategies change over time and how norms and strategies mediate prominent social-ecological challenges, contributing to the possibility of effectively confronting such challenges in the future.

Introduction and Literature

Institutional scholars have widely documented that institutions, as the shared rules, norms, strategies, and values that shape human decision making (North, 1990; Ostrom, 2005), profoundly influence natural resource management. The institutions in a given system often shape whether resource management will be successful or not (Ostrom, 2005; Ostrom, Gardner, & Walker, 1994). In cases where natural resource management is deemed unsuccessful, people often seek to change the institutions governing that system (Burger et al., 2001; Ostrom, 1990). Understanding how institutions change is a topic rife with difficulties, including observing change over long time scales, different theories about the mechanism of change, and analysis and measurement (Campbell, 2004). In this study, it is argued that understanding how institutions change is an important element of moving towards sustainable natural resource management in systems facing rapid social-ecological changes and a theoretically driven agent-based model (ABM) exploring institutional change in such a system is presented.

Many institutional studies of common pool and natural resources have focused on the role of rules in management decisions, but here management norms and strategies are explicitly operationalized (Crawford & Ostrom, 1995). An agent-based model is utilized

to explore the change in shared strategies when confronted with a social-ecological challenge via two theoretical perspectives: cultural diffusion (Axelrod, 1997) and rational choice (see Ostrom, 2005). Understanding shared norms and strategies (often called 'informal' institutions) is critical to understanding social-ecological systems, especially in decentralized management situations that may place less emphasis on formal rules. The agent-based modeling approach also empowers exploration of different theories that would otherwise be difficult to unpack and observe the implications of over time.

Studies of successful common pool resource management are often case-study based and rely primarily upon analysis of rich qualitative data. More recently, the field has focused on incorporating quantitative data and computational analysis with qualitative data. Advances in the area of computational social science have made agent-based (also known as individual-based) models increasingly appealing to study natural resources and social-ecological systems (SES) (Bonabeau, 2002; Epstein & Axtell, 1996; Heard et al., 2015; Lee et al., 2015). Such computational models provide researchers the opportunity to manipulate a wide variety of system characteristics to construct counterfactual situations, reevaluate past conditions, or explore the impact of added factors that cannot be or are very difficult to directly observe in actual systems. In this sense, agent-based models have been described as virtual laboratories for exploring social-ecological systems (Magliocca, Shelley, & Smorul, 2015). The agent-based model presented here explores the impact of changes in management norms and strategies on the spread of an invasive plant in locally governed forests in Chitwan, Nepal.

Study site and objectives.

Community forests and their user groups are one example of collectively managed social-ecological systems that the institutional literature has explored. Community forestry programs, each giving local users some degree of autonomous resource management, have been established globally (Charnley & Poe, 2007). They include a forest ecosystem and the group of people that actively contribute to the management of the forest resources. Globally, they have encountered differing levels of success. Some are entirely managed by local organizations, while others are formally owned by the national, state, or regional governments with management rights held by locally established community forest management committees (White & Martin, 2002). The complex human-environment dynamics and the heterogeneity in management and decision processes in community forestry situations make them an excellent candidate for agent-based modeling (Borshchev & Filippov, 2004; Janssen & Ostrom, 2006).

Chitwan, Nepal is a district located in the southern region of Nepal, in the sub-tropical Terai climate. Chitwan has been home to formal community forest user groups since the program was formalized in the 1990s by the national Forest Management Act (Gilmour, 2003). These resource users have faced a variety of challenges, such as increasing urbanization, but more recently a rapidly growing invasive plant (*Mikania micrantha*, referred to as Mikania) has disturbed the system. Mikania is a vine-like plant that is particularly difficult to successfully remove due to its biological seed dispersal; if not properly covered/contained in removal efforts during the flowering season, the seeds will further spread the plant (Barreto & Evans, 1995). Mikania grows on both the forest floor and climbs small trees, meaning it is often tangled in fodder and grasses that

community forest users collect. Thus, commonplace resource collection and management efforts have resulted in aiding Mikania dispersal.

The aim of this study is to develop and employ an agent-based model to understand the following questions:

1. How do empirically observed and theoretically hypothesized management norms and strategies in Chitwan impact patterns of Mikania distribution?
2. How does the adoption of norms and strategies change over time and which theory of institutional change, rational choice or cultural diffusion, better fits empirical observations in the system?
3. What are the implications for managing social-ecological systems in the future, including when current institutions do not fit new social-ecological challenges?

This study incorporates two perspectives on how shared norms and strategies for managing Mikania are adopted and change over time: rational choice and cultural diffusion. Much institutional work has focused on operationalizing rules, with less focus on shared norms and strategies (Helmke & Levitsky, 2004; Raiser, 1997). Under a bounded rationality framework, individuals seek to maximize their own utility under cognitive, information, and time constraints (Ostrom, 2005). Experimental economics studies conducted with cultures around the world have shown that there are individuals everywhere who fail to conform to the selfish rational actor theory (Richerson & Henrich, 2012), noting that individuals can act cooperatively or altruistically to seek personal or group benefits. The rational choice sub-model incorporates these findings, allowing individuals to evaluate factors beyond the cost of a norm or strategy. Axelrod (1997)

developed a model of cultural diffusion, where the probability of individuals interacting and adopting new cultural characteristics is based on their level of cultural similarity. I wish to be clear that "cultural diffusion" does not refer to the pseudoscientific concept of hyperdiffusion, where all cultures are assumed to diffuse from a single cultural source (Williams, 1991, p.224). This study extends this approach to explore how shared norms and strategies change over time based on individual interactions. Utilizing these two perspectives in the model assists in unpacking the impact of each process and the outcomes that may arise in comparison to empirical observations from Chitwan. Although the focus of this study is invasive species, the approach and insights related to institutional change are generalizable to other social-ecological systems encountering rapid global environmental change.

How do institutions change?

There are several theories of institutional change (table 5.1). These theories are at times competing, but often elements of separate theories are compatible. Here, two main theories of institutional change are described, while acknowledging there are others. The authors that have theorized institutional change under each of these perspectives often utilize different definitions of 'institution.' In this study, institutions refer to the shared rules, norms, strategies, and values that shape human decision making; they are the 'rules of the game,' in line with North (1990) and Ostrom (2005).

Table 5.1. Common categories of theories of institutional change (summarized from Kingston & Caballero, 2009 and Mahoney & Thelen, 2010)

Type	Description	Examples	Problems	Citations
Centralized	Also described as deliberate/purposeful; this type of institutional change is not usually random or accidental (although, it can have unintended consequences). Often occurs via a political process or collective choice mechanism	Explaining the origin of property rights via 'contracting,' where higher level rules shape the change of lower level property rules; The cost-benefit analysis embedded in Ostrom's constitutional-collective choice-operational rule hierarchy	Has difficulty explaining when/why 'formal' rule are ineffective/ignored and addressing "informal" institutions, such as social norms	Libecap (1994), Ostrom (2005), Alston (1996), Kantor (1998)
Decentralized	Also described as evolutionary (where institutions emerge via a decentralized selection process), incremental; new institutions can emerge at random and sometimes through design	Transaction cost literature where the most efficient/optimal institutions are assumed to survive; Sequences of habits that cause emergent actions; Punctuated equilibrium characterized by long periods of stability and short periods of rapid changes	Often neglects the roles of collective action and political processes in institutional change	Williamson (2000), Veblen (1899), Hayek (1978), Young (1996)
Equilibrium	Combines elements of both decentralized and centralized processes of institutional change. Focus is not on the rules governing behavior, but on behavior. Formal and informal rules are viewed as the means to people achieving a shared set of beliefs about behaviors which result in individual actions.	Institutions generate social behavior; "…institutions emerge as endogenous equilibrium outcomes, reflecting a socially constructed reality." (Kingston & Caballero 2009, p. 171)	Tradeoff in attempting to study formal and informal rules simultaneously	Aoki (2001), Greif & Laitin (2004), Schotter (1981), Kingston & Caballero (2009)

The primary distinction drawn between theories of institutional change is deliberate change that occurs via a centralized mechanism (like collective-choice situations) versus evolutionary change that occurs via a decentralized mechanism

(Kingston & Caballero, 2009). Institutional change that occurs in a deliberate manner in a centralized process (such as through voting to alter legislations) tends to occur more quickly than institutional changes that occur via a decentralized process. It has been noted that 'formal' rules, often defined as written rules (such as laws), are more frequently changed deliberately, whereas 'informal' rules are much slower to change and usually shift in a decentralized process resulting from uncoordinated micro-level behaviors. Informal rules include unwritten agreements, moral or ethical norms, and social norms. Institutional change may also occur, via both centralized and decentralized processes, in a punctuated manner with periods of stability interrupted by points of rapid transition. Understanding rates of institutional change is important to policy makers and stakeholders attempting to deliberately change either formal or informal institutions (Mahoney & Thelen, 2010). A third category of institutional change theories is that of the "equilibrium view" (Kingston & Caballero, 2009), where behaviors and the endogenous nature of institutions (both formal and informal) are the focus. The equilibrium view is fully compatible with both centralized and decentralized theories of institutional change (table 5.1).

The model described in this research is concerned with informal institutions, specifically norms and strategies related to Mikania management. Each of the explored perspectives, rational choice and cultural diffusion, assesses decentralized processes of institutional change, with individuals interacting on the micro-level potentially leading to changes in the composition of norms and strategies on the macro-level over time, via a different mechanism. The shared norms and strategies for Mikania management are endogenous to the system outcomes, thus the model is also compatible with the

equilibrium view of institutional change where institutional changes are viewed as endogenous to the system and people's shared beliefs about behaviors (table 5.1). Rational choice is explored in the first sub-model. In this case, agents engage in a cost-benefit analysis; if the individual benefit of adopting a specific strategy is greater than its cost, the individual can select a costlier institution. But otherwise, the boundedly rational agents assess whether Mikania is present, the value of the land, and if removal is beneficial; with this assessment, they adopt the lowest cost institution. Although the cost-benefit analysis in this model occurs at the micro-level, the process is similar to Ostrom's theory of institutional change where individuals engage in a cost-benefit analysis and agree to institutional change if a 'minimum coalition' is achieved (Ostrom, 2005, p. 61). Instead of the change taking place on the scale of the entire community simultaneously (i.e. individuals are not voting or agreeing on a threshold where everyone will adopt one institution after the 'minimum coalition' is met, such as a majority in democratic voting processes), the change takes place as individuals evaluate the cost of adopting specific strategies over time. The second perspective on change is investigated in the cultural diffusion sub-model based on Axelrod (1997). Axelrod explored how simple interactions between agents with some level of cultural similarity created changes in cultural heterogeneity over time. I modify the model to examine institutional change by modeling Mikania management norms and strategies and tracking the change in these norms and Mikania patterns over time. These strategies change via individual agent interactions and the mechanism of change can be thought of as social learning.

People in Chitwan engage in collective action using shared strategies for Mikania removal, but many of these strategies are inefficient, furthering Mikania dispersal to

different degrees. Thus, the approach facilitates an exploration of how initial configurations of shared strategies and norms, which correspond to different rates of Mikania spreading or redistributing, change over time in an effort to identify efficient institutions and understand how institutional change occurs.

Modeling social-ecological systems.

The concept of social-ecological systems has a long history, with scientific articles discussing the concept over a century ago (Berkes & Folke, 2000), while the last decade has witnessed the emerging of a similar concept of coupled human and natural systems (CHANS; Liu et al., 2007a; Liu et al., 2007b). The concept recognizes that most environmental and social problems cannot be solved without considering the impact of humans on the remainder of the environment and the reverse. In the study of common pool resources, many researchers addressing variations in successful resource management ignore biophysical variables in favor of social ones despite the frequent importance of biophysical variability in resource condition (Agrawal & Chhatre, 2006).

Attempting to model social-ecological systems in an effort to better understand them is full of inherent complexities including scale, boundary, and information issues. As such, the modeling literature contains a diversity of methods including systems dynamics, geographic information systems (GIS), agent-based models (ABM), and various combinations of these approaches (Railsback & Grimm, 2011). Agent-based models of social-ecological systems have explored a wide variety of topics including forest fire regimes, fisheries collapse, and land use and land cover change. Recent studies have indicated that these models could benefit by more explicitly incorporating ecology (Epstein et al., 2013). It is important to recognize that ABMs have contributed to moving

science forward in a variety of fields. For instance, simulations of cooperating and selfish agents' harvest of a renewable resource contributed to increased understanding of the evolution of cooperation (Pérez & Janssen, 2014). In the realm of institutions, ABMs incorporating institutional components have furthered scientific understanding of how institutions impact outcomes in social-ecological systems. For instance, an ABM assisted in understanding the effects of environmental processes on decision making in small scale forestry. By incorporating institutional and ecological data, Leahy et al., (2013) showed that harvesting was driven in part by economic motivation contrary to previous findings. Vallino (2014) utilized agent based modelling to explore the impact of both exogenous and endogenous institutions on the outcomes of forest management. The model simulations support previous findings that the presence of either endogenous or exogenous institutions, including use rules and enforcement, are correlated with better forest conditions over an open access regime. It also led to the insight that exogenously imposed institutional arrangements can be ineffective in sustainable forest management when they harm the "intrinsic environmental motivations" of resource users (Vallino, 2014).

While there is some overlap between other modeling approaches, such as system dynamics (Schieritz & Milling, 2003), ABMs provide the opportunity to more precisely explore the role of individual heterogeneous agents (Grimm et al., 2005) and have been used to model the dynamics of a variety of social-ecological systems, including agricultural decision making (e.g. Bithell & Brasington, 2009; Schreinemachers & Berger, 2011), water management (e.g. Becu et al., 2003; Schlueter & Pahl-Wostl, 2007), and forest management (e.g. Leahy et al., 2013; Vallino, 2014).

Invasive species as a social-ecological challenge.

Invasive species represent one type of challenge facing social-ecological systems and common pool resources and are often interconnected with or exacerbated by other issues such as urbanization, climate change, and environmental pollution (Keller, Cadotte, & Sandiford, 2014). Studies of invasive species have been conducted on plants, animals, and insects, but this section will focus primarily on those conducted with plants. There are thousands of invasive, or non-native, plant species that have been identified globally (Lodge et al., 2006) and they cause varying degrees of impact on people and the environment. Invasive species are most frequently studied in the context of their ecological or economic, but not social, impacts (Rai & Scarborough, 2014; Schuettler, Rozzi, & Jax, 2011). Yet it is recognized that it is important to understand invasive species' social and ecological influences (Atlan & Darrot, 2012). Evaluating invasive species in a social-ecological context allows researchers to more accurately consider the impacts that invasive species have, both on humans and the biophysical world. This approach is important in the face of attempts to manage invasive plants. Without an understanding of how invasive plants impact both the social and ecological subsystems, management attempts may be contentious among social groups with different interests and values (Estevez et al., 2015) or ineffective due to poor understanding of the institutional norms and rules that interact with management efforts. It has been suggested that geographic areas with diverse land uses (referred to as "management mosaics") are more susceptible to invasive species spread, as there are more likely to be a variety of managers with different, conflicting interests involved. As the number of managers in an area increases, the incentive to engage in collective action to remove and manage

invasive species decreases (Epanchin-Niell et al., 2009). In order to foster invasive species management, it is important to understand the social elements of the system, including the interests and values of different stakeholders.

Research examining invasive species in a social-ecological context is nascent, but the body of relevant literature is increasing (Schuettler et al., 2011). Such studies tend to adopt different approaches to exploring the social elements of invasive species, including understanding attitudes and beliefs surrounding invasive plant management (Fischer et al., 2014), exploring risky behavior related to invasive species (Drake et al., 2015), incorporating social elements in landscape modeling of invasive species (Crespo-Perez et al., 2011), and discussing the role of traditional resource management in areas impacted by invasive species (Ticktin, Whitehead, & Fraiola, 2006). There are also a variety of studies addressing the economic impacts of invasive species encompassing the ecosystem services perspective (e.g. Ayanu et al., 2015), utilizing bioeconomic models (Fenichel, Horan, & Bence, 2010; McDermott, Irwin, & Taylor, 2013), and investigating solutions to the international trade related risks invasive species pose (Perrings et al., 2010).

In the case of Mikania management, Murphy et al. (2013) find that efforts to manage Mikania in the future must incorporate plans to reduce burning and to introduce/spread information about the best Mikania removal practices. Successful implementation of these recommendations requires a detailed understanding of the social context, including institutions. Without an understanding of the social-ecological system invasive species occupy, people attempting to remove or manage an invasive species risk running into conflicts among people with different interests and strategies and stagnating

such attempts (Estevez et al., 2015). This methodological approach is generalizable to understand norms and strategies in other systems facing rapid social-ecological changes.

The model.

An analysis of a simple, but theoretically interesting and informative, agent-based model that explores two perspectives on how norms and strategies for Mikania management are adopted and change over time is presented. To increase the generalizability of the findings, the cost of implementing management norms and strategies are parameterized in the model; these parameters can be altered to reflect the cost of different institutions in other systems. This approach is intended to allow exploration of the impact of institutional change on outcomes in the context of other social-ecological systems.

Methods

In a review of the ABM literature studying coupled human and natural systems, An (2012) identified nine primary types of models with their own assumptions about human decision making. These included: assumption based rules, evolutionary programming, empirical rules, preference based decisions, participatory based, institutional based, cognitive, space theory, and microeconomic based models. This ABM does not fall strictly into any of these categories, but rather combines several to create the framework where agents make decisions within the social-ecological system. Specifically, the model is institution based at its core, and assumes that agents make Mikania management decisions based on the associated norms, but it also incorporates cognitive elements. As An (2012) notes, institutional based models are almost inseparably linked to cognitive based models. The model is also informed by

ethnographic fieldwork. The agents in this model represent households distributed on a virtual landscape.

Model overview.

An overview of the model setup and processes is presented here; more detailed information is provided in the Overview, Design elements, and Details (ODD) protocol (An et al., 2014; Grimm et al., 2006, 2010) in Appendix D. The model was implemented using NetLogo (version 5.3.1) (Wilensky, 1999). NetLogo is an open source agent-based modeling platform. One of its disadvantages is its lack of advanced features found in other ABM platforms such as Repast. However, NetLogo has been praised for being user friendly and includes both extensive documentation and a large user community (Brown et al., 2005).

Set up.

There are two distinct, interacting elements within the model: the landscape and the agents. Within the model, the agents represent households that make individual decisions regarding Mikania management. The model can be initialized with between 100 and 1000 agents; all simulations analyzed here were initialized with 100 agents. The agents are aware of their geographic location (in NetLogo, their patch ID), their own features, and the environment (Mikania cover in their patch and the patch's productivity value). Agents are randomly placed on a landscape composed of individual spaces, called patches in NetLogo, and each patch represents one $5ft^2$ plot within a forest. The landscape is represented by a two dimensional grid, consisting of 1024 patches. Each patch has a randomly assigned corresponding 'productivity value' ranging from 0 to 1, where 0 represents highly degraded land or land that is otherwise useless to an agent.

Each patch additionally has an initial 'Mikania cover' value, ranging from 0 to 1, that represents the percent of the patch that is populated with Mikania. The landscape can be setup with a gradient of Mikania cover, with groups of patches initially ranging from 0 to 75 percent cover (0 to 0.75), or with a random distribution of Mikania cover, with each patch randomly assigned a cover value. Conversations with ecological experts working with Mikania data in Chitwan indicated that a gradient of cover more accurately reflects the actual distribution, so it is used as the basis for all analyses presented and discussed in this research. As the goals of this model are theoretically driven, topographic and land use data is not incorporated at this time. Although useful for policy decisions, the use of such data can restrict the interpretation of a model; the model risks becoming more about the particular conditions and less about the processes being studied (Gimblett, 2002).

The agents are initialized with several values, including a random 'value-threshold' (representing in part the value an agent places on Mikania removal for altruistic reasons) ranging from 0 to 1 used in the rational choice sub-model; see the ODD protocol in Appendix D for details. After setup procedures are completed, the model completes procedures to 'remove Mikania' and 'redistribute Mikania'; the latter changes Mikania distribution (i.e. Mikania in a given patch may change) based on a rate of increase, which is explained below. In order to manage Mikania (the 'remove Mikania' procedure), agents enter the rational choice or cultural diffusion sub-models, depending on which sub-model the model analyst has selected (the cultural diffusion and rational choice sub-models are independently processed).

Rational choice.

In the 'rational choice' sub-model (figure 5.1), an agent enters a cost-benefit analysis to adopt a Mikania management strategy. These are outlined in table 5.2. Each agent's 'value-threshold' is intended to allow agents to evaluate their management decisions considering more than time cost and can be thought of as including preferences such as altruistic actions or consideration of other responsibilities such as children. If an agent engages in removal, they remove Mikania from their current location and Mikania changes. The rate of change of Mikania cover in their patch depends on the 'initial amount removed,' which can be altered for sensitivity analysis in the model. In table 5.2, the cost associated with each strategy is accurately ranked based on qualitative fieldwork. However, the removal cost, in terms of time and personal effort, is essentially an ordinal variable- the ordering is accurate, but the distance between the numbers (i.e. how much costlier it is to conduct mechanical removal versus burning) is unknown. Because of this, a sensitivity analysis is conducted to explore the impact of different costs for each strategy, while maintaining the ranking of the costs (Appendix D). See Yang and Gilbert (2008) for a conversation on parametrizing qualitative data.

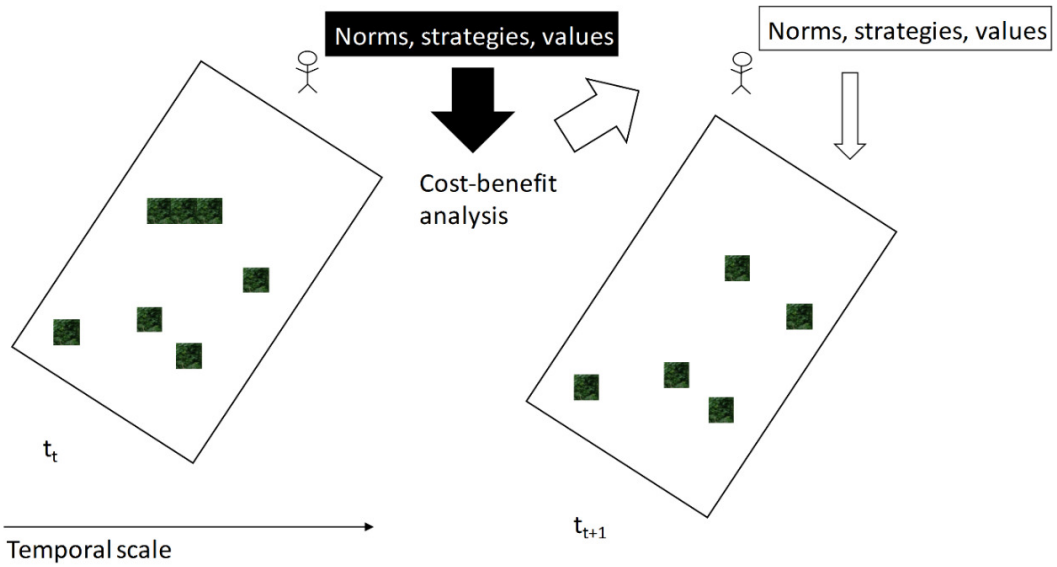


Figure 5.1. A simplified conceptual view of the rational choice sub-model. Mikania cover (the small squares) in the forest changes over time based on changing removal norms and strategies in each model. In this sub-model, agents engage in a cost-benefit analysis to adopt and change removal strategies over time.

Table 5.2. Mikania management strategies and costs for the rational choice sub-model

Management strategy	**Cost[1]**
Do nothing	0
Mechanical removal (pulling)	0.3
Pulling and burying	0.35
Burning	0.2
Best practice*	0.5

*The best practice, or most effective, removal method is thought to be mechanical removal, followed by bagging all of the plant parts, and burning them. This hypothesis will be confirmed or rejected with forthcoming ecological data from Chitwan.

Cultural diffusion.

The second sub-model agents can enter to make Mikania management decisions is 'cultural diffusion' (figure 5.2). This sub-model is a modification of the "Diffusion of Culture" model from open ABM implemented by Sergi Lozano and Michael Maes (Lozano & Maes, 2008) and based on Axelrod's (1997) article. Here, agents each have a set of norms, strategies, and values represented as a randomly assigned string of length n (n ranges from 1 to 20). Each of these traits has m possible features (m ranges from 1 to

20). For example, one of the traits is modeled as ‘Mikania removal strategies’ (table 5.3). This trait can take on five possible values, represented by 0, 1, 2, 3, or 4. Thus, each agent has a string of numbers, of length n; some agents may have identical strings, but most differ by some random degree. In this modification of the model, the first feature is defined as ‘Mikania removal strategy’ and the other features remain abstract representations of other possible norms/values/cultural components. Agents within the sub-model choose to interact with the spatially closest agent based on the similarity of their feature list. If agents are similar, it is possible they will interact. If they interact, they may exchange some of their traits, increasing their similarity. In terms of exchanging heritable, biological elements, this would represent the exchange of genes. The exchange of social elements, such as norms and values, typically occurs via learning or imitation. The “Diffusion of Culture” model investigates a variety of variables that influence how quickly culture homogenizes over time, including a rate of mutation and the inclusion of random interactions. In this modification, the focus is on tracking the impact of the initial percentage of agents with each management strategy. Here again, if an agent engages in removal, they remove Mikania from their current location and Mikania changes (the percent decrease depends on the removal strategy). The rate of change in their patch depends on the ‘initial amount removed,’ which can be altered for sensitivity analysis in the model.

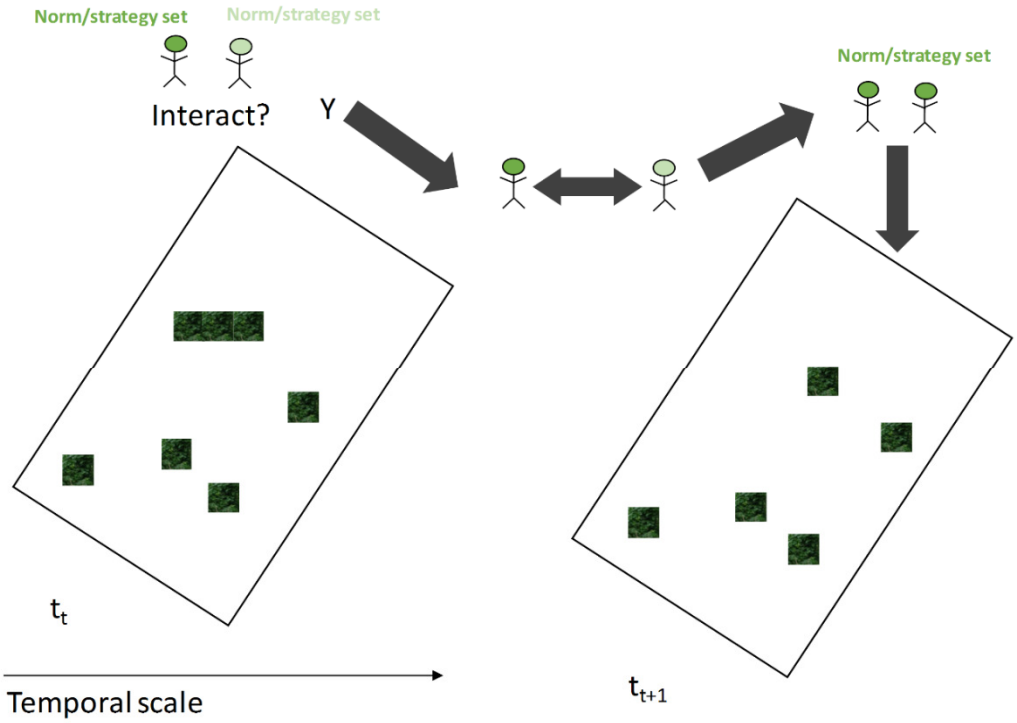


Figure 5.2. A simplified conceptual view of the cultural diffusion sub-model. Mikania cover (the small squares) in the forest changes over time based on changing removal norms and strategies in each model. In this sub-model, agents interact based on the similarity of their set of values/strategies/norms. When agents interact, they randomly exchange some of their shared strategies, leading to changes and homogenization over time.

Table 5.3. Mikania removal strategies and associated feature value in cultural diffusion sub-model

Mikania removal strategy	**Feature value (trait) in model**
Do nothing	0
Best practice	1
Mechanical removal (pulling)	2
Pulling and burying	3
Burning	4

Redistributing the Mikania.

Each Mikania removal strategy is tracked within the model based on an agent's current cost (rational choice) or the value of the first feature (trait) (cultural diffusion). Each removal strategy then corresponds to a specific probability that Mikania will increase and eventually spread into a neighboring patch. For example, engaging in

burning could increase the Mikania cover in a given patch by 10 percent due to seed dispersal. The values for the rate of increase for each strategy were selected based on a combination of literature and expert opinion. The values for the rate of increase were also systematically varied in the model to explore the impact of different rates and can be adjusted as new information is available. When the Mikania cover of a patch is greater than 0.5 (based on expert opinion and sensitivity analysis; see the ODD protocol), the Mikania from that patch spreads to a neighboring patch.

Parameters, validation, and verification.

The model parameters are primarily informed by previous literature and empirical observations from ethnographic fieldwork conducted in Chitwan in 2014. Although most agent-based models are validated using quantitative data, there has been a growing conversation about the importance of incorporating qualitative data into the model creation and validation processes and several authors have assessed agent-based models informed by ethnographic data (Agar, 2005; Dean et al., 2000; Huigen, Overmars, & de Groot, 2006; Yang & Gilbert, 2008). Agent based modeling as a whole relies on intuition and creativity that are developed with experience (Railsback & Grimm 2011). There are a few books and many articles written on the subject of agent based modeling, but they each stress that while it is good science to follow standardized protocols like ODD documentation and some form of model validation and testing, no modeling process is identical and building, refining, and testing a model will be a unique experience. For example, Railsback and Grimm (2011) outline an order for designing, building, and testing ABMs, but they note that these heuristics will not always work and all models may not involve the same steps. It thus becomes vital that a researcher creating an agent-

based model is thorough in documenting the modeling process in an effort to provide other researchers with a replicable study.

Validation of ABMs takes on a variety of definitions in the literature, but can generally be thought of as the process through which models are assessed for either their ability to represent their intended, limited process or their ability to produce outcomes in the "real" world (Zeigler, Praehofer, & Kim, 2000). There is not a singular process for model validation or analysis, and model validation is often difficult (Brown et al., 2005), with several scholars recognizing that models for complex open systems cannot truly be validated (Oreskes, Shrader-Frechette, & Belitz, 1994). Following advice from Railsback and Grimm (2011) and An et al. (2005), model validation included checks for structural validity, including conversations with experts, and a comparison of empirical fieldwork and model output. Verification was an iterative process that included a continuous debugging of the model as it was coded, running extreme value tests (where model responses when parameters were set to extreme values were assessed), and sensitivity analyses (assessing how the model responded to small parameter changes). The results of the extreme value tests and sensitivity analysis largely comply with the qualitative data and field observations (for detail see the ODD protocol in Appendix D).

Additionally, sixteen different scenarios to explore the impact of the percentage of agents adopting the best practice removal method in the cultural diffusion sub-model are explored (table 5.4). These scenarios are designed to test the hypothesis that higher initial percentages of agents adopting the best practice removal method will reduce Mikania, even with burning still occurring. There are four categories of scenarios classified as high, low, or moderate burning. The percentage of agents initially adopting the best

practice management method is then varied systematically, which represents part of a one-at-time sensitivity analysis (ten Broeke, van Voorn, & Ligtenberg, 2016).

Table 5.4. Parameters for cultural diffusion scenarios

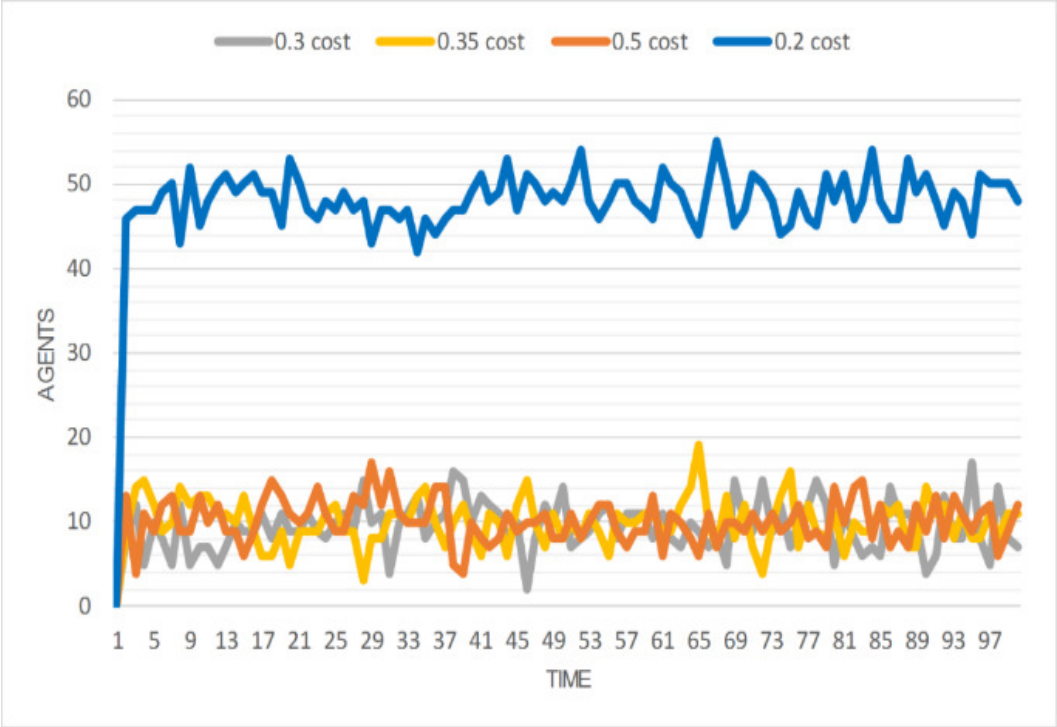
	Initial best practice	Initial burning	Initial pulling
High burning, high mechanical removal	0.05	0.4	0.4
	0.1	0.4	0.4
	0.3	0.35	0.35
	0.5	0.25	0.25
Moderate burning, high mechanical removal	0.05	0.25	0.4
	0.1	0.25	0.4
	0.3	0.25	0.4
	0.5	0.25	0.4
Low burning, high mechanical removal	0.05	0.1	0.4
	0.1	0.1	0.4
	0.3	0.1	0.4
	0.5	0.1	0.4
Moderate burning, moderate mechanical removal	0.05	0.25	0.3
	0.1	0.25	0.3
	0.3	0.25	0.3
	0.5	0.25	0.3

Results

Due to stochastic variables in the model (including agent variables like 'value threshold' and patch variables like 'productivity value'), the results are the averages of 30 model runs. Results from 60 model runs were very similar, so only the averages of 30 runs are presented. Due to the agents' fixed spatial configurations and value thresholds, the model parameters stabilized around 100 time steps; thus, each model was stopped after 100 time steps.

Baseline comparison of rational choice and cultural diffusion.

In each scenario, Mikania gradually decreases over time, but that Mikania decreases more in the cultural diffusion scenario (figure 5.4). In the baseline rational choice scenario, without monitoring or sanctions for engaging in burning, most agents select the least costly management strategy (figure 5.3, top). In the baseline cultural diffusion scenario, very few agents start out with the best practice management strategy, and the numbers do not vary much through the simulation (figure 5.3, bottom). With the initial amount of Mikania removed set to greater than 20 percent, Mikania gradually declines over time. When this parameter is less than 20 percent, Mikania continues to gradually increase over time.



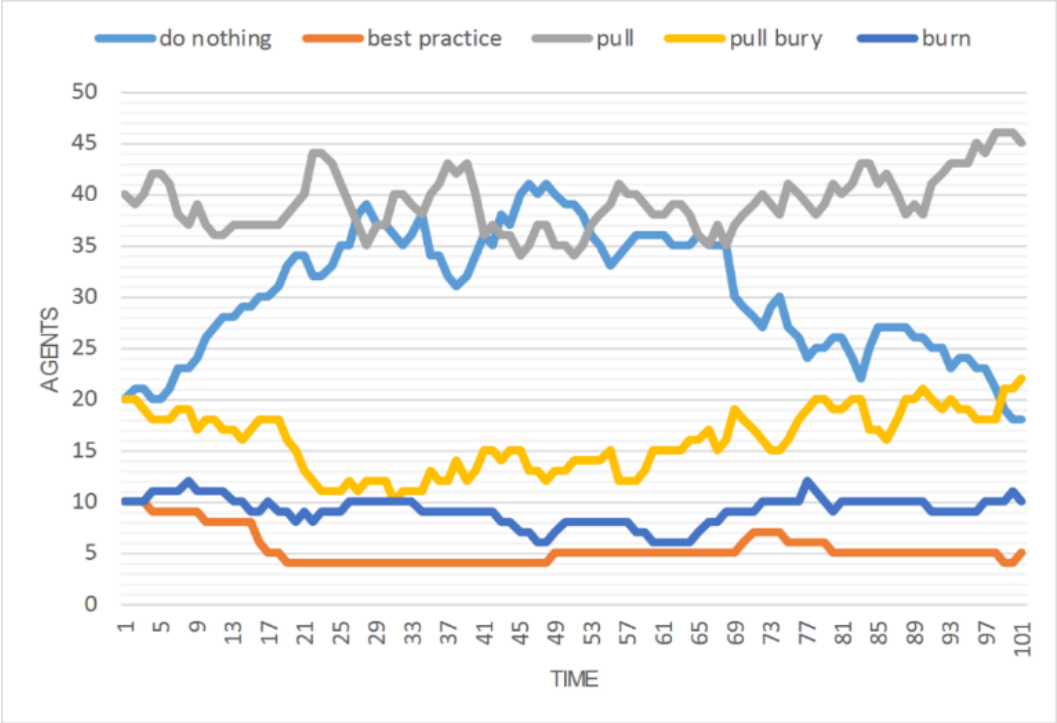
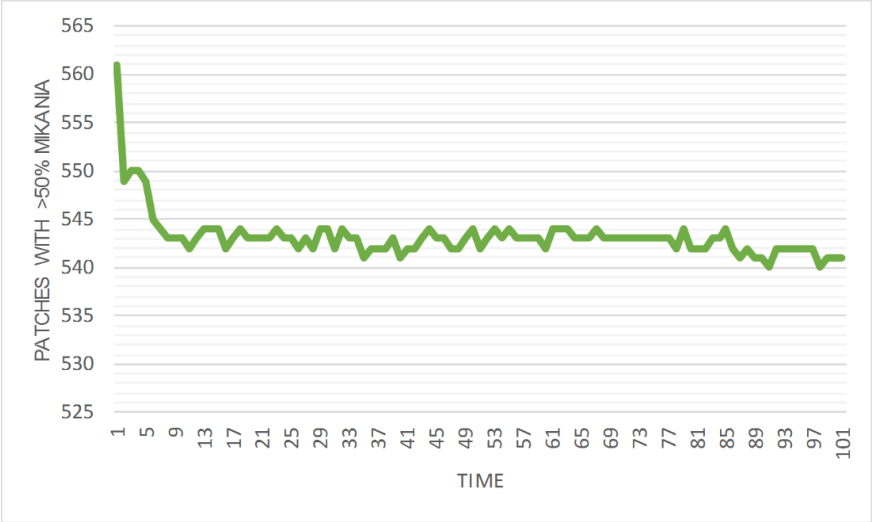


Figure 5.3. Top: change in agents' adoption of Mikania management strategies over time in baseline rational choice model (no monitoring or sanctions for burning). 0.2 is the cost parameter of the least costly method, burning; 0.3 = mechanical, 0.35 = pull and bury, 0.5 = best practice. Bottom: change in number of agents' adopting Mikania management strategies over time in baseline cultural diffusion model.



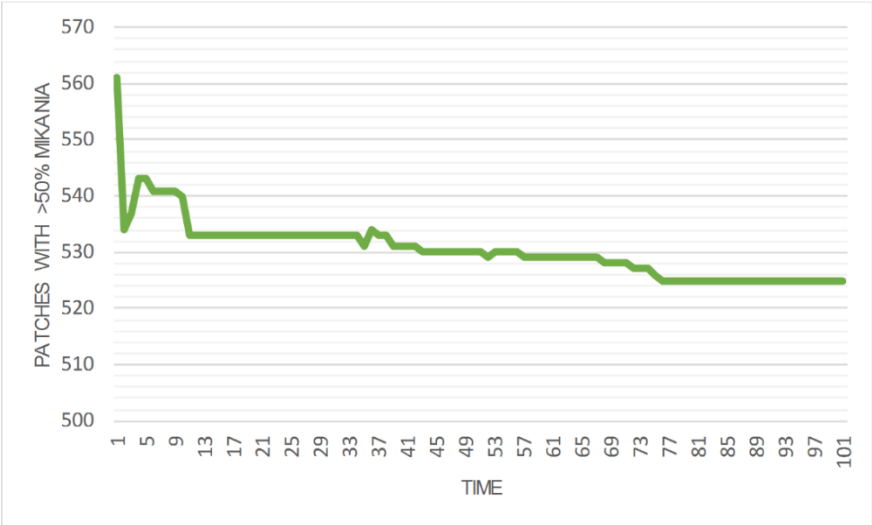


Figure 5.4. Top: change in Mikania over time corresponding to rational choice runs in top of figure 5.3. Bottom: change in Mikania over time corresponding to rational choice runs in bottom of figure 5.3.

Cultural diffusion scenarios exploring the impact of best practice adoption and initial Mikania removed.

The cultural diffusion model enables exploration of the change in management strategies over time when the percentage of agents initialized with the best practice strategy is altered. Each group of scenarios explores how altering the initial percentage of agents with the best practice strategy (5 to 50 percent) impacts Mikania when other

agents pursue different levels of burning and mechanical removal. The first group of scenarios (figure 5.5) sets the initial amount of Mikania removed to less than 20 percent, while the second group of scenarios (figure 5.6) sets the initial amount removed to greater than 20 percent. In the first group of scenarios, Mikania gradually increases over time, while in the second it gradually decreases over time. In all cases, increasing the percentage of agents adopting the best practice method resulted in Mikania either increasing the least or decreasing the most.

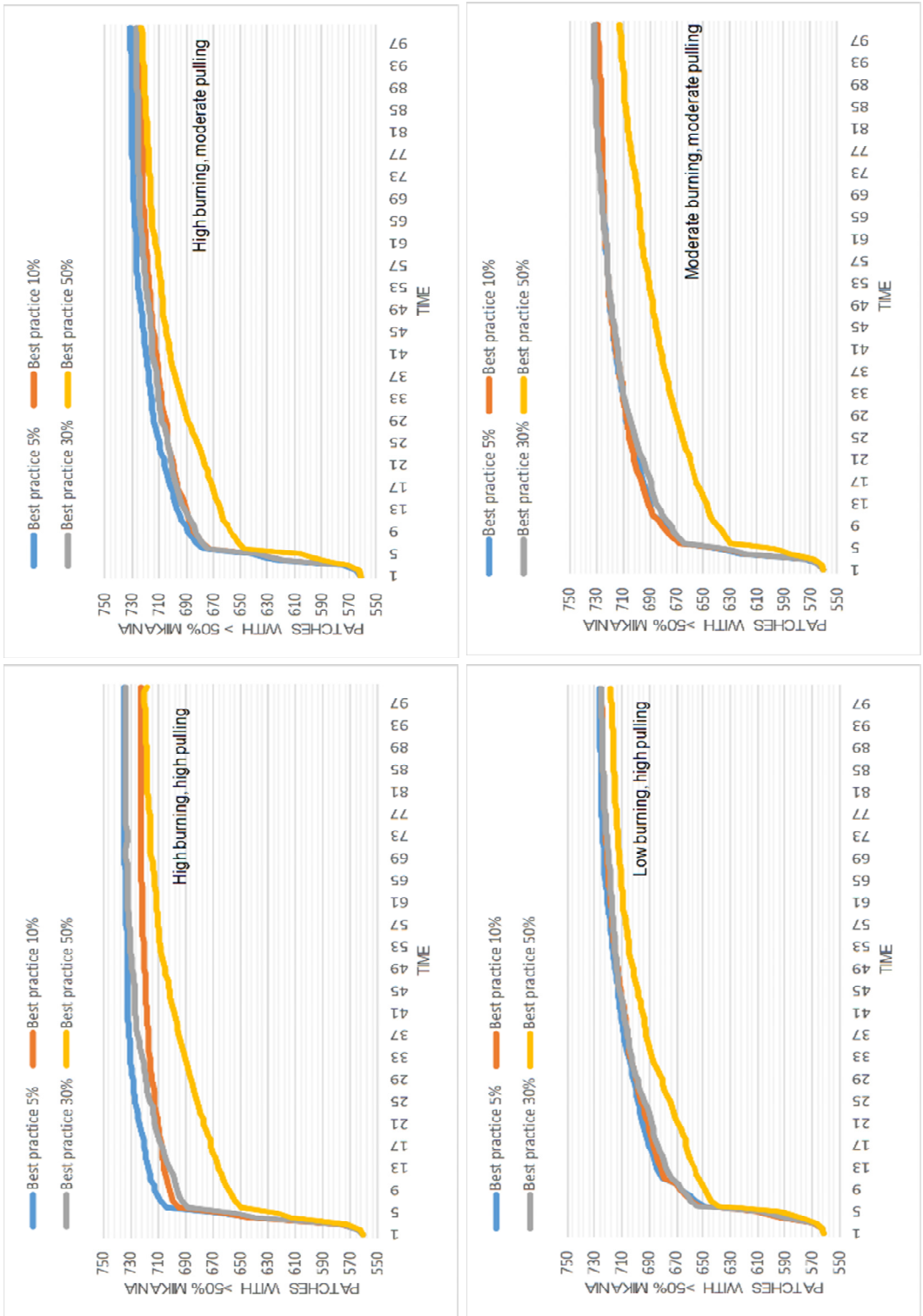


Figure 5.5. Cultural diffusion scenarios with lower initial removal.

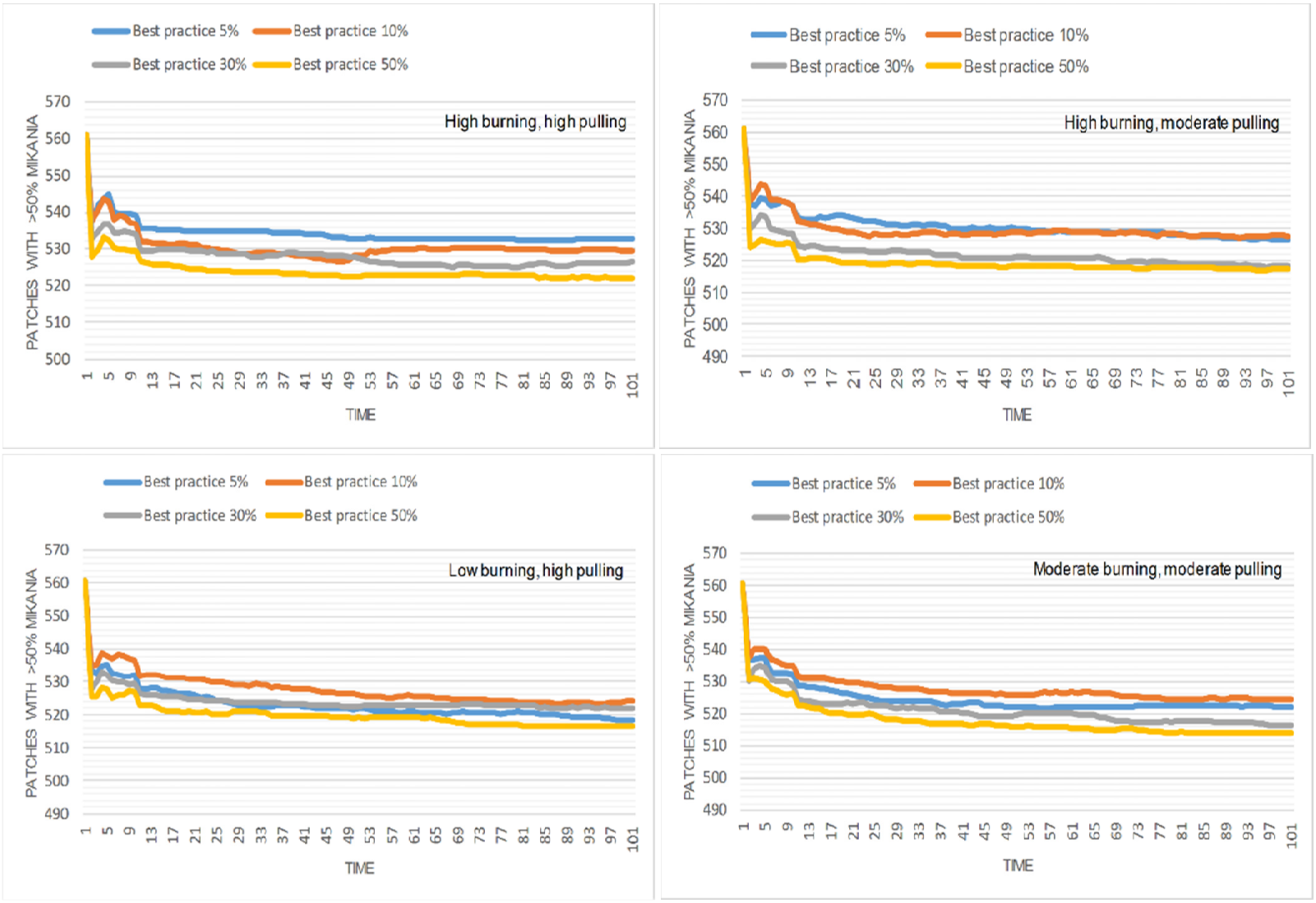


Figure 5.6. Cultural diffusion scenarios with higher initial removal.

Validation.

To understand which of the theoretical perspectives, rational choice or cultural diffusion, most closely represents the situation in Chitwan, qualitative fieldwork conducted in Chitwan and later household surveys that confirm much of the earlier fieldwork is utilized. Fieldwork and an understanding of on-the-ground conditions can be an important indicator of model validity (Yang & Gilbert, 2008). The fieldwork described here was conducted in 2014 and included interviews with over 87 individuals from five case study community forests in Chitwan. The household survey data were collected in 2015 and included 1041 households in the catchment areas of 21 Chitwan community forests.

In the rational choice model baseline, without monitoring or sanctioning for excessive burning, most of the agents adopt the least costly strategy (burning). This is not the case in Chitwan, where only 17 percent of households reported burning Mikania. Based on interviews, discussing burning can sometimes be a sensitive subject as some community forests have rules against burning. Thus, the actual number of households engaging in burning is possibly higher than that reported in the household survey, but it is unlikely the percentage of agents engaging in burning reaches the levels in the rational choice baseline model. With the introduction of monitoring and sanctioning the number of agents adopting the least costly strategy drastically declines. However, regular monitoring and sanctioning for burning does not formally exist in Chitwan community forests. Considering this, and consistent with a large empirical and experimental literature on rational choice and natural resources (see Ostrom, 2005), it is unlikely that the rational

choice sub-model accurately represents how institutional change occurs in Chitwan community forests.

The cultural diffusion perspective presents a more plausible possibility for how management norms and strategies may change over time in Chitwan and other systems facing rapid social-ecological change. In Chitwan, many people reported engaging in collective action to remove Mikania based on their neighbors' decisions or unspoken social norms that required at least one person from a household to participate. This decision making process is similar to the learning and imitation mechanism modeled in the cultural diffusion sub-model. In fact, several recent studies have concluded that most humans do not conform to the rational actor model (Richerson & Henrich, 2012) and that humanity's ability to socially learn and imitate is what has allowed humans to thrive in changing environmental conditions (Mathew & Perreault, 2015). The observation that decision making in Chitwan is often based on social norms and interactions means that cultural diffusion is a possible mechanism for institutional change in Chitwan, but it does not confirm that cultural diffusion is the actual or only way institutions will change over time. I believe comparison of the cultural diffusion model with other theories of institutional change is an interesting and vital step for understanding institutional change in future work.

It is difficult to validate models with outcomes that may change and occur over very long time scales, such as institutional change. Although this continues to be an issue for ABMs (Bithell and Brasington 2009), even models that are difficult to validate provide insights for future theoretical work, a discussion point for stakeholders, and can inform future policy-oriented conversations and modeling efforts.

There are several opportunities for further validation in the future. One option includes engaging stakeholders in role playing games and organized conversations about model assumptions (Castella, Trung, & Boissau, 2005; Janssen & Ostrom, 2006). Such information about perceptions of model validity from people in the system being modeled can be critical in understanding and validating key model assumptions and for thinking about different ways to model and compare different mechanisms for institutional change. Another area for future work is pattern oriented modeling. Pattern oriented modelling (POM) (Grimm et al., 2005) is one method to create models representative of the systems they model. Railsback and Grimm (2011) describe POM as "…the use of patterns observed in the real system as the additional information we need to make ABMs structurally realistic and, therefore, more general and useful, scientific, and accurate" (p. 227). POM is fundamentally based on the "standard" scientific method involving creating models that can largely reproduce patterns. An ABM can be pattern oriented by creating a model that produces real world pattern-like outcomes; this is especially necessary in models that are intended to support decision making. Statistical analyses can also be useful in pattern oriented modeling for determining patterns to be analyzed within the model, but often important patterns are qualitative in nature (Railsback & Grimm, 2011). Thus, further qualitative fieldwork could inform POM efforts.

Discussion

The model assessed here explored how agents initially selected Mikania management norms and strategies, and how these changed over time, via two different theoretical mechanisms of decentralized institutional change. The model contributes the ability to make these dynamics of institutional change trackable and easier to explore,

understand, and manipulate. The cultural diffusion perspective supported exploration of how institutions gradually shift over time in response to changes in sets of shared norms, strategies, and values based on meetings with other similar agents (figure 5.3, bottom; figures 5.5 and 5.6). The rational choice perspective demonstrated institutional change subject to agents seeking to maximize their benefits and reduce their costs, considering their preferences (figure 5.3, top). The model results from each of these perspectives are largely intuitive based on common pool resource, cooperation, and economics literature but the computational approach enabled simultaneous comparison of these perspectives in a generalizable manner. Somewhat counterintuitively, the model also shows that the initial percentage of agents adopting the best practice, or most efficient, Mikania removal method is not as important in reducing Mikania spread as the initial amount of Mikania removed.

In this discussion, the results are first explored from the rational choice and cultural diffusion sub-models, noting the major implications for each. Finally, the concept of institutional fit and other implications are examined.

Rational choice.

Many of the results from this sub-model are intuitive from previous research. In particular, the finding that the majority of agents select the least costly common pool resource management strategy (here, burning Mikania) is consistent with utility-maximizing agents engaging in a cost-benefit analysis (figure 5.3, top). Only agents with a high value-threshold (reflecting variations in preferences and values) will adopt a method that is personally costly to them. When well known institutional design principles are incorporated, such as monitoring and sanctions (here, an ‘excessive burning fee’ that

is not shown graphically in the results), the number of agents engaging in burning as a management strategy decreases. Thus, consistent with the commons literature, one way to have agents adopt management practices that reduce the spread of Mikania, but are more personally costly, is to implement monitoring and associated sanctions (Anderies, Janssen, & Ostrom, 2004).

Cultural diffusion.

Here, the goal was to explore institutional change via multiple experiments where the initial percentage of agents adopting the best practice management strategy was adjusted (figures 5.5 and 5.6). One of the main findings from the scenarios is that agents' adoption of the best practice removal strategy does result in Mikania declining or increasing the least, but the initial amount of Mikania removed from a patch is more important in determining whether Mikania decreases or increases over time. In the context of Chitwan and Mikania, a major challenge to successful removal is that the current organized collective management covers relatively small areas of the forests. The importance of the initial amount of Mikania removed indicates that successful management may include removing more Mikania in a given area at once, while additionally expanding the forest area covered in removal efforts to reduce the amount of Mikania that reoccurs in previously cleared areas.

The results also indicate that ecological factors may be driving the continued Mikania invasion more than human ones. Even with half of the agents initially adopting the best practice removal method, Mikania can still increase over time depending on the initial amount of Mikania removed. While the initial amount removed is a human

controlled factor, it may be very difficult to increase removal efforts due to the associated time costs.

Institutional fit and introducing new management information.

In cases where there are historical norms that exacerbate a newer social-ecological disturbance, implementing best practices for common pool resource management like monitoring and sanctioning may not be effective. In Chitwan, the norm of burning for other reasons (i.e. traditional agricultural or forest management practices) is long standing (Nagendra, 2009), but unintentionally aids in Mikania dispersal (Murphy et al., 2013; Ram, 2008). Because of the relative ease of burning in terms of labor/time compared to other management options, some agents still opt for this strategy even when monitoring and sanctioning are introduced, which contributes to Mikania's continued spread. The case of fit between existing institutions and current social-ecological challenges has been previously addressed (Dietz, Ostrom, & Stern, 2003; Folke et al., 2007; O. Young, 2002), with the conclusion that institutions need to change and evolve in order to sustainably govern the commons. In these cases, the introduction of outside information may be useful in supporting such governance and change.

In the case of Chitwan and Mikania, people engage in burning both because it is a less costly strategy, but also because they believe it will have some level of success in removing Mikania. As Mikania is a relatively new disruption, many households lack access to information on effective removal. Even local community forest management committees do not always hold this information. Thus, as new disturbances appear as global climate and social structures continue to change, natural and common pool resource management situations may require increased access to new knowledge coupled

with best practices. Introducing new information to communities that are managing their own natural resources, particularly in communities with large populations of indigenous people, may not always be welcome due to past experiences with colonialism, paternalistic knowledge imposition, and the disrespect of local ecological knowledge (Davis & Wagner, 2003; Gratani et al., 2011; Mazzocchi, 2006; Nightingale, 2005). Thus, the information provider, an outsider versus a community member, is important (Nightingale, 2005). It is also important that the community desires outside information or assistance with assuaging a disturbance or the information provided is unlikely to be welcomed or utilized. When exogenous institutions are imposed, they may crowd out the community's intrinsic environmental motivation to manage a resource sustainably When endogenous, participatory management norms, established at least in part by community members, are in place, intrinsic environmental motivation may allow the community to more successfully manage their natural resource (Vallino, 2014). This is important to consider in the context of Chitwan when introducing a new "best practice" management method.

Overall, the model indicates that future attempts to catalyze institutional changes through a centralized, intentional process should consider implementing incentives for switching to the newer "best practice" management strategy. The result that implementing monitoring and sanctions allows burning to continue indicates that switching to the best practice method is not a problem necessitating increased enforcement and sanctioning, but rather a "carrot" problem, requiring greater incentives to encourage the switch. This is an interesting finding that merits further research, as previous studies have found that punishment and rewards can work together to maximize

cooperation in some cases (Andreoni, Harbaugh, & Vesterlund, 2002), although users will frequently choose implementing rewards systems over punishments (Sutter, Haigner, & Kocher, 2010).

Further, institutions could change over time due to the introduction of new institutions, or the shifting composition of existing ones, via migration processes. Migration is an important part of the history of the Chitwan Valley, with new migrants regularly entering and others immigrating to nearby countries to send remittances back to family members (Bohra & Massey, 2009; Massey, Axinn, & Ghimire, 2010). The introduction of new norms and strategies via migration is a process that could be explicitly modeled in future efforts.

The press of Mikania, resilience, and the role of ABMs.

The invasion of Mikania represents a press disturbance in that it has invaded over a long period of time and the changes resulting from the invasion have accumulated and will continue to accumulate over years. Press disturbances may contribute to pulse disturbances, which occur over a short period of time (either once or reoccurring) and are often catastrophic (Arens & West, 2008). For example, climate change is a press disturbance, but catalyzes pulse disturbances (like natural disasters or hospitable environments for invasive species).

Press and pulse disturbances are often evaluated in the context of the resilience of a system (Berkes, Colding, & Folke, 2003; Collins et al., 2011). The more difficult it is to alter the functions of a system and shift it out of its current state when faced with disturbances, the more resilient the system is said to be (Holling, 2001). From an anthropocentric perspective, when people within a system decide that the function of

their current system is desirable, it is also likely desirable to create and maintain resilience within that system. Sustainability and resilience are often linked because creating a sustainable system can be aided by understanding the current state of the resources in the system and how those resources respond to changes, such as press and pulse disturbances. Agent-based models have been implemented to understand mechanisms of resilience in natural resource management, exploring how different types of management respond to changes in factors like information and level of resource availability (e.g. Schlueter & Pahl-Wostl, 2007). Creating and maintaining resilience of the corresponding system in the face of disturbances involves increasing adaptability, or the ability of actors in the system to influence resilience by reacting to external and internal system factors (Folke et al., 2010). This concept is similar to increasing adaptive capacity to successfully adapt, but adaptability focuses on the ability to respond to changes to maintain the current state of the system. Adaptability can be increased through stakeholder inclusion and the incorporation of local knowledge (Folke et al., 2010).

Further, resilience can be strengthened by deliberately bringing together stakeholders at different scales, including citizens, local organizations, and government (Walker & Salt, 2006). With more insight into how different institutions might impact the spread of Mikania and the resilience of the system, decision makers can make more informed decisions regarding the structuring of rules. As Andersson (2004) noted, it can be more difficult to change the biophysical elements of a system than it is to work together to redesign institutional elements, such as norms and rules surrounding Mikania management. This is potentially encouraging or discouraging in this case. The model indicates that shifting historical norms and engaging in best practice removal may help

reduce Mikania, but on the other hand, if biophysical elements are playing a greater role in Mikania invasion than people, it may be very difficult to effectively reduce Mikania.

ABMs have played a role in resource management decision making processes in a variety of contexts. For instance, researchers have recently used ABMs to aid policy makers in understanding future scenarios when social and ecological parameters are changed (Matthews et al., 2007). The agent-based model presented here could potentially be one very important element informing future management efforts including understanding how different press and pulse disturbances impact institutional change and Mikania over time. The model was designed so that the parameters could be altered to explore institutional change in other social-ecological systems, but it could also be extended to include more Chitwan specifics (like geographic information systems, social networks, etc.) to attempt to explicitly predict Mikania distribution in Chitwan. Further, agent-based models have also been designed in a process known as companion or participatory modeling where stakeholders are actively involved in structuring the model from the start to increase its structural validity and community relevance (Moss, 2008), which is another potential future research avenue.

Conclusions

In this research, a simple agent-based model was constructed and assessed to explore how two different perspectives of institutional change impacted outcomes in a social-ecological system facing rapid change. Agent-based models can serve as amazing virtual laboratories that simultaneously allow researchers to explore generalizable properties and local implications (Magliocca et al., 2015); they can further the study of different theories of institutional change important to natural resource management that

would otherwise be challenging to observe and assess. Ethnographic interview and observation data was employed to inform an understanding and validity of the two perspectives and it was concluded that (1) it is unlikely the rational choice perspective represents how institutions change in Chitwan over time and (2) it is possible institutional change in Chitwan follows the cultural diffusion perspective, underscoring the importance of social learning in communities faced with variable environmental conditions found to be important in previous research (Mathew & Perreault, 2015). The latter is an important area for further study, especially comparing cultural diffusion to other perspectives of institutional change and exploring the implications of institutional change in other social-ecological systems.

CHAPTER 6

CONCLUSION

This dissertation employed a mixed methods approach to understand how institutions, as the shared, rules, norms, strategies, and values that shape human decision making, mediated social-ecological outcomes in a system faced with rapid change. To explore this concept, I analyzed several components of the management of an invasive plant, *Mikania micrantha*, in community forests in Chitwan, Nepal. Each element of this dissertation contributed a distinct perspective on the role of institutions in social-ecological systems confronting rapid change. Here, I recap the major findings and contributions, and discuss the study's limitations and future directions.

Research Questions and Main Findings

The overarching question that this dissertation investigated was: How do institutions mediate outcomes in social-ecological systems facing rapid changes? Specifically: How do institutions mediate Mikania management and outcomes in Chitwan community forests? Each chapter was guided by related questions that aided in answering the principal questions in greater detail.

In chapter 2, I addressed the following: What actors should de jure be involved in Mikania management and what does Mikania management actually look like de facto, or on-the-ground? Through an institutional analysis employing the institutional analysis and development framework to better understand the participants in Chitwan community forestry and their interactions, I learned that community forest operations in the buffer zone were heterogeneous in their relationships with government and non-government actors. I additionally learned that trust played a vital role in structuring these interactions,

and subsequently, the access each community had to forest and Mikania management information and resources.

In chapter 3, I addressed equity and asked: Who has access to community forest resources? What factors influence community forest membership? Access to resources was conceptualized in terms of community forest membership, while recognizing that there are other ways to obtain forest resources. A hierarchical linear statistical model provided insight into questions of access and I discovered that reliance on the forest resources and ethnicity were two important drivers of community forest membership. These findings were tied to livelihood transitions and Nepal's historical relationships with different ethnicities.

In chapter 4, I investigated collective action, asking: What factors are affecting collective action related to Mikania in Chitwan community forests? Building upon chapter 3, these questions were also addressed with a hierarchical linear statistical model and informed by the equity model results. I found that collective action was also influenced by reliance on community forest resources. Additionally, perception of Mikania invasion as a problem at both the community forest and household levels influenced whether a household participated in collective Mikania management efforts.

In chapter 5, I explored institutional change and asked: How does the adoption of norms and strategies change over time and which theory of institutional change, rational choice or cultural diffusion, better fits empirical observations in the system? The development and analysis of an agent-based model allowed me to explore these two perspectives of institutional change. I discovered that cultural diffusion is a better fitting model for institutional change in Chitwan compared to rational choice. Model results also

supported ethnographic and ecological data indicating that a historical norm for burning (primarily for agricultural purposes) aids in the spread of Mikania even when it is not the dominant removal strategy.

Contributions to the Growing Field of Environmental Governance

This dissertation makes several theoretical contributions to the growing interdisciplinary field of environmental governance (see Lemos & Agrawal, 2006). The overall mixed methods approach (figure 1.9) is generalizable to understand how institutions mediate outcomes from social-ecological challenges in any system. This dissertation has illustrated the unique combination of insights that can be gained via a mixed methods approach; these contributions are outlined here.

Combining institutional and content analyses, I discovered that community forest members had become isolated in dealing with Mikania invasion due in part to a lack of trust between members and other actors. It is my hope that the propositions developed based on these findings will provide insight to both stakeholders engaging in the complicated process of invasive species management and natural resource managers seeking to understand how lack of trust influences management.

In complementary econometric models, this dissertation explored equity and collective action. Institutions and equity have seldom been studied together, especially in a manner that contextualizes quantitative analyses with rich qualitative data. In order to link these two areas of study, I explored the influences on access to resources via community forest membership in Chitwan and discovered that certain ethnic groups are more likely to be excluded from membership and that reliance on the forest resources is

key in joining. These findings were intimately tied to collective action, as I found membership to be an important driver of collective action.

Collective action research has infrequently combined qualitative and quantitative approaches, despite the fact that this approach has the potential to further the generalizability of related findings. Understanding the drivers of collective action in a more systematic way has important implications for many global environmental issues; if stakeholders are equipped with information about who participates in collective action and their motivations, efforts to encourage and increase collective action may become more successful over time. Additionally, the collective action model contributed to the field's understanding of how perception of an issue (in this case, Mikania invasion as problematic or benign) shapes communities' collective action efforts. Enhanced understanding of the drivers of differing perceptions of collective action problems is the next step for such research, which directly ties into climate change and other common pool resource management literature where perception of the issue has been found to be highly influential in collective action success.

The agent-based model presented in this dissertation reinforced previous research, supporting the finding that rational choice seldom represents how people behave in resource management situations. My comparison of two perspectives of institutional change paves the way for future comparisons of the cultural diffusion perspective to other difficult to observe theories of institutional change. Methodologically, the agent-based modeling approach assists researchers in explicitly testing theoretical ideas that are often unfeasible to examine in real time (like institutional change); these models can then be compared with available empirical data from a given system to assess their validity. Such

information can facilitate the examination of alternative paths toward sustainable governance of stressed resources and inform efforts to deliberately change or design institutions.

Ultimately, this dissertation advances environmental governance researchers' understanding of how institutions mediate prominent social-ecological challenges, with my focus being invasive species, and contributes information that may aid stakeholders in addressing such challenges in the future.

Policy Relevance of the Findings

In addition to theoretical contributions, there is an opportunity for the dissertation findings and future work to inform policy efforts in Chitwan and in the broader context of natural resource management. It is important to understand social-ecological systems holistically in order to inform important policy decisions in a variety of contexts (Agrawal, 2014; Ostrom, 2005). The mixed methods approach employed in this dissertation can be utilized with data from other systems to create a multi-dimensional understanding of how institutions are impacting natural resource management options and strategies. This approach could be especially fruitful for policy efforts when combined with participatory research directly involving a specific community.

In this research, I discovered several drivers of collective action in Chitwan. Systematically understanding the motivation behind collective action efforts more generally is a vital part of initiating and sustaining collective efforts to solve a wide variety of human-environment problems globally. In Chitwan, and other cases in the future, the factors that influence collective action could inform policy efforts related to Mikania management. All of the findings presented in this research are a starting point

for discussion related to Mikania management with stakeholders in Chitwan (and potentially communities elsewhere dealing with Mikania), ranging from sensitive topics such as the role of trust in communities to information that could be relevant for long-term planning, such as how strategies for Mikania management may change over time under different conditions. It is important to present any and all of this information as a scientific perspective on these issues, with this perspective being one of several possible traditions of analyzing information and informing management decisions. This research should be interpreted in the context of other information, such as local ecological knowledge and concerns. By considering these equally important sources, stakeholders can decide what information is relevant to their communities and personal definitions of success, and make cognizant decisions based on a holistic view of the issues and options.

Limitations and Future Directions

Chapter 2.

This chapter focused on understanding collective action solely in Chitwan community forest groups. However, Mikania has invaded other forest systems throughout India and China. In the future, I would like to collaboratively explore a cross-site comparison of communities in India and China also dealing with the invasion of Mikania. What generalities could be drawn from these sites and if there are differences in collective action and management success, what drives them?

Additionally, this chapter explored government and non-government actors at multiple levels and ultimately found that the community forest members were primarily isolated in dealing with Mikania. This chapter could have also scrutinized these actors via polycentric governance theory, focusing on how power dynamics differed between the

different levels and if and how this contributed to trust issues; this is an interesting direction for future analyses. Relatedly, there are other natural resource management issues where trust is important (such as resource extraction (e.g. mining) or changing rules for extraction/use). How has trust been fostered in these cases and what are the lowest cost (time, monetary, or other) ways to consistently overcome issues of trust to foster successful natural resource management?

Chapter 3.

This chapter conceptualized equity in access to natural resources in terms of community forest membership, but there are numerous other avenues to approach equity in resource access. For instance, in Chitwan fieldwork provided the knowledge that some households illegally harvest forest resources from the national park. What are the characteristics of households illegally harvesting in the national park and what are their motivations? Are they prohibited from legal access elsewhere? Or does the condition of their community forest or convenience factor into their decisions? Additional ethnographic work could contribute to answering these questions. Institutional analysis in general has seldom incorporated considerations of equity. The creation of a framework for integrating institutional analysis and dimensions of equity, including power and resource access is another future direction. Ideally, such a framework would draw attention to this issue and provide interested researchers a starting point for their own work.

Chapter 4.

The collective action model only included Chitwan data. In order to make generalizable statements about the drivers of collective action, especially in the context of

newer or developing threats like Mikania invasion, it will be important to explore cross-site comparisons and information. Additionally, the model only explored data at the household and community forest level. There are other scales that are potentially relevant, such individuals rather than entire households, that could be included in future efforts.

Chapter 5.

With an agent-based model, there are a seemingly endless number of potential modifications and additions. While Railsback and Grimm (2011) recommend avoiding adding too much complexity to a model due to the increased difficulty of understanding and interpreting its outcomes, there are a variety of future directions for the institutional change agent-based model. First, the most pertinent next step is to implement and compare other perspectives of institutional change and explore different mechanisms of the social learning modeled in the cultural diffusion perspective. There are not currently formal rules regarding Mikania management. It would be interesting to compare the impact of rules and a collective choice (intentional change) mechanism for adopting new management strategies (as opposed to the evolutionary or unintentional change process currently implemented).

The model did not include topographic or land use information to tie the model explicitly to Chitwan's terrain. In the future iterations, movement, migration, and other dynamics could be implemented, especially in the context of participatory or companion modeling, where the model would be developed by working directly with community members to ensure the accuracy of model mechanisms in the minds of people living in the system.

In general, with regard to all of the chapters, there is substantial opportunity to extend the inclusion of and integrate additional ecological data, including information on forest health and other invasive plants. Future efforts could more explicitly incorporate such data to examine its impact on collective action in Chitwan.

Institutions as "Underlying Building Blocks" of Human Behavior?

This dissertation has been devoted to understanding how institutions influence an array of outcomes, ranging from collective action efforts, to resource access via membership, to patterns of Mikania distribution. Institutions have been shown to be important and influential in each of these cases, contributing to the variety of literature supporting the crucial influence of institutions in social-ecological systems. Although institutions are not always the most important or influential factors in understanding human behavior, they frequently play a vital role in a considerable diversity of situations (Ostrom, 2005). In Understanding Institutional Diversity (2005), Elinor Ostrom poses the following questions:

> Can we dig below the immense diversity of regularized social interactions in markets, hierarchies, families, sports, legislatures, elections, and other situations to identify universal building blocks used in crafting all such structured situations? If so, what are the underlying component parts that can be used to build useful theories of human behavior in the diverse range of situations in which humans interact? Can we use the same components to build an explanation for behavior in a commodity market as we would use to explain behavior in a university, a religious order, a transportation system, or an urban public economy? Can we identify the multiple levels of analysis needed to explain the regularities in human behavior that we observe? Is there any way that the analyses of local problem solving, such as the efforts of Maine lobster fishers for the last eighty years to regulate their fisheries…, can be analyzed using a similar set of tools as problem solving at a national level… or at an international level…? My answer to these questions is yes. (pp. 5-6)

Institutions represent these "underlying building blocks" of human behavior in many contexts. It is my hope that this dissertation has contributed to a small part of understanding these building blocks as they pertain to natural resource management in social-ecological systems. It is my goal to continue investigating the role that institutions play in shaping human decision making processes and outcomes in a variety of social-ecological systems, contributing to generalizable science serving successful environmental governance.

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APPENDIX A

INSTITUTIONAL REVIEW BOARD APPROVAL AND INFORMATION

ASU Knowledge Enterprise Development

Office of Research Integrity and Assurance

To:	Scott Yabiku Social Sci
From:	for Mark Roosa, Chair Soc Beh IRB
Date:	03/20/2013
Committee Action:	**Exemption Granted**
IRB Action Date:	03/20/2013
IRB Protocol #:	1303008959
Study Title:	CNH: Feedbacks between human community dynamics and socio-ecological vulnerability in a biodi

The above-referenced protocol is considered exempt after review by the Institutional Review Board pursuant to Federal regulations, 45 CFR Part 46.101(b)(2) .

This part of the federal regulations requires that the information be recorded by investigators in such a manner that subjects cannot be identified, directly or through identifiers linked to the subjects. It is necessary that the information obtained not be such that if disclosed outside the research, it could reasonably place the subjects at risk of criminal or civil liability, or be damaging to the subjects' financial standing, employability, or reputation.

You should retain a copy of this letter for your records.

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Entered IRB:
Initial approval: 3/19/2013
Effective:
Approval end:
Modified: 3/15/2016 8:02 AM

1303008959 : Nepal CNH

Principal investigator: Scott Yabiku
Submission type: Initial Study
Primary contact:
IRB coordinator: Susan Metosky

IRB office: ASU IRB
Letter: None

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Document	Description

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APPENDIX B

DETAILS RELATED TO THE CHITWAN CASE STUDY COMMUNITY FORESTS

Chapter 2 presented an analysis of five selected community forests in the buffer zone in Chitwan, Nepal: Tamur, Ghaghara, Trishuli, Koshi, and Gandaki. These forests represent a mix of ecological types, sociodemographics, and governance capacity; additionally, all were a part of an ecological survey in 2013. The analysis is based on semi-structured interviews with approximately 87 individuals and participant observation in Chitwan, Nepal conducted by Abigail Sullivan and Rajendra Ghimire between May and July 2014. The case study communities are identified solely by pseudonyms (rivers in Nepal) because some information discussed may be sensitive to these small communities.

Summary

Across the five community forests, there is variation in the concern about Mikania, perceived extent and spread of Mikania within the forests, the methods used for Mikania removal (burning, pesticide use), and the organization of community members to deal with Mikania (large groups organized after monsoon, hiring individuals; focused on removal along fence, widespread efforts within the interior of the community forest). There is substantial variation in the collaboration with outside entities, specifically non-governmental organizations (NGOs) and Chitwan National Park. Some communities regularly work with NGOs, while others have little connection. Only one case study forest collaborated with an NGO for an invasive species program. Some communities trust the national park, while others see it as corrupt and unresponsive to community needs. Finally, there is variation in the major problems identified by the community forests: invasive species, human-wildlife conflict, flooding, forest degradation, and pollution.

Interviews

Types of interviewees and general information.

Twenty-five interviews were conducted with community forest user group members. While interviews usually focused on one individual or household, they almost always became group events where neighbors' opinions were given. The interviewee composition was representative of the ethnic composition and educational status of each of the communities. It is possible that Brahmin were under represented in the interviews and that females were oversampled. I under-sampled young women (18-21 years) who were less likely to participate in an interview with males or older females present; additionally, there were fewer young men, as many were overseas. I was able to interview both farmers and non-farmers, but it was very difficult to find people that did not farm in some capacity.

NGOs interviewed.

Interviews were conducted with two conservation-oriented NGOs, both working in Chitwan and with some of the case study communities. They have each worked on Mikania issues, but it is not the focus for either organization. NGO A focuses on Mikania more; NGO B believes the problem is declining. NGO A was very concerned about Mikania and they have several ongoing experiments to determine the best methods for removing Mikania and its optimal growing conditions. NGO B is more concerned about poaching; during the interview, the representative actually asked why Mikania was such a

focus of conversation. NGO B interestingly had presented an educational workshop in Ghaghara to more than 50 people on Mikania and wildlife management, but this was only mentioned by the president of the governance committee. This NGO B program also focused on wetlands management, which several community members mentioned.

Tourism.

Interviews revealed that tourism organizations did not play an important role in any of the five case studies. One case (Tamur) indicated they would like to see more tourism in their community in the future, but none were working with or had contact with outside tourist organizations. Tamur had some Nepali tourists that opted to take elephant tours, providing the community forest governance committee with some extra income. However, tourists that took elephant tours were rare and not a large source of income for the community forest.

Invasive Plants: Mikania, Lantana, and Chromolaena

Mikania.

All of the community forests mentioned invasive species and all mentioned Mikania within their forest, but there was variation in the level of concern. Ghaghara and Trishuli specifically were the most concerned about Mikania. Interviewees discussed how it was affecting grass collection. There was great variation in what the communities were doing to manage Mikania. Interviewees in Trishuli and Gandaki talked about burning for invasive species management, as well as to promote grasslands (note in Trishuli and Gandaki the Presidents denied burning). Cutting and pulling was mentioned in all community forests. Pesticide use was only mentioned in Tamur and Gandaki. Only one interviewee (in Koshi) reported seeing Mikania on their farmland, which was very near the community forest fence. No one else reported seeing Mikania (or Lantana) on their farmland- they have strictly found it in the forest and along the forest fence.
One interviewee (the community forest governance committee president in Ghaghara) reported a group he organizes to remove Mikania uproots it from within the forest and throws it all into the Rapti River.

Lantana.

Interviewees in each community also mentioned the presence of Lantana, but it was not viewed as being as much of a threat or nuisance as Mikania. In Tamur the President was very concerned about Lantana, more so than Mikania, but that was the only interview where Lantana was a bigger concern. The president also talked about how they are trying to entice deer to eat Lantana, although to no avail. On the main road on the way to Tamur, there were men hired by the government to cut Lantana growing along the roadside. They simply cut it with machetes (without pulling the roots up) and left it in piles by the roadside. Some people mentioned not wanting to get rid of Lantana because it has colorful flowers and is aesthetically pleasing.

Chromolaena.

Chromolaena was not mentioned by as many people, or in every community. NGO A mentioned it being problematic to wildlife in the area because they cannot digest it.

Table B.1. Invasive plants present and methods of removal in case studies

	Tamur	Ghaghara	Trishuli	Koshi	Gandaki
Mikania	✓	✓	✓	✓	✓
Chromolaena	✓	✓		✓	
Lantana	✓	✓	✓	✓	✓
Burning			✓		✓
Cutting	✓	✓	✓	✓	✓
Pulling	✓	✓	✓	✓	✓
Pesticides	✓				✓

Governance

Relationships within community forests and levels of trust.

There are numerous relationships among the community forest user group members and the governance committee in each case study. For example, all community forest user group members interviewed reported some level of interaction with the buffer zone committee and many reported indirectly conveying concerns to Chitwan National Park through the buffer zone committee members. The governance committees in each forest communicate with the national park, buffer zone committee, and village development committees about a variety of issues relevant to the community forest. However, there are a few key differences in the case studies.

Collaboration and interaction with NGOs is different in each case. (NGO connections include all NGOs working with the communities, not only ones related to Mikania). For instance, in Trishuli, NGOs are very integrated, interacting with the governance committee, community forest user group members and other user groups, and village development committees. They provide resources like toilets and wells and in some cases provide skills based trainings. Gandaki presents the opposite case, as they have little to no integration with NGOs. Interviewees in Gandaki reported no connections with any type of NGOs.

The strength of the relationships between different groups and individuals within a community forest user group is also different between the cases. For example, community forest user group members in each case have either direct or indirect connections with the national park. However, the level of trust in the national park is very different in each case. In particular, Ghaghara, Koshi, and Trishuli interviewees reported low levels of trust in the national park. Community forest user group members in Trishuli expressed concern that the park officials were corrupt and not sharing enough monetary resources with the buffer zone forests.

Additionally, Gandaki is the only case study with ties to the district forest. They are not registered with the district forest, but because of their proximity to a highway and the district forest office, the district forest occasionally communicates with the community forest governance committee.

Collective action and governance capacity.

Collective action for Mikania removal and management was also highly varied. In Tamur and Ghaghara there were organized efforts to cut and pull Mikania within the forest right after the monsoon for at least the past five years. Trishuli had groups, but they were not centrally organized and were not necessarily only targeting Mikania. Koshi and Gandaki did not organize groups in the past year. Koshi previously had groups that attempted to cut and pull, but because they are not currently allowed in the forest, they are no longer able to organize. Ghaghara paid individuals to pull Mikania along the fence, but it was not a group effort. Ghaghara also hired people to burn (not confirmed by the governance committee), but this was not organized across the community forest.

Major Problems

There was substantial variation in the problems mentioned by interviewees in the different forests. All interviewees were asked about flooding, wildlife, invasive species, and community forest resources. Industrial pollution was mentioned without prompting in Gandaki; in this case three interviewees discussed an industrial facility that had water discharges onto their field. All community forests discussed having lack of community forest resources in some capacity, but in Koshi the forest has been completely shut down except for one collection day a month due to forest health and wildlife issues (rhino attacks). In Koshi, the Nepali army is within the forest and attempting to protect the people from rhinos. The forest is closed because of the wildlife, but also because it is degraded.

Table B.2. Major problems in each case study CF

	Tamur	**Ghaghara**	**Trishuli**	**Koshi**	**Gandaki**
Flooding	✓	✓	✓	✓	
Wildlife: Rhinos	✓	✓	✓	✓	
Wildlife: Elephants	✓	✓			
Wildlife: Tigers		✓			
Wildlife: Deer and boar	✓	✓	✓	✓	✓
Mikania and Lantana		✓	✓		✓
Stressed/Limited CF resources				✓	
Industrial pollution					✓

Interview Details

Table B.3. 2014 interview details

Interviewed:	**Tamur**	**Ghaghara**	**Trishuli**	**Koshi**	**Gandaki**	**Non-CF**
Community forest governance committees (CFGC)	CFGC president, male	CFGC president; 4 CFGC members (all male)	CFGC president, male	CFGC president, male	CFGC president, male	
National park, district forest officials, buffer zone committee						2 Chitwan National Park officials in the Buffer Zone section; male; Brahmin; 2 male officials in the buffer zone committee office
Community forest members	5 individuals as focus of interviews; overall: 10 females, 6 males; female age range: 23-50, male age range: 20-44	5 individuals as focus of interviews; overall: 10 females, 7 males; female age range: 18-45, male age range: 19-57	5 individuals as focus of interviews; overall: 10 females, 10 males; female age range: 20-60, male age range: 20-60	5 individuals as focus of interviews; overall: 6 females, 7 males; female age range: 20-44, male age range: 18-71	5 individuals as focus of interviews; overall: 7 females, 7 males; female age range: 22-50; male age range: 20-60	
NGOs						Officials from two conservation-oriented NGOs. Both male.
Non-family organizations						Tourism organizations were not interacting with the case study forests.

*Interviewees were only counted in the larger sample if they actually spoke during the interview. There were many young women with small children who sat in on the interviews, but did not actually participate.

Table B.4. Historical population and livelihood information (prior to 2005) used to inform the 2014 case study fieldwork described in chapter 2.

	Tamur	Ghaghara	Trishuli	Koshi	Gandaki
Population (households)	341	832	1035	200	1833
Dalit	45	unknown	566	60	550
Janajati	130	unknown	100	60	367
Non-member	unknown	5200	225	25	3000
Notes		Non-member data is likely inaccurate. Large Janajati community			Non-member data is likely inaccurate
Livelihoods					
Percentage with cattle	81-100%	81-100%	61-80%	81-100%	81-100%
Percentage collecting forage	81-100%	41-60%	61-80%	0-20%	0-20%
Grass/fodder (tickets)	341		400	Bidding system	
Grass/fodder (bhari)	8000		35000		
Grass/fodder (days)			60		
Last timber sale year		2009	2006	2008	2009
Timber sale (cubic feet)		1000		200	3125
Fuelwood sale year	2009	2009			
Fuelwood sale (tickets)					2500
Fuelwood sale (cubic feet)		2496			
Notes	Wood sale some years; no timber sale. No data on amounts	Every year have same amount for sale	Highly variable ticket sales/collection days	Timber sales infrequent; no wood sales or tickets	Every year same number of tickets for fuelwood and amount of timber

Historical Population Information

There are big differences in ethnic and caste makeup of the member households, as well as differences in the number of non-member households in the larger community. Trishuli has a large Dalit population (54% of member households), while Tamur (38%) and Ghaghara (based on participant observation) have large Janajati populations. In Koshi and Gandaki, Dalits are approximately 30% of the member household population,

while Janajati are 30% and 20%, respectively. In Trishuli 82% of eligible households are members while in Koshi 88% of eligible households are members. Historical data for Ghaghara and Gandaki are likely underreported, but in Ghaghara 14% of eligible households were estimated as members and in Gandaki 38% were members. Gandaki is much more urbanized than the other areas, so a relatively low membership of 38% may have been accurate, but it is likely that the Ghaghara figures are historically accurate.

Historical Livelihood Information

With regard to livelihoods, most households in these communities own cattle with 81-100% of households in Tamur, Ghaghara, Koshi, and Gandaki and 61-80% in Trishuli owning cattle. There is variation in the reliance of households on the community forest for forage collection. At the low end in Gandaki and Koshi only 0-20% of households collect fodder from the community forest. During an interview in Gandaki, a woman stated she doesn't currently collect forage from the community forest (and hasn't for five years), but she wanted to maintain membership just in case she might need it in future years. In contrast, collection is limited in Koshi because of wildlife conflict and degradation. Currently, Koshi is guarded by the Nepali Army, with troops stationed within the forest to protect the community from rhinos. Because of this resource collection is severely curtailed.

Additionally, in Koshi, the forest conditions are such that the community must rely on external sources of forage because it is unavailable within the forest, which stands in contrast to Gandaki where most people are accessing outside resources even though community forest resources are available. In Ghaghara 41-60% of members collect forage from the forest, in Trishuli 61-80% collect, and at the high end 81-100% of Tamur members collect. During interviews, in Trishuli respondents stated that goats are purposely grazing in the forest to deal with Mikania. In Tamur, respondents indicated there was grazing within the forest, but only along the fence line. Additionally, in Tamur the community members discussed how there were few outside economic opportunities, so households were more dependent on the forest due to their remote location further from urban areas.

Timber and fuel wood sales in these community forests varies, as well. Gandaki has an annual timber and fuel wood sale with 3125 cubic feet of timber sold and 2500 fuel wood collection tickets sold. Ghaghara also has an annual sale with 1000 cubic feet of timber sold and 2496 cubic feet of fuel wood. Tamur has infrequent fuel wood sales, but no timber sales. Trishuli and Koshi have infrequent timber sales.

APPENDIX C

ENGLISH AND NEPALI INTERVIEW GUIDES

Semi-structured interview guide: Governance structures and invasive plant management in five Chitwan community forests

Interview mode: In person

A. Respondent information

Male Female

Age:

Women's user group member: Yes No

Community forest member: Yes No

Governance committee member: Yes No

Governance committee leader: Yes No

Chitwan national park official: Yes No

Other:

B. Interviewer information

Place of interview:

Community forest: Size of community forest: Large Medium Small

Interview date:

Interviewers: Abigail Sullivan and _____

Interview time: Start time: End time: Total time:

Interview number:

C. Mikania and chromolaena invasive plant questions

*Questions may be altered and other questions may be asked depending on the respondent's answers

If respondent is a community member or a governance committee member, continue to question 1. If respondent is a Chitwan National Park official, skip to section D.3.

1. Are you aware of any invasive plant species in your community? What do you think about them?

Respondent viewed them as a problem or negative: Yes No
Species respondent mentioned: Mikania Chromolaena Other:_____

If respondent does not mention any invasive species: Have you heard of Mikania or Chromolaena plants in your community or others?
Do you have a farm? Yes No

If respondent farms: Have you seen these [species they described] in your fields? If so, have you done anything to remove them?

2. Where do you get information to make invasive plant management decisions?

- Have you worked with other NGOs?
  List NGOs mentioned, if any:

- Have you taken part in any educational programs? When did these take place?
  List programs, if any:
  List dates, if any:

- What do you think about these [previous programs taken part in or NGOs worked with]?
  - Do you see these as successful? Why or why not?

If respondent is an individual community member, ask question 3 and continue to question 4. If respondent is a governance committee member, skip to question 4.

3. Has the presence of [any invasive plants mentioned] changed the time you spend looking for forest resources?

Increased time: Decreased time: Time was not changed: Other:

- Has the presence of [invasive plants mentioned] changed any of your habits or goals? For example, do you purchase wood and fodder instead of collecting it?

  Habits changed:

- If the respondent farms: Has the presence of [invasive plants mentioned] impacted your farming decisions? Have the resources you invest in farming changed?
  - If your investment in farming has shifted, what have you shifted these resources to? (For example, education)

4. Have you or anyone in your community organized a group to weed/clear the [invasive plants mentioned]? Yes No

If yes, have you participated? Yes No Other:

Could you estimate how many people participated with you?

If respondent is a governance committee member ask question 5 and continue to question 6. If respondent is a community member skip to question 6.

5. Has your community considered creating wetlands to attract fauna?
   - If so, for what reasons?
   - If not, why? Did the presence of invasive plants in your community contribute to your decision?

6. Have you ever seen or heard of burning or tree cutting in your community forest?
If so, do you know if it was to remove [invasive plant species mentioned] or for another reason?

D. Migration, urbanization, and governance interactions

We just asked you some questions about invasive plants in your community; now we would like to ask a few questions about your community in general.

D.1 Questions for community forest governance leader or members. If community member, skip to section D.2

1. Does your governance committee tend to follow your formal management plan for making management decisions, or do you have other unwritten agreements for management decisions?

2. How do you decide what issues are most important in your community? Do you hold hearings with your community members or do community members bring issues to the committee?

3. What issues have been prominent in your community?

Did the respondent mention: Wildlife dangers: Women's access to resources: Other:

4. Do you interact with Chitwan National Park officials?

If no: Does your community have interest or need to interact with them more?

If yes:

- How do you communicate with them? In person or via email, for example?
- How often do you communicate with them?
- What topics do you usually discuss?
- Do you feel your interactions are frequent enough?

5. Do you interact with the buffer zone committee?

If no: Does your community have interest or need to interact with them more?

If yes:

- How do you communicate with them? In person or via email, for example?
- How often do you communicate with them?
- What topics do you usually discuss?
- Do you feel your interactions are frequent enough?

6. Do you interact with District Forest officials?

If no: Does your community have interest or need to interact with them more?

If yes:

- How do you communicate with them? In person or via email, for example?
- How often do you communicate with them?
- What topics do you usually discuss?
- Do you feel your interactions are frequent enough?

7. Do you interact with the Village Development Committees?

If no: Does your community have interest or need to interact with them more?

If yes:

- How do you communicate with them? In person or via email, for example?
- How often do you communicate with them?
- What topics do you usually discuss?
- Do you feel your interactions are frequent enough?

8. How do you view migrants to Chitwan? Does your community forest accept new members?

9. Has your community forest been affected by increasing urbanization in Chitwan? If yes, how so?

D.2 Questions for individual community members:

1. Has anyone in your household ever migrated outside of Nepal? If yes, why?

- If yes, has your household received additional income?

- Has this additional income changed your perspective of your community forest membership in any way?

2. Has your household been affected by increasing urbanization? If yes, how so?

D.3 Questions for National Park Officials

1. Are you aware of any invasive plant species in the park or buffer zone? What do you think about them?

Respondent viewed them as a problem or negative: Yes No
Species respondent mentioned: Mikania Chromolaena Other:_____

2. Where do you get information to make invasive plant management decisions?
   - Have you worked with other NGOs?
     List NGOs mentioned, if any:

   - Have you taken part in any educational programs? When did these take place?
     List programs, if any:
     List dates, if any:

   - What do you think about these [previous programs taken part in or NGOs worked with]?
     - Do you see these as successful? Why or why not?

Now we would like to ask some more general questions about your interaction with other groups outside your colleagues.

3. Do you interact with any of the community forest governance committee members or leaders?

If no: Does your community have interest or need to interact with them more?

If yes:

- Which community forests do you interact with?
- How do you communicate with them? In person or via email, for example?
- How often do you communicate with them?
- What topics do you usually discuss?
- Do you feel your interactions are frequent enough?

4. Do you interact with the buffer zone committee?

If no: Does your community have interest or need to interact with them more?

If yes:

- How do you communicate with them? In person or via email, for example?
- How often do you communicate with them?
- What topics do you usually discuss?
- Do you feel your interactions are frequent enough?

5. Do you interact with District Forest officials?

If no: Does your community have interest or need to interact with them more?

If yes:

- How do you communicate with them? In person or via email, for example?
- How often do you communicate with them?
- What topics do you usually discuss?
- Do you feel your interactions are frequent enough?

6. Do you interact with the Village Development Committees?

If no: Does your community have interest or need to interact with them more?

If yes:

- How do you communicate with them? In person or via email, for example?
- How often do you communicate with them?
- What topics do you usually discuss?
- Do you feel your interactions are frequent enough?

Thank you for taking the time to participate in this interview.

मानिस तथा सामूदायिक वन व्यवस्थापन बिचको अन्तरसम्बन्धको अध्ययन

क. उत्तरदाता सम्बन्धी जानकारी

क्र.स	उत्तरदाताहरुको नाम	वर्ष/वर्ग	लिé	
			महिला	पूरुष
ज्ञ				
ट्र				
घ				

उत्तरदाता आमा समुहको सदस्य	हो	होइन
उत्तरदाता सामुदायिक बनको सदस्य	हो	होइन
उ.सा.बनको व्यवस्थापन समितिको सदस्य	हो	होइन
उ.सा.बनको व्यवस्थापन समितिको अध्यक्ष	हो	होइन
उ.चितवन नेशनल पार्कको कर्मचारी	हो	होइन

ख. अन्तरवार्ता सम्बन्धी जानकारी

सामुदायिक बनको नाम: _____ ठेगाना _____

अन्तरवार्ता लिएको ठाउ _____

सामुदायिक बनको क्षेत्रफल(साईज) ज्ञ. ठुलो ट्र. मध्यम घ. सानो

अन्तरवर्ता नं. ☐☐☐ अन्तरवार्ता मिति: _____

अन्तरवार्ताकारको नाम: _____

अन्तरवार्ता	शूरु गरेको समय	अन्त भएको समय	जम्मा लागेको सयम (मिनेट)
लिन लागेको अवधि			

ख०८ ग: लहरे बनमारा र बनमारा तथा अन्य मिचाह प्रजातिका बिरुवाहरु

अहिलेको ठीक समय: _____

ग.० अन्तरवार्ता लिनेको लागि: बाहिरी पाना हेरेर चिन्ह लगाउनुहोस्

ज्ञ ☐ उत्तरदाता सामूदायिक बनको सदस्य वा व्यवस्थापन समितिमा हुन्नुहुन्न।

द ☐ उत्तरदाता चितवन राष्ट्रिय निकुञ्जको कर्मचारी हुनुहुन्न ।

→ ख०८ ३ मा जानूहोस्

ग.ज्ञ तपाई तपाईको समुदाय तथा बन जंगलमा पाईने मिचाहा प्रजातिका बिरुवाबाट सचेत हुनुहुन्छ वा सो बिरुवालाई चिन्नुहुन्छ ?

ज्ञ. ५ ☐ ण. ऐन ☐

ग.ज्ञ.ज्ञ ति बिरुवाहरु के के हुन ?

ग.ज्ञ.द तपाईले लहरे बनमारा र बनमाराको बारेमा समुदायमा वा गाउ३र तिर सुन्न भएको ५ ?

ग.ज्ञ.घ तपाईले खेतिपाती गर्नुहून्छ ?

ज्ञ. गर्छु ☐ ण. गर्दिन ☐

ग.ज्ञ.ङ तपाईले लहरे बनमारा र बनमारा गाउ३र तिर वा खेतवारीमा देख्नू भएको ५ कि ऐन ?

ज्ञ. ५ ☐ ण. ऐन ☐

ग.ज्ञ.ज्ञ तपाईले लहरे बनमारा र बनमारा लाई खेतवारी बाट हटाउनको लागी केहि गर्नुभयो ?

ग.द्द तपाईले लहरे बनमारा र बनमारा लाई हटाउनको वा उचित व्यवस्थापन गनू पर्छ भन्ने कूरा कहाबाट थाहा पाउनूभयो ?

ग.द्द.ज्ञ कुनै गैह्सरकारी संस्था संग मिलेर गर्नुभयो कि, अरु कोहि सग मिलेर गर्नुभयो ?

ग.इ.इ गैह्सरकारी संस्थाले गरेको कूनै शैक्षिक कार्यक्रमहरुमा तपाईले भाग लिनु भएको थियो वा ५ ? ५ भने कहिले भाग लिनु भएको थियो ?

कार्यक्रमको नाम	कार्यक्रम भएको मिति
_____	_____
_____	_____

ग.इ.घ गैह्सरकारी संस्थाले गरेको अरु कूनै पनि कार्यक्रमहरुमा तपाईले भाग लिनु भएको थियो वा ५ ? ५ भने कहिले भाग लिनु भएको थियो ?

ग.इ.ङ ति कार्यक्रमहरु सफल भएका थिए कि थिएनन ?

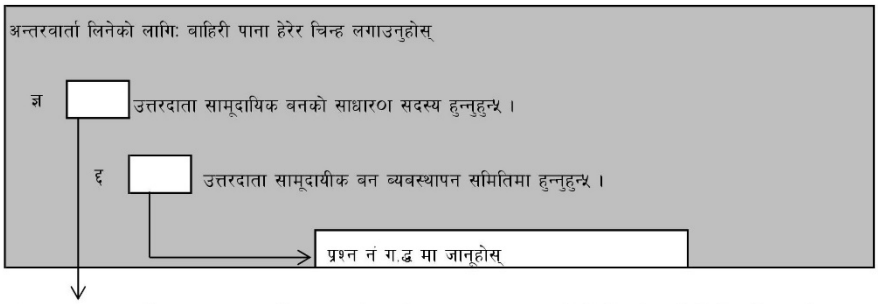
सफल भएका थिए भने, कसरि भएका थिए

_____

सफल भएका थिएनन भने, कसरि भएनन

_____

ग.घ



ग.घ.ज जंगलमा वा सामुदायिक बनमा बनमा मिचाह प्रजातिका विरुवा समय अनुसार बर्ष्रहेको ५ कि, ३ँरहेको ५ कि, उस्तै ५ ?

बर्ष्रहेको ५	३ँरहेको ५	उस्तै ५

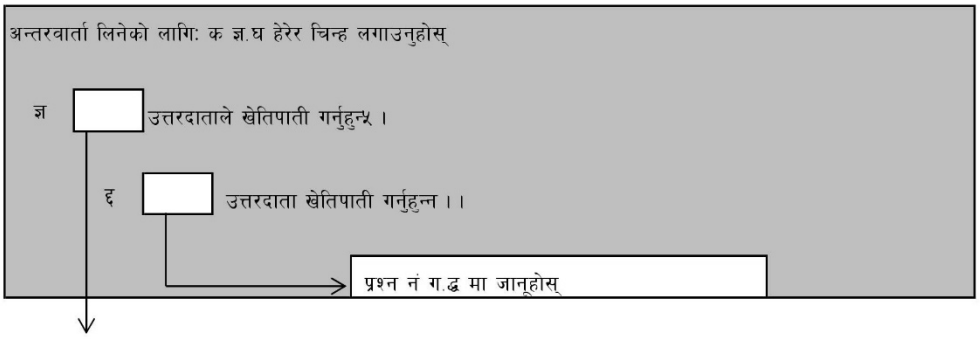
अन्य खुलाउनुहोस् _____

ग.घ.इ जंगलमा वा सामुदायिक बनमा बनमा मिचाह प्रजातिका विरुवा(बनमारा) समय अनुसार बर्ष्रहेको कार्ण तपाईले का७ वा ३ाप्तसपात बनबाट खोजेर ल्याउनुको साधो किन्नु भएको ५ ?

ज्ञ. ५	ए. ग्रैन

ग.घ.इ सामुदायिक वन व्यवस्थापन समितिले समूदायका मानिस संग यहाको समस्याको बारेमा ५लफल गर्ुै ?

ग.घ.घ



ग.घ.ढ तपाईहरुको खेतवारीमा मिचाह प्रजातिका बिरुवाहरु आउनाले तपाईले खेतिपाती नगर्ने निर्ाय गर्नु भएको ५ ? वा खेतिपाती गर्दा लाग्ने खर्च व९ने वा ३६ने (परिवर्तन) भएको ५ ?

ग.घ.छ यदि तपाईले खेतिपातीमा गरेको लगानी अन्त कतै लगाउनु भयो भने के मा लगाउनु हुन्५ ?

जस्तै: शिक्षा, व्यापार आदि

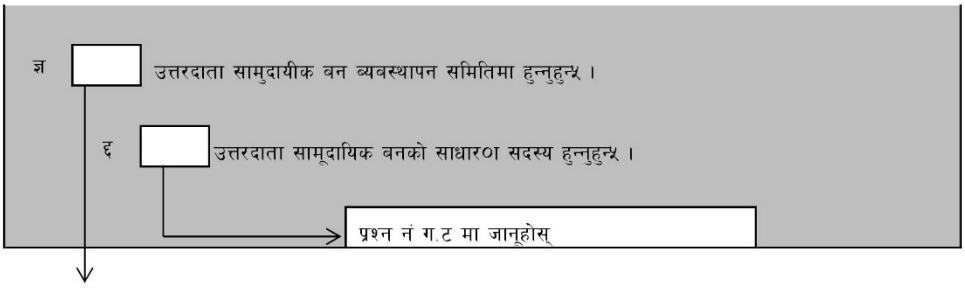
ग.ढ तपाईले, तपाईको समुदायको मानिसहरु मिलेर वनमारा तथा अरु मिचाहा प्रजातिका बिरुवाहरु नियन्त्र०ाका लागी कामहरु गर्नु भएको थियो ?

ग.ढ.ज्ञ तपाई त्यो कार्यक्रममा सहभागी हुनुभएको थियो ?

ग.ढ.इ त्यो कार्यक्रममा तपाईसंग अन्दाजी कतिजना मानिसहरु सहभागी हुनुभएको थियो ?

_____ जना

ग.छ अन्तरवार्ता लिनेको लागि: बाहिरी पाना हेरेर चिन्ह लगाउनुहोस्



ग.छ.ज्ञ तपाईको समूदायले जंगलि जनावरहरुको आकर्ष०ाको लागी जलासयको निर्मा०ा (पानीको पोखरी) बनाउनु भएको ५ ?

ग.छ.ट्र बनाउनु भएको ५ भने, किन बनाउनु भएको होला ?

ग.छ.घ बनाउनु भएको ्रैन भने, मिचाहा प्रजातिका बिरुवाहरुले गर्दा तपाईले सो जलासय नबनाउने नि०ाय गर्नु भएको हो ?

ग.ट तपाईले, कहिल्यै तपाईको सामुदायिक बनमा आगो लगाएको वा रुखहरु काट्देको देख्नु वा सुन्नु भएको थियो वा ५ ?

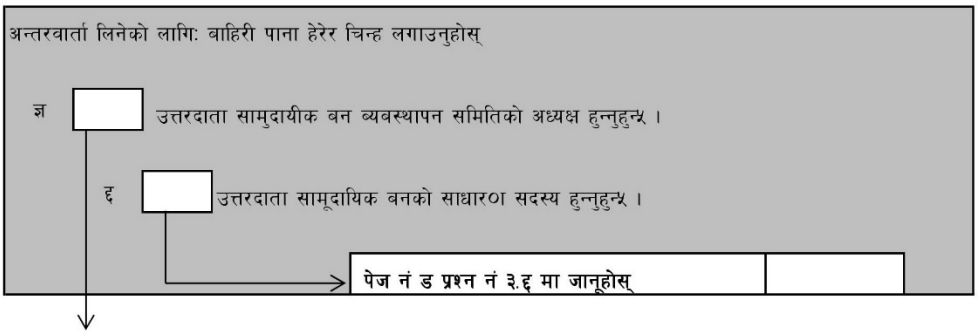
ज्ञ. ५ ण. ्रैन

ग.ट.ज्ञ यदि ५ भने, तापईले थाहा पाएसम्म सामुदायिक बनमा, रुखहरु काट्देको वा आगो लगाएको मिचाहा प्रजातिका बिरुवाहरु नियन्त्र०ा गर्नका लागी हो कि, अरु नै कार०ाले हो ?

ख०८ ३: बसाई सराई, शहरीकर०ा तथा शु(शाषन अन्तरक्रिया

अहिले सम्म हामीले मिचाहा प्रजातिका बिरुवाहरुको बारेमा कुरा गऱ्यौ । अब हामी समुदाय साधार०ा कुराहरु जस्तै बसाई सराई, शहरीकर०ाको बारेमा कुरा गरौ ।

३.ज्ञ



३.ज्ञ तपाईहरुको बन व्यवस्थापन समितिले औपचारीक रुपमा लिखित योजना तथा नि०ायहरु लागु गर्नु हुन्न कि, अलिखित योजना तथा नि०ायहरु लागु गर्नु हुन्न ?

३.ट्ट तपाईहरुको बन व्यवस्थापन समितिले तपाईका समूदायमा भएका कुराहरु कसरी नि०ाय गर्नुहुन्न ? साथै सामूदायीक बनमा साधार०ा सदस्यहरुले समस्याहरु ल्याउन्न ?

३.घ तपाईका समूदायमा भएका मूख्य मुख्य समस्याहरु (कुराहरु) के के हुन ?

जंगलि जनावरको भय

महिलाहरु लाई श्रोत साधनमा अधिकार

अन्य

३.द्ध तपाईले सो को बारेमा चितवन नेशनल पार्कका कर्मचारी संग कुरा गर्नु भएको ५ ?

यदि ्रैन भने

३.द्ध.ज्ञ तपाईको यस समुदायका मानिसहरु चितवन नेशनल पार्कका कर्मचारी संग कुरा गर्न चाहन्न्न वा कुरा गर्न आवस्यक ५ ?

यदि ५ भने

३.द्ध.ङ तपाईहरुले कसरि चितवन नेशनल पार्कका कर्मचारी संग कुरा गर्नु हुन्छ ?

व्यक्तिगत (पियरसन) इमेल, वा अन्य

३.द्ध.घ तपाईहरु चितवन नेशनल पार्कका कर्मचारीसंग कत्तिको कुरा गर्नु हुन्छ ?

३.द्ध.द्ध तपाईहरु चितवन नेशनल पार्कका कर्मचारीसंग धेरैजसो के के बारेमा कुरा गर्नु हुन्छ ?

३.द्ध.छ तपाइलाई चितवन नेशनल पार्कका कर्मचारीसंग को ५लफल पर्याप्त भए जस्तो लाग्छ ?

३.छ तपाइले मध्यवर्ति उपभोक्ता समिति संग कुराकानि गर्नु भएको ५ ?

यदि ९ैन भने

३.छ.ञ तपाईको यस समुदायका मानिसहरु मध्यवर्ति उपभोक्ता समितिसंग कुराकानि कुरा गर्न चाहन्छन वा कुरा गर्न आवस्यक ५ ?

यदि ५ भने

३.छ.ङ तपाईहरुले कसरि मध्यवर्ति उपभोक्ता समितिका कर्मचारीहरु संग कुरा गर्नु हुन्छ ?

व्यक्तिगत (पियरसन) इमेल, वा अन्य तरिकाबाट

३.छ.घ तपाईहरु मध्यवर्ति उपभोक्ता समितिका कर्मचारीसंग कत्तिको कुरा गर्नु हुन्छ ?

३.छ.द्ध तपाईहरु मध्यवर्ति उपभोक्ता समितिका कर्मचारीसंग धेरैजसो के के बारेमा कुरा गर्नु हुन्छ ?

३.छ.छ तपाइलाई मध्यवर्ति उपभोक्ता समितिका कर्मचारीसंग को ५लफल पर्याप्त भए जस्तो लाग्छ ?

३.ट तपाइले जिल्ला वन समिति कार्यलय संग कुराकानि गर्नु भएको ५ ?

यदि ५ैन भने

३.ट.ज्ञ तपाईको यस समुदायका मानिसहरु जिल्ला वन कार्यालयसंग कुराकानि कुरा गर्न चाहन्५न वा कुरा गर्न आवस्यक ५ ?

यदि ५ भने

३.ट.ट्र तपाईहरुले कसरि जिल्ला वनका कर्मचारीहरु संग कुरा गर्नु हुन्५ ?

व्यक्तिगत (पियरसन) इमेल, वा अन्य तरिकाबा६

३.ट.घ तपाईहरु जिल्ला वनका कर्मचारीसंग कत्तिको कुरा गर्नु हुन्५ ?

३.ट.द्ध तपाईहरु जिल्ला वनका कर्मचारीसंग धेरैजसो के के बारेमा कुरा गर्नु हुन्५ ?

३.ट.छ तपाइलाई जिल्ला वन समितिका कर्मचारीसंग को ५लफल पर्याप्त भए जस्तो लाग्५ ?

३.ठ तपाइले गा¤उ विकास समिति कार्यलय संग कुराकानि गर्नु भएको ५ ?

यदि ५ैन भने

३.ठ.ज्ञ तपाईको यस समुदायका मानिसहरु गा¤उ विकास कार्यालयसंग कुराकानि कुरा गर्न चाहन्५न वा कुरा गर्न आवस्यक ५ ?

यदि ५ भने

३.ठ.ट्र तपाईहरुले कसरि ग¤ाउ विकासका कर्मचारीहरु संग कुरा गर्नु हुन्५ ?

व्यक्तिगत (पियरसन) इमेल, वा अन्य तरिकाबा६

३.ठ.घ तपाईहरु गा¤उ विकासका कर्मचारीसंग कत्तिको कुरा गर्नु हुन्¤ ?

३.ठ.ङ तपाईहरु गा¤उ विकासका कर्मचारीसंग धेरैजसो के के बारेमा कुरा गर्नु हुन्¤ ?

३.ठ.छ तपाइलाई गा¤उ विकास समितिका कर्मचारीसंग को ¤लफल पर्याप्त भए जस्तो लाग्¤ ?

३.ड चितवनमा बसाई सराई बारे तपाइको धार०ा के ¤ ? तपाईको सामुदायिक बनले बसाई सराई आउने नया मानिसहरु लाई सदस्यता दिन्¤ ?

३.ढ चितवनमा ब९दै गएको शहरीकर०ाले तपाईको सामुदायिक बनमा असर गरेको ¤ ? ¤ भने कसरि असर गरेको ¤ ?

३.द्द समुदायका सदस्यहरु संग लिने व्यक्तिगत प्रश्न

३.ज्ञ तपाईको परिवारको सदस्य कोहि कहिल्यै नेपाल बाहिर जानुभएको ¤ ? ¤ भने किन जानुभएको हो ?

यदि ¤ भने

३.ज्ञ.ज्ञ तपाईको परिवारको अरु थप आम्दानी हुन्¤ ?

३.ज्ञ.द्द तपाईको परिवारको अरु थप आम्दानीले गर्दा तपाईको सामुदायिक वनको सदस्यता रहने नरहने कूरामा महत्व राख्¤ ?

३.द्द तपाईको परिवारलाई ब९रहेको शहरीकर०ा बा३ असर परेको ¤ ? यदि ¤ भने कसरी असर परेको ¤ ?

३.घ तपाईहरुले सामूदायीका बनको कर्मचारी र नेशनल पार्कको कर्मचारी लाई यहाको समस्याको बारेमा भन्नू भएको ¤ ?

३.घ चितवन नेशनल पार्कका कर्मचारीहरु संग लिने

३.ज्ञ तपाईहरु नेशनल पार्क र मध्यबर्ति बनहरुमा भैएको मिचाहा प्रजातिका बिरुवाहरु (लहरे बनमारा, बनमारा, गाजर झार (पार्थेनीयम) को बारे सचेत हुनुहुन्छ ?

उत्तरदाताले समस्या छ भन्नु भएमा

के बिरुवाले समस्या पारेको छ ?

लहरे बनमारा बनमारा अन्य _____

३.ज्ञ तपाईहरुले मिचाहा प्रजातिका बिरुवाहरु व्यवस्थापन सम्बन्धि जानकारी कहाबाट पाउनु भयो? (लहरे बनमारा, बनमारा, गाजर झार (पार्थेनीयम) को बारे सचेत हुनुहुन्छ ?

३.ज्ञ.ज्ञ यदि अरु गैह सरकारी संस्थासंग मिलेर काम गरेको भए नाम हरु उल्लेख गर्नुहोस् ।

गैह सरकारी संस्था

३.ज्ञ.ट्ट तपाईहरुले मिचाहा प्रजातिका बिरुवाहरु व्यवस्थापन सम्बन्धि शैक्षिक कार्यक्रममा भाग लिनु भयो ?

लिएमा, कहा लिनुभयो

त्यस्ता कार्यक्रमहरु सफलता पुर्वक सम्पन्न भएको देख्नुभयो ?

कार्यक्रम सफल भएमा पनि कसरी भयो? नभएमा कसरी भएन

हामी तपाई सग केहि साधार०ा यसैसंग सम्बन्धित केहि प्रश्नहरु सोध्न गैरहेका छौ । तपाईले कुनै सामुदायिक बन भन्दा बाहिरका अरु अन्य समुहहरु संग कत्तिको कुराकानी वा छलफल कत्तिको गर्नुहून्छ त्यो कुरा सोध्न चाहन्छु ।

३.घ तपाइले सामुदायिक बन व्यवस्थापन समितिको सदस्य वा अध्यक्षसंग कुराकानि गर्नु भएको छ ?

यदि ऐन भने

३.घ.ज्ञ तपाईको सग समुदायका मानिसहरु सामुदायिक वन समिति सदस्य वा अध्यक्ष हरु कुराकानि गर्न चाहन्छन वा कुरा गर्न आवस्यक ५ ?

यदि ५ भने

३.घ.इ तपाईहरुले कुन सामुदायिक वन समिति सदस्य वा अध्यक्षसंग कुराकानी गर्नु भएको थियो वा ५ ?

व्यक्तिगत (पियरसन) इमेल, वा अन्य तरिकाबाट

३.घ.घ तपाईहरु सामुदायिक वन समिति सदस्य वा अध्यक्षसंग कत्तिको कुरा गर्नु हुन्छ ?

३.घ.ङ तपाईहरु सामुदायिक वन समिति सदस्य वा अध्यक्षसंग धेरैजसो के के बारेमा कुरा गर्नु हुन्छ ?

३.घ.घ तपाइलाई सामुदायिक वन समिति सदस्य वा अध्यक्षसंग को ५लफल पर्याप्त भए जस्तो लाग्छ ?

३.ङ तपाइले मध्यवर्ति उपभोक्ता समिति संग कुराकानि गर्नु भएको ५ ?

यदि ऐन भने

३.ङ.ज्ञ तपाईं मध्यवर्ति उपभोक्ता समितिसंग कुराकानि कुरा गर्न चाहनु हुन्छ वा कुरा गर्न आवस्यक ५ ?

यदि ५ भने

३.ङ.इ तपाईहरुले कसरि मध्यवर्ति उपभोक्ता समितिका कर्मचारीहरु संग कुरा गर्नु हुन्छ ?

व्यक्तिगत (पियरसन) इमेल, वा अन्य तरिकाबाट

३.ङ.घ तपाईहरु मध्यवर्ति उपभोक्ता समितिका कर्मचारीसंग कत्तिको कुरा गर्नु हुन्छ ?

३.ङ.ङ तपाईहरु मध्यवर्ति उपभोक्ता समितिका कर्मचारीसंग धेरैजसो के के बारेमा कुरा गर्नु हुन्छ ?

यदि ५ भने

३.ट.इ तपाईहरुले कसरि गा¤उ विकासका कर्मचारीहरु संग कुरा गर्नु हुन्५ ?

व्यक्तिगत (पियरसन) इमेल, वा अन्य तरिकाबा६

३.ट.घ तपाईहरु गा¤उ विकासका कर्मचारीसंग कत्तिको कुरा गर्नु हुन्५ ?

३.ट.ङ तपाईहरु गा¤उ विकासका कर्मचारीसंग धेरैजसो के के बारेमा कुरा गर्नु हुन्५ ?

३.ट.छ तपाइलाई गा¤उ विकास समितिका कर्मचारीसंग को ५लफल पर्याप्त भए जस्तो लाग्५ ?

तपाईहरुको सहयोग र समयको लागी धेरै धेरै धन्यवाद १ तपाईहरुले दिनू भएको जानकारीहरु हाम्रो लागि धेरै महत्वपूर्ण ५न् ।

हवस त अहिलेलाई विदा हून्यू १

"नमस्कार"

अहिलेको ीक समय:

APPENDIX D

OVERVIEW, DESIGN CONCEPTS, AND DETAILS PROTOCOL

Overview

Grimm et al. (2006) are the creators of a protocol that seeks to standardize the description of agent-based models (ABM) and provide a tool with which to think about designing an ABM. Since its inception, the protocol has been widely accepted and applied in both the ecological and social science literatures. It was updated in 2010 (Grimm et al., 2010), but the basic elements of the protocol were largely unaltered. In this appendix, I follow the ODD, with a few modifications and additions for coupled human and natural systems (CHANS) based on An, Zvoleff, Liu, & Axinn (2014), to present a detailed version of the agent-based model presented in chapter 5.

Table D.1. Grimm et al. 2010 Overview, Design Concepts, and Details Protocol

Elements of the ODD protocol		
Overview	1. Purpose 2. Entities, state variables, and scales 3. Process overview and scheduling	
Design concepts	4. Design concepts	
	Basic elements	Adaptation
	Observation	Learning
	Emergence	Sensing
	Objectives	Stochasticity
	Prediction	Interaction
	Collectives	
Details	5. Initialization 6. Input data 7. Sub-models	

Purpose

This model is intended to explore how different institutions, or rules and norms, change over time in a social ecological system facing rapid change. I explore two perspectives of institutional change, rational choice and cultural diffusion, and how these in turn influence a social-ecological outcome. In particular, this model is informed by data from locally governed community forests in Chitwan, Nepal and seeks to understand how shared management norms and strategies influence the spread of a rapidly growing invasive plant, *Mikania micrantha*. The primary purpose of this model is to explore which theoretical perspective of institutional change is most plausible in Chitwan and draw insights about institutional change that are relevant to any social-ecological system facing global environmental changes. Thus, although the model is informed by data specific to Chitwan, I make an effort to keep the model as general and simple as possible such that it can be altered in the future to explore different aspects of the Chitwan system or other social-ecological systems. In line with the theoretical intent of the model I do not incorporate some spatial elements like land use maps and topography that might decrease the generalizability of the model (Gimblett, 2002); this is one avenue for future work. This model is intended to identify theoretically relevant patterns in managing common pool resources facing global changes (like invasive species) and it is my position that such advancements in the theory can be useful in informing relevant future policy and stakeholder conversations.

Entities, State Variables, and Scales

The model is constructed in NetLogo, where spaces are represented as "patches." Agents are randomly placed on a landscape composed of individual spaces, called patches in NetLogo, and each patch represents one $5ft^2$ plot within a forest. The landscape is represented by a two dimensional grid, consisting of 1024 patches (see table D.2 here and "set up" section in accompanying manuscript for more details). I present both patch, agent, and global variables in table D.2.

The lowest level agent in the model is a household and the model can be initialized with 100 to 1000 households, which are randomly distributed on the landscape; the baseline is 100 households. Each patch represents an area of community forest land. The patch can either be highly productive to an agent, or completely degraded. Each patch is invaded by percentage of Mikania, which varies depending on the set up (gradient distribution versus random distribution; see table D.2). Many of the values in the model are abstract and based on logic or literature to explore underlying processes. The ranking/ordering of some of the parameters was determined from ethnographic fieldwork conducted in Chitwan in 2014 (see Yang & Gilbert (2008) for a related discussion). The model runs indefinitely (no stopping condition), but all simulations were stopped after 100 time steps because outcomes stabilized at this point.

Table D.2. Variables included in the model

Variable	Features	Explanation
Agent_removed	Initialized to 0 for every agent	Changes to 1 if agent removes Mikania
Num_HH	100-1000 in increments of 50	The number of agents in the model
Mikania_cover	Patch variable; initialized between 0 and 1	A value of zero corresponds to zero percent Mikania, a value of 1 corresponds to 100 percent of the patch being covered with Mikania.
Only used in cultural diffusion sub-model		
Number_of_regions	Initial value varies depending on number of features and traits selected	An outcome variable; the number of distinct cultural regions currently in the model
Regions_list		A list of identifiers for each region
Closest-person	Equals the closest agent to the current agent based on agents' x and y coordinates	Used to determine who the agent will evaluate if they interact

Feature_nhb		After two agents have interacted, this is used to copy the value of one of the agent's features to the active agent
Overlap		The overlap between two agents, i.e. their similarity. This determines whether the agents will interact and adopt traits
Chosen-feature		The feature that will be adopted by the active agent
New-trait		The feature adopted from the active agent's neighbor
Feature	Initialized as a string of length N (N = 1 to 20; number of traits)	Abstract numerical list of the cultural features (including shared strategies and norms) of each agent
Region_id		The region an agent belongs to
Institution_type	Equals 0, 1, 2, 3, or 4, corresponding to the first item in the feature list	Used to track the management strategy the agent has adopted
Featval0	Equals the value of the first item in an agent's feature list (0, 1, 2, 3, or 4)	Used to model the 5 different Mikania management norms and the change in their composition over time
Number_of_traits	Ranges from 1 to 20	
Number_of_Features	Ranges from 1 to 20	
Mutation_rate	Ranges from 0 to 0.1 in increments of 0.0005	The rate of mutation, via random change in features. Turned to zero for all model analyses; Is an area for future exploration
Random_interaction	Ranges from 0 to 100 percent	Turned to zero for all model analyses; Is an area for future exploration
Only used in rational choice sub-model		
Productivity_value	Patch variable; randomly initialized between 0 and 1	A value of 0 indicates the patch is completely degraded/not useful to the agent; the lower the value, the less likely an agent will remove Mikania from the patch

Value_threshold	Each agent is randomly assigned a value between 0 and 1	Used in the cost-benefit analysis; if the value is greater than 0.5, the agent randomly selects a method other than the least costly method
Removal_cost	Initialized at zero, changes as agents make management decisions	Keeps track of the current management strategy an agent has adopted
Removal_list	List containing the possible Mikania removal costs (0.2, 0.3, 0.35, 0.5)	Each removal strategy corresponds to a cost
Three_removal_list	List containing the Mikania removal costs, less burning	Used when excessive burning fee is implemented (can only be implemented when "monitor_and_sanction_burning?" is turned on); agent selects alternative removal method if engaging in removal
Times_burned	0 when simulation begins; updated after agent burns	Count of times agent has burned; used when "monitor_and_sanction_burning?" is turned on
Num_bp	Ranges from 0 to 1	Slider in NetLogo; used to set the initial percentage of agents employing the best practice strategy
Num_nothing	Ranges from 0 to 1	Slider in NetLogo; used to set the initial percentage of agents not engaging in removal
Num_pull	Ranges from 0 to 1	Slider in NetLogo; used to set the initial percentage of agents employing the mechanical removal strategy
Num_pull_bury	Ranges from 0 to 1	Slider in NetLogo; used to set the initial percentage of agents employing the pulling and burying strategy
Num_burn	Ranges from 0 to 1	Slider in NetLogo; used to set the initial percentage of agents employing burning
Monitor_and_sanction_burning?	True, False	Button in NetLogo. Turns on/off the monitor and sanction burning procedure
Observe?	True, False	Button in NetLogo. Turns on/off the observe procedure; not included in model analysis

Process Overview and Scheduling

Figure D.1. presents a view of the sub-models and scheduling. In each time step, an agent makes decisions about which Mikania management strategy to adopt (including doing nothing). An agent will either enter the rational choice or cultural diffusion sub-model to make this decision depending on which is turned "on" in NetLogo (the sub-models can be

controlled using a "button" in NetLogo. The agents will enter the sub-model (rational_choice? or cultural_diffusion? that is "on"). The agents only enter one of the decision making sub-models at a time. After making management decisions, the next sub-model updates the amount of Mikania in each patch based on the agents' selected strategies.

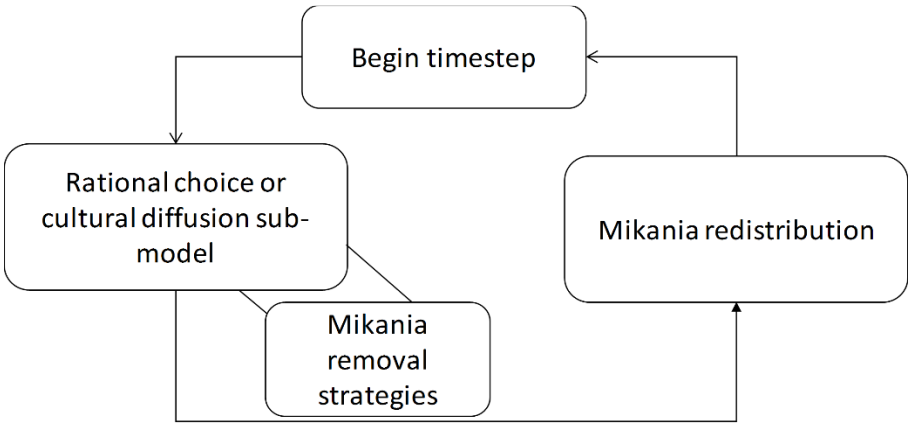


Figure D.1. Processes and scheduling

Design Concepts

Basic elements.

The model draws on theory from common pool resource and collective action literature, as well as literature on cultural dissemination, cooperation, and social learning (An, 2012; Axelrod, 1997; Mathew & Perreault, 2015; Ostrom, 1990). Changes in institutions (shared strategies and norms for Mikania management) influence the amount of Mikania in a given patch, which influences the cost of the agent's actions and future management decisions/institutional change.

Adaptation.

In the cultural diffusion sub-model, agents can adopt another agent's Mikania removal strategy if the similarity of their feature lists equals or exceeds the threshold. Other adaptation could be possible in future models, but is not currently present. For instance, agents can change their behaviors (their selected removal strategy) in response to others and the environment, but the parameters that determine these behaviors are currently fixed. For instance, an agent's "value threshold" in the rational choice sub-model does not change over time.

Observation.

Data are collected for testing and observation using the BehaviorSpace extension in NetLogo (see https://ccl.northwestern.edu/netlogo/docs/behaviorspace.html and https://www.openabm.org/book/3138/how-use-behavior-space). I observe two primary outcomes: the change in Mikania over time and the change in composition of management strategies over time. The model allows for additional observation of other factors including the impact of observation in the rational choice case and the impact of a

mutation rate and random interactions in the cultural diffusion case. However, these are not explored in this analysis of the model.

Emergence.
Changes in the composition of norms and strategies emerge over time based on low-level agent interactions and decisions. The agents' interactions and decisions are governed by the sub-model features, either rational choice or cultural diffusion (see Table 2 and process overview section).

Objectives.
The objective of the agents depends on the behavioral/institutional sub-model. In the rational choice sub-model, an agent's goal is to maximize their utility subject to their own set of preferences (modeled in the value-threshold). In the cultural diffusion sub-model, agents do not seek to maximize an objective; they may adopt other similar agent's strategies and norms on the basis of interactions.

Prediction.
Agents do not use prediction in their decisions.

Learning.
One feature in the rational choice sub-model that is not analyzed in the accompanying chapter is "observation." Agents observe their closest eight neighbors when the "observe" feature is turned on and may change their behavior to the most common behavior. In the cultural diffusion sub-model, the implicit mechanism of exchange of norms and strategies between similar, interacting agents is social learning or imitation.

Sensing.
Each agent knows their own set of preferences in the rational choice sub-model. Each agent is assumed to know the productivity of each patch (the "productivity-value"). These each inform agent decisions in the model. The agents do not know the total amount of Mikania in the world (global information).

Interaction.
In the rational choice sub-model, agents can check the behavior of other agents if the observe or monitor features are turned on. In the cultural-diffusion sub-model, agents have the opportunity to interact with each other at each time step. If they are similar enough, an agent will meet with its closest neighbor and possibly exchange cultural information.

Collectives.
In Chitwan, households belong to a specific community forest user group, but these groups are not explicit in the model. Rather it is assumed that some of the variation in the model (such as the agents' sets of preferences) stems from different institutions within each community forest group.

Initialization
See table D.2 for the values all agents and patches are initialized with. The baseline scenario in the rational choice sub-model does not include the monitor_and_sanction_burning feature. In the cultural diffusion sub-model, the initial percentage of agents adopting each management norm can be systematically altered to explore the impact on outcomes over time.

Input Data
No input data is used in this model.

Submodels
Both the rational choice and cultural diffusion sub-models are theoretically driven and are informed by previous literature. The parameters for the cost of each of the management strategies in the rational choice sub-model were ranked based on ethnographic fieldwork. The model code is thoroughly commented and available at https://github.com/asulli/ABMwork.

CHANS Characteristic Features
Human-environment systems have been known to exhibit features such as time lags, resilience, heterogeneity, and feedback loops (An et al. 2014). This model exhibits resilience to Mikania reduction beyond specific thresholds (once Mikania takes over the world, it is very difficult to remove or control). There is heterogeneity in the management strategies adopted over time. One of the feedbacks observed in the rational choice sub-model includes the relationship between the selected strategy, Mikania redistribution, and subsequent impacts on agents' strategy selection. For example, an agent may select burning as their removal strategy; burning is associated with the highest rate of Mikania increase in the agent's current patch after removal. If an agent continues to select burning as their removal method due to its low cost, the amount of Mikania in the patch will continue to increase and there will be an additional removal cost to the agent in patches with a density greater than 0.5; if the cost of removal becomes greater than the productivity of the patch the agent may decide to stop removing Mikania (a "do nothing" strategy) depending on their "value threshold."

Verification and Validation
Model validation is discussed in the accompanying chapter 5 manuscript and sensitivity analysis and extreme value tests, part of verification, are discussed below.

Simulation experiments and sensitivity analysis.
Below are results from sensitivity analyses and extreme value texts.
Table D.3. Extreme value tests: Rational Choice

Parameters	Default value	Min, Max	Mikania cover: min, max
Initial-people	100	100, 1000	542.3, 1080.7
Monitor_and_sanction_burning?	False	False, True	542.4, 528.5
Observe?	False	False, True	542.3, 541.4

At t=100, average of 30 runs

Table D.4. Extreme value tests: Cultural diffusion

Parameters	Default value	Min, Max	Mikania cover: min, max
Initial-people	100	100, 1000	524.2, 1061.3
Num_bp	0	0, 1	507.8, 524.3
num_burn	0.15	0, 1	527.2, 538.1
Number_of_Features	5	1, 20	546.2, 529.3

At t=100, average of 30 runs

To calculate the sensitivity Sx, below, the following formula was used (An et al., 2005; ten Broeke, van Voorn, & Ligtenberg, 2016):

Sx = (ΔD/D)/(ΔI/I) where I is the value of the independent variable, ΔI is the change in I, D is the value of the dependent variable, and ΔD is the change in D in response to the change in I.

Table D.5. Sensitivity analysis for selected model parameters: Rational Choice

Variable	Default value	Perturbation + 50%	Change in Mikania cover (number of patches with >50% cover)	Sensitivity
Initial-people	100	150	4.6	0.006
Initial-mikania	0.3	0.45	2.8	0.004

At t=100, average of 30 runs

Table D.6. Sensitivity analysis for selected model parameters: Cultural diffusion

Variable	Default value	Perturbation + 50%	Change in Mikania cover (number of patches with >50% cover)	Sensitivity
Initial-people	100	150	1.1	0.001
Initial-mikania	0.3	0.45	1.8	0.002
Num_bp	0	0.05	0.1	0.0001
num_burn	0.15	0.25	2.3	0.003
Number_of_Features	5	8	5.9	0.007

At t=100, average of 30 runs

[1]number_of_features and number_of_traits were rounded to the nearest whole number since half features are illogical