Abstract

Managing social-ecological systems increasingly requires collaboration among diverse teams with a wide range of worldviews and perspectives. Increased attention to the social and cultural factors that shape environmental outcomes is needed for these collaborative teams to function effectively. Mental models are cognitive representations of the external world which guide an individual's thinking, decision-making, and behavior. They are critical elements of collaborative environmental management because they shape our understanding of social-ecological systems, our perceptions of environmental problems, and our preferences for certain management actions. In this paper, we describe an iterative process of constructing and revising mental models at both individual and small group levels over the course of a year in a community-based conservation area in the Ethiopian highlands. We compared mental models of the conservation area from four groups involved in management to identify commonalities and differences in the way people conceptualize the area. While we found high variability in mental models both within and across groups, most participants perceived social, economic, and political variables to be the key drivers of change in this system. Economic variables were also identified as key sensitivities, along with biotic and livelihood variables. However, groups differed considerably in how they thought about relationships between these variables, particularly political and economic variables. We used interviews with participants to assess how they learned throughout the mental modeling process, finding evidence of changes to stakeholder relationships, system understanding, and the time horizons used in planning. Women farmers differed from other groups at multiple stages in our process, both in the structure of the models they produced and in the social learning they experienced. Our study was strengthened by the iterative process that allowed individuals and small groups to reflect on their own understanding and share it with others, resulting in increased communication, mutual respect, and understanding among members of the management team. These findings point to the complementarity of both individual and group-level mental modeling

for nuanced system understanding, and emphasize the need for diverse perspectives in collaborative environmental management in order for holistic understanding of both problems and solutions to emerge.

1. Introduction

Social-ecological systems are complex, adaptive systems that exhibit nonlinear dynamics, indirect effects and feedbacks, emergent properties, and heterogeneous links across space and time (Liu et al. 2007). These characteristics can cause unanticipated outcomes that make environmental management difficult, especially considering the rapid rate of global environmental change occurring worldwide (Pepin et al. 2015; Steffen et al. 2011). Oftentimes, the challenges facing social-ecological systems are multidimensional problems that lack clear definitions or solutions (Chapin et al. 2008). Managing these complex systems and challenges increasingly requires collaboration among diverse teams with a range of knowledge types and worldviews so that the boundaries of the problem can be understood from multiple perspectives, and the scope of potential solutions can be expanded (Tengö et al. 2014; Hoffman et al. 2017). In practice however, the benefits of collaborative environmental management have proven difficult to achieve, and research shows this failure is often due to insufficient attention to the social and cultural factors that shape environmental outcomes (McCusker and Carr 2006).

Social-ecological systems exist simultaneously as objects in the physical world (e.g., plants, rocks, people) and as cognitive constructs in the minds of the humans living there (Demeritt 2002). These cognitive constructs or “mental models” are internal representations of the external world that guide an individual’s thinking, decision-making, and behavior (Jones et al. 2011). Mental models are incomplete reflections of how the world works, and incorporate both concrete and abstract concepts (Johnson-Laird 1983). For example, a person’s mental model of a river might include physical characteristics like water or rocks as well as the values that person has regarding nature, clean water, or recreation. Because an individual's cognition is inseparable from their cultural and social environment (Roberts 1964; D'Andrade 1981), mental models are shared to an extent within a broader culture or social group and influence the formation of norms and institutions in that group (Halbrendt et al. 2014). Group mental models are thus comprised of culturally-derived ideas and practices and socially transmitted knowledge about how the world functions.

Mental models are critical elements of collaborative environmental management because they shape our understanding of human-environment relationships, our perceptions of environmental problems, and our preferences for advocating certain decision options over others (Jones et al. 2011; Moon et al. 2019). Differences in people's mental models are neither good nor bad, but may exacerbate barriers to effective communication and decision-making if they are not adequately understood and respected (Biggs et al. 2011). Mental modeling activities have been used in collaborative environmental management across a wide range of contexts, including detecting climate change signals (Gray et al. 2014), examining differences in the perceived impacts of conservation agriculture (Halbrendt et al. 2014), building consensus regarding natural disaster adaptation strategies (Henly-Shepard et al. 2015), and promoting cross-agency management of invasive species (Moon and Adams 2016). These projects seek to facilitate a holistic understanding of a system or problem so that the diverse stakeholders involved in management can create a shared vision or pathway towards action.

Developing this holistic understanding through the sharing of mental models requires some form of learning. Mental models evolve and change over time in response to new information and interactions among people in social networks (Reed et al. 2010). Understanding how mental models change, and how this change impacts collaborative environmental management, requires better understanding of how people learn – both as individuals and in groups. Social learning, which derives largely from theories of organizational management (Argyris & Schon 1978), is an iterative group process where learning occurs at the level of the individual but is situated in a particular social and cultural context (Lave & Wenger 1991; Keen et al. 2005). This is the definition we use in this paper, which differs slightly from those who consider social learning to occur when change permeates throughout an entire society (Reed et al. 2010), or learning conducted by society at large through broad institutional change (Woodhill 2002).

Structured mental modeling exercises, where mental models are collectively described and discussed, can facilitate social learning (Gray et al. 2014). Sharing mental models can enhance communication among members of a social-ecological system management team by making visible (i.e., graphically representing or describing) the similarities and differences in system understanding, and thus enabling teams to overcome obstacles that can prevent the incorporation of diverse knowledge types (Biggs et al. 2011; Henly-Shepard et al. 2015). Scholars largely agree that social learning is a normative and desirable outcome in environmental management (Armitage et al. 2008), as it has been shown to improve understanding of social-ecological systems (Walters & Holling 1990), to foster adaptation and collective action (Pahl-Wostl et al. 2007), and to build trust among diverse individuals (Reed et al. 2010) - all of which contribute to improved collaborative environmental management (Lang et al. 2012). However, few studies have examined the relationship between mental models and social learning with sufficient length and depth to provide empirical rather than anecdotal observations of learning.

In this paper, we describe an iterative process of constructing and revising mental models at both individual and small group levels over the course of a year. We present a case study of a community-based conservation area in the Ethiopian highlands, with participants from four social groups involved in environmental management. We conceptualize these groups on a gradient from local to scientific knowledge based primarily on their occupation, level of formal education, and social networks. The objectives of the research are to (1) understand how mental models of the social-ecological system vary among these groups, and (2) assess the social learning experienced by participants in the mental modeling process, with the aim of contributing to more empirically-informed theories and methods for facilitating collaborative environmental management.

2. Methods

2.1 Study Area

The Guassa Community Conservation Area (hereafter 'Guassa') is located in the Menz Gera woreda (similar to a county) of the Amhara Region of Ethiopia (Figure 1). Ranging from 2,600 – 3,560 m.a.s.l., this 78 km^2 area receives a mean annual precipitation of 1,650 mm (Fashing et al. 2014). Guassa supports many endemic and threatened species, including the critically endangered Ethiopian wolf (*Canis simensis*) and the gelada monkey (*Theropithecus gelada*) (Ashenafi et al. 2005). Guassa is named after the guassa grasses (*Festuca macrophylla*) that are valued by local communities for their use as thatch, rope, construction material, and forage (Ashenafi and Leader-Williams 2005; Steger et al. 2020).

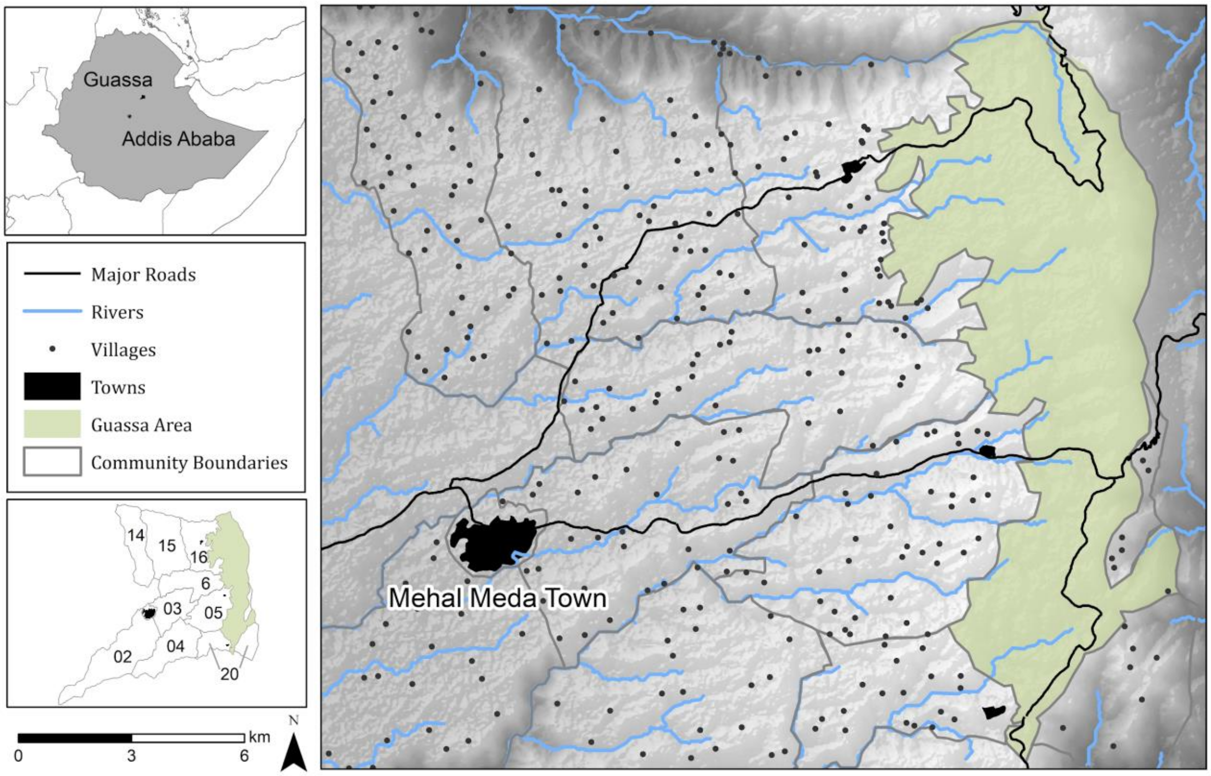

Figure 1. Map of Guassa and its surroundings. Top inset map shows the location of Guassa in relation to the capital city of Addis Ababa, Ethiopia. Bottom inset map shows the nine communities involved in the study and their administrative identification numbers.

Guassa has undergone significant political and land management changes throughout its 400+ year history (Fischer et al. 2014). The area was managed for hundreds of years according to the Qero system of communal management that restricted access to the grasses through brief open seasons every few years (Ashenafi & Leader-Williams 2005). In 1975, the agrarian reform transferred land ownership to the state, and community control over Guassa management declined. Community efforts to re-establish exclusive rights to the area were supported by international conservation efforts in the late 1990s, leading to a new co-management regime between local farmers and government agencies (Ashenafi & Leader-Williams 2005; Fischer et al. 2014). In 2012, exclusive use rights to the area were formally restored to the nine communities with ancestral rights by Amhara

Regional Regulation No. 97. Since 2010, grazing and firewood collection have been banned inside Guassa due to perceived threats to sustainability and the endangered Ethiopian wolf.

Currently the management team is composed of five representatives from each of the nine communities (the "Guassa Committee"), and about 20 other individuals from two government offices. The Guassa Committee is structured so that one of each community representatives is a woman, as they have historically been excluded from Guassa management (Ashenafi and Leader-Williams 2005). These groups manage the area collaboratively, with final decision-making power in the hands of the Guassa Committee. This diverse and relatively new co-management team makes Guassa a compelling case study for investigating the role of social learning and mental models in collaborative environmental management.

2.2 Measuring Social Learning

In this study, we assessed social learning using interviews. Four Ethiopian scientists interviewed participants in Amharic (~15-20 minutes per person) after each workshop regarding what they learned from the modeling exercise and discussion, how they anticipate using the model in their management decisions, and whether their understanding of other participants' perspectives changed throughout the workshop. Interviews were translated to English and transcribed. We used in vivo coding (Corbin and Strauss 2015) and inductive thematic analysis to describe trends in the kinds of learning reported by participants and how it changed across the three workshops (Boyatzis 1998). This research was reviewed and approved by Colorado State University's Institutional Review Board (361-18H), and was conducted with free, prior and informed consent of all participants. Participants were modestly compensated for their time.

2.2 An Iterative Process of Clarifying and Communicating Mental Models

Individual mental modeling exercises can promote equitable collaborative processes by allowing participants to construct and reflect on their own knowledge of the system without other individuals dominating (Reed 2008). However, collective mental modeling exercises have been shown to increase the likelihood of social learning, largely due to the detailed discussions that emerge from the process (Gray et al. 2014). We combined these two methods in our approach to maximize the benefits, choosing an iterative structure to allow participants adequate time to reflect on their responses, think critically about the system, and become comfortable sharing their perspectives (Figure 2). This iterative approach is rare in the literature, despite its theorized benefits for social learning (Henly-Shepard et al. 2015).

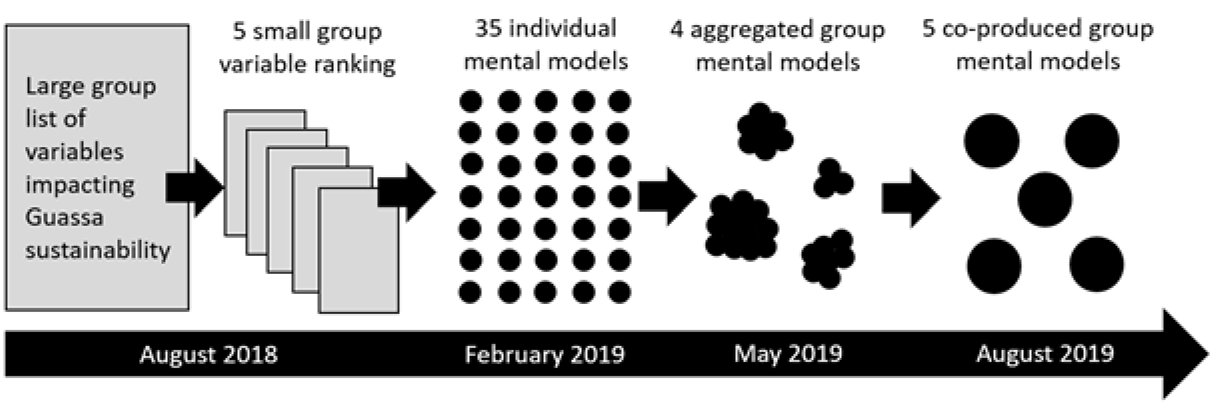

Figure 2. The iterative process of eliciting, refining, and communicating mental models. Community workshops occurred in August 2018, February 2019, and August 2019.

In August 2018, we convened a workshop as part of an on-going effort to better align scientific research in Guassa with the needs of local communities and managers. Participants came from the Guassa Committee (n=27, three each from nine communities), scientists (n= 6), the local administration office (n=5), and the Guassa Conservation office (n=3). These 41 workshop participants (12 women and 29 men) collaboratively identified variables thought to impact the sustainability of the Guassa area, where we collectively defined sustainability as a desired future with abundant guassa grass harvests, continued co-management, increased wildlife populations, and increased tourism. Workshop participants, separated into small groups, then ranked the variables to identify which were perceived as most influential on Guassa sustainability. We used the software ANTHROPAC (Borgatti 1996) to analyze the variable ranking data and calculate Smith's salience value (S) from zero to one for each variable, considering both the frequency of the variable across lists from each respondent and its position within each of those lists (Borgatti 1996). Salience values closer to one indicate good agreement across the respondents.

In February 2019, 38 workshop participants were asked to help clarify the strength and direction of relationships between each variable. Participants used a matrix with 25 variables listed across the first column and the first row, corresponding to the 19 variables identified in the first workshop plus six additional variables representing valuable ecosystem services in the area (Steger et al. 2020). In each cell, participants described how the variable in that column header impacts the variable in each row. There were six response options: "Strong Increase," "Weak Increase," "No Impact," "Weak Decrease," "Strong Decrease," and "I don't know". Participants were given as much time as necessary to complete the matrix (~one to two hours), with translators present if questions arose. A total of 35 people completed their matrices.

We included 30 of these matrices in the development of aggregated, small group mental models. We excluded five responses because they had the same answer for all relationships, or had only completed part of the matrix, indicating they were unreliable responses. We grouped respondents according to livelihood and gender, resulting in four primary groups: government workers (n=7), women farmers (n=7), men farmers (n=13), and scientists (n=3). These groups were organized *a priori* to reflect a gradient of local to scientific knowledge. One woman was present in the government worker group, and one in the scientist group. We transformed the categorical data into numeric values, where a strong relationship was +/-0.75, a weak relationship was +/-0.25, 'No impact' was 0, and 'I don't know' was NA. We then calculated the mean and standard error for each relationship to identify where respondent groups had the highest internal agreement regarding which variables had the strongest impact on the system. High agreement occurred when the 95% confidence interval did not include zero, indicating that most respondents felt the relationship was either strongly negative or strongly positive.

At a third workshop in August 2019, 37 participants reviewed and revised the mental models created for their small group. They discussed the uncertain relationships in the aggregated mental models, attempted to resolve their differences, and produced a single new matrix for the small group following their discussions. We divided the men farmers into two smaller groups to facilitate conversations with more equal participation from everyone involved. Farmers living in communities 16, 6, 05, and 20 were in the "near Guassa" group, while all others were in the "far from Guassa" group (Figure 1). On the second day of this workshop, we came together as a large group to discuss the most significant differences among groups.

In our analysis, we first aggregated the 25 variables into eight broad categories to show general relationships between concepts across the different group models. We calculated the percent of strong relationships (+/- 0.75) assigned between each concept to illustrate patterns of influence between concepts using Sankey diagrams. We then digitized the five small group mental models in the online software Mental Modeler (mentalmodeler.org). Mental Modeler uses graph-theory based analysis (Gray et al. 2012) to quantify which variables have the strongest and most frequent influence on other variables in the system (outdegree centrality) and which variables are most strongly and frequently influenced by other variables (indegree centrality). Outdegree centrality is the row sum of absolute values in the matrix, while indegree centrality is the sum of column absolute values. Larger values indicate a larger number of connections between variables as well as stronger relationships between them (Gray et al. 2012). We used these two metrics to compare across mental models, referring to variables with high outdegree centrality as “key drivers” in the system and variables with high indegree centrality as “key sensitivities”. We ranked the variables in descending order of indegree and outdegree centrality to identify the key drivers and key sensitivities according to each group.

3. Results

3.1 Individual and Aggregate Mental Models

Workshop participants identified 19 variables influencing the sustainability of Guassa (Table 1), with human population (S=0.92), rainfall (S=0.86), and community awareness (S=0.84) as the most influential variables with the highest Salience values.

Variable	Description	Salience	Concept Grouping
Human population	The number of people living around Guassa	0.92	Social
Rainfall	Amount of precipitation in and around Guassa	0.86	Abiotic
Community awareness	The level of awareness community members have about the importance of protecting Guassa	0.84	Knowledge
Unemployment	The number of people without land, livestock, or wage labor	0.79	Economic
Illegal users	The number of people who cut guassa grass and shrubs outside the agreed-upon time	0.67	Management
Livestock population	The number of livestock belonging to the people living around Guassa	0.65	Livelihood
Political instability	The degree of uncertainty about future actions the government might take	0.57	Political
Temperature	Temperature in and around Guassa	0.56	Abiotic
Firewood consumption	The amount of firewood used by households	0.55	Livelihood
Uncoordinated protection	The degree of independent actions taken by community members regarding Guassa	0.54	Management
Agricultural expansion	The expansion of agricultural lands into previously uncultivated areas	0.49	Livelihood
Invasive plants	Plants (both native and exotic) that are rapidly expanding their range into previously unoccupied areas	0.42	Biotic
Fire	Wildfire in and around Guassa	0.41	Abiotic
Deforestation	Harvesting trees from native and plantation forests	0.4	Livelihood
Leadership	The strength of local leadership	0.38	Political
Animal diseases	The presence of animal diseases	0.36	Biotic
Plant diseases	The presence of plant diseases	0.23	Biotic
Regime change	A change in the ruling party or change in the structure of the national government	0.17	Political
Research	Scientists (Ethiopian and foreigners) conducting research in and around Guassa	0.13	Knowledge
Freshwater	The amount of freshwater originating from Guassa	---	Abiotic
Guassa grass	The amount of guassa grass occurring in Guassa	---	Biotic
Crops	The amount of crops produced by farmland	---	Livelihood
Income	Household income	---	Economic
Wildlife population	The number of wildlife living in and around Guassa	---	Biotic
Tourism	The number of non-residents visiting the area	---	Social

Table 1. Workshop participants identified, defined, and ranked 19 variables with the highest perceived impact on the sustainability of Guassa. Six additional variables were added based on locally-valued ecosystem services in the region, which were not included in the ranking and do not have Salience values. Variables were grouped into eight broad concepts during analysis.

Results from the second workshop and aggregated small group models revealed a more nuanced interpretation of system dynamics across participant groups (Table A1, Appendix). Of the 600 possible relationships between variables, women farmers agreed only 120 of them were strong (20%), men farmers agreed on 212 (35.3%), scientists agreed on 288 (48%), and government workers agreed on 332 (55.3%). This resulted in a more complicated aggregated mental model for government workers compared to the other groups. Overall, women farmers agreed on the lowest number of impactful variables compared to other groups.

3.2 Co-Produced Mental Models

During the third workshop, government workers again created the most complicated model, while scientists created the least complicated mental model. Both groups of men farmers (near and far) and government workers created models that defined relationships between almost every single variable in the system, while scientists and women farmers only defined about half of the possible relationships. This could indicate differences in how these groups think about the complexity of the system, or merely differences in how these groups respond to requests for information. Scientists also identified the largest number of relationships (n=26) that represented critical uncertainties in the system (i.e., by marking them “I don’t know”); they were most uncertain about the potential impacts of invasive plants and regime change on social variables like community awareness and uncoordinated protection (Table A2, Appendix).

Examining patterns in the conceptual relationships revealed the strongest relationships across groups seem to occur between the social, economic, livelihood, political, and knowledge concepts (Figure 3). However, this analysis does not account for women farmers, who did not emphasize the impact of certain concepts over others, with diagrams showing roughly even influence across concepts (Figure 3). Scientists, on the other hand, clearly considered political and economic concepts to have the strongest impacts in this system, with economic, livelihood, and management concepts on the receiving end. Government workers identified social and knowledge concepts as the most influential, primarily impacting social and economic concepts. Men farmers near to Guassa considered the social concept to have the strongest impacts in the system, with knowledge, economic, and livelihood concepts the most impacted. Men farmers far from Guassa did not assign many strong relationships at all, but those they identified focused on knowledge as the most influential concept and political as the most sensitive. Finally, this analysis revealed that while government workers made the most complicated model overall, most of the relationships they defined were weak to moderate and therefore do not appear in the conceptual diagrams.

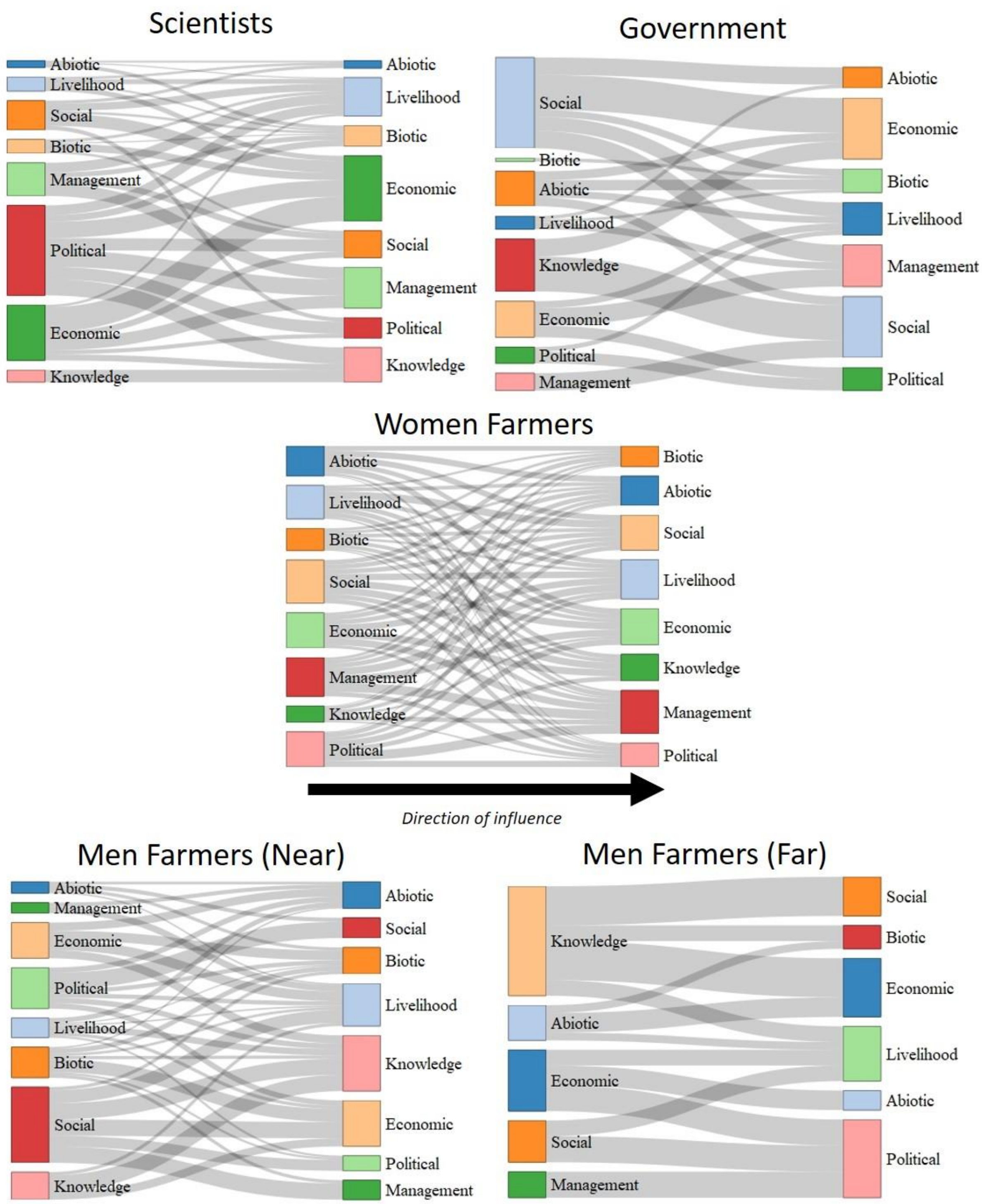

Figure 3. Sankey plots illustrate how key concepts influence one another. Line thickness indicates a higher percent of strong relationships between concepts (+/- 0.75).

Delving into individual variables and relationships of all strengths, we found limited agreement across groups regarding the key drivers and sensitivities in the Guassa system. Three variables emerged as key drivers with high mean outdegree centrality across groups, indicating they are thought to frequently impact other variables in the system: human population, unemployment, and political instability (Figure 4). Similarly, three variables emerged as key sensitivities with high mean indegree centrality across groups, indicating they are frequently impacted by other variables in the system: income, wildlife populations, and guassa grass (Figure 5). These results differ from the conceptual analysis by revealing two biotic variables as key sensitivities, though the emphasis on social, economic, and political variables remains constant.

Still, there was considerable range in the relative ranking of each variable by each group. For example, government workers considered research to be the strongest driver of change in Guassa, while women farmers considered it the weakest driver. Three groups (men farmers near/far and government workers) considered regime change one of the strongest drivers of the system, while women farmers and scientists considered it a relatively weak driver of change in the system. There was somewhat better agreement regarding the key sensitivities of the system, but large disparities still appeared. For example, women farmers considered human population to be the most sensitive variable in the system, while scientists ranked it as one of the least sensitive.

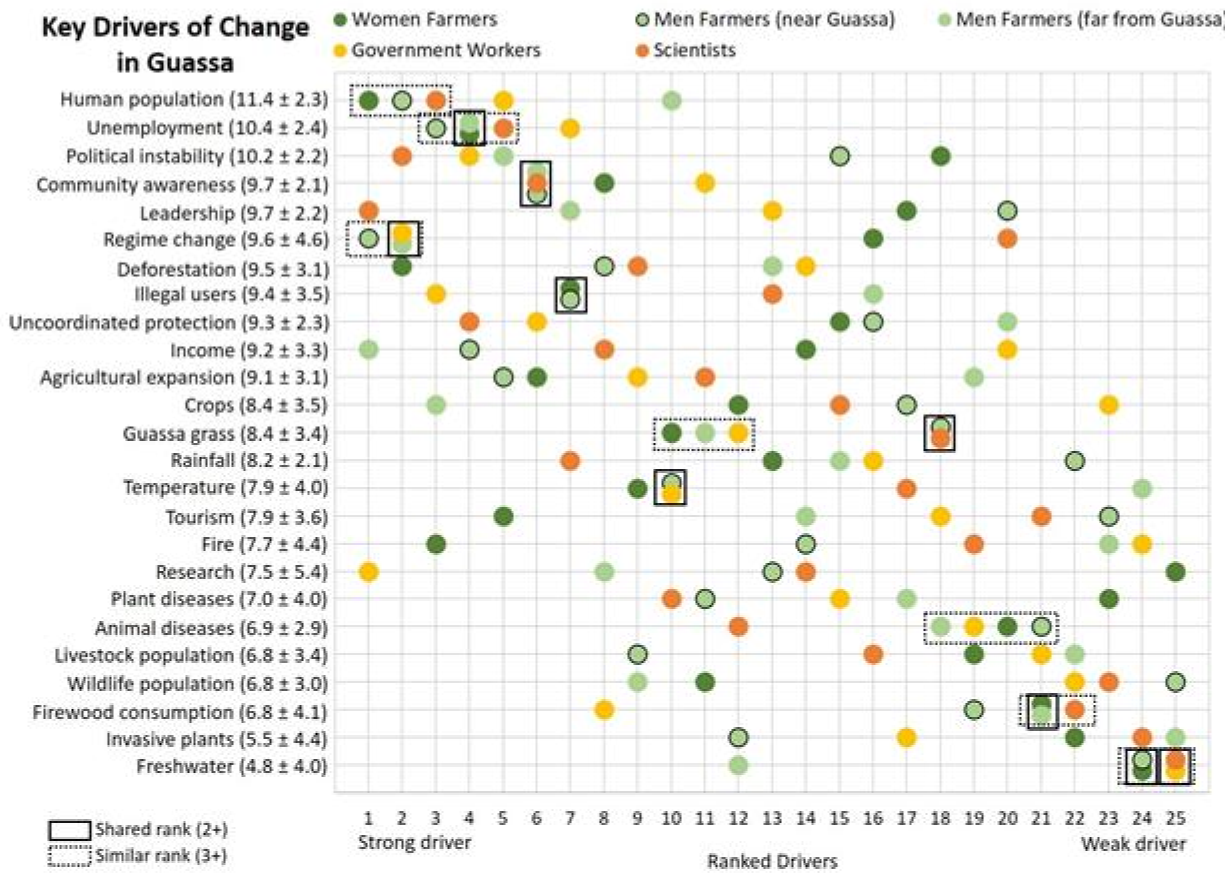

Figure 4. Variables are presented in order of declining mean outdegree centrality across groups, with the relative ranks of each small group presented as colored circles. Mean and standard deviation outdegree centrality are given in parentheses next to the variable names. Solid black boxes indicate a variable that received the same rank across two or more small groups, while dashed black boxes indicate a variable that received similar ranks across three or more groups.

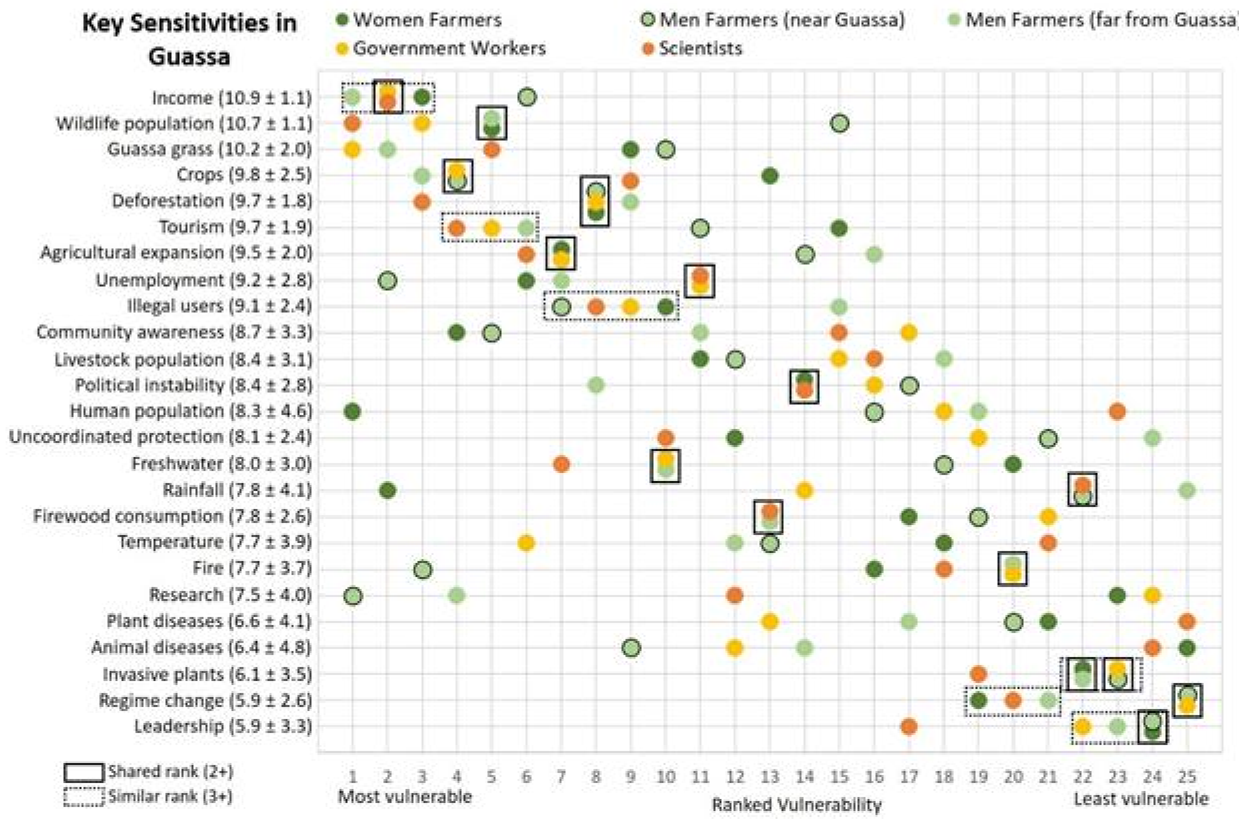

Figure 5. Variables are presented in order of declining mean indegree centrality across groups, with the relative ranks of each small group presented as colored circles. Mean and standard deviation indegree centrality are given in parentheses next to the variable names. Solid black boxes indicate a variable that received the same rank across two or more small groups, while dashed black boxes indicate a variable that received similar ranks across three or more groups.

Focusing on just the strongest drivers and most sensitive components of each group model enables a more nuanced comparison of these highly complicated models (Figure 6, Tables A3 and A4 in Appendix). Due to identical indegree/outdegree values on several variables, the number of variables in these simplified models ranged from seven to ten. Social, economic, and livelihood variables were found in all simplified group mental models (Figure 6), demonstrating the primacy of these concepts. Income was the only variable found across all five models. Women farmers identified human population as both the strongest driver and the most sensitive component in the Guassa system, potentially reflecting the traditionally domestic role of women in Ethiopian culture. Meanwhile, men living far from Guassa identified income as both the strongest driver and the most sensitive aspect of the system. Women farmers were the only group to include all three of the highly influential variables identified in the first workshop (human population, rainfall, and community awareness). All groups except scientists included a knowledge variable (i.e., community awareness or research). All groups except women considered a political variable (i.e., leadership, political instability, or regime change) a key driver of the system. Government workers did not consider political variables to have strong impacts on many other variables as evidenced by our conceptual analysis (Figure 3), yet they considered regime change and political instability to have low to moderate influence on almost every other variable in the system - thus earning these variables high outdegree centrality in the network.

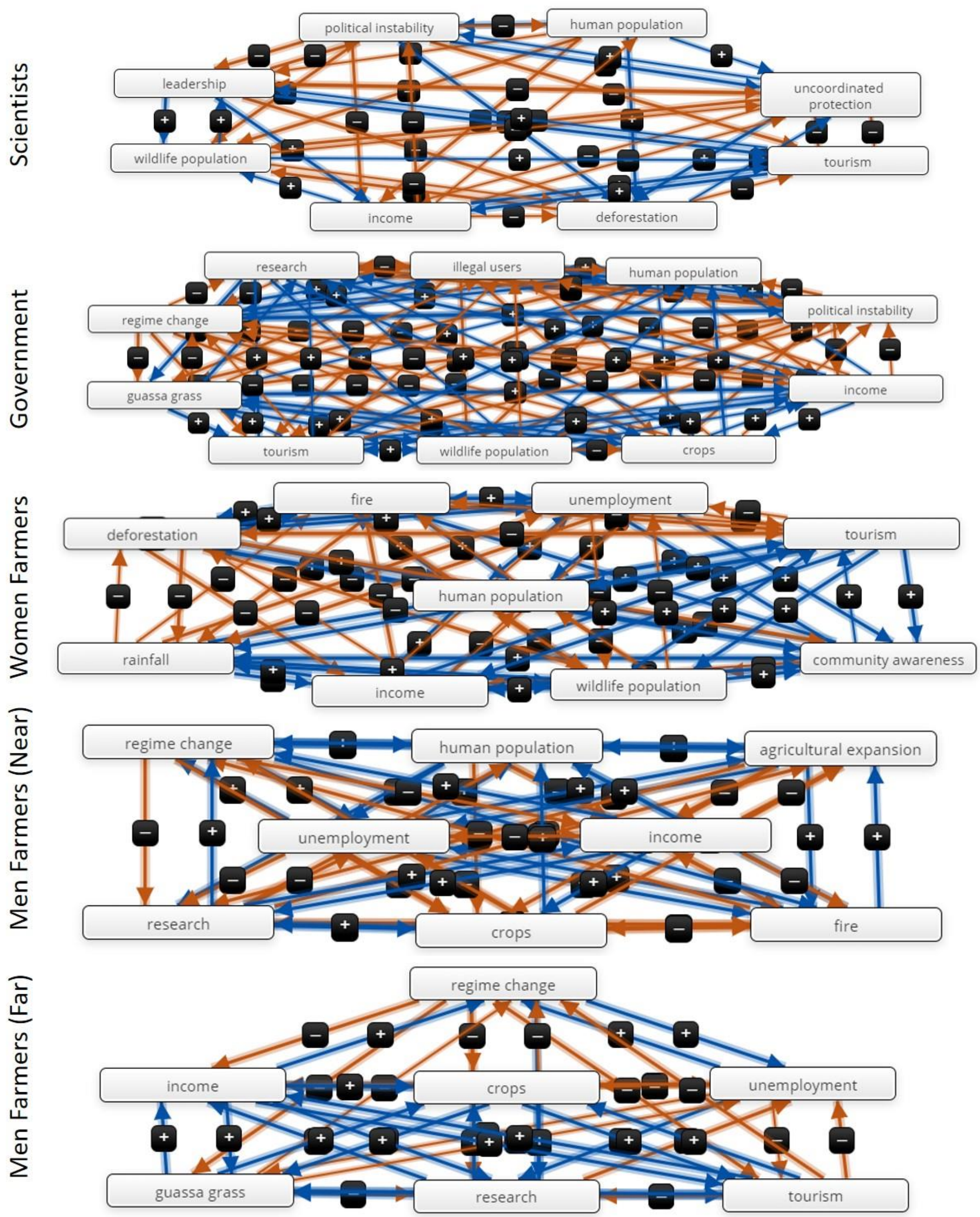

Figure 6. Co-produced mental models showing only the strongest drivers and sensitivities identified by each group. Key drivers (highest outdegree centrality) are placed at the top row of

each mental model, and key sensitivities (highest indegree centrality) are placed on the bottom row. In cases where variables were identified as both drivers and sensitivities, they are placed in the center (i.e., in all three farmers' models).

Although political and economic variables were nearly ubiquitous across group models, the relationships between these variables were not consistent across groups. Government workers and scientists viewed these as mutually negative relationships – they perceived that an increase in income would cause a decrease in political instability/regime change, and an increase in political instability/regime change would likewise cause a decrease in income. Men farmers from both groups agreed that a regime change would cause a decrease in income, but they believed an increase in income would lead to higher likelihood of a regime change, which differed from how government workers and scientists thought about this relationship.

The large group discussion shed light on why relationships differed across groups. For example, women farmers and men farmers far from Guassa agreed that as human population increases, income also increases because there is more work available when there are more people around. The other groups felt that an increasing human population would decrease income because limited resources would have to be shared among more people, and the increased pressure on Guassa would result in lower income opportunities from it. Another key difference in understanding related to the influence of leadership on regime change. Scientists and government workers agreed that strong leadership would decrease the likelihood of regime change because people would be less likely to revolt when their needs are met. Men and women farmers disagreed, saying that good leadership brings about increasingly democratic processes and equal power sharing so that regime change is more likely when there is good leadership. These descriptions reflect significantly different understandings of governance among participant groups and help clarify why conflicting relationships were reported between political and economic variables.

As the discussion continued, small groups became more likely to change their answers to reflect the opinions of the other groups. Women farmers often had the only dissenting opinion, and scientist facilitators halted the conversation when we realized the women were immediately changing their answers without offering a rationale for their original perspective.

3.3 Learning Experienced by Workshop Participants

Over the course of the three workshops, participant interview responses became increasingly more nuanced as the mental modeling exercises became more complex. There were 29 participants who completed all three post-workshop interviews, six participants with two interviews each, and two participants with only one interview each (total = 37 participants). In the first workshop, one of the common themes in farmers' responses was the importance of identifying threats to Guassa (n=20, 54.1%), often with additional insights into how this can assist in future planning. One farmer commented, "By ranking the variables, I learned that if we prioritize the problems early it can help our future preparedness." However, some respondents took a more extreme interpretation, focusing on the need to "control all the threats to Guassa" rather than reflecting on the general importance of identifying threats. Women reported experiencing this type of learning more than either group of men farmers, while government workers did not report this kind of learning. The focus on envisioning a sustainable future for Guassa in the first workshop prompted a second common theme surrounding the novelty and need for long-term planning (n=22, 59.5%), which was reported by all three conservation officers and over half of men farmers living near Guassa. "We are used to planning for five years but not twenty," remarked a conservation officer.

By the third workshop, both men and women farmers' responses focused more on the complexity of the Guassa system rather than threats to it (n=19, 51.4%). One farmer commented, "I learned that everything is connected, and that harming one aspect may cause unintended consequences." Another farmer similarly exclaimed, "the guassa grasses are dependent on so many things!" Another common theme in the third workshop was the importance of discussion as the source of learning (n=18, 48.6%). "Discussion is always better for our community," reported a priest. Discussion offered some participants the opportunity to understand other people's perspectives without a need to find consensus. One woman reflected, "it is always better to see things and ideas in different ways." However, four respondents valued discussion specifically for the opportunity to reach a consensus. One man explained, "Before the discussion, there were different ideas. After the discussion, we came to one idea. Discussion makes us change our ideas."

Across workshops, participants frequently reported changing the way they thought about one another's ideas and perceptions of the Guassa system, though this was typically a general statement without concrete examples. One changing bias emerged from the responses of just a few government workers. At the first workshop, a conservation officer commented that he felt there were "gaps in understanding between government officials and the public." Then, at the second workshop, a government worker commented that another man had "surprised me a lot, because he put forward constructive ideas even though he is a farmer." This was one of the only types of learning commonly reported by government workers. These biases were not observed in interviews from the third workshop, where participants tended to focus on differences in individual ideas and perspectives rather than group-level assumptions or stereotypes.

The value of the women's participation in the workshop was a common theme in the women's interviews, with nearly half the women (n=5, 45.5%) saying something about the importance of including women in these types of meetings. These responses may reflect growing within-group support for stronger women voices in Guassa management. However, no men made any remarks in their interviews regarding the importance of including women.

4. Discussion

In this paper, we described an iterative process of constructing and revising mental models at both individual and small group levels over the course of a year in a community-based conservation area in the Ethiopian highlands. We compared mental models of the conservation area across groups involved in management to identify commonalities and differences in the way people conceptualize the area, using interviews to understand the kinds of learning experienced throughout the process. Our results advance theoretical understanding of mental modeling and social learning processes alongside improved place-based understanding of this social-ecological system, with insights for facilitating successful collaborative environmental management.

4.1 Individual vs. culturally-shared knowledge

Insights from cognitive anthropology reveal that all the knowledge about a culture cannot be stored within a single brain, and so there is a division of labor in who knows what – certain social positions or experts will know more than others (D'Andrade 1981). Therefore, it is reasonable that mental models would vary even among groups that share a dominant culture depending on the everyday activities and values of the individual participants, as people will tend to focus on variables and processes that are of direct importance to them (Klein et al. 2014). Our mental modeling process revealed that all groups involved in managing Guassa focused primarily on social components as the drivers of change in the system, while ecological elements were more commonly perceived as sensitivities or vulnerable elements. Despite this general agreement at a conceptual level, we found very high diversity when considering specific variables and their relationships to one another. The lack of internal agreement within small groups and wide disparities in group mental models reveal that relying on a small number of representatives from different social groups is insufficient to capture widespread cultural knowledge through mental modeling in this context. Rather, our results point to the need to more closely examine the relative influence of individual and group-level processes on social learning (Järvelä et al. 2010), and to recognize there will be heterogeneity in system understanding even among highly similar individuals.

For example, the influence of individuals is illustrated most clearly by comparing the two groups of men farmers. While the farther communities are less involved in day-to-day Guassa management, participants in these two groups still belong to the same general social group. Yet their co-produced mental models of the system overlap very little, indicating that individual experiences may be a stronger driver of system understanding at this scale than cultural knowledge. Meanwhile, women participants in our study showed the least internal agreement as individuals and had co-produced models that diverged most frequently from the other groups. They insisted this was not due to a lack of understanding about the mental modeling process, but rather differences in the way they think about these variables and Guassa.

These findings emphasize the need for conceptual modeling and discussion among specific management groups so that the individuals involved clearly understand one another's perspectives in relation to a particular system or problem (Etienne et al. 2011). It also suggests that high turnover in the individuals involved in environmental management may be detrimental to effective collaboration, as it disrupts the development of mutual understanding and trusting relationships among competent managers (Fabricius and Collins 2007). However, individuals involved in management must also represent diverse socio-cultural groups to avoid the disenfranchisement of certain groups, and we encourage future researchers to carefully consider how they approach stakeholder identification (Butler and Adamowski 2015).

4.2 Conceptual learning

In the space of a two-day workshop, participants were able to identify gaps in the way they were thinking about the Guassa system (i.e., not recognizing threats) and use other people's ideas and perspectives to fill those gaps. The focus on "threats" in the first workshop may have arisen through issues with translation, as words like "variables" or "system components" did not retain their meaning when translated into Amharic and we used words like "threats" and "benefits" to help generate the list of important variables. However, there was a clear tendency for participants to focus on threats over benefits, as evidenced by the kinds of variables included in the initial list and the interview results. These kinds of changes are an indication of single-loop or conceptual learning, filling in gaps in their cause-and-effect understanding of the system and constituting a re-structuring of participants mental models (Pahl-Wostl et al. 2009; Baird et al. 2014).

Women, more than any other group, reported experiencing this type of learning, perhaps because their historical role on the periphery of Guassa management has prevented them from these types of discussions in the past (Ashenafi and Leader-Williams 2005). For example, women differed from other groups in their belief that increasing human populations would have a positive impact on the guassa grasses, demonstrating that they did not initially conceive of humans as a threat to the ecological system the way other groups did. After hearing the explanations of other groups, women agreed that higher human populations would likely result in more harvesting of guassa grasses, which they had not considered. However, women did not share their ideas about why human population would lead to higher guassa grasses – perhaps because they were uncomfortable being the sole dissenting opinion. These results highlight a need for good facilitation and adequate representation from marginalized groups so that outside perspectives are not immediately assumed to be incorrect (Reed et al. 2008). This need is particularly strong in cultures where consensus is highly valued, as the cultural pull towards universal agreement may override the expression of valid and valuable system understanding.

4.3 Shifting planning to forward-thinking strategies

Psychological research suggests that people rarely think about the future beyond five years (D'Argembeau et al. 2011), and have particular difficulty imagining the future beyond 15-20 years (Boschetti et al. 2015). In our study, participants reported increasing the timeframe they used to think about Guassa planning, which is an aspect of improved "systems thinking" or double loop learning (Dyball et al. 2007). This shift in the time frame used to think about the future is notable because the way humans perceive time has been shown to impact their goals and strategies for action. For example, socioemotional selectivity theory asserts that time horizons influence motivations, and particularly goals related to knowledge acquisition and regulating emotional states (Carstensen 2006). When time is perceived as open-ended, or on longer time horizons, and individual's goals will more likely revolve around planning, gathering information, and expanding the breadth of their knowledge. When short time horizons are perceived, as is typically the case when people age, an individual will more likely prioritize goals and actions that optimize their psychological or emotional well-being (Carstensen 2006).

While individuals from all groups reported expanding their planning time frame, it was more common among men farmers and government workers compared to women farmers. This might be because men are more central to Guassa decision making processes. Differences in how individuals experience learning about time horizons must be considered in environmental management given the potential impacts to decision making and planning processes. For example, if Guassa managers are commonly only considering five years into the future, they might be more likely to support activities that result in unsustainable resource use over longer time spans (e.g., more frequent guassa grass harvests). Therefore, while mental modeling processes do not necessarily need to include discussions of time horizons, we found this to be a valuable social learning outcome. However, we did not set out explicitly to examine attitudes towards the future, which arose due to our discussion about threats to the Guassa area. We therefore encourage a more systematic approach to facilitating this type of learning, potentially through the use of established questionnaires (Boschetti et al. 2016).

4.4 Relationship building

Our study was strengthened by the iterative process that allowed individuals and small groups to reflect on their own understanding and share it with others. Participants' descriptions of how discussion enhanced their learning underscores the "social" component of social learning, as participants valued the opportunity to compare and evaluate their individual and shared knowledge. While this was an intensely time-consuming process, it was valuable to explore and understand the diversity of knowledge and system understanding at the early stages of our collaborative research efforts. One distinct advantage was the increased communication among members of the management team, as discussion appeared to facilitate the development of more trusting and open relationships. As a critical element of successful collaborative research (Dietz et al. 2003; Lang et al. 2012), this communication and the increased mutual respect and understanding that emerged from it are promising indicators for future adaptive management of Guassa (Fazey et al. 2014; Fujitani et al. 2017). In particular, the observed social divisions between men farmers and government workers stand out as an example of relationship building that occurred during this process. These groups had the most similar mental models, yet post-workshop interviews indicated that they did not recognize how much they had in common until discussions revealed their shared perspectives.

Women farmers also experienced important relationship building, both within their group and with other members of the management team. Women farmers experienced the least internal agreement regarding strong relationships in their aggregated group models, yet they identified the highest number of strong relationships when allowed to discuss and co-produce a single group model. The strong influence of social context on women farmers' models reinforces the idea that individual and group-level mental modeling exercises are different, yet complementary processes that cannot simply be substituted for one another (Gray et al. 2014). Furthermore, these results emphasize the need for careful facilitation of group mental modeling processes to ensure certain groups do not dominate over others (Reed et al. 2008). Although our results support the claim that group-level modeling is more likely to encourage social learning (Gray et al. 2014; Henly-Shepard et al. 2015), we believe individual-level modeling should be included when possible as it can provide much-needed points of clarification when group models are hampered by socio-cultural barriers such as disagreement in a group discussion, power asymmetry among participants, or resistance in the identification of knowledge gaps or uncertainty. Finally, although only women participants reported their presence being a valuable outcome of the workshops, this theme from the interviews might be indicative of a normative change or triple-loop social learning just beginning. However, it is too soon to tell for sure whether other groups will place the same value on women's participation in Guassa management in the years to come.

5. Conclusions

Considering their long history on the periphery of Guassa management, it is perhaps unsurprising that women farmers produced mental models that differed more frequently from the other groups. Yet, the differences we observed even among highly similar groups of men farmers indicate that individual experiences were more influential during these mental modeling exercises than shared, cultural knowledge. Despite some differences in which groups experienced what types of social learning, it appears this mental modeling process has encouraged stronger, more open relationships among the management team overall. Our findings point to the complementarity of both individual and group-level mental modeling for nuanced system understanding, and emphasize the need for diverse perspectives in collaborative environmental management in order for holistic understanding of both problems and solutions (Tengö et al. 2014; Hoffman et al. 2017). We encourage further long-term research into the relationship between mental modeling and social learning, with particular attention to how socio-cultural context that influences individual learning.

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