

A Human-Centered Approach to Designing an Invasive Species Eradication Program
Anna R. Santo

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Michael G. Sorice, Chair
Christopher B. Anderson
Timothy Baird

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ABSTRACT

The increasing scope and speed of biological invasions around the world is a major concern of the modern environmental conservation movement. Although many ecological impacts of biological invasions are still not well understood, there is a general consensus that exotic, invasive species are a primary driver of extinctions globally. By altering ecosystem structure and function, invasive species also affect human quality of life; however, not all impacts lead to negative outcomes.

Given that invasive species have diverse impacts on society, their management in human-dominated landscapes is a wicked problem wherein the resolution is as much an issue of social value as technical capacity. The purpose of my research was to understand the propensity for engaging private landowners in an effort to eradicate an invasive species on an inhabited island. Specifically, I investigated private landowner perspectives on eradicating the North American beaver (*Castor canadensis*) from the Tierra del Fuego (TDF) island archipelago in Argentina and Chile. The beaver was introduced in 1946 and has since become a central conservation issue due to its long-lasting changes to local hydrology, nutrient cycling, riparian vegetation, food webs, and aquatic and terrestrial species assemblages.

Because eradication requires near complete cooperation from stakeholders and no research had been conducted to understand the perspectives or willingness of private landowners to cooperate, my objectives were to: 1) characterize the links private landowners make between the presence of beavers and impacts to the ecosystem services in their riparian areas, and 2) explore the role of a market-based incentive program to increase landowner cooperation in eradication efforts.

Through semi-structured interviews, I elicited landowner mental models of how beavers impact the ecosystem services they receive from their riparian lands. I found that TDF ranchers prioritized provisioning ecosystem services, and held diverse and idiosyncratic beliefs about how beavers influence these outcomes. TDF ranchers may not recognize the beaver as a highly salient problem because they do not connect them to reductions in ecosystem services that are important to them. Among those who do

perceive beavers affecting important ecosystem services, there is no clear, unified understanding of how the beavers disturb the ecosystem and key ecosystem services.

Additionally, in a broadly administered survey, I used a factorial vignettes to examine the role of program structure and other program-related factors on landowners' willingness to participate in a voluntary eradication program. Overall, landowners were willing to cooperate in an incentive program to eradicate beavers. They were positively motivated by greater financial compensation, an increased expectation that the program would be successful, and the program assuming full responsibility for its implementation. Other factors returned mixed results indicating that further research may be required.

In diverse, human-inhabited, and privately-owned landscapes, conservation requires collective action—i.e., the high threshold of participation needed for eradication to be achieved. Understanding the knowledge systems that cause landowners to perceive value or risk serves as a first step in understanding behaviors, and can also serve as a framework for crafting more effective outreach, as current communication about the beaver and the proposed eradication may not resonate with private landowners. Further, barriers to inaction can be overcome by understanding landowner needs and how program-related factors influence the potential for cooperation.

In sum, by putting human needs at the forefront of program design, conservation planners can better understand stakeholder perspectives, reduce barriers to participation, and ultimately increase cooperation and improve conservation outcomes.

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Chapter 1: Introduction

1.1 Introduction

The increasing scope and speed of biological invasions around the world is a major concern of the modern environmental conservation movement (McNeely 2001, Perrings et al. 2010). Humans have both purposefully and accidentally transported thousands of species outside of their native ranges (Larson 2005, Mooney 2005), and a small number of these exotics outcompete native species as they invade their new range. Although many ecological impacts of biological invasions are still not well understood, there is a general consensus that exotic, invasive species are a primary driver of extinctions globally. The Millennium Ecosystem Assessment found that invasive species are one of the five “most important direct drivers of change in ecosystems” (MEA 2005, p.14). Others have ranked invasive species as the second highest overall threat to biodiversity on the planet (Wilcove et al. 1998). Given the magnitude of their impact, ecologists have invested considerable time and resources trying to understand the impact of biological invasions on ecosystem structure and functioning.

In addition to extensive ecological research, there is a growing body of literature that is investigating the multiple social, economic, and cultural impacts of biological invasions (e.g., Pfeiffer and Voeks 2008, Marshall et al. 2011). Healthy ecosystems provide great value to humans through ecosystem services (i.e., the benefits that nature provides) (De Groot et al. 2002, MEA 2005, Pfeiffer and Voeks 2008, Pejchar and Mooney 2009, Chan et al. 2012); thus, by altering ecosystem structure and function, invasive species affect human quality of life. However, not all impacts lead to negative outcomes; people can be socially, economically, culturally, or emotionally dependent on invasive species (Pfeiffer and Voeks 2008, Gobster 2011, Marshall et al. 2011). As thinking on the issue evolves, some scientists question, even

reject, the notion that introduced species are inherently “destructive” (Robbins 2004, Davis et al. 2011), arguing that this is a socially constructed value judgment undermining scientific credibility (Larson 2005, Schlaepfer et al. 2011). Invasive species have diverse impacts on society; thus, a nuanced evaluation strategy can help determine whether action should be taken to manage them.

Effective invasive species management requires balancing the multiple ecological and ecosystem service impacts of a species (Davis et al. 2011), as well as technical limitations. There are two major management options for reducing the harmful impacts of invasive species. First, by implementing ongoing control efforts, a species’ population numbers and thus impacts can be kept low. Or alternatively, the species can be removed entirely from a landscape in a total eradication. With exponentially advancing technology (Towns and Broome 2003, Carrion et al. 2011), attempts to eradicate invasive species from islands and continental settings are becoming increasingly successful (Howald et al. 2007). To date, there have been over 1,200 successful vertebrate eradications on islands, the majority of which have been mammals (Glen et al. 2013). Given high success rates and improved techniques, eradication is often a preferred management strategy when biological invasions destroy natural resources (e.g., fisheries, waterways), infrastructure (e.g., roads, culverts), or other aspects of human well being (e.g., noise pollution, aesthetics, disease vectors) (Mooney 2005). As a result, environmental managers are planning increasingly complex and extensive eradications, and have started to target human-inhabited areas for eradication efforts (Zabala et al. 2010, Malmierca et al. 2011, Glen et al. 2013).

Targeting human-inhabited landscapes for eradication campaigns layers social complexity on top of technical complexity. Stakeholders have diverse and sometimes opposing beliefs about the species’ impacts to livelihood or quality of life outcomes. Conflicts around

invasive species management are often rooted in divergent attitudes or values, making them a “wicked problem” with no clear resolution (e.g., Game et al. 2014). Further, human presence complicates eradication campaigns because it limits the range of feasible and socially acceptable eradication strategies available to practitioners. Eradications often require techniques incompatible with human settlements (e.g., aerial broadcast of toxins) or activities that landowners may not condone or allow on their land (e.g., shooting animals) (Saunders et al. 2011, Wilkinson and Priddel 2011). Finally, due to the all-or-nothing nature of eradication campaigns, a lack of support or access by a single landowner can delay or completely derail an eradication effort (Gardener et al. 2010, Wilkinson and Priddel 2011). Human-inhabited areas are typically managed by multiple private landowners with heterogeneous land-management objectives; as a result, eradication efforts in these areas are especially challenging because they require collective action and coordination, even when the issue may not be salient or agreeable to residents (Epanchin-Niell et al. 2010). Even if a landowner prefers eradication, they face difficult trade-offs when considering engaging with an eradication program. For example, they may be concerned about liability, find it to be prohibitively costly (i.e. time, labor, money), or feel it requires an undesirable sacrifice of their independence. They may not trust the institution implementing the program, or they may not feel competent to engage in activities effectively (i.e. live trapping, safe herbicide application) (e.g., Stokes et al. 2006, Cocklin et al. 2007, Sorice et al. 2011, Moon et al. 2012, Sorice et al. 2013). Furthermore, perceptions of other landowners’ actions or beliefs may generate social pressure to engage or not engage with a conservation program (e.g., van Dijk et al. 2008).

A successful eradication campaign requires widespread support and cooperation for a program that will achieve conservation objectives. Three approaches are commonly implemented

to achieve a desired conservation behavior from private landowners, 1) education that motivates the desired action, 2) regulatory tools (“command-and-control”), or 3) incentive-based approaches that make a desired behavior more attractive to landowners (e.g., Cocklin et al. 2007). In the event that inaction stems from lack of information or understanding of the damages caused by an invasive species, targeted communication can sometimes motivate behaviors (Morgan et al. 2002). However, although outreach and education is a commonly used approach, it is costly and often does not efficiently achieve environmental objectives (Cocklin et al. 2007). If landowners understand and recognize risks but still fail to take action, other regulatory or policy approaches may be necessary. Command-and-control regulation is widely used to achieve desirable behavior (i.e. legislation, standards, licensing, bans, etc.). Although this strategy is common and can be successful, it is often criticized as adversarial, suppressing creativity, and in many cases it fails to meet conservation objectives (Cocklin et al. 2007, Engel et al. 2008, Layzer 2008). Furthermore, landowners typically react negatively to top-down regulation, especially when it is developed without considerations of constraints (Cocklin et al. 2007, Sorice et al. 2013).

An alternative to education or top down regulation, market-based incentives (i.e., payment for environmental services, or PES) compensate landowners for securing environmental goods and services (Wunder 2005) and may be used to overcome the limitations of voluntary and regulatory processes (Milne and Niesten 2009). The rationale is as follows: biodiversity is a valuable commodity, and conservation is an alternative land use to which we should assign a value (Ferraro and Kiss 2002, Donlan 2009, Milne and Niesten 2009). PES have been successful at achieving conservation objectives, especially in Latin America (Wunder 2005, Pagiola 2008); however, they can have hidden costs (e.g., Wunder 2005, Cocklin et al. 2007, Engel et al. 2008,

Milne and Niesten 2009, Weibel et al. 2010, Ferraro 2011). Although theory assumes people make rational economic decisions (Ferraro and Kiss 2002), this is not always the case. In practice, people make decisions based on a variety of factors, such as social norms (Sorice et al. 2011), autonomy in decision making, level of trust (Sorice et al. 2013), local interest in protecting indigenous territory/community resources from outsiders, or establishing a long-term relationship with an outside organization (Milne and Niesten 2009). Thus, a successful conservation incentive program will take into consideration local stakeholders' needs, preferences, and social conditions.

The human-centered design approach recognizes that the way a program is structured and administered serves as its own set of incentives from which landowners receive benefits and incur costs (Sorice et al. 2013, Gelcich and Donlan 2015). This approach consists of an iterative process for defining stakeholder beliefs, values, needs, desires, constraints, and experiences as a means to design a conservation program that achieves widespread, voluntary participation. Often overlooked, both program structure and implementation can lead to reduced participation, ultimately undermining the collective action needed to achieve conservation goals (Sorice and Donlan *in press*). With a human-centered approach, program designers can integrate direct interaction with stakeholders (i.e., interviews, surveys, focus groups), academic literature, and expert opinion to co-design programs with private landowners that meet their objectives and needs. Then, these programs must be adaptively co-managed to address emerging concerns, problems, or barriers to continued participation. Although the human-centered design approach has been broadly applied in other disciplines, its application to the field of conservation program design is a relatively recent development (Brown and Wyatt 2010). By using this approach to consider user needs in the program's design phase, conservation campaigns can be crafted so

they will be more attractive to stakeholders, ultimately resulting in high voluntary participation and widespread support (Sorice and Abel 2015, Sorice and Donlan *in press*).

1.2 Case Study: Invasive Beavers in Tierra del Fuego, South America

In 1946, when the Argentine government released North American beavers (*Castor canadensis*) to the remote Tierra del Fuego (TDF) archipelago (Fig. 1.1), the plan to start a fur trade actually triggered the largest landscape-level change to the ecoregion since the last ice age (Anderson et al. 2009, Anderson et al. 2012). This region is unique by many measures; the temperate forest biome of southwestern South America hosts the most extensive temperate forests in the southern hemisphere, and the world's southern-most forested ecosystem. Furthermore, TDF is internationally recognized as one of the last remaining "pristine" wilderness areas in the world (Mittermeier et al. 2002, Anderson et al. 2006, Rozzi et al. 2006). Although just 20 beavers were translocated 70 years ago, today, the South American beaver population has increased to over 100,000 individuals (Lizarralde et al. 2004, Skewes et al. 2006) and has expanded to mainland Chile (Wallem et al. 2007). As an ecosystem engineer, beavers cause long-lasting changes to local hydrology, nutrient cycling, riparian vegetation, food webs, and aquatic and terrestrial species assemblages (Lizarralde et al. 2004, Simanonok et al. 2011, Henn et al. 2014). In this new context, beavers have no natural predators, and the region's riparian vegetation has not evolved the necessary resilience to recover from the beaver's impacts (Anderson et al. 2009). As a result, throughout TDF the beaver is converting sub-Antarctic forests to meadows (Wallem et al. 2010). As the continental beaver population multiplies, ecologists expect their territory to expand to at least 35 degrees latitude, approximately as far north as Uruguay, unless a coordinated control or eradication slows their expansion (Wallem et al. 2007).

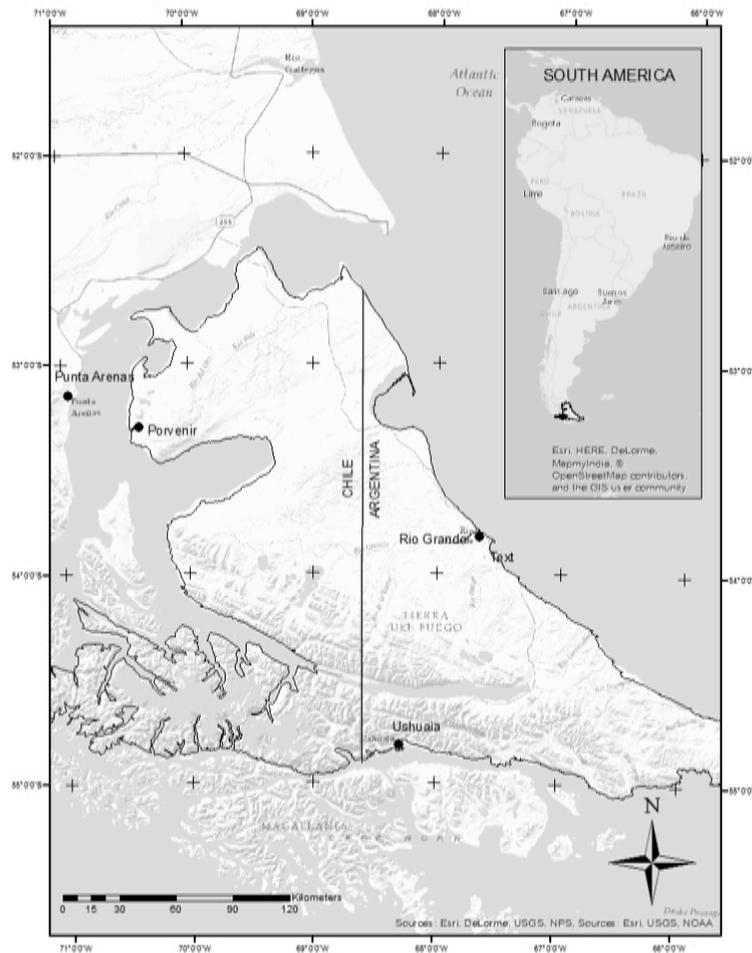


Fig. 1.1. Map of Isla Grande, the largest and most populated island of the Tierra del Fuego Archipelago. The Chilean-Argentine international border bisects the island (Chile ~29,000 km², Argentina ~18,000 km²). Private sheep and cattle ranches dominate the grasslands in the northern portion of the island. The forested south consists of large tracts of state-owned land, private protected areas, and private forestry operations.

Beavers drive more than just ecological change in the region; they have also integrated into TDF's social landscape. Many parts of Tierra del Fuego consist of privately owned, working landscapes, like sheep and cattle ranches, forestry operations, sport fishing tourism outfits, or mining operations. Beavers indiscriminately destroy forests, grazeable pasture, or infrastructure (e.g., bridges, fences) on TDF's working lands (Schüttler et al. 2011, SAG 2015). But, the impacts are not all bad; people can be socially, economically, culturally, or emotionally

dependent on invasive species (Pfeiffer and Voeks 2008, Gobster 2011, Marshall et al. 2011). In TDF, beavers sometimes complement rural operations by increasing water availability or clearing bushes from pastures. Furthermore, the beaver has become a regional cultural icon, with restaurants, ski resorts, and local recreation centers named after the rodent; a niche beaver tourism industry has also emerged. The beaver's impact to TDF's social and ecological landscapes can be seen literally from a 30,000-foot view as you gaze down through an airplane window at enormous patches of flooded forest; it can also be detected in subtle, spray-painted graffiti on the shadowy corners of TDF's city streets (Fig. 1.2). More than just a biological invasion, the beaver has successfully invaded and altered the region's ecosystems, economy, and culture.



Figure 1.2. Beaver graffiti in downtown Ushuaia, one of the main population areas in the Argentine portion of Tierra del Fuego. The caption reads, “Ushuaia: Your worst predator is ignorance.”

Due to growing concern about the beaver's ecological and socioeconomic impacts, in 2008 the Argentine and Chilean governments formalized an agreement to initiate the largest eradication ever attempted worldwide—over 7 million hectares across two countries (Menvielle et al. 2010, Malmierca et al. 2011). Over 50 researchers, policy makers, and representatives from the public and private sectors convened in the first bi-national meeting on the topic of beaver control to make this decision. Each country had already independently attempted to initiate beaver control efforts (Parkes et al. 2008, Anderson et al. 2012), but the binational nature of this decision was unprecedented, and has broad implications for the region's social and ecological landscapes.

Although there is top-down, binational support for eradication, the proposed eradication requires the support of over 300 private landowners who have diverse experiences, beliefs and opinions about the beaver and its impacts. Despite the integral role of private landowners in achieving this ambitious conservation goal (Menvielle et al. 2010) and the many possible barriers to their participation, little is known about landowners' beliefs or attitudes towards beavers or their willingness to participate in coordinated management actions. A small number of studies have begun to characterize the general public's perceptions of native and exotic species (Schüttler et al. 2011) and the status and potential threats to watershed ecosystem services (Zagarola et al. 2014), but to the best of my knowledge, no one has formally characterized TDF private landowners' beliefs and opinions about beavers. Given their day-to-day interactions with beavers and their decision-making power regarding control or eradication, it is especially important to focus on the factors that drive landowner attitudes and willingness to cooperate for the TDF beaver eradication to be successful.

1.3 Conceptual Framework

A useful framework for conceptually linking the beaver's ecological and social impacts and the proposed eradication in TDF is Collins et al.'s (2011) social-ecological systems framework (Fig. 1.3). This framework recognizes that human behavior and ecosystem function are inherently linked. Human actions modify landscapes (i.e., the introduction or eradication of beavers), which alters ecosystem structure and functioning. Ecosystems provide myriad values to humans through ecosystem services, which are the benefits that nature provides (De Groot et al. 2002, MEA 2005, Pfeiffer and Voeks 2008, Pejchar and Mooney 2009, Chan et al. 2012). Thus, ecosystem structure and function feed back to influence human outcomes. Because this system incorporates feedbacks, people can learn from unexpected outcomes and alter future behaviors. Furthermore, external drivers, such as market forces, unchangeable legislation, or climate change can influence either human behavior or ecosystem structure.

As the framework suggests, for private landowners to be willing to engage in an eradication program, beavers must affect ecosystem services in a way that substantively alters landowner livelihoods or well being. Thus, a thorough understanding of stakeholders' beliefs about how the beaver influences ecosystem services can help practitioners understand TDF ranchers' attitudes towards beavers and thus their willingness to cooperate with the proposed eradication.

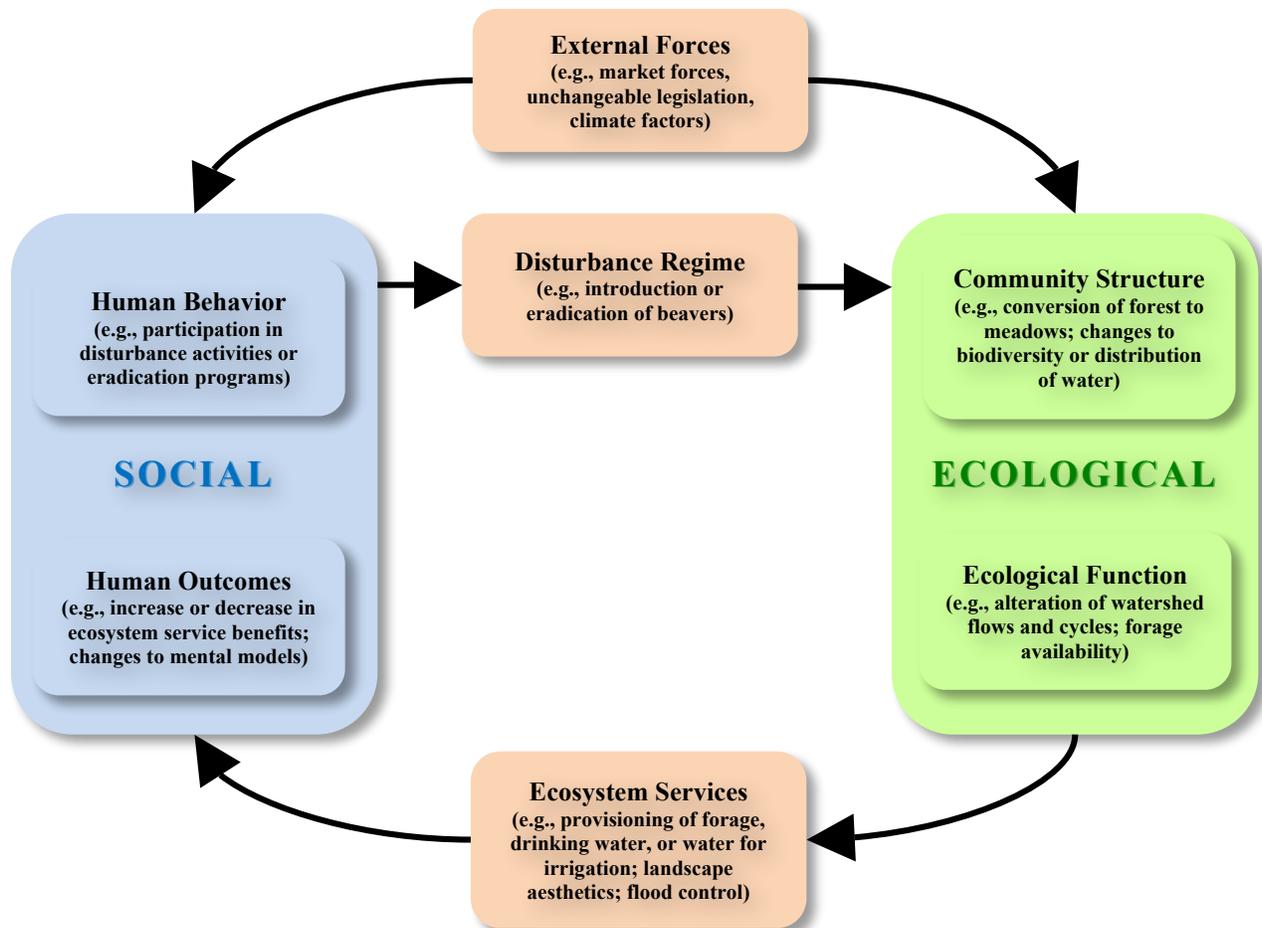


Figure 1.3. Social-ecological systems framework applied to the beaver invasion and proposed eradication in Tierra del Fuego, South America (Collins et al. 2011).

My research fits within this framework in two ways. First, landowners behave based on their personal model of a social-ecological system. That is, each landowner has their own mental model that represents how their behavior (e.g., benign neglect of invasive species) perpetuates change in ecosystems that then feeds back and affects their ability to maintain their livelihood and well-being. The problem, however, is that individual mental models of a social-ecological system may be incomplete or in error. For example, spatial and temporal discontinuities in the behavior-impact relationship may inhibit a landowner's ability to understand the ultimate impact of a land management practice. Because little is known about private landowners' perspectives

and knowledge regarding the impact of beavers on the TDF ecosystem and thus on the landowners' own well-being, an exploration of whether and how landowners make connections between beavers and changes to both ecosystem services and individual outcomes is warranted.

The second reason my research fits in the social-ecological framework is because conservation incentive programs alter the cost-benefit ratio of cooperating to achieve conservation outcomes. As such, incentives are a market or policy tool (i.e., human behavior) whose purpose is to feed back to human outcomes and increase a landowner's well being. This then further modifies human behavior (via collective action), and, with enough participation in a program, eradication occurs. The change in the disturbance regime affects the ecosystem and facilitates the restoration of desired ecosystem services. Thus, conservation incentive programs can serve as a key driver of human behavior and ultimately conservation outcomes.

1.4 Purpose and Objectives

In this thesis, I apply the human-centered design approach to the proposed beaver eradication program in Tierra del Fuego, South America. Specifically, my research questions in this thesis were: 1) Do TDF landowners think beavers change the ecosystem services that they highly value? If so, how? And how can communication about the proposed eradications incorporate local knowledge and priorities? 2) How does the structure of voluntary incentive programs affect TDF landowners' willingness to participate in beaver eradication and reforestation efforts?

I answered these questions using two-step research approach. First, through semi-structured interviews, I elicited landowner "mental models," or internally-held, cognitive belief structures, of how beavers impact the ecosystem services they receive from their riparian lands (chapter 2). Using graph theory, I explicitly represented mental models with cause-and-effect

diagrams called “cognitive maps.” By aggregating individual cognitive maps, I identified cultural knowledge about the beaver’s impacts, as well as important intermediate ideas through which landowners cognitively connect beavers to salient ecosystem services. The theory of reasoned action posits that beliefs about the ecosystem service consequences of engaging with a program influence attitudes and intentions to act, and ultimately participation itself (Fishbein and Ajzen 2010). Thus, underlying beliefs are key to understanding attitudes and patterns of engagement in coordinated actions. I compared the most highly salient ideas in TDF landowners’ mental models to current communication about the beaver and proposed eradication. I offer suggestions for how future communication strategies can integrate stakeholder priorities and local knowledge into targeted messages so that they better resonate with ranchers.

Second, in a broadly administered factorial vignette survey, I examined TDF landowners’ willingness to participate in structurally varied voluntary eradication programs. I present a collaborative research paper that explores how program structure and expected outcomes are related to TDF landowners’ willingness to participate in coordinated conservation actions. An oversimplified model of human motivations assumes that paying landowners will lead to enhanced participation and thus conservation outcomes; however, landowners integrate many competing economic and noneconomic factors into their decision to participate or not in voluntary campaigns. Thus, a more comprehensive understanding of the factors that drive and inhibit landowner participation is needed. We identified key, population-wide preferences for structural attributes of a proposed eradication campaign, as well as possible program factors that divide a population’s willingness to participate. By focusing on user needs during the design phase, program administrators can build programs that complement landowners’ land-use objectives, enhance cooperation, and thus improve conservation outcomes.

This research fills a significant gap in social research about the beaver invasion in Tierra del Fuego. To date, dozens of papers have been published investigating the ecological impacts of beaver invasion, but there is no understanding of private landowners' perceptions of or attitudes towards beavers in TDF. Furthermore, no one has systematically characterized private landowners' willingness to participate in coordinated eradication efforts, or their preferences regarding program design. The two studies presented in this thesis are a first step in an iterative process to understand how local beliefs and preferences can be strategically incorporated into the beaver eradication campaign in order to increase participation and thus efficacy of the program.

Chapter 2: Exploring Ranchers' Knowledge Systems of an Invasive Species

Anna R. Santo

Virginia Tech

Department of Forest Resources & Environmental Conservation

Michael G. Sorice, Chair

Christopher B. Anderson

Timothy Baird

May 4, 2013

Blacksburg, VA

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Anna R. Santo

ABSTRACT

Full cooperation of private landowners is indispensable for the success of an invasive species eradication program; however, little is known regarding how landowners link invasives to the ecosystem services they value from their land. Mental models represent internally held belief structures about how the world functions. In this chapter I characterize private ranchers' beliefs about how invasive North American beavers in Tierra del Fuego (TDF) alter ecosystem structure and function, and thus affect ecosystem service outcomes. Specifically, my objectives were to:

1. Identify the ecosystem services landowners in TDF value from their riparian areas,
2. Generate mental models representing landowners' knowledge system linking beavers to ecosystem services,
3. Explore aggregated mental models to identify the structure and level of consensus (local knowledge) among landowners.

I used semi-structured interviews, freelistings, qualitative coding, and graph theory to build and aggregate cognitive maps that represent TDF ranchers' mental models of how beavers affect ecosystem services. I found that landowners focus primarily on provisioning services (drinking water, forage, and irrigation) but also on general non-provisioning services (general system health, landscape aesthetics). High diversity but low consensus in the models suggests that beliefs about the beaver's impacts to key ecosystem services are largely idiosyncratic and divergent. Furthermore, there is evidence that beavers are not a highly salient issue for a considerable number of TDF landowners. My findings inform the discussion about how to build a salient communication strategy that incorporates local perceptions, priorities, and knowledge.

Currently, most outreach about the planned eradication in TDF focuses on the beaver's destructive impacts to the region's biodiversity and ecosystems. I suggest that future messaging shift its focus and incorporate two specific elements of local knowledge.

Keywords: mental model, cognitive map, local knowledge, social network analysis, invasive species, Tierra del Fuego

Chapter 2: Exploring Ranchers' Knowledge Systems of an Invasive Species

2.1 Introduction

Around the world, conservation planners are implementing invasive species eradication campaigns in order to avert ecological change, economic loss, and negative social impacts to human communities. The introduction of an invasive species can change species assemblages, alter ecosystem structure and function, and thus change ecosystem services (i.e. benefits generated by nature) (Simberloff 2013). Although these changes can result in both positive and negative impacts to human communities, eradication is a preferred management strategy when biological invasions destroy natural resources (e.g., fisheries, waterways), infrastructure (e.g., roads, culverts), or other aspects of human well being (e.g., noise pollution, aesthetics, disease vectors) (Mooney 2005).

Designing an eradication program that works requires a human-centered approach that recognizes that building landowner support is integral to improving conservation outcomes. An oversimplified model of human motivations assumes that paying landowners will lead to enhanced participation and thus conservation outcomes; however, as discussed above, landowners integrate many competing economic and noneconomic factors into their decision to participate or not in voluntary campaigns. Thus, a more comprehensive understanding of landowner participation is needed. The theory of reasoned action posits that beliefs about the consequences of engaging with a program influence attitudes and intentions to act, and ultimately participation itself (Fishbein and Azjen 2010). Thus, underlying beliefs are key to understanding patterns of engagement in coordinated actions. A human-centered approach to program design incorporates landowner beliefs and perceptions about the risk or benefits of participating into the structural design of conservation programs (Sorice et al. 2013, Gelcich and

Donlan 2015). Using this approach, conservation practitioners can identify and address key underlying beliefs that may act as barriers to participation in conservation actions.

A first step in the human-centered design (HCD) approach is to understand perceptions about how participating in a conservation program can increase a landowner's personal and social risk. Private landowners typically make management decisions (i.e., whether to participate in an eradication program) based on generations of historical experience as well as their own direct experiences that help them understand how their ranching system works (Isaac et al. 2009; Berkes et al. 2002; Halbrendt et al. 2014). Consequently, one place to start in an HCD approach for the design of an eradication program is to understand landowners' experiences with and belief structures about the target invasive species. Despite the important role of experience and tradition in private land management, most landscape-scale conservation interventions are developed based on an empirically generated, scientific understanding of the world (Halbrendt et al. 2014), with little to no understanding of how local stakeholders perceive the issue. When planning an eradication program, a detailed characterization of a landowner's beliefs about the invasive species can provide insight into why they choose to participate or not in voluntary campaigns.

Explicitly representing private landowners' knowledge system about how invasive species influence their well being can help conservation practitioners identify key beliefs that orient a landowners' conservation priorities. An individual's internally held, cognitive understanding of how the world functions is sometimes called a "mental model" (e.g., Johnson-Laird 1983). These tools help individuals simplify and understand complex and uncertain conditions in order to make real-world decisions (e.g., Jones et al. 2011; Gray et al. 2014). Mental modeling is particularly useful for understanding complex socio-ecological problems

where public involvement is desired (Hoffman et al. 2014; Jones et al. 2011; Ozesmi and Ozesmi 2004). The framework has been used to study diverse social-ecological issues, like fire management (Zaksek and Arvai 2004), climate change (Bostrom et al. 1994; Morgan et al. 2002; Gray et al. 2014), adoption of conservation agriculture practices (Halbrendt et al. 2014), and water management (Stone-Jovicich et al. 2011). By building explicit representations of landowners' internally held mental models, conservation practitioners can examine the structure and patterns of beliefs that drive their real-world decisions.

Cognitive maps are perhaps the most useful way to explicitly represent mental models because their structures reveal specific beliefs and patterns of thinking about complex systems (Eden 2004). A "cognitive map" is a network of nodes and directed ties that represent an individual's understanding of cause-and-effect relationships within a specific topic area (Morgan et al. 2002; Breakwell et al. 2004). They represent key elements ("nodes") of a system, as well as the causal relationships that connect those elements ("ties") (Özesmi and Özesmi 2004). These maps can be analyzed using social network analysis (SNA), which is a set of methods for understanding network structure based on the number and distribution of nodes and ties. Applying social network analysis to cognitive maps can reveal patterns of thinking, including whether an individual's understanding of a phenomenon is simple or complex, hierarchical (i.e., some ideas have a strong, top-down influence on others) or democratic (i.e., many interconnected ideas). Further, using social network analysis to examine cognitive maps allows a researcher to characterize the relative roles of particular ideas in a mental model. For example, SNA metrics can indicate if a concept is highly central (i.e. connections to other well-connected nodes), commonly held, or if it drives change in the model (Özesmi and Özesmi 2004; Borgatti et al. 2013; Knoke and Yang 2008).

Identifying areas of agreement across individual landowners' mental models is also important as shared beliefs indicate knowledge; that is, local knowledge can be inferred from consensus (Boster 1986 and [cited in] Romney et al. 1986). A knowledge system refers to a coherent set of mental constructs, cognitions, and practices held by individuals within a community (Gray et al. 2012). Local knowledge consists of the shared beliefs that develop among a community of people over time; these beliefs orient behavior and cultural norms (Romney et al. 1986). Landowners draw on local knowledge of ecological and socio-economic contexts to more accurately predict the outcomes of their decisions at a local scale (Abel et al. 1998a). Identifying consensual beliefs across landowners' cognitive maps can reveal specific features of local knowledge that orient a community of landowners' decisions about engaging or not with an eradication program.

Where shared, local knowledge about an invasive species exists, conservation planners can incorporate consensual beliefs into targeted messages in order to clearly communicate how supporting an eradication program can complement local stakeholders' own management objectives. A persuasive message consists of three parts: an advocated position, a set of arguments in support of the position, and specific factual evidence supporting the arguments (Ajzen 1992). Personal construct theory poses that recipients tend to accept messages that fit within their current belief structures (Kelly 1955; Eden 2004; Salmon 1981; Abel et al. 1998a), suggesting that using evidence that conforms to landowners mental models to advocate for participation in eradication will improve the efficacy of the message. Private landowners tend to focus on short-term, and local-scale outcomes because they depend on their land for their livelihoods (Halbrendt et al. 2014). However, eradication campaigns are often planned to increase long-term or regional-scale benefits (i.e. protection of an endangered species), a

currency that may not be salient to private landowners (Oppel et al. 2010). Although many animal and plant eradications enhance agricultural or ranching outcomes (i.e., less incidental herbivory, reduction in disease transmission, improved water quantity or quality), communication about conservation intervention is often based on practitioners' intuition, rather than an empirical understanding of stakeholder priorities, values, or knowledge (Halbrendt et al. 2014; Stokes et al. 2006; Manfredi 1992). Due to this disconnect, eradications that may actually complement landowners' goals may not be perceived as such. In a worst-case scenario, landowners may perceive a campaign as in direct conflict with their management objectives. This causes a lose-lose situation in which opportunities to improve both conservation and livelihood outcomes are lost.

Aggregating cognitive maps is perhaps the most useful means for exploring the nature of shared local knowledge in social groups (Carley and Palmquist 1992). Mental models are based in graph theory, and can thus be represented in diagram form or as adjacency matrices. In matrix form, model nodes identified as causal factors populate the rows and nodes that are affected by causal nodes populate the columns. The cell values of the matrix indicate the strength, direction, and valence (i.e., positive or negative effect) of connections between the nodes. Matrices can be summed to create an aggregated group model that represents all concepts and linkages elicited by all participants in a study (Papageorgiou 2014; Kosko 1987). For a representative sample of individuals, an aggregated group model represents the knowledge system of that social group. Because the group model incorporates variables and linkages from various individual models, it is considered to be a complex system, containing feedbacks and emergent properties (Eden 2004).

The system of interest in this study is private ranchers' mental models of their water sources (rivers, streams, lakes, ponds, bogs, wetlands, and springs) and riparian areas, which are the lands bordering waterbodies (e.g., Stoffyn-Egli and Willison 2011). Water and riparian areas provide important ecosystem services to agriculturalists, such as freshwater and riparian vegetation, water purification, natural hazard mitigation (i.e., flood control), recreational opportunities, and landscape beauty (e.g., Vidal-Albarca Gutierrez and Suarez-Alonso 2013). Invasive species can either enhance or impede these ecosystem services by altering community structure (e.g., vegetation cover, species composition) or ecological processes (e.g., hydrology, nutrient cycling, pollination rates, soil formation, disease transmission), (e.g., Hajzlerova and Reif 2014; Pejchar and Mooney 2009).

The Tierra del Fuego (TDF) Archipelago in South America provides an informative case study to understand how mental models can be used to assist in invasive species eradication. The Argentine government released 20 North American beavers (*Castor canadensis*) to Tierra del Fuego in 1946 in a failed attempt to "enhance" the islands fauna with valuable furbearing species. Since then, the population has grown to an estimated 100,000 individuals (Lizarralde et al. 2004; Skewes et al. 2006), and has recently crossed to the South American continent (Wallem et al. 2007). Conservation planners are concerned about the beaver's impacts because as an ecosystem engineer, beavers dramatically change riparian structure and function; they cause long-lasting changes to hydrology, nutrient cycling, riparian vegetation, food webs, and aquatic and terrestrial species assemblages (Lizarralde et al. 2004, Simanonok et al. 2011, Anderson et al. 2014). Furthermore, these changes alter successional patterns by suppressing seedling regeneration, which ultimately leads to long-term conversion of sub-Antarctic forests to meadows (Wallem et al. 2010). In 2008, the Argentine and Chilean governments formalized an

agreement to launch the largest eradication ever attempted—over 7 million hectares across two countries (Menvielle et al. 2010; Malmierca et al. 2011). However, this eradication plan requires the participation of over 300 private landowners. Most landowners in TDF (60%) believe the beaver is somewhat or very damaging to their land, and over half (52%) somewhat or strongly dislike beavers. They also overwhelmingly view beavers as somewhat or very damaging to TDF (80%). Yet, only a small minority of landowners regularly hunts beavers on their land (Santo et al. *unpublished data*). Given their day-to-day interactions with beavers and their decision-making power regarding eradication, it is especially important to understand private landowner beliefs and concerns about beavers that drive these attitudes and thus willingness to cooperate or not with this eradication program. Yet, this study is the first characterization of TDF landowner beliefs about how the beaver changes ecosystem structure, function, and the production of ecosystem services.

The purpose of my study was to understand how landowners in South America perceive the beaver influencing ecosystem services provided by their water and riparian areas. I elicited TDF landowners' mental models of water and riparian areas and beaver impacts using semi-structured mental models interviews (Morgan et al. 2002). I built and aggregated cognitive maps that explicitly represent the TDF ranching community's mental models, and used social network analysis to answer several questions:

- 1) Which ecosystem services do TDF landowners perceive and value from the ecosystems where beavers live (i.e. watercourses and riparian areas)? And, do they perceive beavers impacting these services?
- 2) Are there systematic patterns of agreement in the way ranchers connect beavers to the benefits they receive from their riparian areas? And, what are the highest consensus

causal pathways by which landowners perceive beavers influencing highly valued ecosystem services?

- 3) Do group mental models of how beavers influence ecosystem services differ across salient services? That is, are they structurally similar? And what are the key intermediate concepts that connect beavers to salient ecosystem services?

By characterizing local knowledge about the beaver's impacts, I identified beliefs and values that are salient to landowners. Conservation practitioners can incorporate this knowledge into messaging about the proposed eradication program in order to build messages that conform to landowners' mental models, and will thus be more effective at building broad public support.

2.2 Study Area

Isla Grande de Tierra del Fuego (hereafter referred to as “Tierra del Fuego” or “TDF”) is the largest and most populated island in the archipelago located south of the Strait of Magellan (52° S, 70° W; Fig. 2). TDF is characterized geographically by four ecoregions: arid steppe; deciduous southern beech forests (*Nothofagus antarctica*, *N. pumilio*); broadleaf evergreen forests (*N. betuloides*, *Drimys winteri*); and Magellanic moorlands (*Sphagnum* spp. bogs) (Fig. 1; Moore 1984).

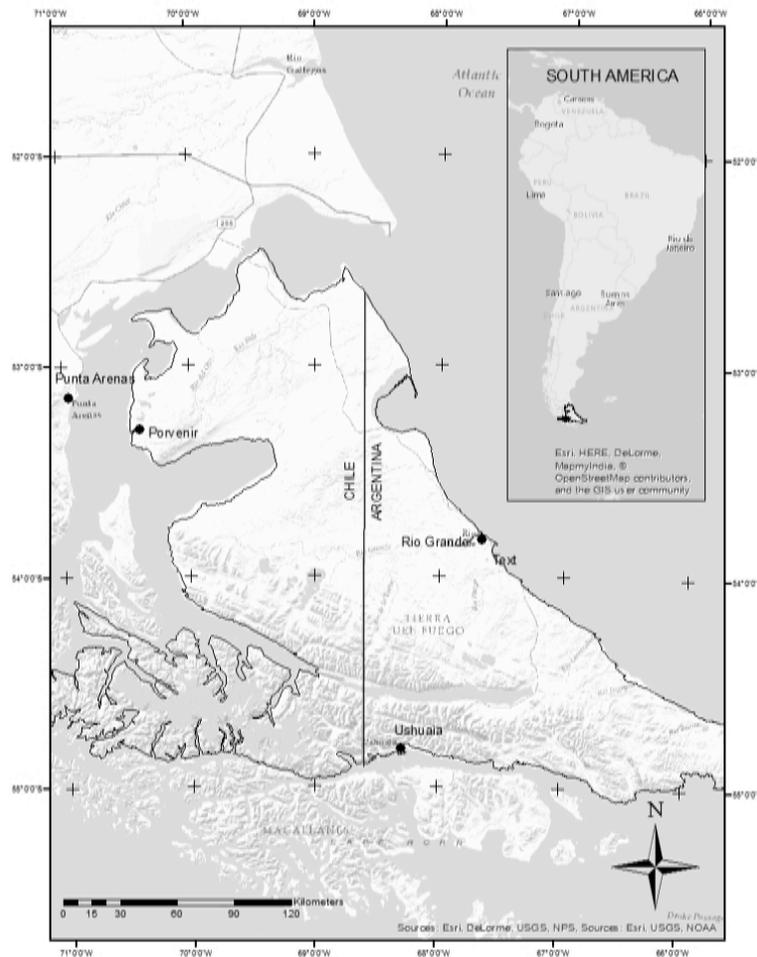


Fig. 2.1. Map of *Isla Grande*, the largest and most populated island of the Tierra del Fuego Archipelago. The Chilean-Argentine international border bisects the island (Chile $\sim 29,000$ km², Argentina $\sim 18,000$ km²). Private sheep and cattle ranches dominate the grasslands in the northern portion of the island. The forested south consists of large tracts of state-owned land, private protected areas, and private forestry operations.

The international border between Chile and Argentina politically bisects TDF, and human populations across both sides of the island are highly concentrated in urban areas. The largest population centers are Ushuaia (pop $\sim 57,000$), Rio Grande (pop $\sim 70,000$), and Tolhuin (pop $\sim 2,600$) in Argentina (INDEC 2014), and Porvenir (pop. $\sim 5,400$) in Chile (INE 2002). Land tenure in TDF is a mixture of private and public ownership. Most privately held land in the northern half of the island is owned by individual families or *sociedades anónimas* (incorporated

groups of shareholders) and operated as sheep or cattle ranches. Forestry companies, conservation NGOs, and governments manage most of the forested areas in southern TDF. The principal economic activities on the Argentine portion of the island are social services, commercial activities (i.e., restaurants, tourism), manufacturing, transportation, construction, fisheries, timber harvesting, real estate, and mining (DGEC 2010), while the Chilean portion relies mostly oil and gas exploration, and ranching (SDRA 2014).

2.3 Methods

Despite a growing interest in cognitive mapping, there is currently no consensus regarding the most appropriate way to elicit individuals' causal belief systems (Hodgkinson et al. 2004; Lynam et al. 2012; Jones et al. 2011). My approach to eliciting and representing cognitive maps was novel but based on Morgan et al.'s (2002) Risk Communication approach. It relied on three steps: 1) ranchers developed lists and ranked ecosystem services provided by riparian areas, 2) they described how each benefit they listed is produced by the ecosystem, and 3) they explained how the beaver affects the production of each ecosystem service. I used transcripts from each interview to build and analyze individual and social cognitive maps representing landowner beliefs about beavers. This strategy allowed me to identify beliefs and values based on the landowner's own perspective (Ozesmi and Ozesmi 2004; Morgan et al. 2002; Spradley 1979). Local agencies and landowner groups helped refine interview questions and content.

2.3.1 Sampling

The population of interest was all individuals currently serving as the primary decision-maker for ≥ 300 ha of privately held, non-corporate land on TDF. In Argentina, private land parcels are typically $\geq 10,000$ ha. Ownership of a small number of properties in Argentine TDF is contested because the government never granted some colonizers legal title to properties they

inhabit. In this study, I defined ownership as currently holding an exclusive, legal title to a piece of land. In Chile, various land reforms divided and redistributed land into *estancias* (i.e., ranches $\geq 2,500$ ha), *parcelas* or *chacras* (parcel or tract ~ 100 - $2,500$ ha), and *hijuelas* (plots typically < 100 ha). *Hijuelas* and smaller *parcelas* are typically non-productive land immediately outside of the small town of Porvenir. I focused on landowners with larger properties because many small parcels and plots are unmanaged. I also excluded from sampling and analysis properties without surface water (river, stream, lake, pond, wetland, bog, or spring) that could serve as beaver habitat. The unit of analysis was a property's primary decision-maker, typically the landowner.

I obtained publicly available land registry data for private properties in Argentine and Chilean TDF. For many properties, ownership information was incomplete or outdated; to improve the quality of my landowner lists, I iteratively triangulated and updated ownership information in consultation with public and private institutions. The final sample frame included 49 and 134 landowners in Argentina and Chile respectively ($N = 183$). I was unable to identify ownership information for one parcel in Argentina and approximately 20 parcels in Chile. Because I continued to work with this population of landowners after completing the interviews reported here (additional work with same population reported in chapter 3), I was able to improve the accuracy of my sampling frame in later stages of research. The final sampling frame that I report here represents my best current understanding of land ownership in TDF after completing all stages of research.

Because landowner characteristics and experiences may be different across ecological or political contexts, I used a stratified random sampling strategy to include landowners from both Argentina and Chile who owned forested and non-forested land in my sample. I overlaid private

land ownership boundaries onto the island's biomes using Geographic Information Systems and randomly selected participants from each country in a ratio roughly proportional to the number of landowners on each side of the island. Within each country, I sampled equally from forested and non-forested areas. In the single case that an individual was the decision-maker for land in both countries, I categorized this person by country of primary residence.

From July to November 2014, I contacted landowners from each of the four landowner categories to invite them to participate in my study. I used professional connections, mutual acquaintances, and participating landowners to initially contact potential participants. In rare cases when I was unable to locate acquaintances, I called or visited addresses listed on the land registry. After acquaintances facilitated introductions, I coordinated in-person interviews with landowners in public locations (e.g., coffee shops and hotel lobbies), private homes, or offices. Meetings lasted 45-180 minutes. I chose to interview a maximum of 40 landowners because past mental model studies have approached theoretical saturation (i.e., very few or no new ideas in subsequent interviews) after around 20-30 interviews (Morgan et al. 2002).

2.3.2 Data Collection

My interviews consisted of four main sections. First, to build rapport (Jennings 2005), I began interviews with a series of questions about the landowner's background and land characteristics. Second, I asked landowners to generate a list of ecosystem services that they believed water or riparian areas on their land provide. Third, I elicited cognitive maps of how those ecosystem service benefits are produced. Finally, I asked landowners whether they believed beavers influence each ecosystem service, and if so, how they caused change.

Because no prior work had been done in this area, I chose this open-ended interview strategy with prompts and probes in order to maximally capture diverse ideas that were framed in

the participant's perspective (Bailey 2007; Isaac et al. 2009). With open-ended formats there is less chance of the interviewer introducing ideas to participants than in structured methods (Morgan et al. 2002). Conversational exchange also reduces ambiguity for both the researcher and respondent as it allows the interviewer to prompt and probe, and the participant to ask clarifying questions (Morgan et al. 2002; Jones et al. 2011; Breakwell et al. 2004).

Freelisting

To understand which ecosystem services landowners perceive and value from their riparian areas (research question 1) I employed freelisting, a technique that consists of asking a participant to consider a domain and then prompting them to list all elements of that domain that they can brainstorm (Weller and Romney 1988; Quinlan 2005). The method allows a researcher to identify the elements that are most salient to research participants, and common responses among participants represent that population's cultural understanding of the domain (Weller and Romney 1988). In this study, I asked landowners to think about all of the sources of water on their land (lakes, ponds, rivers, streams, springs, wetlands, bogs) and the land adjacent to water bodies (hereafter referred to as "riparian areas"). They freelisted the "benefits" (i.e. ecosystem services) that these areas provide. I prompted landowners by saying:

I am interested in understanding the benefits you get from having water and riparian areas on your land. I want to ask you to talk generally about any kind of benefit that comes to mind. There are no right or wrong answers.

After each new idea was described, I iteratively probed participants to further explain their statements until their answers produced no new ideas (Morgan et al. 2002). The benefits listed by each individual landowner were used as the based for creating cognitive maps.

After participants exhausted the benefits they could brainstorm, I asked them to order their list of benefits from most to least important to them (1 = most important). Following this

sorting task, I asked each participant a set of follow-up prompts based on the Millennium Ecosystem Assessment's (2005) typology of ecosystem services. Prompts were designed to encourage thinking about the four categories of ecosystem services: provisioning, supporting, regulating, and cultural. They included questions like, "Do you get anything directly from riparian areas?" "Do you use your riparian areas for anything not directly related to ranching?" Although the use of prompts and probes can run the risk of introducing ideas to participants, it is an effective way to ameliorate problems of memory or recall (Borgatti et al. 2013). As participants mentioned new benefits, I recorded them on small note cards.

Cognitive Maps

In my second interview phase, I used the benefits that each participant freelisted as a framework for eliciting cognitive maps. These influence diagrams represent landowners' cause-and-effect beliefs about how ecosystem structure and function lead to the production of ecosystem services. I employed a semi-structured, face-to-face interview format that started with broad ideas and slowly focused in on more specific concepts (Morgan et al. 2002). This portion of my interviews consisted of two main sections. First, I probed participants to describe how the ecosystem functions to produce the services that they freelisted. I asked them to describe all of the elements that go into the production of each ecosystem service benefit, and how those elements are related to each other (e.g., higher wind velocity increases topsoil erosion). Second, in order to answer research questions 2 and 3, I prompted them to describe if and how beavers affect the production of each benefit. As participants described processes, I further prompted them to explain each idea until no new ideas were produced (Morgan et al. 2002). As each landowner mentioned related elements, I created influence diagrams that visually represented the

causal connections. Throughout the interview I iteratively validated connections to ensure accuracy.

At the end of the interview, each participant received a small token gift, which was a CD containing the final reports created from previous unrelated research projects that were conducted with the same population of rural landowners. I selected this item after a partner (local research institution) informed me that some landowners had requested information about previous studies in which they had participated or that had been conducted on their land.

2.3.3 Data Analysis

Freelisting

In order to understand which ecosystem services TDF landowners perceived and valued from riparian areas (research question 1), I used the ranked freelist data to calculate Sutrop's salience (S) for each ecosystem service benefit mentioned. Salience (S) is a function of the frequency with which an ecosystem services was listed (F) divided by the product of the total number of participants included in the analysis (N), and mean position (mp) or relative rank, of each ecosystem service.

$$\text{Eq. 1} \quad S = F / N(mp) \quad (\text{Smith and Borgatti 1998; Sutrop 2001})$$

Freelisting studies assume that the order in which items were mentioned indicates their relative salience to a landowner (i.e., if an element was mentioned first, it is the most important to that participant. If it was last, it is least important). Thus, order is a proxy for the relative importance of each element. In lieu of assuming that order indicates salience, after the freelisting exercise I asked participants to explicitly rank each ecosystem service by order of importance to them. I used this information to determine each element's mean position in the salience calculation.

Cognitive Map Construction

I transcribed all interviews in F5 transcription software in the interviewee's original language (Spanish $n = 41$; English $n = 2$). When necessary, a native speaker helped transcribe audio that was difficult to understand.

Following transcription, I used a five-step process to build and analyze cognitive maps. First, I coded interview text using NVivo 10 software, and second, I built cognitive maps using Mental Modeler software (Gray 2013). To code and build these maps, I searched interview transcripts for explicit or implicit cause-and-effect relationship statements using a "Cause concept/linkage/effect concept" framework (Ozesmi and Ozesmi 2004). I used an exploratory approach, meaning that I coded concepts as I discovered them, rather than searching for predefined concepts (Carley and Palmquist 1992). While coding, I translated concepts from Spanish transcripts to English codes, retaining original language as precisely as possible in order to preserve meaning. I iteratively re-read each transcript to check codes and linkages after completing each cognitive map. As I added nodes and ties to the cognitive maps, I recorded whether each tie represented an increasing effect (+1) or decreasing effect (-1) between two nodes (Knoke and Yang 2008). Once models were completed, my third step was to export their corresponding adjacency matrices into Microsoft Excel. Fourth, I imported adjacency matrices into UCINET (Borgatti et al. 2002a) and Netdraw (Borgatti et al. 2002b) for cognitive map analysis and visualization, and finally, I exported final social network metrics into Stata for further statistical analysis.

Cognitive Map Transformations

In order to increase interpretability and reduce redundancy in my models, I identified and collapsed nodes with identical or similar meanings prior to aggregating the cognitive maps (Gray et al. 2012; Özesmi and Özesmi 2004; Borgatti et al. 2013). I iteratively revisited interview

transcripts to verify that concepts were sufficiently similar to justify aggregation. And finally, a second researcher reviewed and critiqued the list of proposed nodes to collapse in order to increase validity of the coding and thus trustworthiness of the results (Lincoln and Guba 1985).

Before collapsing nodes, I converted all ties with negative valence (-1) to a positive valence (+1). Thus, all ties retained information about their direction (i.e., node A causes an effect on node B), but not the nature of the relationship (i.e., whether it is an increasing or decreasing effect). Although dichotomizing reduces information in the model, methods for analyzing data with both positive and negative ties are not well developed. Maintaining valence values adds complexity and can cause some measures to lose their meaning (Borgatti et al. 2013).

Beaver-to-Ecosystem Service Sub-Model Construction and Analysis

To examine landowner beliefs about how beavers influence ecosystem services (research question 1), I built and analyzed models that represented all pathways by which research participants perceived beavers influencing two particular ecosystem services of interest (hereafter I refer to these as “beaver-to-ecosystem service sub-models,” or “sub-models”). I built two sub-models that represented beliefs about two of the most salient ecosystem services identified from the freelist activity: human drinking water availability and livestock forage availability. To build these models, I first aggregated all individual cognitive maps that included the node representing the ecosystem service of interest. Next, I identified all pathways from the “beaver abundance” node to the ecosystem service of interest in each aggregated model. Finally, I extracted matrices that included only the nodes that fell on direct or indirect pathways from beaver to the ecosystem service of interest. Due to computational limitations, the pathways extraction was limited to paths of seven ties or less.

To identify systematic patterns of agreement in the way ranchers connect beavers to ecosystem services and highest-consensus pathways between beavers and the target ecosystem services (research question 2), I created a series of “drill down images” to illustrate the robustness of pathways. Path robustness (R) is a metric I created to indicate how idiosyncratic or shared a series of dyadic connections from beaver abundance to the target ecosystem service is. I report it as a level of consensus (e.g., if a particular ecosystem service was included in 25 participants’ cognitive maps, and a pathway connecting beavers to that ecosystem service persists in the model until a level of consensus of tie strength 23, then $R = 23/25 = 92\%$). I let the data guide me in choosing the lowest consensus model for reporting the drill down images, which I selected to be the first sub-model with few enough nodes that it became interpretable (about 40 nodes). I also let the data guide my selection of increments for increasing the level of agreement between images. To limit the overall number of images to interpret, I chose the largest increment possible that still captured major changes in the sub-model as level of consensus increased. The analysis ended when the last remaining direct or indirect path disconnected beaver abundance from the target ecosystem service.

To characterize whether beaver-to-ecosystem service sub-models differed across salient ecosystem services (research question 3), I quantitatively characterized and qualitatively compared the structures of the sub-models for the two target ecosystem services. I used whole-network measures to characterize complexity and patterns of thinking, and node-level metrics to understand the relative roles of individual ideas within landowners’ cognitive maps.

First, I characterized complexity and patterns of thinking by reporting the number of nodes (N) and ties (C) in each sub-models, the density (D) of nodes and ties, hierarchy index (H), and the number of unique pathways from beaver to the ecosystem service of interest (P) in each

sub-model. Higher numbers of nodes, ties, density, or pathways indicate more complex beliefs about how the beaver influences ecosystem services (Eden 2002). A lower hierarchy index suggests that a person thinks more democratically (nodes are evenly interconnected) than hierarchically (some nodes have stronger influence than others) (Özesmi and Özesmi 2004). Democratic thinking is integrative, and suggests that stakeholders perceive more options for intervention in a system (Gray et al. 2014a; Gray et. al 2014b), although each intervention might have a lesser overall impact on an outcome. Although a single density value is hard to interpret, density values can be compared across networks that have a similar number of nodes, as my two sub-models did (Borgatti et al. 2013). Density is calculated as the number of ties (C) in a model as a proportion of the total possible connections between nodes (N) (Özesmi and Özesmi 2004; Wausserman and Faust 1994; Knoke and Yang 2008):

$$\text{Eq. 2} \quad D = C/[N(N-1)] \quad (\text{Hage and Harary 1983})$$

Hierarchy Index is calculated with the following equation, where N is the number of nodes, and U_A is the outdegree of node A (i.e., number of outgoing ties emerging from node A):

$$\text{Eq. 3} \quad H = [12/(N-1)N(N+1)] * \sum_A [(U_A - (\sum U_A)/N)]^2 \quad (\text{MacDonald 1983})$$

H can range from 0 to 1; when H equals one, the map is fully hierarchical, and when H equals 0, it is fully democratic.

In addition to characterizing complexity and patterns of thinking, I examined the roles of individual nodes in the sub-models to help answer which ideas played key connecting roles in TDF landowners mental models of each ecosystem service (research question 3). There are three ways for nodes to represent salient ideas in ranchers' cognitive maps. A node can be included on: 1) one or more high-consensus pathway(s) (i.e., high-level drill down images), 2) many idiosyncratic pathways, or 3) be tightly connected to other well-connected concepts.

To understand which nodes were most pivotal in landowners' understanding of how beavers influence each target ecosystem service, I calculated node pathway occurrence scores for each node. Node pathway occurrence (O) is another new metric that I created; for any sub-model of pathways connecting node A (i.e., beaver abundance) to a node B (i.e., ecosystem service), node pathway occurrence is the percentage of all node A-to-node B pathways that pass through a third node C. The measure can be calculated using the following equation, where T_{AB} is the total number of pathways from node A to B in the sub-model, and $T_{AB,C}$ is the number of pathways from AB that include node C:

$$\text{Eq. 4 } O_C = T_{AB,C} / T_{AB}$$

The measure is reported as a proportion. For example, if there are 1000 pathways that connect node A to node B, and 700 of them contain node C, $O_C = 700/1000 = 0.70$).

To assess the overall level of influence of individual nodes in the beaver to ecosystem service sub-models, I calculated beta centrality for each node. Beta centrality is a measure of the “total amount of potential influence a node can have on others via direct and indirect channels” (Borgatti et al. 2013, p. 171). It shows how connected the variable is to other variables, as well as the cumulative strength of these connections. The beta centrality (C_b) of node i in an adjacency matrix (A) is calculated using the following equation, where α is a normalization factor and β is an attenuation factor that controls the extent to which nodes connected by longer paths are weighted in the centrality measure:

$$\text{Eq. 5 } C_b = \sum_j A_{ij} (\alpha - \beta c_j) \quad (\text{Bonacich 1987; Rodan 2011; Borgatti et al. 2013})$$

The value of α is automatically set so that a network's size is equal to the square root of the sum of squares the node's centralities (Borgatti 2012). The beta value β can be determined using theory or empirically. It is an indicator of the general climate or culture of a network; when

β is positive, connections increase a node's centrality. Conversely, in competitive atmosphere, β can be assigned a negative value so that connections to well-connected nodes diminish a node's centrality (Rodan 2011). Higher magnitudes of β increase the relative importance of long pathways in a node's beta centrality score. In low-density networks, different β values can significantly influence final results (Rodan 2011). The value of β can range from $(-k \text{ to } +k)$, where $k = 1/v^2$ and v is the largest eigenvalue in the solution of the equation $\lambda x = Ax$ (Rodan 2011). Because I wanted to use a beta value that was both positive and high, I chose to use the default value of β in UCINET (this value is positive and 0.5% lower than the maximum possible) (Borgatti et al. 2002).

Finally, to gain an understanding of which ideas have the overall highest importance in each sub-model by my three measures (high consensus paths, path occurrence (O), beta centrality (C_b)), I used the nodes with the highest scores for any of the three measures and conducted a nonmetric multidimensional scaling (NMDS) analysis to provide a multivariate visual representation of the pattern of proximities between nodes. I then conducted a hierarchical cluster analysis with Ward's linkage on the NMDS dimensions to identify groups of nodes with high in-group similarity, and large between-group variation (Kachigan 1991). I qualitatively characterized each cluster of nodes by importance.

2.4 Results

Of the 63 landowners that I attempted to contact, I conducted interviews with 25 and 16 individuals in Chile and Argentina, respectively (raw response rate = 65%). The adjusted response rate was 66% after removing ineligible respondents (e.g., non-contactable due to non-working address; AAPOR 2011a, 2011b). Three interviews were determined to be unusable in final analysis (e.g. participant refused my request to record the interview [$n = 1$], significant

interruptions [$n = 2$]). The final usable sample size was 38 interviews. As reported in past literature, mental model elicitation took between 45 and 180 minutes (Gray et al. 2012; Özesmi and Özesmi 2004; Eden et al. 1979; Kosko 1991).

2.4.1 Participant demographics

Participants exhibited diverse demographic characteristics, including: age, size of land parcels, gender, and nationality (Table 2); however, the typical participant was a Chilean male, around age 55, managing around 12,000-15,000 hectares.

Table 2.1

Demographic characteristics of landowners included in final mental model analysis

	Min	Max	Mean	SE
Age	26	86	57	1.14
Hectares managed	365	107,000	13,587	1,518
Gender (# participants)	109 male (81%)		25 female (19%)	
Nationality (# participants)	97 Chile (73%)		37 Argentina (27%)	

2.4.2 Freelisting

Participants listed 61 unique ecosystem service benefits from their water and riparian lands (Table 3) (research question 1). Individually, landowners mentioned 3 to 15 benefits each, and the four most salient were all provisioning services, including: human drinking water ($S = 0.30$), animal drinking water ($S = 0.29$), better forage/grass ($S = 0.20$), ability to irrigate ($S = 0.15$). The most salient cultural, supporting, and regulating ecosystem services, respectively, were landscape beauty ($S = 0.09$), general system health/balance of nature or biodiversity ($S = 0.07$), and erosion control ($S = 0.06$).

Table 2.2

Ecosystem services mentioned in freelisting exercise, sorted by salience (S) score. The first column, ecosystem service (ES) type, indicates whether each benefit listed is best categorized as a provisioning (i.e., products obtained from ecosystems), cultural (i.e., nonmaterial benefits people obtain through spiritual enrichment, cognitive development, reflection, recreation, and aesthetic experiences), supporting (i.e., services necessary for the production of all other ecosystem services), or regulating (i.e., benefits from the regulation of ecosystem processes) ecosystem service (MEA 2005).

ES Type	Ecosystem Service Benefit	Freq.	Sum ranks	Av. rank	S
P	Human drinking water	24	52.5	2.19	0.30
P	Animal drinking water	32	95.5	2.98	0.29
P	Better forage/grass	28	105.5	3.77	0.20
P	Ability to irrigate	23	94.0	4.09	0.15
C	Landscape beauty	17	86.0	5.06	0.09
S	System health/Balance of nature/biodiversity	9	32.0	3.56	0.07
R	Erosion control	8	30.0	3.75	0.06
R	Air purification	2	2.0	1.00	0.05
C	Ecotourism	12	72.0	6.00	0.05
P	Ability to generate hydropower	11	66.0	6.00	0.05
S	Improve soil health	4	9.0	2.25	0.05
P	Ability to garden for sustenance	7	33.0	4.71	0.04
C	Sport fishing opportunities	10	69.0	6.90	0.04
P	Domestic uses	5	20.0	4.00	0.03
C	Economic benefit for the region	3	8.0	2.67	0.03
R	Climate regulation/water cycle	1	1.0	1.00	0.03
P	Sense of personal security for the future	4	22.0	5.50	0.02
C	Personal satisfaction	4	23.0	5.75	0.02
P	Ability to bathe animals with anti-parasitic medicine	4	25.0	6.25	0.02
R	Forest generates oxygen	3	15.0	5.00	0.02
P	Exploit timber/forest	3	15.0	5.00	0.02
R	Clean water/Water purification	3	15.5	5.17	0.02
C	Family bonding	2	7.0	3.50	0.02
S	Water cycle purifies the environment	3	16.0	5.33	0.02
C	Educational benefit	1	2.0	2.00	0.01
S	Increase mineral deposits/Soil fertility	1	2.0	2.00	0.01
C	Feeling of personal inspiration	3	20.0	6.67	0.01

P	Biodiversity provides economic options (i.e., farming, tourism, etc)	3	21.0	7.00	0.01
P	Ability to exploit peat bogs	3	25.0	8.33	0.01
P	Potential to sell the water	3	25.0	8.33	0.01
P	Hunting and fishing for subsistence	3	27.0	9.00	0.01
P	Higher property values	2	12.0	6.00	0.01
P	Removes bushes without machines	1	3.0	3.00	0.01
P	Animals have food (economic benefit)	1	3.0	3.00	0.01
P	Natural barriers for livestock	2	13.0	6.50	0.01
P	Panning for gold	2	13.0	6.50	0.01
S	Water to support all flora	1	4.0	4.00	0.01
P	Household pet drinking water	1	4.0	4.00	0.01
R	Wild animals clean the land	1	4.0	4.00	0.01
P	Better germination of the grass - better business	1	4.0	4.00	0.01
C	Recreational opportunities	2	17.0	8.50	0.01
R	Carbon sequestration	2	18.0	9.00	0.01
C	Spiritual benefit	1	5.0	5.00	0.01
C	Conservation of rural lifestyle	1	5.0	5.00	0.01
C	Improves quality of live for everyone on ranch	1	5.0	5.00	0.01
R	Reduce evaporation	1	5.0	5.00	0.01
P	Wild animals hunt wildlife, not lambs	1	5.0	5.00	0.01
P	Can feed wildlife to domesticated animals	1	5.0	5.00	0.01
P	Shorter distance for livestock to walk to water	2	22.0	11.00	0.00
S	Diversity of ecosystems	1	6.0	6.00	0.00
P	Producing healthy food/products for people	1	6.0	6.00	0.00
P	Magnetic energy of water has health benefits	1	6.0	6.00	0.00
R	Natural plague control	1	6.0	6.00	0.00
C	Enjoys watching wildlife	1	7.0	7.00	0.00
R	Purifies the land	1	7.0	7.00	0.00
P	Increased income	1	7.0	7.00	0.00
P	Ability to farm trout	1	7.0	7.00	0.00
C	Community development opportunities	1	8.0	8.00	0.00
R	Pollination	1	9.0	9.00	0.00
P	Ability to exploit special clay/mud	1	9.0	9.00	0.00
R	Forests absorb contamination	1	10.0	10.00	0.00

2.4.3 Cognitive Maps

Cognitive Map Construction

From the qualitative coding of my interview transcripts in NVivo, I created 934 unique codes. Many of these nodes represented similar or related ideas (i.e., “level of water quality for drinking,” and “potability of water”). To increase interpretability and reduce redundancy, I collapsed these 934 nodes to 471 final nodes (see Appendix C for full list).

2.4.4 Beaver-to-Ecosystem Service Sub-Model Analysis

I selected “human drinking water availability” and “forage amount” as two highly salient ecosystem services for building my beaver-to-ecosystem service sub-models. Of my 38 individual cognitive maps, 34 and 32, respectively, included the nodes for human drinking water and forage amount.

Pathway Robustness

The following drill down images show the nodes and ties that remain in the sub-models at different levels of consensus. They indicate the robustness of pathways connecting beaver abundance to two ecosystem services, human drinking water availability (Fig 2.2a-f) and amount of forage (Fig 2.3a-h) (research question 2). I began my drill down images with a consensus level of $n \geq 4$ because this was the first level at which the images became interpretable, considering that each sub-model had nearly 300 nodes and hundreds of thousands of pathways. In both sub-models, this level represented roughly 12% consensus. I chose to increase the level by small increments (one interviewee, or roughly 3%) because pathways dropped off quickly from the model as level of consensus increased.

At a level of $n \geq 4$ ($R = 4/34 = 12\%$), 39 nodes and 27 paths remained in the beaver-to-human drinking water sub-model (Fig. 2a). Landowners perceived beavers directly affecting five nodes in the sub-model, including: amount of planted trees, forest, animal waste, turbidity, and the abundance of beaver dams. Within the model, three main themes emerged from the nodes that connect beavers to human drinking water: 1) water quality and cleanliness (i.e., turbidity, salt in water, velocity of water, insects, cleanliness of water, water quality for drinking); 2) soil, vegetation, and trees (i.e., amount of forest, planted trees, topsoil, erosion, amount of vegetation, amount of forage, soil fertility, level of soil moisture); and 3) water abundance and distribution (i.e., evaporation, size/intensity of flooding, surface water available, drought, precipitation). To reach the node for human drinking water availability, all paths passed through at least one of three penultimate nodes: water quality for drinking, groundwater, or surface water availability, suggesting that landowners perceive beavers impacting drinking water through two main avenues: by influencing water availability or potability of water.

At the next step in the drilldown procedure ($n \geq 5$ or $R = 15\%$) 13 nodes dropped from the model, and seven paths remained connecting beaver abundance to human drinking water (Fig. 2b). Although the three identified themes persisted in this higher-consensus model, considerable model detail was lost at this level of consensus.

At levels of $n \geq 6$, or $R = 18\%$, the number of remaining nodes sharply declined from 26 to 9, and three pathways persisted (Fig. 2c). All nodes related to soil, vegetation, or trees disappeared, and two general pathways remained connecting beavers to human drinking water availability. The first path showed beaver dams, ponds, and diversions of waterways altering the quantity of water, and thus drinking water availability. The second suggested that by building

dams, beavers change the velocity of water, which affects water cleanliness and water quality, and thus the availability of drinking water.

Nearly all of the remaining detail in the model dropped off at a level of $n \geq 7$ ($R = 21\%$). At this level of consensus, all nodes related to water quality disconnected, and the two remaining pathways focused solely on the beaver's influence on distribution and availability of water. Finally, at a level of $n \geq 8$, one single pathway remained connecting beavers to human drinking water through beaver dams, ponds, and surface water availability. This pathway persisted to a level of $n \geq 13$ ($R = 38\%$), at which point it also dissociated (Fig. 2e, f). The tie that ultimately broke the highest consensus pathway was the connection between beaver dam abundance and surface water availability.

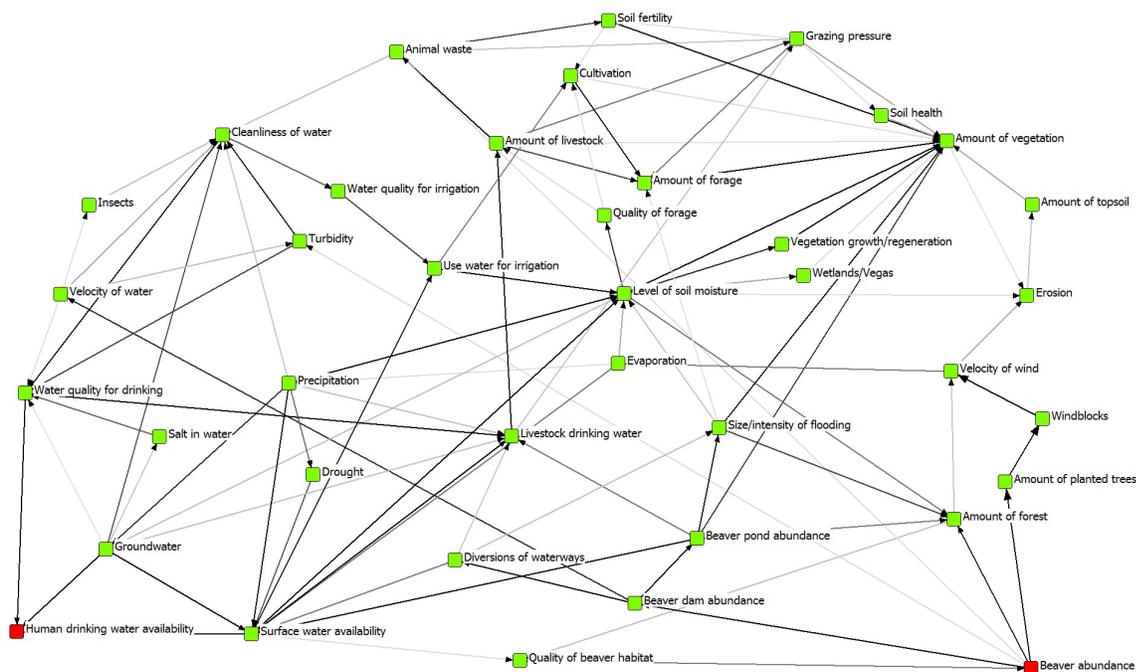


Figure 2.2a. Beaver-to-drinking water sub-model. Level of agreement $n \geq 4$ ($R = 12\%$). This cognitive map includes 39 nodes and 27 unique pathways (geodesic distance ≤ 7) connecting beaver abundance to human drinking water availability.

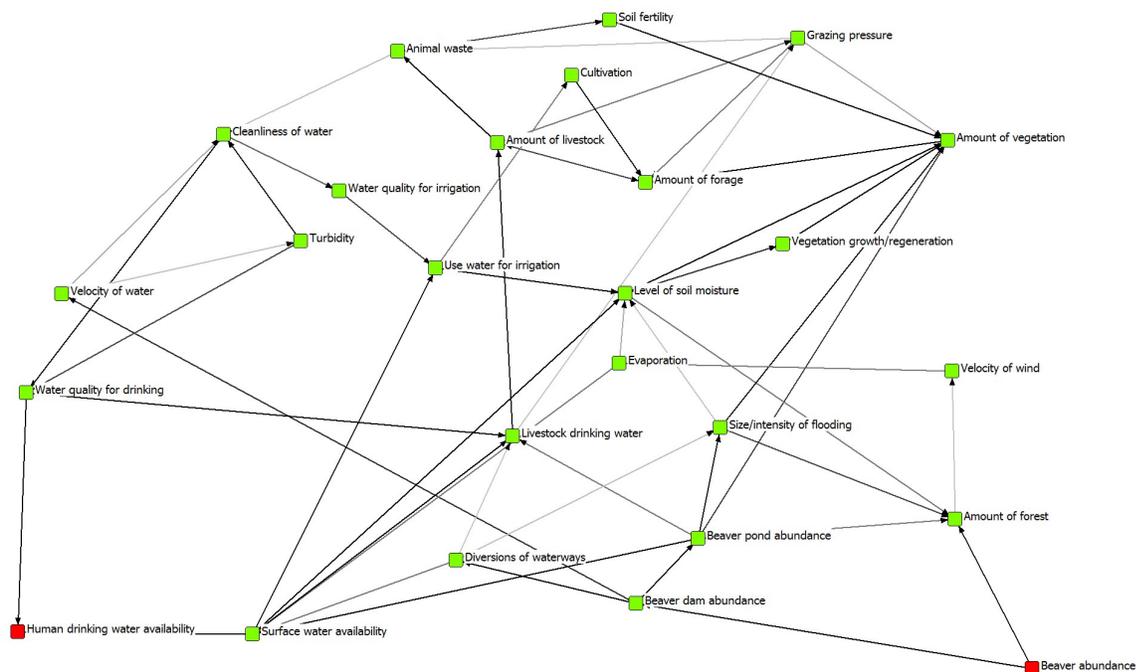


Figure 2.2b. Beaver-to-drinking water sub-model. Level of agreement $n \geq 5$ ($R = 15\%$). This cognitive map includes 26 nodes and 7 unique pathways (geodesic distance ≤ 7) connecting beaver abundance to human drinking water availability.

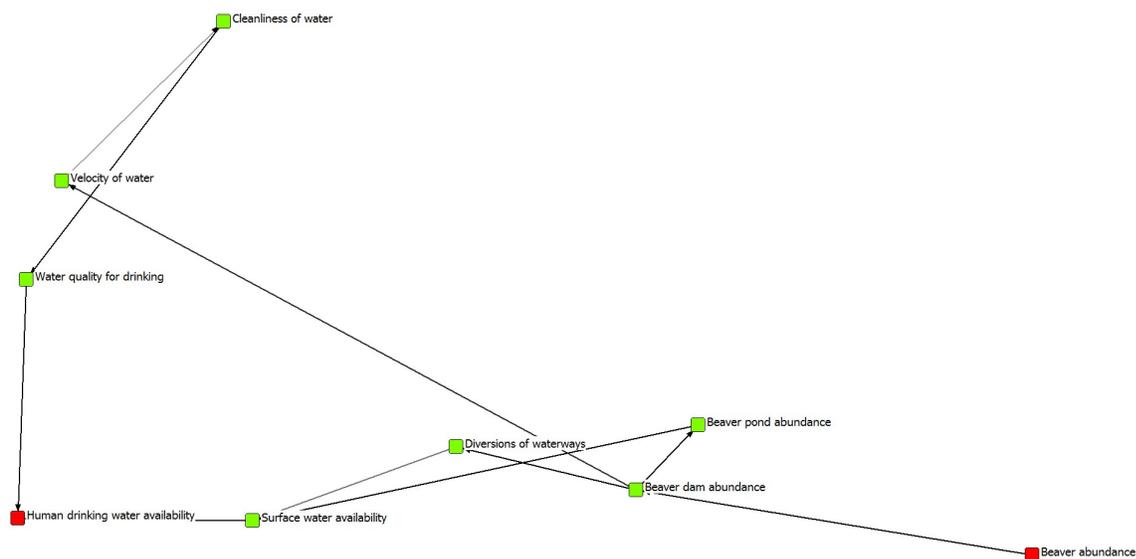


Figure 2.2c. Beaver-to-drinking water sub-model. Level of agreement $n \geq 6$ ($R = 18\%$). This cognitive map includes 9 nodes and 3 unique pathways (geodesic distance ≤ 7) connecting beaver abundance to human drinking water availability.

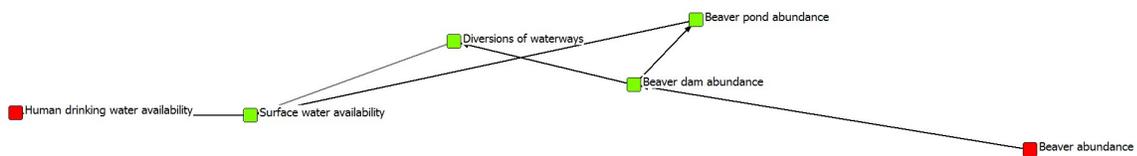


Figure 2.2d. Beaver-to-drinking water sub-model. Level of agreement $n \geq 7$ ($R = 21\%$). This cognitive map includes 6 nodes and 2 unique pathways (geodesic distance ≤ 7) connecting beaver abundance to human drinking water availability.

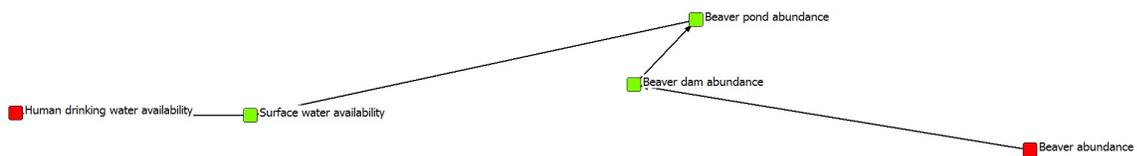


Figure 2.2e. Beaver-to-drinking water sub-model. Level of agreement $n \geq 8$ ($R = 24\%$) through $n \geq 13$ ($R = 38$). This cognitive map includes 5 nodes and 1 unique pathway (geodesic distance ≤ 7) connecting beaver abundance to human drinking water availability.



Figure 2.2f. Beaver-to-drinking water sub-model. Level of agreement $n \geq 14$ ($R = 41\%$). The highest consensus path dissociated between beaver pond abundance and surface water availability.

In the “amount of forage” sub-model, there were 38 nodes and 101 pathways connecting beavers to amount of forage at a level of agreement of $n \geq 4$ interviewees ($R = 4/32 = 13\%$) (Fig. 2.3a). Landowners perceived beavers directly influencing four nodes: beaver dam abundance, amount of forest, planted trees, and turbidity. Five predominant themes emerged at this level of consensus: 1) livestock and grazing pressure (i.e., grazing pressure, amount of livestock, livestock drinking water, animal waste); 2) irrigation and cultivation of the land (i.e., cultivation, use of water for irrigation, water quality for irrigation); 3) abundance and quality of water (i.e., surface water availability, water quality for drinking, groundwater, drought, cleanliness of water, velocity of water, turbidity, evaporation, precipitation); 4) soil and vegetation (i.e., amount of vegetation, soil health, level of soil moisture, amount of topsoil, erosion); and 5) trees and windblocks (i.e., amount of planted trees, windblocks, velocity of wind). To reach the amount of forage node, all pathways passed through at least one of six nodes: amount of livestock, grazing

pressure, cultivation, amount of vegetation, use water for irrigation, or size/intensity of flooding. These nodes can be roughly categorized into three main avenues for beavers to influence forage: by affecting existing natural vegetation that livestock graze, by affecting a landowner's ability to cultivate forage, or by affecting the amount of livestock on the land.

After increasing the level of consensus to $n \geq 5$ ($R = 16\%$), 13 nodes disappeared from the sub-model (25 remain) and 43 pathways persisted (Fig. 2.3b). All nodes associated with the trees and windblocks theme disappeared; all other themes remained, but with reduced detail.

As I increased the level of consensus from $n \geq 5$ ($R = 16\%$) to $n \geq 6$ ($R = 19\%$), two nodes dropped out of the model (turbidity and soil health) and several ties between remaining nodes disappeared (Fig. 2.3c), resulting in 18 remaining pathways. This suggests that much of the interconnectedness of ideas and theme areas disappeared at this level of consensus. Connections that disappeared included: diversions of waterways influence size/intensity of flooding, and thus forage; or grazing pressure influences animal waste and thus water quality.

At a level of $n \geq 7$ ($R = 22\%$), 16 nodes and eight paths remained in the sub-model. There were no changes between the $n \geq 7$ and $n \geq 8$ models, so I report them in a single figure (Fig. 2.3d). At $n \geq 7$, all nodes related to water abundance and water quality disappeared, except for "surface water availability." Three main groups of pathways from beavers to forage emerged in the data. The first was related to beavers influencing the amount of livestock and grazing pressure on the land. Specifically, landowners believed beaver dams and ponds affect the availability of surface water, which influences livestock drinking water, and ultimately the amount of livestock on the landscape. Livestock directly affect forage (i.e., perhaps by consuming or trampling it), and also indirectly affect it through grazing pressure (i.e., perhaps higher grazing pressure decreases relative abundance of preferred forage species). Another group of pathways at $n \geq 8$ included

beavers affecting surface water availability, and thus the ability to irrigate and cultivate forage. The third set connected beavers to the amount and growth rate of naturally occurring (i.e. non-cultivated) vegetation, which can be used as forage. Beaver activity directly (i.e., by flooding) and indirectly (i.e., by changing local hydrology) affects vegetation. There was also a feedback loop in this model. Landowners perceived that the amount of forage affects the amount of livestock on the land, that animal waste affects soil fertility, and this ultimately influences vegetation and forage.

As I increased the level of consensus from $n \geq 8$ to $n \geq 9$ to $n \geq 10$, there were only minor changes to the sub-model. At $n \geq 9$, two nodes disappeared (cultivation and grazing pressure) (Fig. 2.3e), and at $n > 10$ ($R = 31\%$), two more disappeared (animal waste, soil fertility) (Fig. 2.3f). At $n \geq 10$, the feedback loop connecting amount of forage through amount of livestock, soil fertility, and back to amount of forage also disconnected. At $n \geq 10$, five pathways persisted.

The highest consensus pathways connecting beavers to forage amount occurred at $n \geq 11$ ($R = 34\%$) (Fig. 2.3g). At this level, four pathways remained in the sub-model, suggesting that there was no single, most agreed-upon pathway connecting beavers to forage. There were three main final pathways, all of which started with beavers building dams and ponds. In the first, ponds increase water availability, which affects livestock drinking water availability, and thus the amount of livestock and forage. The second connects ponds to water availability, which then influences soil moisture and thus vegetation and forage. The increase in soil moisture can either happen directly (i.e., naturally-occurring increase in soil moisture alongside a pond) or indirectly (i.e., through irrigation of the land). Finally, beaver ponds cause flooding, which can directly affect the amount of vegetation (i.e., drowning the plants) and forage. The final pathways broke at two points (Fig. 2.3h): beaver pond abundance dissociated from surface water availability, and

size/intensity of flooding dissociated from amount of vegetation.

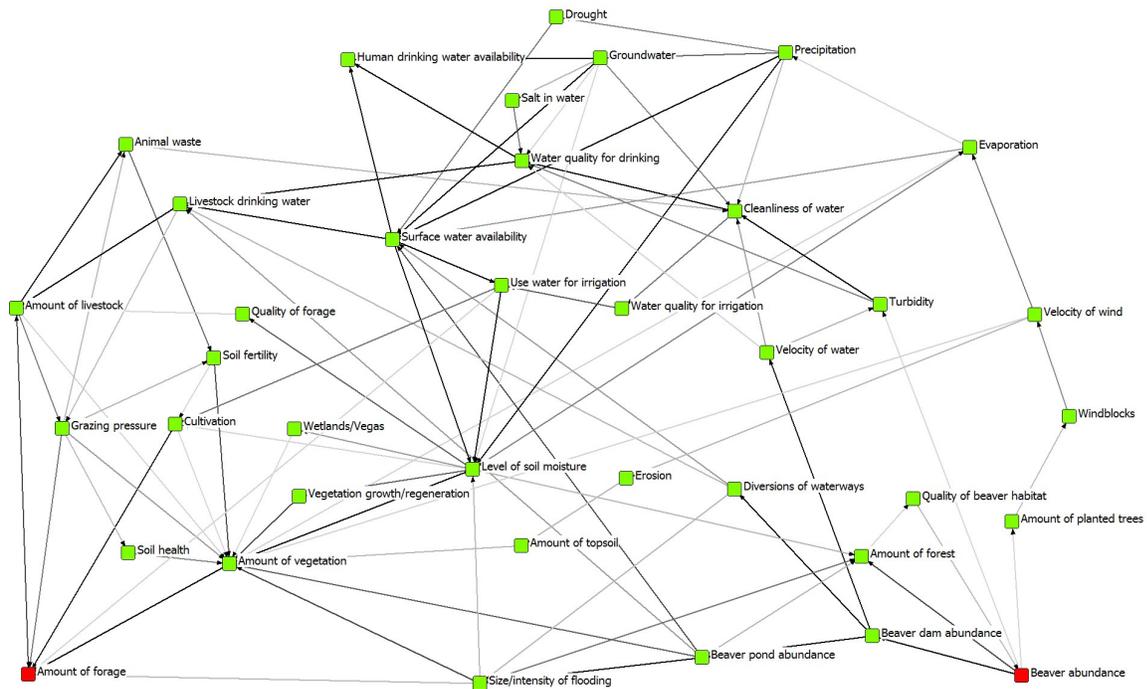


Figure 2.3a. Beaver-to-forage sub-model. Level of agreement $n \geq 4$ ($R = 13\%$). This cognitive map includes 38 nodes and 101 unique pathways (geodesic distance ≤ 7) connecting beaver abundance to amount of forage.

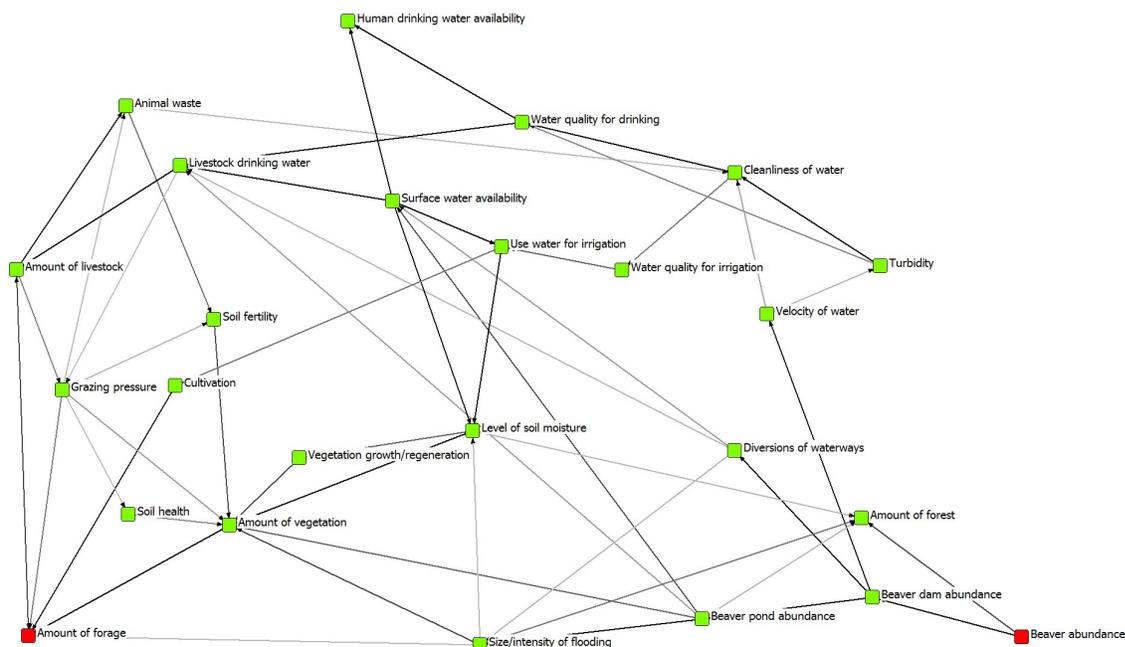


Figure 2.3b. Beaver-to-forage sub-model. Level of agreement $n \geq 5$ ($R = 16\%$). This cognitive map includes 25 nodes and 43 unique pathways (geodesic distance ≤ 7) connecting beaver abundance to amount of forage.

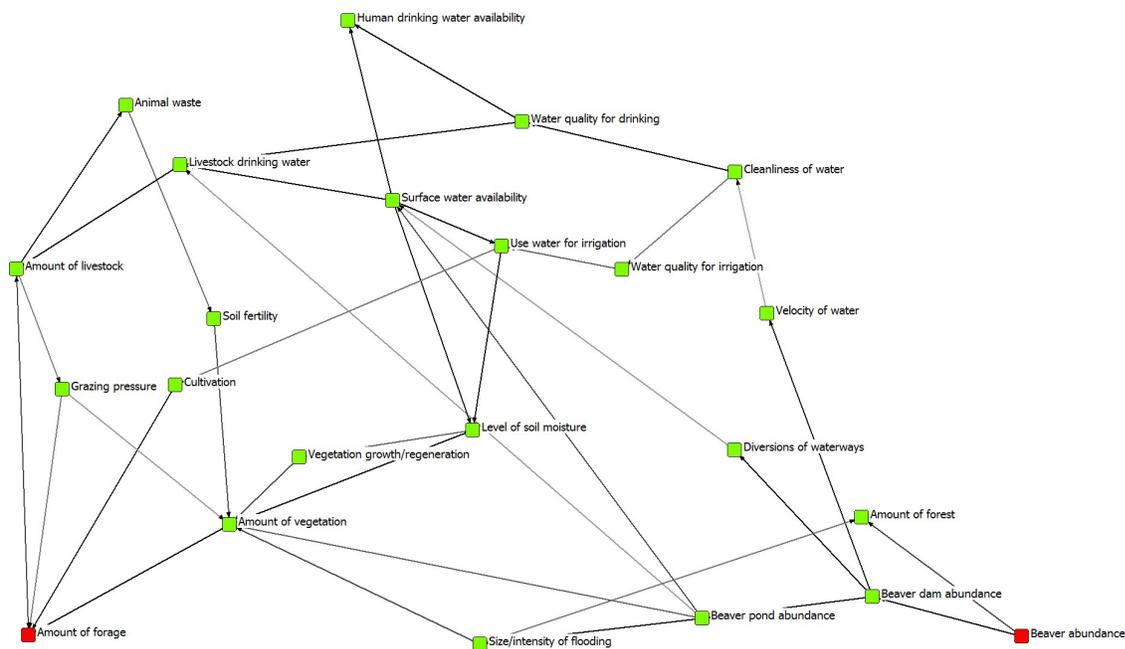


Figure 2.3c. Beaver-to-forage sub-model. Level of agreement $n \geq 6$ ($R = 19\%$). This cognitive map includes 23 nodes and 18 unique pathways (geodesic distance ≤ 7) connecting beaver abundance to amount of forage.

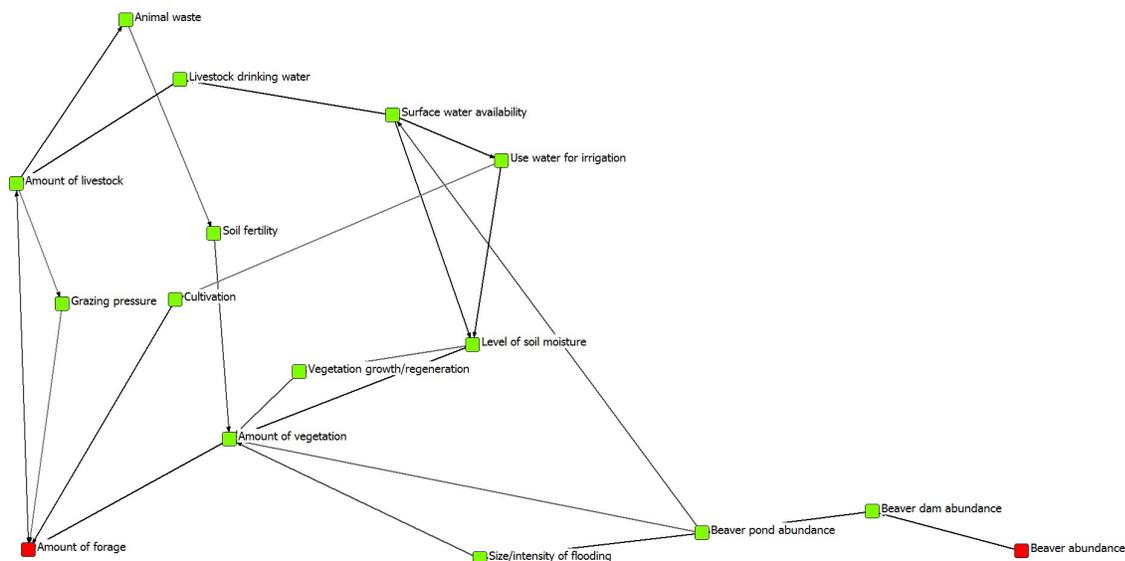


Figure 2.3d. Beaver-to-forage sub-model. Level of agreement $n \geq 7$ ($R = 22\%$) through $n \geq 8$ ($R = 25\%$). This cognitive map includes 16 nodes and eight unique pathways (geodesic distance ≤ 7) connecting beaver abundance to amount of forage.

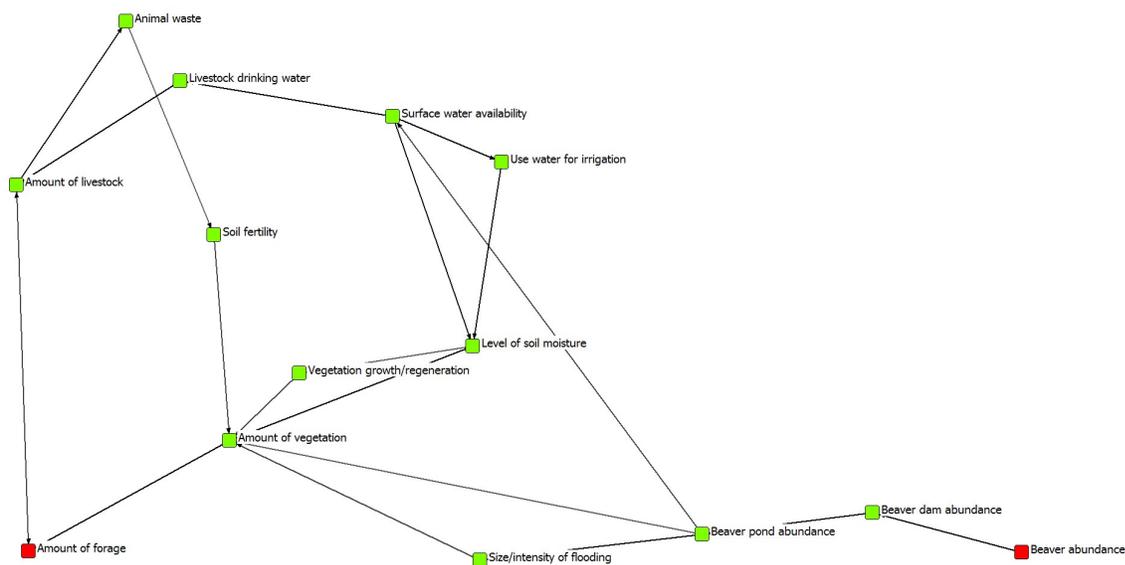


Figure 2.3e. Beaver-to-forage sub-model. Level of agreement $n \geq 9$ ($R = 28\%$). This cognitive map includes 14 nodes and six unique pathways (geodesic distance ≤ 7) connecting beaver abundance to amount of forage.

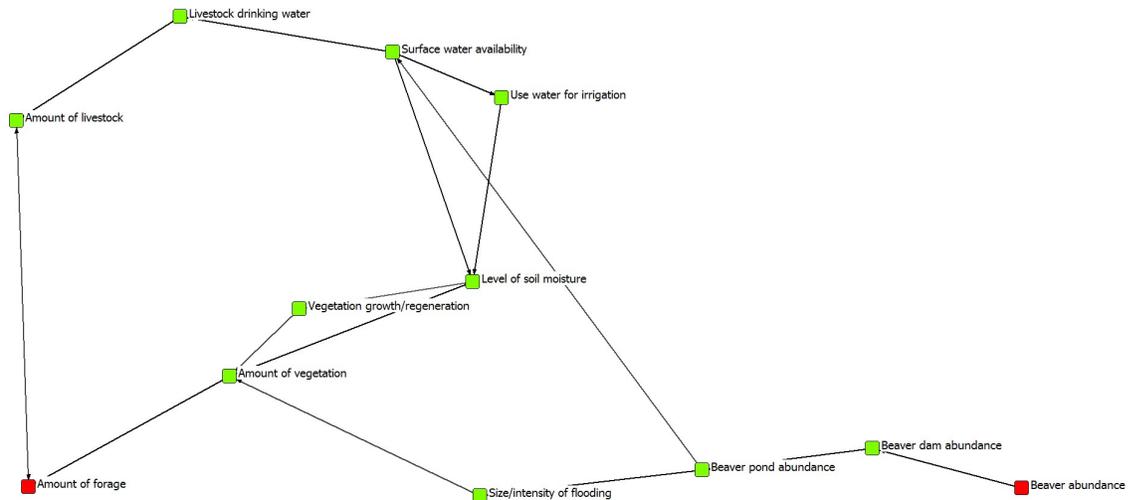


Figure 2.3f. Beaver-to-forage sub-model. Level of agreement ≥ 10 ($R = 31\%$). This cognitive map includes 12 nodes and five unique pathways (geodesic distance ≤ 7) connecting beaver abundance to amount of forage.

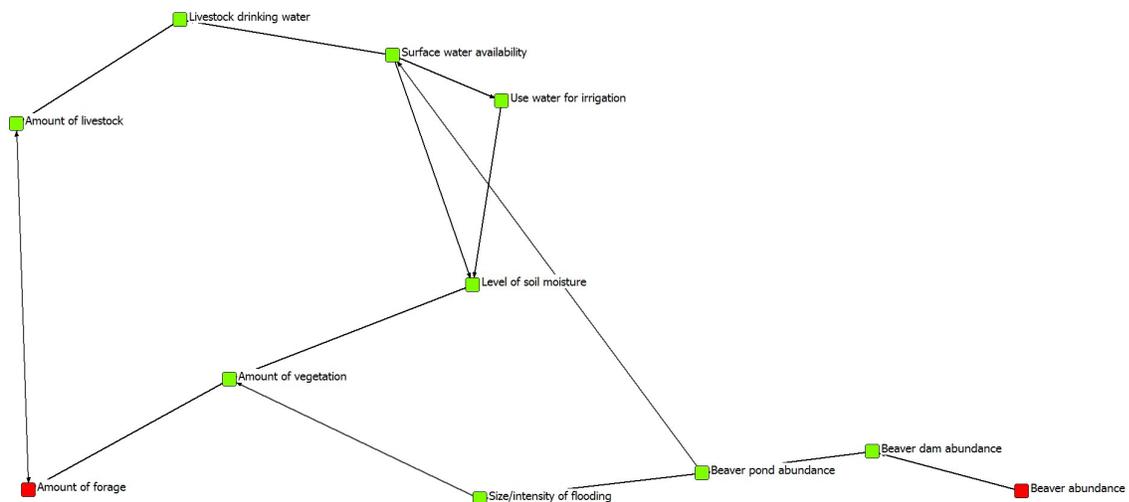


Figure 2.3g. Beaver-to-forage sub-model. Level of agreement ≥ 11 ($R = 34\%$). This cognitive map includes 11 nodes and four unique pathways (geodesic distance ≤ 7) connecting beaver abundance to amount of forage.

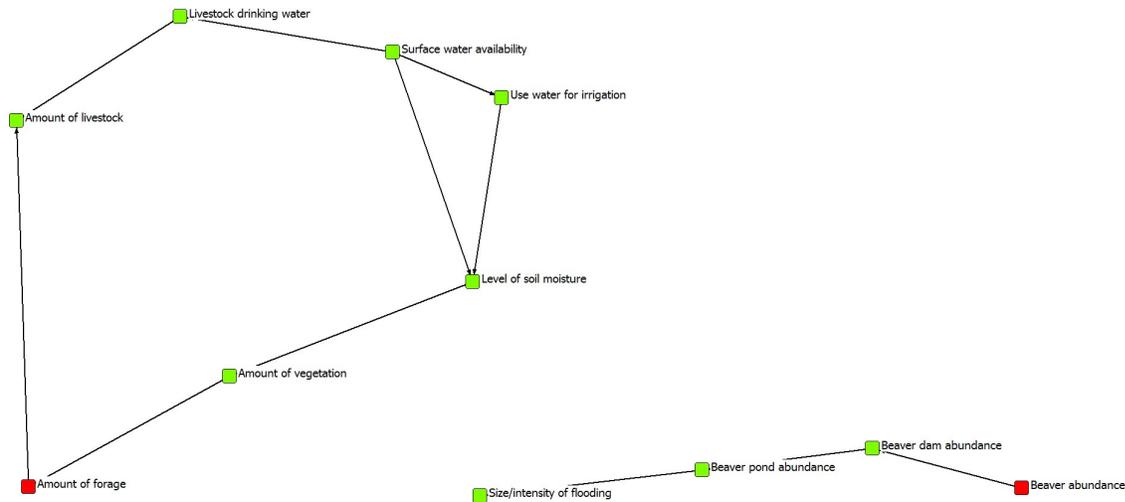


Figure 2.3h. Beaver-to-forage sub-model. Level of agreement $n \geq 12$ ($R = 38\%$). The highest consensus path dissociated at two points: beaver pond abundance dissociated from surface water availability, and size/intensity of flooding dissociated from amount of vegetation.

Characterizing and Comparing Sub-Models

In this section, I use network-level metrics to identify and compare patterns of thinking across salient ecosystem services (research question 3). These metrics are calculated using any node or tie mentioned by one or more landowner in beaver-to-ecosystem service sub-models (i.e., level of consensus $n \geq 1$). The two overall sub-models were structurally similar in number of nodes, ties, density, and hierarchy index (Table 2.3), suggesting that landowners conceptualized these domains similarly. They perceived a comparable number of elements (N) in each sub-model (293 in drinking water; 297 in forage). The number of ties (C) is the number of relationships perceived between nodes in the whole network, and was used to calculate the network's density. Density values were nearly equivalent and very low, this suggests that both sub-models exhibited similar levels of complexity and were similarly dispersed (i.e., loosely connected). Finally, low hierarchy index (H) values indicated that landowners exhibited

democratic patterns of thinking about both domains (i.e., high integration and interdependence of ideas in the network) (Özesmi and Özesmi 2004); meaning, they perceived beavers influencing each ecosystem service in diverse and interconnected ways.

Although the networks were similar by every structural measure, the beaver-to-forage sub-model included more than double the number of pathways from beaver to ecosystem service as the beaver-to-drinking water sub-model (Table 2.3). There were considerably more feedback loops and nodes involved in feedback loops in the forage sub-model than drinking water (133,632 paths and 114 nodes versus 41,908 paths and 91 nodes), which may partially account for the difference. Further, there were marginally more nodes in the forage sub-model ($N = 297$) than in the drinking water sub-model ($N = 293$). Because the number of paths increases exponentially as the number of nodes increase, a small difference in number of nodes could cause a large difference in pathways. Along with the drill down images, these results indicate that landowners perceive more idiosyncratic pathways with more feedbacks connecting beavers to forage, and fewer, stronger (i.e., highly shared) paths with fewer feedbacks connecting them to drinking water.

Table 2.3

Network-level social network analysis metrics for characterizing the structure of two models that show pathways connecting beavers to ecosystem services

Metric	Beaver to Human	
	Drinking Water Sub-Model	Beaver to Forage Sub-Models
Number of nodes (N)	293	297
Number of ties (C)	1802	1793
Density (D)	0.021	0.02
Hierarchy Index (H)	0.0053	0.0049
Number of pathways (P)	192,435	528,388

Relative Roles of Concepts in Sub-Models

In addition to characterizing the overall patterns of thinking, I used three node-level metrics to characterize the relative importance of ideas within the sub-models. Specifically, I identified the nodes with the highest scores for three measures of importance: highest-consensus pathways (from the drill down images), pathway occurrence (O), and beta centrality (C_b). By looking at these measures in combination, I identified nodes that were the most influential overall in the network's structure, and thus can be considered the key connecting ideas in landowners' mental models of the target ecosystem services (research question 3).

Overall, pathway occurrence values were low. Scores ranged from 0.00 to 0.43 in the beaver-to-human drinking water sub-model and 0.00 to 0.41 in the beaver-to-forage sub-model, and only about 5-6% of nodes were included in more than 10% of pathways (Tables 2.4; 2.5). The generally low pathway occurrence shows that even the most pivotal nodes in the sub-models were still in a minority of all pathways. This means that although some nodes did fall on many more paths than others, no nodes were indispensable in connecting beavers to either ecosystem service because many alternate paths existed that excluded those nodes.

Beta centrality results indicate that some nodes were significantly more influential due to their connectedness than others in the network. Scores ranged from 2 to 132,350 in the drinking water sub-model (Table 2.4), and from 2 to 94,456 in the forage sub-model. Given the large number of low-beta centrality nodes and the small number of high beta centrality nodes, it appears that many nodes are only peripherally connected to others in each sub-network, while few are well connected.

Using natural breaks in the data, I identified the highest-valued nodes in each sub-model for each of the three metrics of importance (high consensus paths, path occurrence, beta

centrality) to include in further analyses. First, I included all nodes in each sub-model that occurred on a path of level $n \geq 4$ (or $R = 12$ or 13%); this consisted of 37 in the drinking water sub-model and 39 nodes in the forage sub-model. Second, I found a natural break in pathway occurrence scores (proportion of all pathways that a node falls on) at $P \geq 0.10$. Including all nodes of $P \geq 0.10$ meant retaining 18 and 17 nodes, respectively. Finally, I found a natural break in the beta centrality scores at around 19,500. At this level, I identified 15 and 13 nodes from the drinking water and forage sub-models to include in further analysis. Due to overlap in nodes that scored highly in these three networks (e.g., a single node had high pathway occurrence and high beta centrality), the total numbers of nodes included in further analysis were 46 and 43, respectively, in the drinking water and forage sub-models (Tables 2.4, 2.5).

Next, given the high number of nodes with high values for at least one metric of importance, I used nonmetric multidimensional scaling (NMDS) to further interpret patterns among these nodes. The NMDS analyses created visual representations of the high importance nodes from each sub-model along two dimensions. For the drinking water sub-model (Fig. 2.4), dimension 1 (y-axis) was strongly related to each node's highest-consensus path; nodes that appear on higher-consensus pathways are located at the top of the graph. Dimension 1 also appears to have a weak relationship with both beta centrality and path occurrence such that higher scores are located higher up on the chart. The second dimension (x-axis) appears to be positively related to beta centrality and negatively related to path occurrence. Hence, well-connected nodes appear further to the right, while nodes that occur on many different paths appear further to the left. In the forage sub-model (Fig. 2.5), dimension 1 (y-axis) again appears to have a strong, positive relationship to the highest-consensus paths variable, and weak positive relationships with beta centrality and path occurrence. The second dimension (x-axis) appears to

have opposite relationships as in the drinking water sub-model's NMDS analysis; it is negatively related to beta centrality, and positively related to path occurrence. Hence, well-connected nodes appear to the left and nodes on many diverse pathways occur to the right.

Finally, in my hierarchical cluster analyses, no cluster stopping rule indicated any single most suitable solution regarding number of clusters for either network. I explored the data and found the results to be meaningful and interpretable when I retained three clusters in each. In the drinking water sub-model, group one included just three nodes that scored highly by all three measures: highest-consensus path, path occurrence, and beta centrality (Table 2.6). This group represents "gatekeeper" nodes; it includes nodes representing beaver dams, ponds, and surface water availability. Thus, the pathway from beavers to dams to ponds to surface water availability is key in landowners' overall understanding of the network. Group two included many more nodes, but they were on just moderately high consensus pathways, with moderate path occurrence, and low beta centrality. These nodes bridge the gatekeeper and outcome nodes (human drinking water availability). The diversity of nodes in this group suggests that many intermediate ideas have similar moderate importance within mental models. Finally, group three included nodes on few and low-consensus paths, but they were well connected to other influential nodes. A closer examination led me to discover that these nodes directly influence the gatekeeper nodes. Thus, they may not be key concepts in connecting beavers to human drinking water, but they are additional factors beyond beavers that exert influence on the system.

In the beaver-to-forage model, 16 nodes that were high by all three measures populated group 1; these are core ideas connecting beavers to forage in landowners' mental models. They include ideas like: soil fertility and moisture, vegetation growth and abundance, cultivating and irrigating the land, and water abundance and distribution. Group 2 included nodes on moderately

high pathways with moderately high beta centrality, but with low path occurrence. These nodes are somewhat important intermediaries between beavers and forage, and landowner perceptions of their roles are fairly streamlined. Finally, group three included nodes on low-consensus pathways, with low beta centrality, but moderate path occurrence. These are ideas that bridge beavers and forage through diverse, idiosyncratic beliefs that are not highly shared among the population of landowners.

Table 2.4

Node-level metrics for characterizing roles of individual nodes within a network of pathways connecting beaver abundance to human drinking water availability. The highest values for each metric were selected for inclusion based on natural breaks in the data ($R \geq 4$; $P \geq 0.10$; $C_i \geq 19,500$) to increase interpretability.

Code (#)	Node	Highest consensus path (R)	Path Occurrence (P)	Beta Centrality (C_b)
1	Beaver dam abundance	13	0.13	77575.27
2	Beaver pond abundance	13	0.14	58387.70
3	Surface water availability	13	0.43	83733.66
4	Diversions of waterways	7	0.16	32870.87
5	Cleanliness of water	6	0.16	7760.70
6	Velocity of water	6	0.04	6285.52
7	Water quality for drinking	6	0.28	7623.93
8	Amount of forage	5	0.06	10232.33
9	Amount of forest	5	0.24	14941.77
10	Amount of livestock	5	0.12	12735.25
11	Amount of vegetation	5	0.23	16017.56
12	Animal waste	5	0.07	5512.43
13	Cultivation	5	0.03	7756.34
14	Evaporation	5	0.09	36709.23
15	Grazing pressure	5	0.04	8801.29
16	Level of soil moisture	5	0.14	26542.77
17	Livestock drinking water	5	0.02	13103.31
18	Size/intensity of flooding	5	0.11	18613.94
19	Soil fertility	5	0.02	8664.77
20	Turbidity	5	0.10	4982.92
21	Use water for irrigation	5	0.11	25999.80

22	Vegetation			
	growth/regeneration	5	0.01	7209.88
23	Velocity of wind	5	0.04	19230.16
24	Water quality for			
	irrigation	5	0.00	6804.92
25	Amount of planted trees	4	0.04	3881.60
27	Drought	4	0.03	23443.32
28	Erosion	4	0.02	983.32
29	Groundwater	4	0.10	76044.18
31	Precipitation	4	0.09	132349.86
32	Quality of beaver habitat	4	0.01	18189.28
26	Amount of topsoil	4	0.03	4709.15
36	Wetlands/Vegas	4	0.01	2739.29
33	Quality of forage	4	0.02	2493.60
34	Salt in water	4	0.01	2463.47
35	Soil health	4	0.02	3578.70
30	Insects	4	0.01	1229.52
37	Windblocks	4	0.01	3531.79
70	Water quality	.	0.37	1423.96
43	Odors	.	0.17	902.96
56	Naturalness	.	0.14	5008.46
69	Water for domestic uses	.	0.10	2618.00
64	Season	.	0.01	83463.13
59	Climate change	.	0.03	49288.14
55	Man-made drinking			
	water holes for livestock	.	0.01	29607.21
44	Climate/air temperature	.	0.03	26962.12
40	Beavers hunted	.	0.02	20834.32

Table 2.5

Node-level metrics for characterizing roles of individual nodes within a network of pathways connecting beaver abundance to forage availability. The highest values for each metric were selected for inclusion based on natural breaks in the data ($R \geq 4$; $P \geq 0.10$; $C_i \geq 19,500$) to increase interpretability.

Cod		Highest consensus	Path	Beta
e (#)	Node	path (R)	Occurrence (P)	Centrality (C_b)
1	Amount of livestock	11	0.19	14336.91
2	Amount of vegetation	11	0.41	19595.93
3	Beaver dam abundance	11	0.12	54606.54
4	Beaver pond abundance	11	0.03	43694.18
5	Level of soil moisture	11	0.31	25831.88
7	Size/intensity of flooding	11	0.08	17227.09
8	Surface water availability	11	0.24	69147.59
9	Use water for irrigation	11	0.21	25468.96
6	Livestock drinking water	11	0.06	14121.36
10	Vegetation growth/regeneration	10	0.08	6831.58
12	Soil fertility	9	0.15	9360.61
11	Animal waste	9	0.08	5183.63
13	Cultivation	8	0.15	9359.04
14	Grazing pressure	8	0.13	10655.76
15	Amount of forest	6	0.19	9738.50
16	Cleanliness of water	6	0.08	6646.32
17	Diversions of waterways	6	0.15	25715.34
19	Velocity of water	6	0.02	5291.69
20	Water quality for drinking	6	0.02	7097.81
18	Human drinking water availability	6	0.00	180.66
22	Turbidity	5	0.02	4100.18
21	Soil health	5	0.06	4388.47
24	Amount of topsoil	4	0.11	4012.21
27	Evaporation	4	0.05	27726.66
28	Groundwater	4	0.02	57221.91
29	Precipitation	4	0.10	94456.25
30	Quality of beaver habitat	4	0.01	8080.16

33	Velocity of wind	4	0.04	15101.86
34	Wetlands/Vegas	4	0.01	2435.38
31	Quality of forage	4	0.08	2761.35
32	Salt in water	4	0.00	2337.26
26	Erosion	4	0.03	826.10
23	Amount of planted trees	4	0.05	3438.18
35	Windblocks	4	0.01	3265.96
25	Drought	4	0.01	17070.40
36	"Naturalness"	.	0.16	3849.10
49	Health of pastures	.	0.15	3008.58
65	System health/Ecological balance	.	0.12	500.33
63	Responsible livestock management strategy	.	0.12	5579.61
43	Exotic/Invasive species	.	0.11	2388.55
64	Season	.	0.00	51529.01
40	Climate change	.	0.02	33519.82
53	Man-made drinking water holes for livestock	.	0.01	25522.37

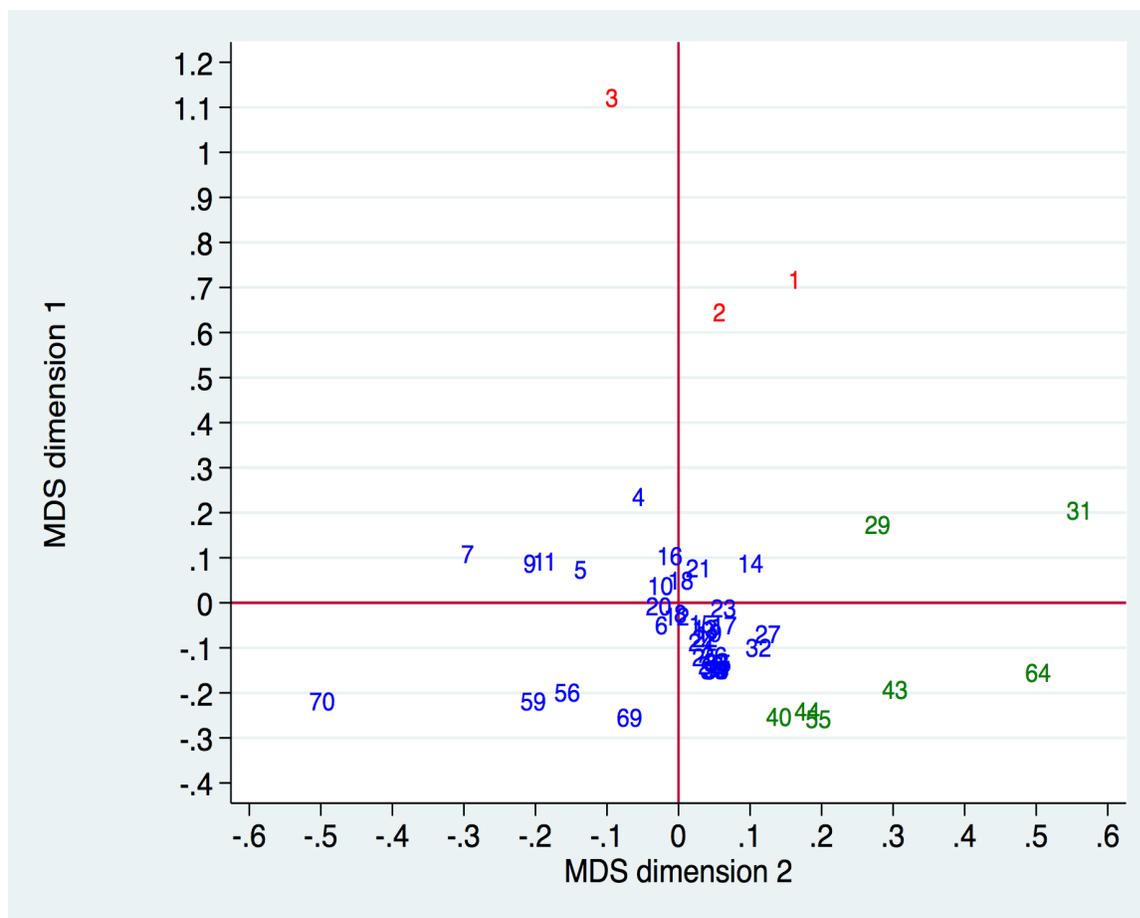


Figure 2.4. Nonmetric multidimensional scaling of nodes that occurred on high-consensus pathways, had high pathway occurrence values, or high beta centrality in the beaver-to-human drinking water sub-model. Dimension 1 has a strongly positive relationship to highest-consensus path and weakly positive relationship with beta centrality and path occurrence. Dimension 2 is positively related to beta centrality and negatively related to path occurrence. Numbers represent specific nodes within the beaver-to-drinking water sub-model (see Table 2.4).

Table 2.6

Three groups of nodes in beaver-to-human drinking water sub-model as determined by hierarchical clustering with Ward's linkage.

	Group 1	Group 2	Group 3
Highest Consensus	High (mean = 13; SD = 0; median = 13)	Moderate (m = 4.39; SD = 1.4; md = 5)	Low (m = 1.86; SD = 1.46; md = 1)
Pathway Occurrence	High (m = 44841; SD = 32977; md = 26428)	Moderate (m = 16336; SD = 17048; md = 8189)	Low (m = 7871; SD = 7457; md = 5354)
Beta Centrality	High (m = 73232; SD = 13219; md = 77575)	Low (m = 10433; SD = 9333; md = 7417)	Moderate (m = 59793; SD = 40220; md = 49288)
# Nodes	3	36	7
Nodes	<ul style="list-style-type: none"> • Beaver dam abundance • Beaver pond abundance • Surface water availability 	<ul style="list-style-type: none"> • Water for domestic uses • Insects • Quality of beaver habitat • Animal waste • Salt in water • Amount of planted trees • Naturalness • Amount of forage • Wetlands/Vegas • Water quality for irrigation • Diversions of waterways • Amount of vegetation • Vegetation growth/regeneration • Velocity of wind • Erosion • Level of soil moisture • Water quality • Livestock drinking water • Odors • Amount of livestock • Velocity of water • Water quality for drinking • Amount of topsoil • Soil health • Cleanliness of water • Cultivation • Use water for irrigation • Size/intensity of flooding • Drought • Evaporation • Grazing pressure • Turbidity • Soil fertility • Amount of forest • Quality of forage • Windblocks 	<ul style="list-style-type: none"> • Man-made drinking water holes for livestock • Season • Climate/air temperature • Precipitation • Climate change • Beavers hunted • Groundwater

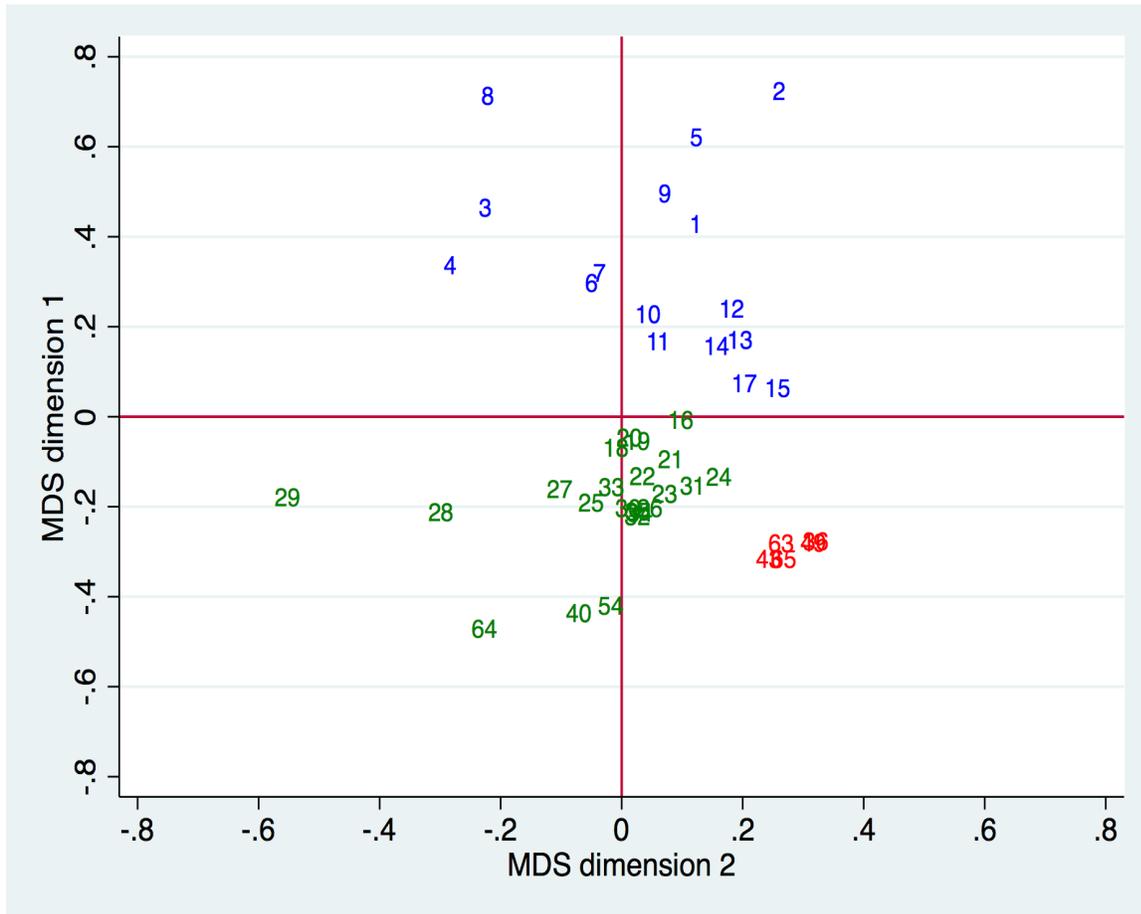


Figure 2.5. Nonmetric multidimensional scaling of nodes that occurred on high-consensus pathways, had high pathway occurrence values, or high beta centrality in the beaver-to-forage sub-model. Dimension 1 has a strongly positive relationship to highest-consensus pathway and weakly positive relationship with beta centrality and path occurrence. Dimension 2 is positively related to path occurrence and negatively related to beta centrality. Numbers represent specific nodes within the beaver-to-forage sub-model (see Table 2.5).

Table 2.7

Three groups of nodes in beaver-to-forage sub-model as determined by hierarchical clustering with Ward's linkage.

	Group 1	Group 2	Group 3
Highest Consensus Pathway Occurrence	High (mean = 9.69; SD = 1.82; median = 11)	Moderate (m = 4.05; SD = 1.46; md = 4)	Low (m = 1; SD = 0; md = 1)
Beta Centrality	High (m = 0.16 ; SD = 0.1; md = 0.15)	Low (m = 0.03; SD = 0.03; md = 0.02)	Moderate (m = 0.13; SD = 0.02; md = 0.12)
# Nodes	16	22	5
Nodes	<ul style="list-style-type: none"> •Vegetation growth/regeneration •Beaver dam abundance •Level of soil moisture •Livestock drinking water •Amount of vegetation •Amount of forest •Animal waste •Use water for irrigation •Size/intensity of flooding •Cultivation •Beaver pond abundance •Grazing pressure •Amount of livestock •Surface water availability •Diversions of waterways •Soil fertility 	<ul style="list-style-type: none"> •Windblocks •Cleanliness of water •Salt in water •Precipitation •Water quality for drinking •Turbidity •Soil health •Quality of forage •Wetlands/Vegas •Evaporation •Climate change •Quality of beaver habitat •Drought •Man-made drinking water holes for livestock •Velocity of wind •Velocity of water •Groundwater •Erosion •Amount of topsoil •Season •Amount of planted trees •Human drinking water availability 	<ul style="list-style-type: none"> •Naturalness •Exotic/Invasive species •Responsible livestock management strategy •Health of pastures •System health/Ecological balance

2.5 Discussion

I used freelist, cognitive mapping and social network analysis to identify: 1) the ecosystem services that landowners perceive and value from their water and riparian areas, 2) local knowledge about how beavers influence two highly salient ecosystem services, and 3) key structural similarities and differences between landowners' mental models of beaver impacts. Because this research was exploratory, I used an open-ended strategy to maximally capture diverse ideas from the research participants' perspective.

I found that landowners prioritized provisioning ecosystem services; there were low levels of consensus regarding beliefs about the beaver's impacts to two salient ecosystem services, and landowners hold many more idiosyncratic beliefs about how beavers influence forage than they do human drinking water availability. My findings inform the discussion about how to build a salient communication strategy that incorporates local perceptions, priorities, and knowledge to promote a proposed beaver eradication in TDF. Furthermore, this explicit characterization of local knowledge can facilitate learning between landowners, who have great local knowledge, and conservation practitioners, who have access to scientific knowledge regarding the beaver.

In general, two possible conclusions can be drawn from the low levels of consensus in my two beaver-to-ecosystem service sub-models. Firstly, diverse and divergent understandings suggest that there is no singular "local knowledge" shared by the entire population of landowners regarding the beaver's impacts to the target ecosystem services. There were hundreds of thousands of pathways connecting beavers to each ecosystem service, but the number of pathways decreased exponentially as the level of consensus increased. This rapid dissolution of pathways suggests that beliefs about the mechanisms by which beavers affect salient ecosystem services are diverse and idiosyncratic, rather than widely shared among landowners. Given this

diversity in beliefs, there may not be one single message that will resonate with this entire population. Rather, it is possible that there are multiple “local knowledges” that reflect the different experiences of different groups of landowners (i.e., Stone-Jovicich et al. 2011), and individualized messages could be crafted for each group. Although no pathways were unanimously consensual, some beliefs about the beaver’s impact to ecosystem services were still much more widely held than others, and incorporating these messages into targeted communication will ensure that the messages will resonate with a high number of landowners in this diverse population. Second, low consensus suggests that beavers impacting ecosystem services may not be a highly salient issue for a considerable number of landowners. The highest-consensus pathway in both sub-models was intuitive and relatively direct; it showed that beaver activity influences surface water availability, and water availability influences drinking water. Yet, this highly intuitive pathway dissociated at the tie connecting beaver ponds to surface water availability at just 38% consensus. This suggests that many landowners perceive beavers and beaver activity, but only some landowners explicitly connect beaver activity to changes in ecosystem structure and function. Hence, shared knowledge about the beaver’s impacts to ecosystem structure and functioning may be limited because some landowners perceive that beavers exert little to no influence on the target ecosystem services. Additional analysis would be necessary to definitively make this claim; however, if true, this result suggests that knowledge of impacts may not be influential in landowners’ decisions to participate, and building support for the eradication may require the use of externally-motivating strategies, like financial incentives or social rewards for participation (Sorice et al. 2011).

TDF landowners perceived two main avenues connecting beavers to human drinking water availability; these pathways could represent key beliefs about how eradication will affect

the ecosystem service outcome that is most salient to this population of landowners. The most highly consensual pathway was that beavers influence drinking water by affecting surface water availability. Although this is a seemingly intuitive path, beavers affect water availability in multiple ways in TDF. They can increase local water availability by retaining water behind dams. Alternatively, beavers may decrease regional water availability because they stagnate water and thus increase evaporation. Furthermore, building dams can divert and even cause waterways to dry up, which decreases local surface water availability downstream of beaver activity. Given the range of possible interpretations, I speculate that landowners may have actually conceptualized this connection in dissenting ways, which could lead them to predict opposite outcomes when they consider the proposed eradication. This inability to detect opposing beliefs is a limitation of the social network analysis method that I employed, as I was unable to retain information about the valence of the ties. If my speculation is true, this could have broad implications for the proposed beaver eradication in general; the connection between beavers and water availability is key not only to the production of human drinking water, but also to many of the other high- and moderate-salience ecosystem benefits. Therefore, given the high number of landowners perceiving that beavers influence surface water availability, and the possible importance that divergent beliefs about this relationship can have on perceptions of the ecosystem service consequences of eradication, I suggest that the nature of this relationship should be further characterized in future analyses.

The second highest pathway connecting beavers to drinking water suggested that by influencing drinking water quality, beavers change the availability of human drinking water. At a moderate level of consensus, TDF landowners perceived water velocity affecting turbidity and aquatic insects and thus water quality. There is ample scientific evidence corroborating these

beliefs. By building dams, beavers convert lotic (i.e., fast-moving) aquatic systems to lentic (i.e., slow) ecosystems, which increases turbidity, alters water chemistry, and increases bacterial and algal growth (e.g., Bledzki et al. 2011; Price and Chow-Fraser 2013). Given the high salience and relatively consensual beliefs about how beavers influence human drinking water, this appears to be one of the beaver's ecosystem service impacts that landowners both consistently perceive and highly value.

Scientific literature suggests that beavers negatively impact human drinking water in ways that were not widely perceived and that also pose significant risk to human and livestock health. In North America, beavers are vectors of dangerous water-borne pathogens that can cause illness in humans or livestock, including giardia and cryptosporidium (Dunlap and Thies 2002; Fayer et al. 2006; Isaac-Renton et al. 1987), and although no research has officially confirmed the role of the beaver in transmitting these pathogens in TDF, the beaver's ecological impacts are generally comparable in both contexts (Anderson et al. 2009). In TDF, landowners perceived a number of factors influencing potability at a low level of consensus, including aquatic insects, bacteria, algae, and parasites, or organic debris; however, perceptions of beavers increasing dangerous water-borne pathogens were not widely-shared in TDF. Similarly, research suggests that water quality in abandoned beaver ponds may be worse than in active ponds (Bledzki et al. 2011).

Ideally, important threats to health, safety, or well-being will be highly consensual within stakeholders' mental models; however, this is not always the case. Mental models can be used to identify these important "missing" perceptions in a population's understanding of particular domain. Most studies that apply mental models in this way build an "expert model" and systematically compare nodes and ties in the "expert" versus the "layperson" model (e.g.,

Morgan et al. 2002). Others simply qualitatively compare individual or group models to best scientific understanding of the domain (i.e., Isaac et al. 2009) to identify important differences. When awareness of important risks is low, it may be necessary to develop targeted outreach in order to integrate new ideas into landowners' mental models. Altering a mental model requires restructuring one's understanding of how the world functions, a task that may be extremely difficult and even traumatic for the message recipient (Abel et al. 1998a). For this reason, changing landowners' mental models through educational campaigns is a difficult process that is perhaps only the best strategy when existing beliefs endanger or otherwise threaten the population. In this case, given the important implications that water-borne pathogens and water quality can have on landowner livelihood and quality of life outcomes (i.e., humans or livestock getting sick), targeted education campaigns should promote understanding of these specific beaver impacts. Given that people tend to accept messages that conform to their understanding of the world, these messages will be most effective if they are targeted, simple, clear, and as much as possible, conform to existing mental models.

Beliefs about how beavers affect forage were diverse, but included several main higher-consensus pathways. Landowners believed that the beaver's impact on water quality and availability directly and indirectly affected the amount of livestock on the landscape, and thus grazing pressure. Furthermore, landowners believed that beavers directly and indirectly influence both cultivated and naturally occurring forage by changing both water availability and soil moisture. Again, although the beaver's impact to soil moisture and thus forage may initially seem intuitive, the beaver can influence forage production in both increasing and decreasing ways. For example, in a dry area, additional soil moisture might increase growth rates, but in an already wet environment, additional moisture might actually suffocate a plant's roots. Because

the pathways connecting beavers to water availability and soil moisture to forage could be interpreted as either increasing or decreasing effects, some landowners may feel that eradication will enhance forage for their operation, while others may perceive a loss. Thus, divergent perceptions about this ecosystem service could alter willingness to participate in the proposed eradication. Beavers influencing forage is relatively high salience concept within TDF landowner mental models, so future analyses should investigate the nature of these beliefs and perceptions about ecosystem service outcomes.

My findings that beliefs about beavers in TDF were diverse, divergent, and exhibited low consensus are comparable to other studies in the broader mental models literature. Researchers conceptualize, elicit, and analyze individual and shared mental models in highly different ways (i.e., Lynam et al. 2011; Papageorgiou et al. 2014), complicating direct comparison between studies. However, anecdotally, researchers have reached diverse conclusions about the levels of consensus within and among groups of stakeholders in their mental models studies. Perhaps the study with the most similar research questions used consensus analysis to understand whether mental models of water users in a South African catchment were highly shared, and characterized patterns of agreement (Stone-Jovicich et al. 2011). They found generally low consensus regarding causes and consequences of low river flows, key water users, and priorities for future water use. More commonly, mental model studies identified areas of consensus between groups of stakeholders (i.e., Gray et al 2012; Gray et al. 2014; Zaksek and Arvai 2004; Hoffman et al. 2014; Abel et al. 1998a). For example, Abel et al. (1998a) discovered that there was greater diversity within groups of similar stakeholders than between stakeholder groups regarding mental models of water processes in grazing landscapes in Australia. This suggests

significant individual-level variation in mental models, similar to the pattern I observed in TDF landowners' mental models.

Using Mental Models and Human-Centered Design to Build Strategic Communication

A human-centered approach to program design recognizes that programs will have high voluntary cooperation rates when potential participants perceive high incentives and low disincentives for participation (Sorice and Abel 2015; Sorice and Donlan *in press*). The theory of reasoned action suggests that positive attitudes and intentions to engage with an eradication program are contingent upon landowners perceiving positive consequences of participating (Fishbein and Azjen 2010). Landowners face difficult trade-offs when considering participation in a conservation incentive program, and their mental models guide their understanding of complex domains in order to make the real-world decision to engage or not (Lynam et al. 2011). The explicit representations of the heuristic structures that guide landowner decision making produced in this study can help conservation practitioners understand landowners' rationales for engaging or not with an eradication program, and can also help eradication planners build a strategy for increasing perceptions of the positive consequences of participation.

One way to ensure that landowners perceive the potential positive consequences of participation is to use targeted messages to directly communicate the livelihood and quality of life improvements that participation will generate. An effective message consists of three parts: an advocated position, a set of general arguments in support of the advocated position, and specific factual evidence designed to bolster the arguments (Manfredo 1992). In TDF, the position advocated is that landowners should engage with a proposed eradication program. This position can be supported with general arguments about how beavers negatively impact a suite of salient ecosystem services. Finally, these arguments can be supported using specific local

knowledge about exactly how beavers change ecosystem function. Personal Construct Theory suggests that landowners will be more likely to accept messages that conform to their own beliefs and values (Kelly 1955; Salmon 1981; Abel et al. 1998a). An effective message, then, must include arguments that reference salient outcomes, as well as incorporate evidence that the target audience knows to be true.

Currently, most public outreach and communication about beavers and the planned eradication in TDF focuses on the beaver's destructive impacts to the region's biodiversity and ecosystems, and suggests that eradication is advantageous because it will restore ecological integrity. For example, in the last two years the major newspapers in both Chilean and Argentine TDF have referred to beavers as "the species that devastates native forests," an "ecological disaster," and causing "great damage to the ecosystem" (La Prensa Austral 2014a, 2014b). The government agencies responsible for coordinating the proposed eradication distribute similar messages, describing the beaver as, "a threat to local biodiversity" and "a damaging species that causes a significant negative impact on forest, steppe, and beat bog ecosystems, threatening their biodiversity, watershed dynamics, and nutrient cycles" (MeCON 2014). Furthermore, a primary motive for eradication is to halt forest destruction in TDF and on the South American continent, and thus restore or protect the region's carbon sequestration capacity, and messages about this ecosystem service are increasing. The beaver's impacts to biodiversity, ecosystem health, and climate regulation are undoubtedly important, and messages about these impacts are valuable for increasing awareness of the beaver's impacts. However, because they reflect conservation practitioners' intuition about which ecosystem service impacts are of greatest concern, rather than an empirical understanding of stakeholder priorities, values, or knowledge, they are not effective messages to garner the support of key stakeholders for eradication.

My results suggest that a communication strategy focused primarily on the beaver's impacts to provisioning services and secondarily on the broad ecological impacts of the beaver would be more effective than current messaging for garnering support of TDF ranchers for eradication. The most salient ecosystem services to private landowners were related to inhabiting their ranches and livestock production (i.e., drinking water availability and forage provisioning); this is unsurprising given that landowners depend on these provisioning services for their livelihoods. Beavers cause important impacts to these services in TDF and in other contexts (i.e., Schuttler et al. 2011; Siemer 2013), and there is evidence that experience with beaver's impacts to these services actually increases acceptance of lethal management actions (Siemer 2013). In addition to ecosystem services related to lifestyle and ranching, several cultural, regulating, supporting ecosystem services were also moderately salient to landowners. Many of these services were expressed as general ideas (i.e., overall system health; landscape aesthetics), rather than more specialized ecosystem services that require specific knowledge about ecosystem functioning (i.e., disease control; carbon sequestration). This broad awareness of the beaver's impact to ecosystem health and local culture suggests that messages about the beaver's general impacts to non-provisioning ecosystem services will also resonate with landowners, but that specific messages about detailed ecological impacts will not necessarily reflect the particular concerns of landowners.

Additionally, I suggest that future communication about the proposed beaver eradication targeted towards private landowners incorporate two specific elements of local knowledge. First, they should clearly state that by stagnating waterways, beavers compromise drinking water quality, and second, that by flooding large areas of pasture, beavers reduce forage availability in some parts of TDF. Although consensus was generally low regarding causal mechanisms by

which beavers influence salient ecosystem services, these ideas were consistent within a considerable number of TDF mental models, were clearly interpretable, and are supported by scientific evidence. Furthermore, certain intermediate ideas were more important by my three measures in landowners' perceptions of how beavers influence the two target ecosystem services. Regarding surface water availability, landowners connected beavers to drinking water availability and quality predominantly through their dam- and pond-building activities. Similarly, landowners connected beavers to forage availability through the impacts that dam- and pond-building activities have on the ability to raise livestock, the ability to irrigate cultivated areas, and naturally occurring forage. Given that a well-crafted message includes specific factual evidence to support an argument (Manfredo 1992), and people are more likely to accept messages that fit within their own conceptualization of the world (Kelly 1955; Salmon 1981; Abel et al. 1998a; Jones et al. 2011), clearly incorporating highly shared beliefs about how beavers change salient ecosystem services will strengthen the message that eradication complements management objectives, in spite of the many simultaneous barriers to participation.

Although I propose to incorporate messages that are salient to the largest number of TDF landowners, an alternative strategy might be to build multiple communication strategies for different groups of landowners in TDF. Local knowledge varies from place to place and from population to population (Manfredo 1992). In socially heterogeneous landscapes, it may be more appropriate to develop multiple specialized action plans than a single large action plan in order to accomplish a landscape-scale conservation goal (Mackenzie et al. 2014). Low consensus in the mental models presented here suggests that landowners in TDF have diverse beliefs about how beavers influence ecosystem services. Although I did not investigate demographic or regional differences between mental models, it is possible that differences between groups of landowners

systematically drive this diversity (e.g., Vandenwinkens et al. 2014; Hoffman et al. 2014; Stone-Jovicich et al. 2011; Abel et al. 1998a). A next step would be to conduct an in-depth, comparative analysis looking at systematic differences between groups of mental models that differ based on key covariates. For example, I could compare beliefs held by landowners in Chile versus Argentina, in forested versus grassland landscapes, or in water-abundant versus water-limited landscapes. Or, I could compare groups of demographically similar landowners by grouping them by age, income, land-size, resource dependency, or lifestyle-oriented versus production-oriented landowners. Characterizing differences in belief patterns based on these diverse covariates could be a useful next step in understanding the low consensus observed in group models.

Lessons Learned from a Novel Methodological Approach to Mental Models Elicitation, Construction, and Analysis

The mental models elicitation and analysis approach that I employed contributes to a growing body of literature about how mental models can be used to understand and characterize knowledge systems (e.g., Isaac et al. 2009; Jones et al. 2011; Papageorgiou et al. 2014; Shepardson et al. 2007; Lynam et al. 2011; Carley and Palmquist 1992). For this research, I adapted Morgan et al.'s (2002) Risk Communication approach, which uses an "expert model" as a framework for prompting and coding interview transcripts. I incorporated Morgan, et al.'s (2002) "funnel" interview strategy, meaning that the interview began with broad concepts and slowly focuses in on specific ideas. However, unlike the Morgan et al. (2002) approach, I did not use an "expert" model to guide interview direction or as a framework for coding interview transcripts because I was interested in understanding diverse beliefs from the research participants' perspective. Instead, I employed freelist using an ecosystem service typology

(DeGroot et al. 2011) and a “Cause concept/linkage/effect concept” framework (Özesmi and Özesmi 2004). This strategy allowed landowners to build their own framework for evaluating the beaver’s impacts. This approach has several advantages. First, this strategy generated rich information about landowners’ diverse beliefs. Because this strategy allowed for the inclusion of unlimited variables that were generated from the participant’s perspective (Özesmi and Özesmi 2004; Morgan et al. 2002; Spradley 1979), the cognitive maps generated can be used as a way for conservation practitioners to understand knowledge gaps or increase their own awareness of the beaver’s impacts to rural areas. Although many communication strategies aim to increase the layperson’s understanding of a complex or unfamiliar domain, in many cases experts can learn about previously undocumented impacts, or localized or site-specific knowledge that is sometimes generalized in the process of generating “scientific” knowledge (Isaac et al. 2009). Second, by listing ecosystem services that were salient to them, research participants generated the content for prompts used in later stages of the interviews. This reduced the risk of the interviewer introducing ideas to the interviewee. Third, cognitive maps can be aggregated in order to diagram and quantify shared, local knowledge about the beaver. Although in this case low consensus suggests that there is no universal “local knowledge” about the beaver, in another context high-consensus pathways could be identified as shared local knowledge. Finally, building extensive cognitive maps with directed ties allowed me to study this population’s causal beliefs about specific ideas within a larger network, as well as emergent properties of the aggregated model (Eden 2002).

Furthermore, this novel strategy contributes new social network analysis metrics as well as a framework for studying causal pathways within a cognitive map. Most existing node-level metrics in social network analysis characterize a node’s position or role in a network relative to

all other nodes in the model. In this study, I was interested in understanding each node's role in the pathways connecting two specified nodes in a given network, but was unable to find social network analysis metrics appropriate for answering my research questions, or similarly focused research. The new metrics path robustness and path occurrence characterize a node's contribution to all the directed pathways between one node and another in a network, and could be applied to diverse social network and cognitive mapping studies where the researcher is interested specifically in pathways between two target nodes. For example, these metrics could be applied to a study of how to most efficiently pass information from one person to another target person within a large network, or to understand the most common areas of convergence on paths that connect one place to another.

Although this approach helped answer my specific research questions, novelty is often accompanied by limitations and challenges. The extensive and time-consuming nature of eliciting, transcribing, constructing, and analyzing detailed cognitive maps fundamentally limits the number of research participants that can be included in resource-constrained studies. Although fewer research participants means excluding voices, combining mental models with other diverse methods may be a more appropriate way to capture accurate local knowledge than to select a single alternative method that would allow for increased participant numbers (Isaac et al. 2009). This mental modeling strategy could be appropriately paired with subsequent qualitative or quantitative methods to capture a broader understanding of local knowledge, or to see if patterns hold true across the population. Furthermore, the cognitive maps produced by this approach cannot fully capture landowners' mental models, as mental models are internally-held cognitive structures. Thus, the validity of a mental model depend on the interviewer's elicitation skills, as well as the interviewee's interpretation of interview questions and communication

ability (Abel et al. 1998b). This approach requires a well-practiced interviewer, and a larger role of the researcher in interpreting and condensing concepts in analysis (Pagageorgiou 2014; Breakwell et al. 2004; Morgan, et al. 2002). In this study, I minimized measurement error by conducting practice interviews, adapting the research protocol, using a single researcher to conduct all interviews and all coding, and consulting a second researcher before collapsing concepts in the models. Finally, given that each beaver-to-ecosystem service sub-model was constructed by aggregating multiple cognitive maps, some of the pathways connecting beavers to the target ecosystem services may be emergent properties of the aggregation process (Eden 2004). That is, it is possible that one landowner made a connection from beavers to a given intermediate node in the sub-model, and that another landowner connected that same intermediate node to the target ecosystem service, but no single landowner made the connection all the way from beaver to the ecosystem service through that particular intermediate node. Thus, some pathways represent a sort of mosaic of beliefs held by different landowners.

2.6 Conclusion

The proposed eradication of beavers in TDF has captured worldwide attention (e.g., Choi 2008; Worth 2014; NPR 2011); however, despite the integral role of TDF's private landowners in achieving this ambitious conservation goal (Menvielle et al. 2010), this is the first attempt to systematically understand their beliefs about the exotic beaver. Landowners draw on their belief systems to make real-world decisions (e.g., Jones et al. 2011). Hence, local knowledge about conservation issues (i.e., an invasive species) is fundamentally important to understanding and encouraging participation in coordinated conservation efforts. In TDF, it appears that beliefs and knowledge about the beaver's impact to ecosystem structure and function are diverse and divergent. This suggests that landowners may differentially conceptualize the livelihood and

quality of life outcomes of a successful eradication. Because beliefs about possible outcomes drive attitudes and thus action (Fishbein and Azjen 2010), these beliefs are important predictors of eradication program success.

In this chapter, I argued that the appropriate use of local knowledge in targeted communication can increase participation in voluntary conservation campaigns by: 1) reinforcing existing beliefs about how cooperation complements landowners' land-use objectives, and 2) by increasing awareness of previously unknown risks. Private landowners tend to focus on short-term, local-scale, production-oriented outcomes because their livelihoods depend on them (Halbrendt et al. 2014), yet conservation practitioners and media campaigns about the beaver tend to focus on long-term or regional-scale impacts that have low salience to private landowners (Oppel et al. 2010) even when the conservation goal would increase production. By incorporating an empirical understanding of stakeholder priorities, values, or knowledge into messages (Halbrendt et al. 2014; Stokes et al. 2006; Fishbein and Manfredo, in Manfredo 1992), conservation practitioners can better communicate how a planned eradication complements landowners' goals or how an invasive species threatens key salient ecosystem services.

Currently, local agencies in TDF are developing and implementing an outreach program that could integrate concepts suggested here. Both Chile and Argentina are working on United Nations Global Environmental Fund (GEF)-funded projects to implement pilot eradications and increase awareness of the impacts of invasive species in TDF. Initial outreach materials designed as a part of this program have increased messages about the beaver's impacts to infrastructure and provisioning ecosystem services (i.e., they damage roads, fences, pastures; contaminate Patagonia's "pristine" water) (SAG 2014); however, the primary focus of communication is consistently on the beaver's specific detrimental impacts to forest ecosystems and regional

biodiversity. These messages may be appropriate for the general public; however, these are not the most effective messages to capture the attention of rural ranchers because they do not fall within their range of salient concerns (Abel et al. 1998a). In Chile, a special communication strategy is being developed with TDF's rural population as an intended audience. This is an opportunity to integrate evidence about the beavers' threats to rural livelihoods (i.e., the numbers of hectares of pasture that beavers have destroyed through flooding; the role of beavers in increasing water-borne pathogens like giardia that contaminate drinking water). General messages about damage to ecosystems will also resonate with landowners, but they are less likely to motivate action than specific messages about how beavers compromise the ecosystem services that ranchers most highly value.

Although message content is important, it is not a panacea. Acceptance of a targeted message depends on more than just the content. Message delivery (i.e., a communicator's perceived credibility or other signals of expertise), the message recipient's particular characteristics (i.e., gender, age, self-esteem), or the style of the message (i.e., visual, spoken, or written presentation, use of emotional appeals) all impact the likelihood of a landowner accepting a message (Ajzen, in Manfredi 1992). Thus, it is important to develop an overall communication strategy that plans for both effective message content and delivery. Furthermore, willingness to participate in conservation programs depends on more than knowledge of the species' impacts. Landowners are faced with competing priorities, trade-offs, and limitations that may prevent them from cooperating with voluntary programs. A human-centered approach to program design incorporates landowner beliefs and perceptions about the risk or benefits of participating into the structural design of conservation programs (Sorice et al. 2013, Gelcich and Donlan 2015). Using this approach, conservation practitioners can identify and address key

underlying beliefs that act as barriers to participation through targeted communication, or in other cases, barriers can be reduced through program structure and the use of incentives (e.g., Sorice 2011; see chapter 3). Either way, building landowner support is integral to improving conservation outcomes, and designing an effective program requires a deeper understanding of what drives landowner willingness to cooperate. Characterizing knowledge about the species' impacts to ecosystem service outcomes is one often-overlooked but strategic place to start.

Chapter 3: A human-centered approach to designing invasive species eradication programs on human-inhabited islands

Anna R. Santo

Michael G. Sorice, Chair
Christopher B. Anderson
Timothy Baird

May 4, 2013
Blacksburg, VA

Chapter 3: A human-centered approach to designing invasive species eradication programs on human-inhabited islands

Anna R. Santo

ABSTRACT

Due to potentially conflicting values between conservation organizations and other stakeholders, targeting human-inhabited islands for invasive species eradication campaigns layers social complexity on top of technical complexity. Attaining widespread support and cooperation for eradications requires programs designed to meet diverse stakeholder needs. The Tierra del Fuego (TDF) archipelago serves as an informative case study and model for understanding and incorporating private landowner preferences into a proposed eradication program. We employed a human-centered approach to understand landowner perceptions, preferences, and potential support for a large-scale initiative to eradicate the invasive North American beaver (*Castor canadensis*). We employed a factorial vignette survey to understand how attributes of an eradication program itself are related landowners' decisions to participate. Landowners rated four programs that randomly varied by the contract length, required landowner involvement, institutional administrator, payment, social norms, and probability of a successful eradication. Landowners in TDF were generally more willing to participate under three conditions: (1) increased payments, (2) increased expectations of program success, and (3) low requirements for landowner involvement. Our results suggest that incorporating feedbacks into program design can increase public support, and that landowners in TDF may not express the same preference for autonomy that exists in other regions of the world. Understanding and incorporating stakeholder preferences, perceptions, and beliefs into management strategies is an ongoing challenge for conservation practitioners worldwide. The vignette survey approach provides a cost-effective, rapid, and scalable tool to document and incorporate local values into

conservation program design. Programs built using a human-centered approach will complement landowners' land-use objectives, increase cooperation, and ultimately improve conservation outcomes.

Keywords: castor canadensis, conservation incentive programs, design thinking, eradication programs, factorial vignette survey, invasive species, human-centered design, Patagonia, Tierra del Fuego

Chapter 3: A human-centered approach to designing invasive species eradication programs on human-inhabited islands

3.1 Introduction

Although biological invasions have increased in scope and speed with globalization, the technical ability to eradicate certain invasive exotic species from islands has increased exponentially (Towns and Broome 2003, Carrion et al. 2011). With improved technology, island size is often no longer the limiting factor for eradication campaigns, and large island eradications deemed impossible a decade ago are now taking place (Veitch et al. 2011). To date, there have been over 1,200 successful vertebrate eradications on islands, the majority of which have been mammals (Glen et al. 2013). High success rates (Howald et al. 2007) and improved techniques have lead environmental managers to attempt increasingly complex and extensive eradications, and to begin targeting human-inhabited islands and continental settings (Zabala et al. 2010, Malmierca et al. 2011, Glen et al. 2013).

Targeting human-inhabited islands for eradication campaigns layers social complexity on top of technical complexity. Although invasive species often destroy natural resources (e.g., agricultural crops, forest products), damage built infrastructure, and compromise other aspects of human health and well-being (Mooney 2005), they also create significant material and cultural value for societies (e.g., cuisine, cultural rituals, traditional medicine, sport, ornamentation, cultural icons) (Pfeiffer and Voeks 2008, Estévez et al. 2015). Consequently, conflicts around invasive species management are often rooted in divergent values, making them a “wicked problem” with no clear resolution (e.g., Game et al. 2014). Further, human presence complicates eradication campaigns because it limits the range of feasible and socially acceptable eradication strategies available to practitioners. Eradications often require techniques incompatible with human settlements (e.g., aerial broadcast of toxins) or activities that landowners may not

condone or allow on their land (e.g., shooting animals) (Saunders et al. 2011, Wilkinson and Priddel 2011). Finally, due to the all-or-nothing nature of eradication campaigns, a lack of support or access by a single landowner can delay or completely derail an eradication effort (Gardener et al. 2010, Wilkinson and Priddel 2011). Human-inhabited areas are typically managed by multiple private landowners with heterogeneous land-management objectives; as a result, eradication efforts in these areas are especially challenging because they require collective action and coordination, even when the issue may not be salient or agreeable to residents (Epanchin-Niell et al. 2010).

Given this social complexity, attaining widespread support and cooperation for invasive species eradications on inhabited islands requires programs that are designed to meet stakeholder needs. In some instances, incentives built into the design of an eradication program can increase private landowners' willingness to participate in conservation programs (Sorice et al. 2011). However, to date, efforts to understand landowner preferences for eradication program design have been largely limited to informal stakeholder engagement and community consultations (Glen et al. 2013, Estévez et al. 2015), despite evidence that in-depth stakeholder involvement can improve program design and conservation outcomes (Young et al. 2013).

The Tierra del Fuego (TDF) archipelago in southern Argentina and Chile serves as an informative case study and model for understanding and incorporating landowner preferences into eradication program design for human-inhabited islands. Introduced in 1946, the North American beaver (*Castor canadensis*) population on TDF has increased to over 100,000 individuals (Lizarralde et al. 2004, Skewes et al. 2006), and has recently expanded to mainland Chile (Wallem et al. 2007). Beaver activity directly affects private landowners by destroying grazable pasture and ranch infrastructure (e.g., bridges, fences) (Schüttler et al. 2011). Although

beavers behave the same in TDF as in North America, they have no natural predators, and the region's riparian vegetation has not evolved the necessary resilience to recover from the beaver's impacts (i.e., nutritional or palatability defenses, regeneration mechanisms, high species diversity) (Anderson et al. 2009). As an ecosystem engineer, beavers cause long-lasting changes to local hydrology, nutrient cycling, riparian vegetation, food webs, and aquatic and terrestrial species assemblages (Lizarralde et al. 2004, Simanonok et al. 2011, Henn et al. 2014). These changes alter successional patterns by suppressing seedling regeneration, which ultimately leads to the permanent conversion of sub-Antarctic forests to meadows (Wallem et al. 2010).

Landscape ecologists characterize the beaver's impact as the largest landscape-scale alteration of the forested areas of this ecoregion in the last 10,000 years (Anderson et al. 2009, Anderson et al. 2012), a conclusion that prompted binational support and planning for eradication (Parkes et al. 2008, Funes 2011). In 2008, the Argentine and Chilean governments formalized an agreement to initiate the largest eradication ever attempted—over 7 million hectares across two countries (Menvielle et al. 2010, Malmierca et al. 2011). This eradication effort would require participation and support from over 300 rural landowners in Chile and Argentina who have varied opinions about beavers, their impacts, and control strategies.

We employed a human-centered approach to understand landowner perceptions, preferences, and potential support for a large-scale eradication and restoration campaign. This approach to program design recognizes that the way a program is structured and administered serves as its own set of incentives from which landowners receive benefits and incur costs (Sorice et al. 2013, Gelcich and Donlan 2015). Often overlooked, both program structure and implementation can lead to reduced participation, ultimately undermining the collective action needed to achieve conservation goals (Sorice and Donlan *in press*). Using this framework, we

explored the willingness of ranchers on TDF's largest inhabited island to participate in eradication programs that varied based on program structure and expected outcomes. Our study is a first step in an iterative approach to define landowner needs, desires, constraints, and experiences as a means to design an eradication program that integrates private landowner needs and thus achieves widespread, voluntary participation.

We surveyed non-corporate private landowners in TDF to estimate the importance of program structure and administration, social context, and expected success of the program. We hypothesized that landowners would prefer programs that are less controlling (i.e., allow landowners to do the work on their own and make their own choices), that require shorter commitments, and that provide higher payments. Further, theory about solving collective-action problems suggests that information feedbacks are key signals that drive human behavior (Van Vugt 2009, Abrahamse and Steg 2013). We included two such signals in program scenarios: information about the participation of other landowners, and information about the estimated collective efficacy of the eradication program (i.e., the probability of successful eradication if landowners participate). We hypothesized that feedbacks indicating higher participation or collective efficacy would be related to increased participation. Finally, our initial interviews with landowners suggested that landowners were heterogeneous regarding the institutions that they trust, and we asked landowners to indicate their preference for government or independent non-profit organization (NGO) program administration. Initial interviews with landowners led us to hypothesize that landowners may prefer an NGO to a government-run program.

3.2 Materials and Methods

3.2.1 Study Area

The Tierra del Fuego archipelago is located south of the Strait of Magellan (52° S, 70° W; Fig. 1). The Chilean-Argentine international border bisects Isla Grande, the largest and most populated island of the archipelago. We will hereafter refer to Isla Grande as it is conventionally regarded: Tierra del Fuego or TDF. A large majority of the island's inhabitants (97%) live in urban areas, with Argentine inhabitants (~150,000) greatly outnumbering Chileans (<7,000) (DGEC 2010, SDRA 2014). A highly diverse landscape, TDF is characterized by four ecoregions: arid steppe; deciduous southern beech forests (*Nothofagus antarctica*, *N. pumilio*); broadleaf evergreen forests (*N. betuloides*, *Drimys winteri*); and Magellanic moorlands (*Sphagnum spp.* bogs) (Fig. 1; Moore 1983). The principal economic activities on the Argentine portion of the island are social services, commercial activities (i.e., restaurants, tourism), manufacturing, transportation, construction, fisheries, timber harvesting, real estate, and mining (DGEC 2010), while the Chilean portion relies mostly oil and gas exploration, and ranching (SDRA 2014). Public land makes up about half of TDF. Families or shareholder groups operate large private ranches throughout the island, and forestry companies, conservation NGOs, and governments manage most of the forested areas in southern TDF.

3.2.2 Sampling

The population of interest consisted of all individuals currently serving as the primary decision-maker for ≥ 300 ha of privately-held, non-corporate land on TDF. In Argentina, private land parcels are typically $\geq 10,000$ ha. In Chile, various land reforms divided and redistributed land into estancias (i.e., ranches $\geq 2,500$ ha), parcelas or chakras (parcel or tract ~ 100 -2,500 ha), and hijuelas (plots typically < 100 ha). Hijuelas and smaller parcelas are typically non-productive

land immediately outside of the small town of Porvenir. We focused on landowners with larger properties because many small parcels and plots are unmanaged. The unit of analysis was the landowner, operationalized as the property's primary decision-maker.

We obtained publicly available land registry data for private properties in Argentine and Chilean TDF. For many properties, ownership information was incomplete or outdated; to improve the quality of our landowner lists, we iteratively triangulated and updated ownership information in consultation with public and private institutions. Our final sample frame included 49 and 134 landowners in Argentina and Chile, respectively ($N = 183$). We were unable to identify ownership information for one parcel in Argentina and approximately 20 parcels in Chile. We attempted to census all identifiable landowners between March and June 2014. We used professional connections, mutual acquaintances, and participating landowners to introduce us to other landowners. In rare cases when we were unable to locate acquaintances, we called or visited addresses listed on the land registry. We coordinated in-person interviews with landowners in public locations, private homes, or offices. Meetings generally lasted 45-60 minutes. We used face-to-face, structured interviews because education levels and access to technology among participants were highly variable, and mail service on TDF is unreliable. Further, in-person interviews ensured all participants were able to ask clarifying questions. We conducted all interviews in participants' native languages, either Spanish ($n = 132$) or English ($n = 1$).

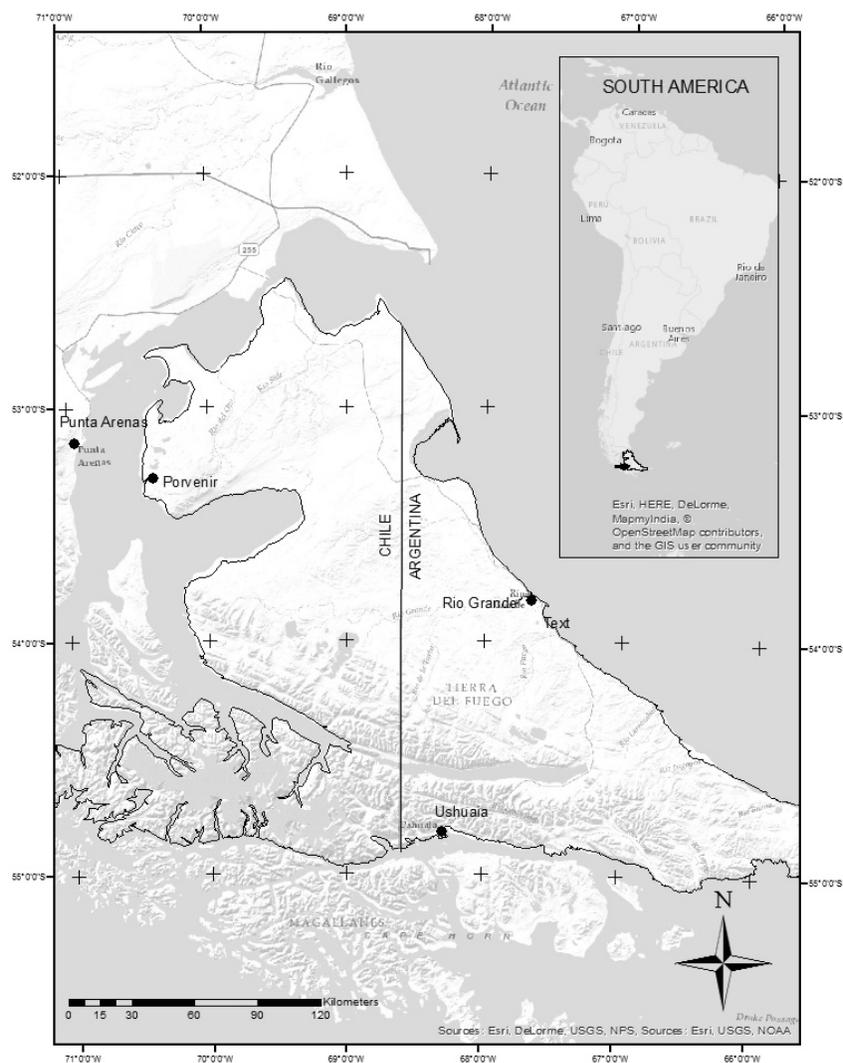


Fig. 3.1. Map of Isla Grande, the largest most populated island of the Tierra del Fuego Archipelago. The Chilean-Argentine international border bisects the island (Chile ~29,000 km², Argentina ~18,000 km²). Private sheep and cattle ranches dominate the grasslands in the northern portion of the island. The forested south consists of large tracts of state-owned land, private protected areas, and private forestry operations.

3.2.3 Survey Design

In factorial surveys, vignettes are hypothetical scenarios (i.e., possible eradication programs) that consist of attributes (e.g., program length) with levels that vary randomly across scenarios (e.g., 2, 6 or 10 years). Each vignette is unique, and individual respondents are randomly assigned a subset of all possible vignettes (Jasso 2006). Because they use a randomized experimental design, factorial vignette surveys are considered quasi-experimental (Wallander et al. 2009). As a respondent evaluates a vignette, they must consider multiple vignette dimensions simultaneously. This joint consideration of multiple independent factors can reduce desirability bias and indirectly reveal preferences for individual program components (Jasso 2006, Andorfer and Otte 2013).

Our eradication program vignettes varied based on: contract length, required landowner involvement, participation of other landowners, probability of a successful eradication, institutional administrator, and payment (Table 1). Each dimension had two, three or four levels. We asked each participant to evaluate a subset of four randomly selected vignettes from the total population of 648 ($3 \times 3 \times 3 \times 3 \times 2 \times 4$) possible programs. In a factorial vignette survey, adding additional vignettes, vignette dimensions, or dimension levels is cognitively burdensome for the participant, and may lead to fatigue that causes error or a break-off in the interview (Jasso and Opp 1997, Jasso 2006). To limit cognitive burden but ensure estimability of all effects of interest, we used an incomplete block design such that each respondent was exposed at least once to all levels of all vignette dimensions in their four vignettes. Landowners scored each vignette on a 7-point Likert-type scale to indicate their stated intention to participate (1 = Extremely Unlikely, 4 = Unsure, 7 = Extremely Likely). Participants could also respond with, “Unsure” if they did not prefer any option on the scale. Below is an example of a vignette.

“The first program I will describe would span 2 years and would rely on you and your workers to kill beavers. You would report them to the program and allow program experts to verify the kills. The eradication program will be run by a Non-Governmental Organization (NGO) that is specifically created to administer this program. You will be paid \$400 each month for your participation, and an additional \$10 for each verified beaver kill. Right now you haven’t heard of any other landowners participating, but the program organizers estimate that there is a 66% chance that the program will be successful if private landowners like you participate.”

Our selection of program attributes and levels was based on landowner participation in other conservation programs, expert opinion, personal experience, and preliminary interviews with landowners in TDF (Abel et al. 1998, Cocklin et al. 2007, Sorice et al. 2011, Moon et al. 2012, Lubell et al. 2013, Sorice et al. 2013). All program attribute levels were selected to provide adequate variation that required landowners to consider tradeoffs, but that remained realistic. For example, based on the third author's experience, a large-scale eradication effort, using hunting and trapping techniques, can take a minimum of 2 years of on-the-ground activities. Recognizing that this eradication is complex and could take many years, we selected an upper bound of 10 years; this upper bound distinguishes it from an ongoing "control" effort. Participation of other landowners and probability of program success were each assigned low, middle, and high values that represent the full range of possible scenarios for those variables. Similarly, levels for landowner involvement and implementing organization reflected the range of possible options available in TDF based on input from key informants.

Table 3.1

Descriptions of vignette attributes and levels in the factorial survey. All participants evaluated four scenarios in which every attribute level appeared randomly in at least one vignette. Text in italics represents working hypotheses based on the literature.

Decision Attribute	Description & Hypothesis	Levels
Program Length	Number of years the landowner is obligated to be in the program. Landowners will prefer short-term conservation programs on their private lands. ^{1,2}	(1) 2 years (2) 6 years (3) 10 years
Required Level of Landowner Involvement	Responsibilities of participating landowners. Landowners will prefer autonomy (i.e., working on the beaver issue without program intervention). ^{2,3,4,5}	(1) You and workers will hunt beavers and report results to program (2) You and workers will hunt beavers and report results to program. Program will verify successes (3) You and workers will notify program of beavers on your land. Program will enter your land and hunt beavers
Participation of Other Landowners	Perceived level of participation by other landowners. An awareness of higher participation will increase willingness to participate. ^{1,6}	(1) You have not heard of any other landowners participating (2) You have heard of some landowners who are participating, and others who are not (3) Most of the landowners you know are participating
Probability of Program Success	Likelihood the program will successfully eradicate beavers if landowners participate. As expectation of collective efficacy increases, willingness to participate will increase. ^{1,3,7}	(1) 33% chance of success (2) 66% chance of success (3) 99% chance of success
Implementing Organization	Organization responsible for administering the program. Willingness to participate will be lower in government-administered programs. ^{3,5}	(1) Non-governmental organization (NGO) (2) Government agency
Monthly Payment	Monthly stipend paid to landowners for participation. Higher payments will increase willingness to participate. ¹	(1) \$200 USD/month (2) \$400 USD /month (3) \$600 USD /month (4) \$800 USD/month

¹Sorice et al. 2011 ²Sorice et al. 2013 ³Moon 2013 ⁴Cocklin et al. 2007 ⁵Peterson and Horton 1995 ⁶Epanchin-Niell et al. 2010 ⁷Abrahamse and Steg 2013

Payment levels reflect amounts above and below the average estimated cost of participation in the program. We estimated participation costs by asking landowners and landowner association representatives from both Argentina and Chile to estimate the total monthly cost of supporting one ranch worker (e.g., salary, taxes, housing and food, communication, transportation). We assumed that the program would only require landowners to dedicate 10 workdays per month toward eradication efforts and that the program would pay 50% of the monthly cost of an additional worker. Our estimated monthly cost for a half-time worker ranged from \$415 USD to \$875 USD (average: \$550 USD). Values were similar between the two countries.

3.2.4 Data analysis

We used a generalized linear mixed model to estimate the fixed effects of program attributes on participants' stated likelihood of participation, and introduced a random effect to control for error due to repeated measurements of individuals (West et al. 2007, Kinsbergen and Tolsma 2013). Our dependent variable was a landowner's rating of their intention to participate in a program. Although social science research often treats 7-point ordinal scales as continuous, our model did not meet linear regression assumptions. Instead, we employed an ordinal model with a logit link. To enhance interpretation, we transformed the reported log odds into odd ratios ($\Omega = e^{\beta}$) and discuss the results in terms of percent change in the odds ($(\Omega - 1) \times 100\%$) (Long 1997). Because there were no differences across landowners in Chile and Argentina, we used a pooled dataset.

Based on the results we dichotomized the ordinal scale and used the same model predictors to estimate predicted probabilities that an average TDF landowner is: 1) moderately likely or extremely likely to participate, and 2) moderately unlikely or extremely unlikely to

participate. These curves represent the median responder created by averaging each participant's model prediction, sorting them and then choosing the median responder. In this case, predicted probabilities were estimated for payments and landowner involvement (Fig. 3a) as well as payments and likelihood of program success (Fig. 3b) while controlling for other program-related components (6-year contract, landowner knows of some ranchers participating, and program is administered by an NGO).

3.3 Results

Of the 183 landowners in our sampling frame, 97 and 37 individuals participated in Chile and Argentina, respectively (raw response rate = 73%). The adjusted response rate was 74% after removing ineligible respondents (e.g., non-contactable due to non-working address; AAPOR 2011b, a). One survey with missing vignette data was also excluded. The final sample size used in this analysis was 133.

Overall, landowners expressed high stated willingness to participate in beaver eradication programs on TDF across scenarios (Fig. 2; $n = 532$ because each landowner responded to four scenarios). Landowners focused primarily on payment levels, expected success of the program, and required level of participation (Table 2). For every \$100-increase in monthly payment, the odds of being more likely to participate increase by 8.9% ($b = 1.08$; $z = 2.19$; $p = 0.03$). Similarly, for every 10% increase in the expected probability that the program would be successful, the odds of a landowner being more likely to participate increase by 12% ($b = 0.01$; $z = 3.42$; $p < 0.01$).

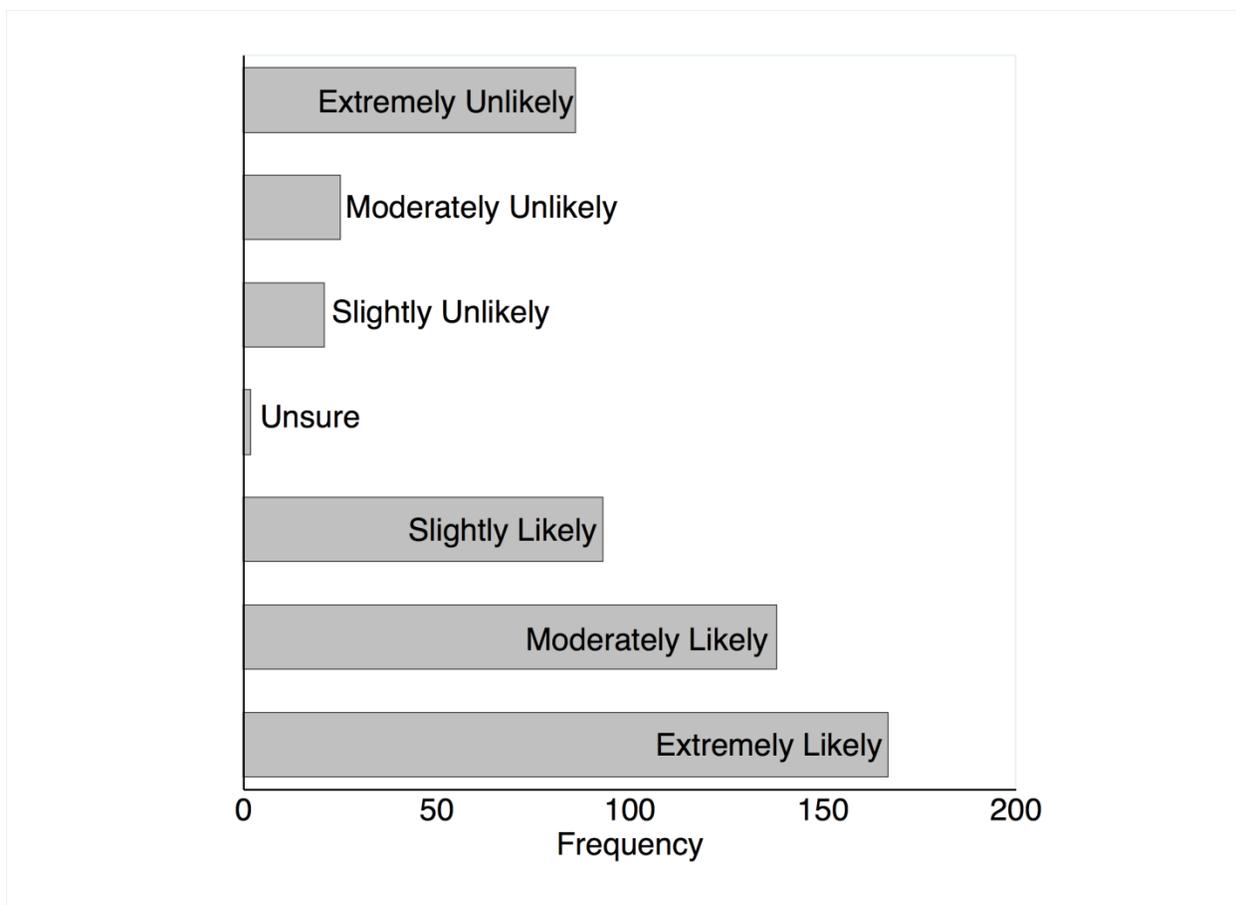


Fig. 3.2. Distribution of landowner ratings of intention to participate in an eradication program. Each of the 133 respondents responded to four unique scenarios that varied randomly in program attributes and attribute levels ($n = 532$). Participants were “moderately” or “extremely” likely to participate in 57% of all scenarios.

Willingness to participate was also related to required level of landowner involvement (Wald $X^2 = 11.97$, $df = 2$, $p = 0.002$). The reference level of involvement asked landowners to hunt beavers and simply report their kills without external verification by program administrators. There was no difference between this baseline and a requirement that landowners kill, report, and permit the program to verify the kill (Table 2). Further, compared to the reference level, landowners preferred a program in which they simply notify administrators about the presence of beavers and then allow the program to enter their land to kill them ($b = 0.72$; $z = 3.29$; $p = 0.01$). The odds of a landowner participating increase by 106% when the program takes responsibility for hunting, compared to a program in which landowners hunt and

simply report their beaver kills. Program duration, social norms associated with participation of other landowners, and implementing organization were not related to willingness to participate.

The predicted probability curves illustrate the effect of payments, landowner involvement requirements, and expected program success for landowners belonging to the "likely to participate" category (i.e., either "moderately likely" or "extremely likely") (top panel of Fig. 3a and 3b) and the "unlikely to participate" category (i.e., either "moderately unlikely" or "extremely unlikely") (Fig. 3). Controlling for other program components, the feedback related to program success and the eradication efforts assumed by the program result in higher probabilities of being in the "likely to participate" category. Further, the slopes of the predicted probabilities indicate landowners in the "likely to participate" group are more responsive to payment, requirements, and expected program success.

Table 3.2.

Ordinal mixed model results with eradication scenario program attributes as fixed effects, respondent as random effect, and intent to participate as the dependent variable ($X^2 = 29.440$, $df = 8$, $p = 0.003$).

Program Component	Estimate	Odds ratio	SE	z	P < z 	95% CI	
Program Length (years)	0.01	1.01	0.03	0.38	0.70	-0.04	0.06
Required Level of Landowner Involvement							
Kill & Report (reference category)							
Kill, Report, Program Verifies	0.13	1.14	0.21	0.62	0.53	-0.28	0.55
Report, Program Kills	0.72	2.06	0.22	3.29	<0.01	0.29	1.16
Participation of Other Landowners							
Not heard of others participating (reference category)							
Heard of some who are participating	-0.13	0.88	0.22	-0.58	0.56	-0.55	0.30
Most landowners you know are participating	0.01	1.19	0.22	0.80	0.42	-0.25	0.60
Probability of Program Success	1.15	3.14	0.34	3.42	<0.01	0.49	1.80
Implementing Organization							
Non-Governmental Organization (reference category)							
Government Agency	-0.03	0.98	0.17	-0.14	0.88	-0.36	0.31
Monthly Payment^a	0.08	1.18	0.04	2.19	0.03	0.01	0.16
Cut Point 1^b	-1.00	0.37	0.44	-2.27	0.02	-1.86	-0.14
Cut Point 2	-0.53	0.59	0.44	-1.22	0.22	-1.39	0.32
Cut Point 3	-0.19	0.82	0.44	-0.45	0.66	-1.05	0.66
Cut Point 4	-0.16	0.85	0.44	-0.38	0.71	-1.02	0.69
Cut Point 5	1.04	2.84	0.44	2.37	0.02	0.18	1.91
Cut Point 6	2.75	15.58	0.46	6.00	<0.01	1.85	3.65
Random Effect	3.66	39.00	0.775	.	.	2.42	5.55

^aTo facilitate reporting and interpretation payment was divided by \$100 US.

^bCut points in ordinal models indicate the thresholds between levels of the intention to participate.

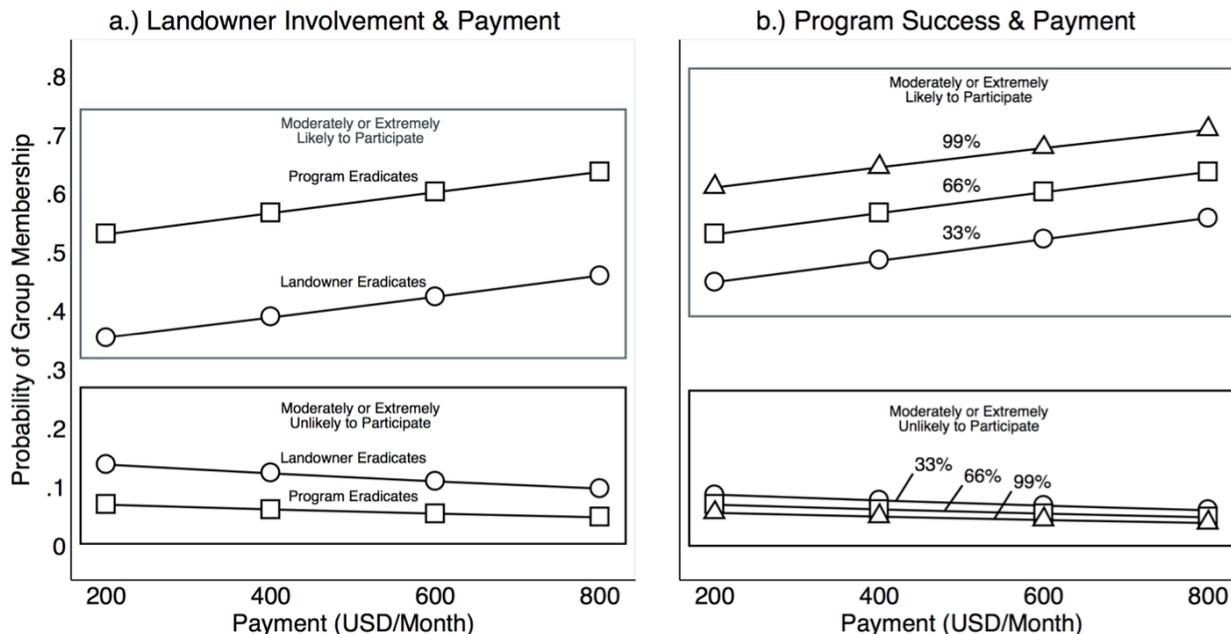


Fig. 3.3. Predicted probability of belonging to the “likely to participate” group or the “unlikely to participate” group based on: a) landowner involvement requirements and payments, and b) expectation of program success and payments. Predicted probabilities were generated holding other program factors constant at representative values.

3.4. Discussion

As a first step in a human-centered approach to designing an eradication program, the factorial vignette survey provides initial insights into private landowner preferences. We found that landowners in TDF were generally more willing to participate under three conditions: (1) higher payments, (2) higher expectation of program success, and (3) a lower required level of landowner involvement. Program length, participation of other landowners, and administering institution were not significant predictors of willingness to participate.

Program-related influences on landowner participation in eradication programs

We found that higher direct payments increase TDF landowners’ willingness to participate in a beaver eradication campaign. Payments serve two potential purposes (Wunder 2005). First, they may reduce barriers to participation by compensating landowners for direct or opportunity costs of cooperation. Second, payments may be perceived as rewards that motivate

participation. Not surprisingly, payments are an integral part of many conservation incentive programs (e.g., Langpap 2006, Norden 2014). However, they are not a panacea and consideration should be given during the design phase to ensure that payments do not unintentionally undermine motivations for cooperation (Ryan and Deci 2000, Frey and Jegen 2001, Muradian 2013, Sorice and Donlan *in press*).

In addition to payments, a higher expectation of program success can increase participation. In reality, uncertainty surrounding the probability of an eradication program's success always exists. Although invasive mammal eradications enjoy a low failure rate (Howald et al. 2007, Keitt et al. 2011), eradications in settings with human inhabitants bring additional risks and complications. Because of the hypothetical nature of our research, we were able to provide landowners with feedback on the ability to achieve eradication at the landscape scale. Our results suggest that cooperation does increase when potential participants receive signals about the potential for a program's success (Van Vugt 2009, Abrahamse and Steg 2013). Incorporating feedbacks into program design can help garner necessary public support for programs that require widespread and continued participation. The identification and quantification of these feedbacks may be an appropriate research agenda for applied ecologists to link ecological responses to program effectiveness.

Based on previous research on ranchers' values, we expected TDF landowners to express their desire for autonomy (Cocklin et al. 2007, Putten et al. 2011, Sorice et al. 2011, Lubell et al. 2013, Moon 2013, Zammit 2013). Landowners expressed their independence by demonstrating that knowledge of how other landowners were acting did not influence their willingness to participate (van Dijk et al. 2008, Stock and Forney 2014). However, we also expected autonomy to manifest itself as a preference for hunting beavers themselves, with minimal intervention from

the program. The high-autonomy condition was potentially appealing to landowners as it relied simply on the honor system—the landowner culls beavers and simply reports to the program without verification. Instead, landowners preferred that the program have access and complete control over beaver eradication on their land.

We consider a number of reasons why landowners may prefer to grant the program access to their land rather than work on it themselves. First, landowners in TDF may perceive a low level of self-efficacy or motivation for addressing the problem. This could be due to a lack of time, resources, or competing priorities. In interviews we conducted as part of a larger study, landowners often expressed greater concern about invasive mink, muskrat, and feral dogs than beaver. Thus, although the beaver invasion is a significant conservation issue for TDF, it may not be perceived as such at the scale of the individual rancher. Additionally, in further interviews, some landowners expressed that their personal involvement (i.e., hunting) was “not worth the effort” or “impossible” because of the current extent of the invasion, and the ruggedness the region's terrain. Second, economic and social instability may discourage landowners from committing limited labor to what they may consider non-essential activities. Regional challenges, such as the decreasing demand for Patagonian wool, natural capital depletion (e.g., desertification, soil loss), tax increases, and a plague of feral dogs have decreased the profitability of TDF's ranches (Ares 2007, Klepeis and Laris 2008, Von Thüngen and Lanari 2010, Livraghi 2011). Decreased stability and income may be barriers to participation for some landowners. Lastly, there has been a gradual shift in the culture of ranching in Patagonia: younger generations have steered away from an isolated, rural lifestyle in favor of urban settings with better access to jobs and social services. This shift has resulted in a widespread shortage of available, trustworthy, and skilled ranch labor throughout the region (Livraghi 2011). Due to

these changes, a key barrier for landowners engaging in beaver eradication on their own may be the inability to afford the time, labor, or financial burden of participation in non-livelihood activities. The preference for passive cooperation, however, is likely an advantage from the perspective of the eradication program because the threshold of cooperation needed to be successful (i.e., landowners allow access) is easier to achieve than ensuring landowners are endeavoring to hunt beavers on their land.

Advancing a human-centered approach to conservation program design

Participant preferences regarding conservation program structure and delivery are often overlooked during program design, yet they substantively influence participation. Participants perceive costs and benefits from the ways in which voluntary agreements are structured and implemented (Sorice et al. 2013). A human-centered design (HCD) approach to conservation planning is based on the idea that programs co-designed and adaptively co-managed with local stakeholders will incorporate stakeholder needs and values into program design, resulting in high voluntary participation and widespread support (Sorice and Abel 2015, Sorice and Donlan *in press*).

Designing and implementing conservation programs that complement landowners' land-use objectives is a multi-phase, participatory process (Sorice and Donlan *in press*). Before conducting this research, we began with landowner interviews, related academic literature, and expert opinion. The goal of our factorial vignette survey was to understand landowner preferences to inform the first stage of eradication program design. A number of our results call for pause, reflexivity, and further in-depth investigation. For example, ranchers tend to be cross-culturally known for their characteristic independence and autonomy (e.g., Trevizo 2003, Fischer

and Charnley 2010, Moon 2013). TDF ranchers' preference for outside intervention on their land may indicate that the program could meet a latent need for assistance in the population.

Additionally, we found no preference for the institution that administers the program despite preliminary interviews that indicated substantial anti-government sentiment. This could be attributed to the fact that landowners anchored on other factors they felt to be more important in the decision context (e.g., payment, involvement requirements); or, the landowner population may be truly divided on which institutions they trust to administer a program. Given the critical importance of the role in institutions engendering trust in participants (Van Vugt 2009), further in-depth research is needed to understand the lack of a definite, population-wide preference in our data. The HCD approach endeavors to identify these key factors that can increase the value of participation for landowners, because they can lead to substantially increased landowner commitment to the program.

Factorial surveys are a cost-effective, rapid, and scalable tool for gaining insight on the preferences of potential participants. The method is especially valuable in the initial stages of program design because it can detect shared or consensual preferences for individual program attributes. Other tools and strategies complement this approach and can provide additional detail regarding stakeholder preferences for program attributes, such as qualitative interviews or focus groups (e.g., Gelcich and Donlan 2015), stated-preference choice experiments (e.g., Sorice et al. 2013), and participatory mapping (e.g., Brown and Raymond 2014).

3.5 Conclusion

As the technical ability to eradicate invasive mammals from islands continues to improve and campaigns target larger inhabited islands (Cruz et al. 2009, Veitch et al. 2011, Glen et al. 2013, Campbell et al. 2015), the challenge of gaining cooperation and coordinating eradication

efforts will increase. People hold diverse views on invasive species from a variety of perspectives: economic, environmental, and individual (cognitive and emotional) (Pfeiffer and Voeks 2008, Gobster 2011, Marshall et al. 2011). Human communities create novel challenges to eradication campaigns by imposing regulations, logistics, and socio-political constraints. Due to their all-or-nothing nature, invasive species eradication programs represent an extreme case where widespread buy-in and coordination is critical and consensual support of local landowners (e.g., access to land) is essential to program success.

Conservation programs that use a human-centered design approach are more likely to maximize participation and buy-in (Donlan 2015, Sorice and Donlan *in press*). Many conservation dilemmas, such as invasive species eradications, are fundamentally based in value judgments. HCD can be used to reveal sources of value to landowners that were previously unidentified and unknown. Further, as in our case, HCD is valuable as an approach to examine assumptions and concepts that might otherwise be considered conventional wisdom. Designing a program under the assumption that landowner autonomy means minimizing program intervention and access would lead to suppressed participation.

Understanding and incorporating stakeholder preferences, perceptions, and beliefs into management strategies is an ongoing challenge for conservation practitioners worldwide. By focusing on user needs during the design phase, program administrators can build programs that complement landowners' land-use objectives, enhance cooperation, and thus improve conservation outcomes.

Chapter 4: Conclusion and Recommendations

Biological invasions are one of the greatest drivers of ecological change worldwide (MEA 2005); and, island systems are particularly vulnerable (e.g., Sax and Gaines 2008). However, in human-dominated island landscapes not all invasions undermine the well being of residents. For example, although invasive species can cause enormous losses to agriculture, fisheries, or the tourism industry, they can also provide new food sources, fuel, medicine, or decoration (e.g., Pfeiffer and Voeks 2008). Consequently, invasive species management is a social issue as much as it is an ecological issue (Estévez et al. 2015).

In addition to effective technical strategies, invasive species management on human-inhabited islands requires an understanding of stakeholder values and their willingness to cooperate with management efforts. For example, where eradication is warranted, some preferred methods may be incompatible with populated areas or may not be condoned by local stakeholders (e.g., Wilkinson and Priddel 2011). Stakeholders hold heterogeneous beliefs, perceptions, and attitudes towards target invasive species; this can lead to conflict, organized protests, or refusal to cooperate with a program (Genovesi and Bertolino 2001, Weeks and Packard 2009). Eradication is an all-or-nothing venture; if a single private landowner refuses to participate, it can compromise an entire eradication effort (Gardener et al. 2010, Wilkinson and Priddel 2011). Thus, I argue that practitioners must align their efforts with stakeholder values and preferences in order to achieve collective action (Dietz et al. 2003, Van Vugt 2009). Eradication planners are increasingly recognizing this need to understand and incorporate local knowledge beliefs, attitudes, and preferences of key stakeholders (Campbell et al. 2015).

My research explored a key conservation issue: the North American beaver is fundamentally altering the ecology and ecosystem services of the Tierra del Fuego Archipelago's

island ecosystem. To some island residents, however, the beaver is celebrated (Fig. 4.1) and even treated as a tourism attraction. Thus, there was a need to obtain a fundamental understanding of how this invasive species is perceived. Previous research focused on island residents living in more urban areas (Schüttler et al. 2011), but no research had yet addressed private landowners, a key stakeholder in efforts to eradicate the species from the TDF archipelago.



Figure 4.1. The invasive beaver is the featured species in a diorama found in the most famous bakery on the Argentine side of the Tierra del Fuego Island.

Using a mental models approach, I sought to explicitly 1) understand the salience of the beaver's impacts on ecosystem services that landowners value, and 2) represent local knowledge about how beavers are connected to salient human outcomes. I found that TDF ranchers prioritized provisioning ecosystem services (e.g., food, forage, water), and held diverse and idiosyncratic beliefs about how beavers influence these outcomes. Furthermore, landowners' conceptual maps linking beavers to these outcomes were loosely-connected, highly democratic, had many pathways. These results indicated that at least some TDF ranchers may not recognize the beaver as a highly salient problem because they do not perceive them influencing ecosystem services that are important to them. Further, among those who do perceive beavers affecting

important ecosystem services, there is no clear, unified understanding of how the beavers disturb the ecosystem and thus these key human outcomes.

I also explored one increasingly utilized approach by which conservation practitioners might motivate TDF landowners to engage in desirable behaviors: the use of voluntary incentive programs to promote eradication. I investigated how structural factors of a proposed eradication program (i.e., program length, required level of involvement, participation of other landowners, probability of program success, implementing organization, and payments) were related to TDF ranchers' willingness to engage with the program. This approach is based on a human-centered design perspective, which recognizes that a program's structure and implementation can encourage or inhibit participation, ultimately enhancing or undermining the ability to achieve collective action.

Although I found evidence supporting the intuitive findings that landowners prefer higher payments and higher expectation that the program will be successful, I unexpectedly found that landowners prefer that the program take full responsibility for hunting on their land. Furthermore, although initial interviews suggested that landowners would prefer non-governmental administration of the eradication program, I found evidence suggesting that there may be heterogeneous preferences for the type of institution (government or non-profit organization) that administers the program.

Contribution of this research

While a number of studies have been conducted on the ecological impacts of beavers as well as island residents' perspectives, no research has focused on TDF's private landowners, key stakeholders that can promote or undermine the success of eradication efforts. Understanding the knowledge systems that cause landowners to perceive value or risk serves as a first step in

understanding behaviors, and can also serve as a framework for crafting more effective outreach, as current communication about the beaver and the proposed eradication may not resonate with private landowners (see chapter 2).

My research on mental models also contributes to the literature on local knowledge. Many studies espouse the perspective that incorporating local knowledge into ecosystem management can improve ecological outcomes and local perceptions of management schemes (e.g., Layzer 2008, Isaac et al. 2009), yet this is a difficult task to accomplish. Representing mental models with cognitive maps allows for an explicit description of local knowledge that can be incorporated into management schemes. In TDF, the diversity of linkages and the lack of consensus in landowners' mental models indicate that highly shared, local knowledge about the beaver is limited. Thus, my work provides a case study that suggests that there may be no singular "local" knowledge, but rather diverse beliefs and knowledge systems about this particular invasive species.

My research also builds on a human-centered approach to conservation program design (Sorice and Donlan in press). In diverse, human-inhabited, and privately owned landscapes, conservation requires collective action—i.e., the high threshold of participation needed for a public good or service to be provided (Ostrom et al. 1999). The human-centered design approach provides a guiding roadmap for how to achieve that collective action. It demonstrates that engaging stakeholders requires more than just designing a program based on conservation practitioners' intuition (e.g., a top-down approach) and relying on financial incentives as the key motivator for participation. Engaging stakeholders is an active process of seeking out local needs, values, opinions, and limitations and taking them into consideration during the design phase of a program. My research applied such an approach by first doing ethnographic

interviews with landowners to understand connections they do or do not make between the species' impacts and their own well being. Second, my research used a holistic approach to investigate landowner preferences for program design as well as tradeoffs they may be willing to make. Once landowner needs are well understood, the next phase of the human-centered design approach would be to involve the landowners themselves in the design of the actual program using participatory processes. This would be followed by an iterative process of testing and prototyping concepts and ideas to identify what works best for the landowner community.

Additionally, this thesis advances a socio-ecological perspective by applying it to a specific, real-world case study. Much “social” or “ecological” research is conducted within disciplinary confines; however, ecosystems are inextricably linked to social landscapes. The Collins et al. (2011) model explicitly links social and ecological systems, and represents the feedbacks that occur between human outcomes and human behaviors (Fig. 1.2). It suggests that ecological and social outcomes are interdependent (Ford-Thompson et al. 2012) because people are part of ecosystems. Thus, ecosystem management consists of altering human behavior to create a socially favorable disturbance regime. In this way, the interdisciplinary model empowers people to consider their own role in crafting local ecosystems and their own outcomes. In my research, I examined the role of the beaver in TDF using this social-ecological perspective. The beaver was introduced to the archipelago in the name of economic development, a social outcome. However, it has caused dramatic ecological change, which has directly and indirectly affected human outcomes. Not all of the changes are undesirable; rather, people are affected by the beaver invasion in multiple positive and negative ways. The social-ecological perspective suggests that the challenge in TDF is to identify more desirable ecological and human outcomes

in the region, and systematically change human behavior in a way that will achieve those outcomes.

Furthermore, this thesis contributes to a growing body of literature recognizing the important role of engaging private landowners in order to eradicate species that are considered harmful in certain contexts. Much literature about invasive species focuses on ecological impacts, or technical aspects of invasive species management (i.e., Mooney and Cleland 2001, Campbell et al. 2015); less is known about stakeholder perceptions of invasive species (e.g., Ford-Thompson et al. 2012). Further, most literature that does investigate stakeholder beliefs, attitudes or preferences regarding invasive species is focused on the general public (e.g., Schüttler et al. 2011) or key institutions or organizations (e.g., Stokes et al. 2006, Binimelis et al. 2007, Ford-Thompson et al. 2012). In this thesis, I specifically investigated private landowner beliefs, attitudes, and preferences regarding invasive species. Given the important role private landowners play in achieving conservation objectives (e.g., Lubell et al. 2013), and the relative dearth of information about how they conceptualize invasive species or eradication programs (e.g., Steele et al. 2006, Conrad 2011), this study provides insight on how to understand and increase landowners' willingness to participate in coordinated eradication programs.

Finally, my research questions led me to both apply well-established methods in new ways, and to develop a new analysis approach. Factorial vignette surveys and cognitive mapping have both been widely applied to many disciplines; however, to the best of my knowledge, neither had been applied to the field of conservation program design. This is a promising new application, and future conservation efforts could benefit from employing these trusted methods to identify locally important factors that influence program success. Further, in analyzing my mental models, I discovered little existing literature guiding researchers on how to analyze

pathways between two endpoint nodes in a social network. Given my interest in perceptions of causal pathways from one node to another in a network, I developed a series of new metrics to characterize the diversity and relative importance of pathways that connect two specified nodes, as well as the relative importance of connecting nodes. These metrics could have diverse applications, and could be built upon to develop a robust new framework for evaluating causal chains within social networks.

Implications

The North American beaver's impact on the TDF and the entire TDF Archipelago is inherently a social-ecological system (Collins et al. 2011). The introduction was the result of a desire to enhance the economic well being of inhabitants of TDF. This failed effort led to consequential changes in the ecosystem. However, my research suggests that the presence of beavers in the system was not perceived to be consequential enough to stakeholders to engage in grass-roots eradication efforts. Other policy tools and instruments are needed. Eradication programs that incentivize landowners show promise but require a considered design approach that seeks to fit stakeholder needs and values.

Both Chile and Argentina recently received funding from the Global Environmental Fund to develop and implement pilot eradications and education and outreach materials related to the beaver in TDF (GEF Project IDs 4768, 5506). These grants are important opportunities to advance the binational agenda of eradication; and, incorporating several findings from this study could improve the efficacy of those efforts. First, although past beaver control pilot projects in TDF rewarded landowners and ranch workers for hunting beavers, my results suggest that a more top-down approach may actually be attractive to ranchers. Landowners expressed high willingness to participate in eradication programs, but they were significantly more likely to

participate when the program offered trained trappers to enter their land than when they relied on ranch workers to trap. This preference for less autonomy was surprising, but it actually represents an advantage from the perspective of the program. Deploying experience trappers is administratively simple, and the ability to hire expert trappers will increase efficiency and thoroughness of beaver removals.

Finally, my characterization of landowner mental models suggests that small changes in the communication strategy used to promote the proposed eradication could increase the likelihood that targeted messages will actually resonate with landowners and thus increase willingness to participate in the beaver eradication. Current messaging is primarily focused on specific ecological impacts, but I found evidence that a communication strategy focused on provisioning services (i.e., drinking water, forage availability, water for irrigation) would be more salient to landowners. Landowners do value ecosystem health, but they conceptualize it in a fairly general way. Thus, messages that the beaver disrupts ecosystem health will also resonate with landowners, but should be secondary to specific information about how the beaver compromises key provisioning services (i.e., beavers are vectors for transmission of giardia, which can cause humans or livestock to take ill).

Future Research

Although this thesis provides initial insight on private landowner beliefs and preferences regarding the proposed beaver eradication program in TDF, many questions remain that could be addressed in future studies. For example, given that this was the first characterization of landowner mental models, I chose to analyze the pooled models of all interview or survey respondents; however, beliefs about beavers were diverse and idiosyncratic, and it is possible that some of the variation in mental models could be systematically explained using additional

individual-level covariate factors (e.g., country of residence, land management goals, etc.).

Future research could specifically investigate how biophysical context, sociopolitical context, or even individual-level characteristics are related to private landowners' mental models. If mental models were systematically different among groups of landowners, this would suggest that multiple strategies might be more effective than one single strategy for promoting conservation behaviors (Mackenzie et al. 2014).

In addition, I used a relatively small sample size for my mental model analysis. This was because my primary interest was eliciting key concepts, and theoretical saturation (the point at which no new concepts are generated) typically occurs between 20-30 interviews (Morgan et al. 2002). Further, building mental models from qualitative interviews is exceedingly time-consuming and inherently limits the sample size (e.g., Isaac et al. 2009). Future work, however, could build on my research and employ a survey to assess mental models more broadly in TDF. Survey research would facilitate the testing of hypotheses related to how landowners conceptualize the beaver's impacts to ecosystem services and is typically a "next step" in mental model research (Morgan et al. 2002). Although I randomly sampled landowners, it is possible that my sample excluded important viewpoints simply because of its small size. A survey could be much more broadly administered, and thus confirm or invalidate the initial patterns that I observed in my limited number of mental models.

My factorial vignette survey explored the influence of program structure and administration on landowner participation, and produced several unexpected results that deserve further investigation. Despite evidence that program length, participation of other landowners, and program administrator generally influence landowner willingness to participate in coordinated conservation actions, we found no statistically-significant, population-level

preference for any of these variables. Landowners may focus less on these variables relative to others, or, they may actually have strong, but divided preferences. Future studies should formally characterize whether these are divisive factors that may require strategic or creative program implementation to overcome (i.e., offer several options for program length; identify a third, highly trusted administrator).

Finally, although private landowners play a key role in determining on-the-ground eradication efforts, political institutions and the general public also direct local conservation priorities and agendas. For example, public opposition to a proposed eradication effort can derail an entire effort (e.g., Genovesi and Bertolino 2001). Some research has characterized which ecosystem services the general public in TDF value (Zagarola et al. 2014); however, beliefs and opinions about beavers and the proposed eradication among the general public in TDF have yet to be fully characterized (Schüttler et al. 2011).

Conclusions

Landscape-scale conservation actions require collective action, and a human-centered design approach to conservation planning can help conservation planners understand the beliefs, values and opinions that lead to increased cooperation. In TDF, I found that current communication strategies do not effectively incorporate local stakeholder values, and that past beaver control programs unknowingly did not incorporate important local preferences for program design. Furthermore, my results suggest that the use of a carefully designed incentive program and communication strategy could increase cooperation. Looking forward, my results support involving local stakeholders in determining the most appropriate avenue for achieving desired conservation objectives. Despite the widespread calls for increased stakeholder involvement in conservation planning over the past two decades, integrating local perspectives is

difficult and sometimes neglected. The research I presented here illustrates that a human-centered design approach can be employed to gather and incorporate local stakeholder beliefs and preferences into the construction of a conservation program. By putting human needs at the forefront of program design, conservation planners can reduce barriers to participation, and thus increase cooperation and improve conservation outcomes (Sorice and Donlan *in press*).

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Appendix A: IRB Approval Letters

 VirginiaTech	Office of Research Compliance Institutional Review Board North End Center, Suite 4120, Virginia Tech 300 Turner Street NW Blacksburg, Virginia 24061 540/231-4606 Fax 540/231-0959 email irb@vt.edu website http://www.irb.vt.edu
MEMORANDUM	
DATE:	July 7, 2014
TO:	Michael G Sorice, Anna Ruth Santo
FROM:	Virginia Tech Institutional Review Board (FWA00000572, expires April 25, 2018)
PROTOCOL TITLE:	Landowner Perspectives of Benefits of Riparian Areas
IRB NUMBER:	13-584
Effective July 7, 2014, the Virginia Tech Institution Review Board (IRB) Chair, David M Moore, approved the Continuing Review request for the above-mentioned research protocol.	
This approval provides permission to begin the human subject activities outlined in the IRB-approved protocol and supporting documents.	
Plans to deviate from the approved protocol and/or supporting documents must be submitted to the IRB as an amendment request and approved by the IRB prior to the implementation of any changes, regardless of how minor, except where necessary to eliminate apparent immediate hazards to the subjects. Report within 5 business days to the IRB any injuries or other unanticipated or adverse events involving risks or harms to human research subjects or others.	
All investigators (listed above) are required to comply with the researcher requirements outlined at:	
http://www.irb.vt.edu/pages/responsibilities.htm	
(Please review responsibilities before the commencement of your research.)	
PROTOCOL INFORMATION:	
Approved As:	Expedited, under 45 CFR 46.110 category(ies) 6,7
Protocol Approval Date:	July 26, 2014
Protocol Expiration Date:	July 25, 2015
Continuing Review Due Date*:	July 11, 2015
*Date a Continuing Review application is due to the IRB office if human subject activities covered under this protocol, including data analysis, are to continue beyond the Protocol Expiration Date.	
FEDERALLY FUNDED RESEARCH REQUIREMENTS:	
Per federal regulations, 45 CFR 46.103(f), the IRB is required to compare all federally funded grant proposals/work statements to the IRB protocol(s) which cover the human research activities included in the proposal / work statement before funds are released. Note that this requirement does not apply to Exempt and Interim IRB protocols, or grants for which VT is not the primary awardee.	
The table on the following page indicates whether grant proposals are related to this IRB protocol, and which of the listed proposals, if any, have been compared to this IRB protocol, if required.	
<i>Invent the Future</i>	
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Office of Research Compliance
 Institutional Review Board
 North End Center, Suite 4120, Virginia Tech
 300 Turner Street NW
 Blacksburg, Virginia 24061
 540/231-4606 Fax 540/231-0959
 email irb@vt.edu
 website <http://www.irb.vt.edu>

MEMORANDUM

DATE: February 9, 2015
TO: Michael G Sorice, Anna Ruth Santo, Alexander Joseph Grieve, Tyler Lee Hemby
FROM: Virginia Tech Institutional Review Board (FWA00000572, expires April 25, 2018)
PROTOCOL TITLE: TDF Beaver Control Incentive Program - Landowner Survey
IRB NUMBER: 14-145

Effective February 9, 2015, the Virginia Tech Institutional Review Board (IRB) Chair, David M Moore, approved the Continuing Review request for the above-mentioned research protocol.

This approval provides permission to begin the human subject activities outlined in the IRB-approved protocol and supporting documents.

Plans to deviate from the approved protocol and/or supporting documents must be submitted to the IRB as an amendment request and approved by the IRB prior to the implementation of any changes, regardless of how minor, except where necessary to eliminate apparent immediate hazards to the subjects. Report within 5 business days to the IRB any injuries or other unanticipated or adverse events involving risks or harms to human research subjects or others.

All investigators (listed above) are required to comply with the researcher requirements outlined at:

<http://www.irb.vt.edu/pages/responsibilities.htm>

(Please review responsibilities before the commencement of your research.)

PROTOCOL INFORMATION:

Approved As: **Expedited, under 45 CFR 46.110 category(ies) 5,7**
 Protocol Approval Date: **March 5, 2015**
 Protocol Expiration Date: **March 3, 2016**
 Continuing Review Due Date*: **February 18, 2016**

*Date a Continuing Review application is due to the IRB office if human subject activities covered under this protocol, including data analysis, are to continue beyond the Protocol Expiration Date.

FEDERALLY FUNDED RESEARCH REQUIREMENTS:

Per federal regulations, 45 CFR 46.103(f), the IRB is required to compare all federally funded grant proposals/work statements to the IRB protocol(s) which cover the human research activities included in the proposal / work statement before funds are released. Note that this requirement does not apply to Exempt and Interim IRB protocols, or grants for which VT is not the primary awardee.

The table on the following page indicates whether grant proposals are related to this IRB protocol, and which of the listed proposals, if any, have been compared to this IRB protocol, if required.

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Appendix B. Response Information and Response Rate Calculations

Response rates (RR = complete interviews/eligible reporting units) are presented to assess potential nonresponse error in survey datasets. Although RR calculation appears simple, differing interpretations of “completeness” or “eligibility” have lead researchers to calculate response rate in many different ways, none of which are a gold standard (Smith 2009). In an effort to standardize response rate calculations in interview research, the American Association of Public Opinion Research created a publicly-available response rate calculator (AAPOR 2011a, b). Using this calculator, the AAPOR proposes six unique measures to describe the range of possible “low” and “high” response rates. Each rate is calculated using different assumptions about interview completeness and participant eligibility.

Additionally, the AAPOR defines further useful measures of response, including cooperation rates, refusal rates, and contact rates. Cooperation rates are the proportion of interviewed respondents to successfully contacted, eligible respondents. Refusal rates are the proportion of eligible cases in which a respondent or household member refuses to be interviewed or breaks off an interview. Finally, contact rates are the proportion of cases in which the researcher communicated with participants or responsible household members. The AAPOR response rate calculator provides several “high” and “low” estimates of each of these additional measures of response. The AAPOR suggests reporting all of these measures to provide a robust analysis of survey response.

To calculate rates for overall response, cooperation, refusal, and contact, interview cases are first divided into four groups: 1) completed interviews; 2) eligible cases that were not interviewed (non-respondents); 3) cases of unknown eligibility; and 4) ineligible cases. In this study, we consider “complete” interviews to be interviews in which participants were asked at

least 80% of the survey questions, regardless of whether they chose to answer them or not.

Partial interviews are interviews in which respondents were asked less than 80% of the survey questions. Eligible non-respondents consist of cases where a respondent or responsible household member declined an interview either directly or indirectly (2.11), an initiated interview was broken-off (2.12), a respondent was never available at a known phone number or address (2.21), or the only form of contact was an answering machine (2.22). Additionally, some unusual circumstances can be classified as eligible non-respondents, such as death during the sampling period (2.31), physical or mental inability to participate (e.g. illness, hospitalization) (2.32), language barriers (2.33), poor or intermittent phone reception (2.34), or that a participant's location or current activity did not permit an interview (2.35). Eligibility was considered "unknown" when it is not known if an eligible household (3.10) or respondent (3.20) lives at a given telephone number or address. Other reasons for unknown eligibility include: numbers that are always busy (3.12), were never answered (3.13), when an answering machine does not indicate whether a number is for an eligible household (3.14), call screening or blocking (3.15), or technical phone problems (3.16). Ineligible cases include situations like respondents should not have been included in the sampling frame (4.10), number is fax/data line (4.20), non-working or disconnected numbers (4.30), nonresident numbers (e.g. business, government offices (4.50). For more detailed information on classifying cases into the four categories, see (AAPOR 2011a, b).

Classification of non-respondents and AAPOR response, cooperation, refusal, and contact rates from our survey are presented below in tables 1 and 2 for chapter 2 data, and in tables 3 and 4 for chapter 3 data collection. For my mental models interviews (chapter 2), response rates ranged from 64.5% (RR1&3) to 66.1% (RR2&4), cooperation rates range 66.7%

(CR1) to 87.2% (CR4), refusal rates were all 9.7%, and contact rates were all 96.8%. For the survey (chapter 3), response ranged from 74.3% (RR1) to 74.9% (RR4), cooperation rates range 80.6% (CR1) to 90.5% (CR4), refusal rates from 7.8% (RfR1) to 8.1% (RfR3), and contact rates from 92.2% (CnR1) to 95.9% (CnR3).

Table B.1

Interview non-response field notes and coding. Codes used to calculate response, refusal, cooperation, and contact rates with AAPOR (2011a, b) response rate calculator.

ID	Code	AAPOR Code description	Description
AR - X01	2.11	Participant refusal	Participant agreed to participate, never again answered phone or returned phone messages
AR - X02	2.35	Location/Activity not allowing interview	Participant living in another province during sampling period
AR - X03	2.11	Participant refusal	Participant agreed to participate, never again answered phone or returned phone messages
AR - X04	2.35	Location/Activity not allowing interview	Participant living in another province during sampling period
AR - X05	2.35	Location/Activity not allowing interview	Participant living in another province during sampling period
AR - X06	2.21	Respondent never available	Unable to contact at known phone number
AR - X07	2.21	Respondent never available	Phone rang, never answered
AR - X08	4.31	Non-working number	Non-working phone number
CH - X01	2.35	Location/Activity not allowing interview	Participant agreed to participate, but unavailable during sampling period
CH - X02	2.11	Participant refusal	Direct refusal, not interested, no time to participate
CH - X03	2.35	Location/Activity not allowing interview	Participant agreed to participate, but unavailable during sampling period
CH - X04	2.35	Location/Activity not allowing interview	Participant agreed to participate, but unavailable during sampling period
CH - X05	2.35	Location/Activity not allowing interview	Participant agreed to participate, but unavailable during sampling period
CH - X06	2.35	Location/Activity not allowing interview	Participant agreed to participate, but unavailable during sampling period
CH - X07	2.35	Location/Activity not allowing interview	Participant agreed to participate, but unavailable during sampling period
CH - X08	2.11	Participant refusal	Participant agreed to participate, never again answered phone or returned phone messages
CH - X09	2.11	Participant refusal	Participant agreed to participate, but then broke appointment
CH - X10	2.32	Physical inability to participate	Not contacted because participant was hospitalized
CH - X11	2.32	Physical inability to participate	Not contacted because participant was hospitalized
CH - X12	2.32	Physical inability to	Participant answered call and responded

		participate	that they couldn't participate because was in the hospital
CH - X13	2.35	Location/Activity not allowing interview	Participant living in another province during sampling period
CH - X14	2.11	Participant refusal	Participant agreed to participate, never again answered phone or returned phone messages

Table B.2

Response, cooperation, refusal and contact rates for chapter 2 interview data using coded cases of non-response cases. Table based on the American Association of Public Opinion Research's Response Rate Calculator. For a complete list of codes that can be used in the calculator, see (AAPOR 2011a, b).

AAPOR CODES	CHILE	ARG	OVERALL
Interview (Category 1)			
1.00 Complete	24	16	40
1.20 Partial	1		1
Eligible, non-interview (Category 2)			
2.11 Refusal	4	2	6
2.21 Respondent never available		2	2
2.32 Physically or mentally unable/incompetent	3		3
2.35 Location/Activity not allowing interview	7	3	10
Unknown eligibility, non-interview (Category 3)			
Not eligible (Category 4)			
4.31 Non-working number		1	1
Total phone numbers used	39	24	63
I=Complete Interviews (1.1)	24	16	40
P=Partial Interviews (1.2)	1	0	1
R=Refusal and break off (2.1)	4	2	6
NC=Non Contact (2.2)	0	2	2
O=Other (2.0, 2.3)	10	3	13
e (estimated proportion of cases of unknown eligibility that are eligible)	1	0.958	0.984
UH=Unknown Household (3.1)	0	0	0
UO=Unknown other (3.2-3.9)	0	0	0
Response Rate 1: $I/(I+P) + (R+NC+O) + (UH+UO)$	0.615	0.696	0.645
Response Rate 2: $(I+P)/(I+P) + (R+NC+O) + (UH+UO)$	0.641	0.696	0.661
Response Rate 3: $I/((I+P) + (R+NC+O) + e(UH+UO))$	0.615	0.696	0.645
Response Rate 4: $(I+P)/((I+P) + (R+NC+O) + e(UH+UO))$	0.641	0.696	0.661
Cooperation Rate 1: $I/(I+P)+R+O$	0.615	0.762	0.667
Cooperation Rate 2: $(I+P)/((I+P)+R+O)$	0.641	0.762	0.683
Cooperation Rate 3: $I/((I+P)+R)$	0.828	0.889	0.851
Cooperation Rate 4: $(I+P)/((I+P)+R)$	0.862	0.889	0.872
Refusal Rate 1: $R/((I+P)+(R+NC+O) + UH + UO)$	0.103	0.087	0.097
Refusal Rate 2: $R/((I+P)+(R+NC+O) + e(UH + UO))$	0.103	0.087	0.097
Refusal Rate 3: $R/((I+P)+(R+NC+O))$	0.103	0.087	0.097
Contact Rate 1: $(I+P)+R+O / (I+P)+R+O+NC+$	1.000	0.913	0.968

(UH + UO)			
Contact Rate 2: $(I+P)+R+O / (I+P)+R+O+NC +$			
e(UH+UO)	1.000	0.913	0.968
Contact Rate 3: $(I+P)+R+O / (I+P)+R+O+NC$	1.000	0.913	0.968

Table B.3

Survey non-response field notes and coding. Codes used to calculate response, refusal, cooperation, and contact rates with AAPOR (2011a, b) response rate calculator.

ID	Code	AAPOR Code description	Description
AR – X04		Participant refusal	Participant agreed to participate, never again answered phone or returned phone messages
	2.11		
AR – X05		Participant refusal	Direct refusal, not interested, no time to participate
	2.11		
AR – X06		Participant refusal	Participant ended telephone call with researcher
	2.11		
AR – X07		Participant refusal	Direct refusal, did not want to participate because of upcoming surgery
	2.11		
			Household-level refusal, spouse stated participant not interested because they did not have beavers
CH - X01	2.11	Household-level refusal	
CH - X02	2.11	Household-level refusal	Household member gave direct refusal
CH - X03	2.11	Household-level refusal	Spouse gave direct refusal
		Participant refusal	Participant agreed to participate, never again answered phone or returned phone messages
CH - X21	2.11		
		Participant refusal	Participant agreed to participate, followed by broken appointment, never returned phone calls
CH - X24	2.11		
			Participant agreed to participate, technical problems during return phone call, didn't return final text message
CH - X25	2.11	Participant refusal	Participant agreed to participate, followed by broken appointment
CH - X26	2.11	Participant refusal	Participant agreed to participate, never returned message
CH - X27	2.11		
			Participant agreed to participate, followed by broken appointment
CH - X30	2.11	Participant refusal	Participant said they do not own land, and not interested in participating
CH - X33	2.11	Participant refusal	
AR – X10	2.21	Respondent never available	Participant agreed to participate, asked researcher to call back, telephone never rang again
CH - X22	2.21	Respondent never available	Participant never available
			Participant never available, never returned message taken by household member
CH - X23	2.21	Respondent never available	Participant never available, household member said participant was traveling, never returned message
CH - X28	2.21	Respondent never available	
			Participant never available, household member said participant was traveling,
CH - X31	2.21	Respondent never available	

			never returned message
			Participant agreed to participate through an acquaintance, researcher never able to contact, household member said to continue calling
CH - X32	2.21	Respondent never available	
AR - X11	2.22	Telephone answering device - message left	Left message, but phone calls never returned
CH - X29	2.3	Other - non-refusal	Participant agreed to participate, technical problems with phone when called back
CH - X18	2.32	Physical inability to participate	Not contacted because participant was hospitalized
CH - X34	2.32	Physical inability to participate	
CH - X19	2.35	Location/Activity not allowing interview	Participant refused because she was not well Participant's mother informed researcher that participant was traveling
CH - X20	2.35	Location/Activity not allowing interview	Participant's sister informed researcher that participant was traveling for health issues
AR - X01	2.35	Location/Activity not allowing interview	Participant agreed to participate, but living in another province during sampling period
AR - X02	2.35	Location/Activity not allowing interview	Participant agreed to participate, but living in another province during sampling period
AR - X08	2.35	Location/Activity not allowing interview	Participant agreed to participate, but traveling during sampling period
AR - X09	2.35	Location/Activity not allowing interview	Participant agreed to participate, but unavailable during sampling period
CH - X04	2.35	Location/Activity not allowing interview	Participant agreed to participate, but traveling during sampling period
CH - X05	2.35	Location/Activity not allowing interview	Participant agreed to participate, but traveling during sampling period
CH - X06	2.35	Location/Activity not allowing interview	Participant agreed to participate, but living in another province during sampling period
CH - X07	2.35	Location/Activity not allowing interview	Participant agreed to participate, but unavailable during sampling period
CH - X08	2.35	Location/Activity not allowing interview	Participant agreed to participate, but living in another province during sampling period
CH - X35	2.35	Location/Activity not allowing interview	Participant agreed to participate, but unavailable during sampling period
CH - X36	2.35	Location/Activity not allowing interview	Participant agreed to participate, but traveling during sampling period, phone call cut off
CH - X37	2.35	Location/Activity not allowing interview	Participant agreed to participate, broken appointment, unavailable during sampling period
AR - X12	3.11	Not attempted	Unable to find contact information
CH - X17	3.11	Not attempted	Advised not to contact for safety reasons
AR - X03	3.13	No answer	Phone rang, never answered

CH - X09	3.13	No answer	Unable to contact at known phone number
CH - X10	3.13	No answer	Unable to contact at known address
CH - X11	3.13	No answer	Unable to contact at known phone number
CH - X12	3.13	No answer	Unable to contact at known phone number
CH - X14	4.31	Non-working number	Non-working phone number
CH - X15	4.31	Non-working number	Non-working phone number
CH - X16	4.31	Non-working number	Non-working phone number
CH - X13	4.5	Non-residence	Non-resident phone number, unable to find contact information

Table B.4

Response, cooperation, refusal and contact rates for chapter 3 survey data using coded cases of non-response cases. Table based on the American Association of Public Opinion Research's Response Rate Calculator. For a complete list of codes that can be used in the calculator, see (AAPOR 2011a, b).

AAPOR CODES	CHILE	ARG	OVERALL
Interview (Category 1)			
1.00 Complete	96	37	133
1.20 Partial	1	0	1
Eligible, non-interview (Category 2)			
2.11 Refusal	7	4	11
2.11 Household-level refusal	3	0	3
2.21 Respondent never available	5	1	6
2.22 Answering machine household-message left	0	1	1
2.30 Other, non-refusals	1	0	1
2.32 Physically or mentally unable/incompetent	2	0	2
2.35 Location/Activity not allowing interview	10	4	14
Unknown eligibility, non-interview (Category 3)			
3.11 Not attempted or worked/not mailed/No invitation sent (internet surveys)	1	1	2
3.13 No answer	4	1	5
Not eligible (Category 4)			
4.31 Non-working number	3	0	3
4.50 Nonresidence	1	0	1
Total phone numbers used	134	49	183
I=Complete Interviews (1.1)	96	37	133
P=Partial Interviews (1.2)	1	0	1
R=Refusal and break off (2.1)	10	4	14
NC=Non Contact (2.2)	5	2	7
O=Other (2.0, 2.3)	13	4	17
e (estimated proportion of cases of unknown eligibility that are eligible)	0.969	1.000	0.977
UH=Unknown Household (3.1)	5	2	7
UO=Unknown other (3.2-3.9)	0	0	0
Response Rate 1: $I/(I+P) + (R+NC+O) + (UH+UO)$	0.738	0.755	0.743
Response Rate 2: $(I+P)/(I+P) + (R+NC+O) + (UH+UO)$	0.746	0.755	0.749
Response Rate 3: $I/((I+P) + (R+NC+O) + e(UH+UO))$	0.739	0.755	0.744
Response Rate 4: $(I+P)/((I+P) + (R+NC+O) + e(UH+UO))$	0.747	0.755	0.749
Cooperation Rate 1: $I/(I+P)+R+O)$	0.800	0.822	0.806
Cooperation Rate 2: $(I+P)/((I+P)+R+O)$	0.808	0.822	0.812
Cooperation Rate 3: $I/((I+P)+R)$	0.897	0.902	0.899
Cooperation Rate 4: $(I+P)/((I+P)+R)$	0.907	0.902	0.905
Refusal Rate 1: $R/((I+P)+(R+NC+O) + UH + UO))$	0.077	0.082	0.078

Refusal Rate 2: $R/((I+P)+(R+NC+O) + e(UH + UO))$	0.077	0.082	0.078
Refusal Rate 3: $R/((I+P)+(R+NC+O))$	0.080	0.085	0.081
<hr/>			
Contact Rate 1: $(I+P)+R+O / (I+P)+R+O+NC+ (UH + UO)$	0.923	0.918	0.922
Contact Rate 2: $(I+P)+R+O / (I+P)+R+O+NC + e(UH+UO)$	0.924	0.918	0.923
Contact Rate 3: $(I+P)+R+O / (I+P)+R+O+NC$	0.960	0.957	0.959
<hr/>			

Appendix C. Cognitive Map Node Collapsing

Table C.1

Nodes collapsed in cognitive maps in order to reduce complexity and increase interpretability of the models. Nodes with “original codes” that represented similar ideas were collapsed into “final code” categories.

Code #	Original code	Final code
1	Level of "naturalness"	"Naturalness"
	Level of human intervention	
	Level of naturalness	
2	Abundance of abandoned beaver ponds	Abandoned beaver ponds
	Amount of time since a beaver pond was drained	
3	Ability for bacteria, microorganisms, insects, and mosses to infect plants	Ability of pathogens to infect plants
4	Ability for plants to absorb soil minerals	Ability of plants to absorb nutrients/minerals
	Ability of plants to absorb nutrients	
5	Ability for soil to absorb fertilizers	Ability of soil to absorb fertilizers
6	Ability to charge batteries	Ability to charge batteries
7	Ability to drive on land	Ability to drive on land
	Likelihood of vehicles getting stuck in mud	
8	Ability to have pets	Ability to have pets
9	Ability to maintain a family legacy	Ability to maintain a family legacy
10	Ability to live on ranch	Ability to maintain rural lifestyle
	Ability to maintain rural lifestyle	
	Ability to maintain tradition of preserving food from garden	
	Ability to perpetuate ranching activities	
	Ability to sustain ranching operation	
11	Ability to operate power tools	Ability to operate power tools
12	Ability to use pathways	Ability to use roads, trails, and pathways
	Level of damage to livestock's pathways	
13	Abundance of birds	Abundance of birds
14	Abundance of wildlife	Abundance of wildlife
15	Access to municipal drinking water supply	Access to municipal drinking water supply
16	Level of access to pastures	Access to pastures
17	Presence of access to peat bogs	Access to peat bogs
18	Level of ease of access to water	Access to water
	Presence of access to water	
19	Presence of road access	Access via roads
20	Level of soil acidity	Acidity of soil
21	Age of trees in forest	Age of trees in forest
22	Amount of produce sold	Agricultural products sold/exported
	Amount of products exported	

23	Amount of air pollution	Air quality
	Amount of smog	
	Level of air quality	
24	Altitude	Altitude
	High elevation location	
25	Amount of fish	Amount of fish
	Amount of fish being removed	
	Amount of fish removed	
	Amount of fish removed from spawning ground	
26	Amount of forage	Amount of forage
	Amount of forage	
	Level of productivity	
27	Amount of forest	Amount of forest
28	Ability to maintain pregnant sheep	Amount of livestock
	Amount of livestock	
29	Amount of meat produced	Amount of meat
30	Amount of planted trees	Amount of planted trees
31	Amount of rural ranches in the region	Amount of ranches
32	Amount of topsoil	Amount of topsoil
33	Amount of vegetation	Amount of vegetation
	Amount of vegetation that is uprooted	
34	Amount of wool produced	Amount of wool
	Amount of wool thrown away	
35	Amount of dead animals	Animal remains
	Amount of dead animals	
	Amount of dead animals in water	
	Presence of animal remains in soil	
	Presence of animal remains in water	
36	Level of influence of animal rights activists	Animal rights activists
37	Amount of fecal material	Animal waste
	Amount of urine	
38	Ability to bathe animals	Anti-parasitic bathing/treatment
	Use of antiparasitic bathing	
	Use of anti-parasitic bathing	
	Use of anti-parasitic supplements	
	Use of anti-parasitic supplements for livestock	
39	Amount of aquatic flowers	Aquatic vegetation
	Amount of aquatic vegetation	
	Presence of algae in water	
	Presence of moss in water	
40	Presence of artisanal fishermen	Artisanal fishermen
	Quality of place for establishing fishing settlement	

41	Quality of place for establishing gold mining settlement	Artisanal gold miners
	Amount of young people interested in gold mining	
42	Location on a north-facing slope	Aspect
	Location on a south-facing slope	
	Location on an east-facing slope	
43	Amount of oxygen produced	Atmospheric oxygen
44	Use of the atomic bomb	Atomic bomb
45	Feeling of freedom	Autonomy
	Level of independence	
	Ability to be self-sufficient and not depend on outside services	
46	Average size of ranch	Average ranch size
47	Amount of bacteria	Bacteria
	Amount of bacteria in water	
48	Amount of bark removed from trees	Bark removed from trees
49	Presence of natural barriers	Barriers to livestock movement
50	Beaver abundance	Beaver abundance
51	Beaver dam abundance	Beaver dam abundance
52	Frequency of removing beaver dams	Beaver dams removed
	Use of dynamite	
53	Beaver house abundance	Beaver house abundance
54	Beaver meat amount	Beaver meat
55	Beaver pelt amount	Beaver pelts
56	Beaver pond abundance	Beaver pond abundance
	Beaver pond abundance	
57	Rate of reproduction of beavers	Beaver reproduction
58	Amount of tunnels	Beaver tunnels
59	Amount of beavers participant hunts	Beavers hunted
60	Amount of living things	Biodiversity
	Level of biodiversity	
61	Abundance of bird eggs destroyed	Bird Eggs
	Amount of bird eggs destroyed	
62	Abundance of bird food	Bird food
63	Opportunities to see birds and other wildlife	Bird/Wildlife watching opportunities
	Opportunity for bird watching	
	Opportunity to see wildlife	
64	Opportunity to go boating	Boating opportunities
	Opportunity to go kayaking	
	Opportunity to go sailing	
65	Use of boilin gwater before drinking	Boiling water
	Use of boiling water before drinking	
66	Opportunity to start bottled water business	Bottled water business

67	Amount of boulders	Boulders
68	Presence of bridges	Bridges
69	Presence of buildings	Buildings
70	Amount of built infrastructure	Built infrastructure
	Presence of infrastructure	
71	Ability to remove bushes	Bushes
	Amount of bushes	
	Amount of bushes removed	
	Amount of unwanted bushes removed	
72	Abundance of butterflies	Butterflies
73	Abundance of calcium in soil	Calcium
74	Opportunity to go camping	Camping opportunities
75	Amount of carbon in soil	Carbon in soil
76	Amount of atmospheric carbon dioxide	Carbon sequestration/Emissions
	Amount of carbon emissions	
	Amount of carbon sequestered	
	Amount of carbon sequestered in plant roots	
77	Castor oil amount	Castor oil
78	Presence of cell service	Cell service
79	Presence of cell towers	Cell tower
80	Use of chlorination	Chlorination
81	Presence of clay in subsurface geology	Clay content of soils
	Presence of clay in surface geology	
82	Ability to exploit special clay	Clay exploitation
	Level of exploitation of special clay	
83	Frequency of cleaning area around water source	Cleaning water source/storage tank
	Frequency of cleaning water storage tank	
84	Concentration of impurities	Cleanliness of water
	Level of sanitary conditions	
	Level of cleanliness of water	
	Level of cleanliness of water	
85	Intensity of climate change	Climate change
86	Buffering effect on temperature	Climate/air temperature
	Diversity of air temperatures	
	Frequency of freezing weather	
	Location in a cold climate	
	Location in a warm climate	
	Quality of climate	
	Quality of climate for tourism	
Temperature of air		
87	Amount of clouds	Clouds
88	Access to beach	Coast/Beach
	Location on coast	
89	Darkness of color of water	Color of water

	Darkness of color of water	
	Darkness of color of water	
	Presence of green color in water	
	Presence of green layer in water	
90	Level of commercial fishing	Commercial fishing
91	Level of aeration of soil	Compaction of soil
	Level of compaction of soil	
	Level of compactness of soil	
	Level of permeability of soil	
92	Amount of money received as compensation for damages	Compensation for damages
	Quality of lawyer negotiating for you	
93	Conservation value of the land	Conservation value of the land
94	Level of contact with neighbor's livestock	Contact with neighbor's livestock
95	Amount of chemicals in soil	Contaminants/Pollution
	Amount of pollution	
	Amount of water pollution	
	Concentration of chemicals in water	
	Presence of noxious substances in water	
96	Level of cooperation among neighbors	Cooperation among neighbors
97	Location in Argentina	Country
	Location in Chile	
98	Quality of place for planting	Cultivation
	Size of planted area	
	Size of planted area	
99	Level of damage to bridges	Damage to bridges
100	Level of damage to buildings	Damage to buildings
101	Level of damage to fences	Damage to fences
102	Level of clogging of ditches	Damage to irrigation infrastructure
	Level of damage to irrigation infrastructure	
103	Level of damage to pipeline infrastructure	Damage to pipelines
104	Level of damage to roads	Damage to roads
105	Abundance of dangerous animals	Dangerous animals
106	Darkness of soil color	Darkness of soil color
107	Amount of dead trees	Dead trees
108	Level of decay of trees	Decay of trees
	Level of rot in tree's center	
109	Amount of decomposing material	Decomposing material
110	Density of forest	Density of forest
111	Density of human population	Density of human population
	Density of human population	
112	Ability to have electricity in houses	Dependable domestic electricity
	Presence of dependable electricity source	
	Presence of dependable source of electricity	

113	Ability to accumulate and hold water for multiple days	Depressions in ground
	Abundance of depressions in ground	
	Location in a depression in ground	
114	Desire to continue living on the land	Desire to maintain rural lifestyle
	Desire to start new projects	
	Desire to work	
115	Presence of dinosaur remains	Dinosaur remains
116	Distance all animals must walk between water sources	Distance livestock must walk
	Distance livestock must walk between drinking water sources	
	Distance livestock must walk between water sources	
117	Vertical distance water must be raised to be used for irrigation	Distance to raise water to be able to irrigate
118	Distance to roads	Distance to roads
119	Distance to town or city	Distance to town or city
120	Distance to ranch house	Distance to transmit electricity
	Distance to ranch houses	
	Distances to ranch houses	
121	Distance to walk	Distance to walk to go fishing
122	Distance to water source	Distance to water
	Distance water must be moved to be used for irrigation	
	Distance water must be moved to be used for irrigation	
123	Amount of diversion of waterways	Diversion of waterways
	Amount of diversions of waterways	
	Level of disturbance to the distribution of water	
124	Diversity of birds	Diversity of birds
125	Diversity of colors	Diversity of landscape features/colors
	Diversity of landscape features	
	Diversity of textures	
	Presence of unique landscapes	
	Variety of colors on landscape	
126	Diversity of plants	Diversity of vegetation
	Diversity of vegetation	
127	Diversity of wildlife	Diversity of wildlife
128	Use of meat for domestic animal feed	Domestic animal feed
129	Level of drought	Drought
130	Amount of dust	Dust
131	Amount of earthquakes	Earthquakes
132	Feeling of pressure to increase income	Economic pressures

	Need to pay rent	
133	Economic value of the land	Economic value of the land
134	Diversity of ecosystems	Ecosystem diversity
135	Amount of energy expended by animals	Energy expended by animals
136	Level of protection of topsoil	Erosion
	Rate of erosion	
	Force of rain hitting the soils	
137	Amount of water evaporated	Evaporation
	Rate of evaporation	
	Rate of evaporaton	
138	Rate of evapotranspiration	Evapotranspiration
139	Presence of evolutionary adaptations	Evolutionary history of the land
	Presence of grazing animals	
140	Abundance of coruros	Exotic/Invasive species
	Abundance of feral pigs and horses	
	Introduction of exotic species	
	Presence of didymo	
	Presence of exotic species	
	Presence of pilosela	
141	Amount of costs	Expenses
	Amount of costs for irrigation	
142	Amount of exposed soil	Exposed soil
143	Amount of fallen trees	Fallen trees
	Amount of trees blown down	
	Number of felled trees	
144	Opportunity for family bonding	Family bonding
145	Feeling of adventure	Feeling of adventure/challenge
	Feeling of being challenged by the elements	
	Opportunity to outsmart animals	
146	Feeling of personal identity as an environmentalist	Feeling of pride/identity
	Feeling of self satisfaction	
	Feeling of self-satisfaction	
147	Feeling of increased inspiration	Feeling of spiritual enrichment/inspiration
	Feeling of spiritual enrichment	
	Level of therapeutic benefit	
148	Ability to support nature	Feelings of connection to/supporting the land
	Feeling of attachment	
	Feeling of being part of the land	
	Feeling of ownership	
	Feeling of supporting ecosystem health	
	Feeling of supporting the planet	
149	Amount of fences constructed	Fences

	Presence of fences	
	Presence of well-maintained fences	
150	Presence of ferry terminal	Ferry terminal
151	Concentration of fertilizers in water	Fertilizers
	Use of fertilizer	
	Use of fertilizers	
152	Presence of filtration system	Filtration system
	Use of water decanting system	
153	Amount of capital invested	Financial investments
	Level of financial investment	
154	Availability of firewood	Firewood availability
155	Presence of fish farming infrastructure	Fish farming infrastructure
156	Ability to operate a fish farming operation	Fish farming operation
	Ability to operate fish farming operation	
157	Abundance of fish food	Fish food
158	Rate of reproduction of fish	Fish reproduction rate
159	Use of fish stocking	Fish stocking
160	Amount of fishermen and women	Fishermen/women
161	Presence of fishing guide	Fishing guide
162	Amount of fishing lodges in the region	Fishing lodges
163	Use of dynamite for fishing	Fishing method
	Use of nets for fishing	
164	Use of catch and release	Fishing restrictions
	Use of fishing restrictions	
	Use of fly fishing	
165	Presence of fissures in ground as it dries up	Fissures in ground
166	Frequency of flash floods	Flash floods
167	Quality of flavor of fish	Flavor of fish
168	Use of flood irrigation	Flood irrigation
169	Number of communities inundated by hydroelectric dams	Flooded human communities
170	Amount of flowers	Flowers
	Diversity of flowers	
171	Availability of food for beavers	Food for beavers
172	Ability to hunt wildlife for food	Food produced for people
	Amount of food produced	
	Amount of food produced for personal consumption	
	Amount of food produced for workers	
173	Amount of forage consumed by livestock	Forage consumed by livestock
174	Force of water	Force of water
175	Presence of a lumber mill	Forest exploitation infrastructure
	Presence of forest exploitation infrastructure	
	Presence of sawmill	

176	Frequency of forest fires	Forest fires
177	Level of health of forest	Forest health
178	Rate of forest regeneration	Forest regeration
179	Abundance of foxes	Foxes
180	Frequency of fish biting your line	Frequency of fish biting
181	Amount of fuel consumed	Fuel consumed
182	Amount of fungus in water	Fungus
183	Ability to have a garden	Garden
184	Location at a high latitude	Geographical location
	Location in a low pressure area	
	Location on an island	
	Presence of islands	
185	Rate of germination of seeds	Germination rate
186	Location on a lateral morain	Glacial deposits
	Presence of glacial deposits	
187	Distance to glaciers	Glaciers
	Presence of glaciers	
188	Amount of gold in ore collected on site	Gold deposits
189	Ability to get permit to take tourists fishing	Government permits
	Ability to get permits for peat bog exploitation	
	Ability to get permits to divert water for irrigation	
	Ability to get permits to exploit forest	
	Ability to get permits to take tourists fishing	
	Ability to get permits to use water	
	Ability to use water	
190	Presence of drinking water regulations	Government regulations
	Use of excessive regulations	
	Use of timber harvesting restrictions	
191	Ability to get government subsidies	Government subsidies
192	Level of gravel exploitation	Gravel exploitation
193	Presence of gravity	Gravity
194	Ability to use pastures for livestock grazing	Grazing pressure
	Amount of cattle grazing	
	Amount of sheep grazing	
	Amount of time livestock are held in corral	
	Amount of time livestock graze a pasture	
	Amount of time livestock have for eating	
	Amount of time livestock spend grazing	
	Amount of time livestock spend grazing a pasture	
	Level of concentration of livestock around water holes	
	Level of overgrazing	
	Number of consecutive years land is in agricultural production	

	Number of years pasture has been exploited	
	Rate of trampling	
195	Level of greenness	Green landscape
	Level of greenness of landscape	
	Level of greenness of landscapes	
196	Presence of ground	Ground
	Presence of soil	
197	Amount of ground water	Groundwater
	Amount of groundwater	
	Amount of springs	
	Depth of groundwater source	
	Depth of groundwater table	
	Presence of aquifers	
198	Abundance of guanacos	Guanacos
	Presence of overpopulation of guanacos	
199	Hardness of water	Hardness of water
200	Frequency of cutting vegetation	Harvesting/cutting vegetation
	Use of occasional cutting of vegetation	
201	Level of damage to pastures	Health of pastures
	Level of health of pasture	
	Level of health of pastures	
	Level of pasture health	
	Quality of pasture	
202	Opportunity to go hiking	Hiking opportunities
	Opportunity to go walking	
203	Level of flatness of topography	Hills/Mountains
	Presence of hills	
	Presence of mountains	
204	Presence of history of indigenous habitation	History of indigenous inhabitation
205	Level of homogeneity of trees in forest	Homogeneity of trees in forest
206	Concentration of artificial hormones in water	Hormones/supplements for livestock
	Use of artificial hormones	
	Use of vitamins for livestock	
207	Opportunity to go horseback riding	Horseback riding opportunities
208	Presence of hot springs	Hot springs/Mud bath
	Ability to operate hot springs	
	Ability to operate mud-bath	
209	Amount of houses	Houses
210	Presence of artificial corners in construction on landscape	Human changes to landscape
	Amount of hills leveled during construction	
	Construction of artificial hills	
211	Presence of human drinking water	Human drinking water availability
212	Ability for humans to exist	Human existence

	Amount of humans breathing	
213	Frequency of people getting sick	Human health
	Frequency of respiratory diseases	
	Level of health of participant	
	Level of healthiness for consumers	
	Level of healthiness of human communities	
	Likelihood that water will make you sick	
214	Amount of people clothed	Human provisioning
	Amount of people fed	
	Number of people the land can support	
215	Amount of tree limbs participant brings to beavers	Humans feeding beavers
216	Level of humidity of air	Humidity
217	Amount of hummocks	Hummocks
218	Amount of hunters	Hunters
219	Opportunity to go hunting	Hunting opportunities
	Opportunity to hunt beavers	
220	Use of hunting restrictions	Hunting restrictions
221	Amount of hydrogen in the soil	Hydrogen in soil
222	Ability to generate hydropower	Hydropower
223	Presence of impermeable clay layer in subsurface geology	Impermeable geologic layer
	Presence of impermeable layer in subsurface geology	
224	Amount of income	Income
	Price for tourists to visit	
225	Level of industrial development	Industrial development
226	Abundance of insects	Insects
	Diversity of insects	
	Amount of insects in water	
227	Introduction of exotic trout	Introduction of exotic fish
	Introduction of fish	
228	Presence of irrigation infrastructure	Irrigation infrastructure
	Presence of sprinkler irrigation system	
229	Amount of employment opportunities	Jobs/employment
	Amount of jobs created for trappers	
230	Amount of labor	Labor
231	Use of locks on gates	Land access restrictions
	Use of private land access restrictions	
232	Frequency of beautiful skies	Landscape beauty
	Level of aesthetic beauty	
	Level of landscape beauty	
233	Size of plant leaves	Leaf size
234	Amount of leaves in water	Leaves in water

235	Amount of leisure time	Leisure time
	Opportunity to escape from work	
236	Level of filtration	Level of filtration
237	Amount of water absorbed by soil	Level of soil moisture
	Amount of water absorbed by the soil	
	Level of soil moisture	
	Level of soil moisture	
	Presence of dry areas	
238	Decision to have a family	Life stage
	Level of life stage of participant	
239	Presence of bathing structure	Livestock bathing structure
240	Presence of livestock drinking water	Livestock drinking water
	Presence of livestock drinking water	
241	Rate of livestock growth in winter	Livestock growth rate
242	Amount of livestock with lung disease	Livestock health
	Amount of parasites on livestock	
	Frequency of livestock developing kidney stones	
	Frequency of livestock developing problems with their hooves	
	Level of deterioration of sheep's teeth	
	Level of health of livestock	
	Level of livestock health	
	Presence of stressed out livestock	
Rate of livestock mortality		
243	Amount of lambs	Livestock reproduction
	Rate of livestock births	
244	Size of lambs	Livestock size
	Size of livestock	
	Weight of livestock	
245	Amount of livestock that get stranded	Livestock stuck/stranded
	Amount of sheep that fall through the ice	
246	Presence of bird mating habitat	Locations for nesting/mating
	Presence of locations for nesting	
247	Amount of man-made access points to water	Man-made access points to water
248	Amount of man-made dams	Man-made dams/irrigation diversions
	Amount of man-made irrigation diversions	
	Number of man-made dams	
249	Amount of constructed water holes	Man-made drinking water holes for livestock
250	Construction of sea lion habitat	Man-made sea lion habitat
251	Amount of materials the beavers steal to build their dams	Materials beavers steal to build dams
252	Medicinal properties of water	Medicinal properties of water
253	Amount of microorganisms	Microorganisms
	Amount of soil microorganisms	

254	Presence of migrating birds	Migrating birds
255	Level of mining activities	Mineral/gold exploitation
	Presence of gold mining activity	
256	Concentration of minerals	Minerals
	Presence of healthy abundance of minerals in soil	
	Presence of healthy minerals in geologic parent materials	
	Presence of healthy minerals in parent geologic material	
	Concentration of minerals in water	
	Presence of healthy concentration of minerals in water	
257	Abundance of minks	Minks
258	Level of moisture in forage	Moisture in plants
	Level of moisture in forage consumed	
259	Presence of monument honoring sheep	Monuments/statues
260	Abundance of mosquitoes	Mosquitoes
	Amount of mosquitoes in water	
261	Location at the mouth of a river where it flows into ocean	Mouth of river
262	Amount of mud	Mud
263	Opportunity to go mushroom hunting	Mushroom hunting opportunities
264	Abundance of muskrats	Muskrats
265	Quality of current culture in government and country	National economic stability
	Rate of economic inflation	
266	Desirability of invading the region	National security
	Level of national security	
267	Use of native tree species	Native tree species
268	Presence of natural gas in ground water	Natural gas in water
	Presence of natural gas in water	
269	Necessity for land manager to live on ranch	Necessity for manager to live on ranch
270	Level of need for electricity	Need for electricity
271	Level of need for irrigation on land	Need for irrigation
272	Amount of noise	Noise
273	Presence of novel attractions	Novel attractions
274	Presence of alpacas	Novel farm animals
	Presence of geese	
	Presence of novel farm animals	
275	Amount of nutrients in soil	Nutrients in soil
276	Abundance of obstacles to wildlife	Obstacles/debris
	Amount of barriers in water bodies preventing movement of fish	

	Amount of barriers in waterbodies preventing movement of fish	
	Amount of barriers in waterbodies preventing movement of fish	
	Amount of objects in water that fishing line could get stuck on	
	Presence of obstacles for fishermen and women to fish	
277	Access to ocean	Ocean
	Distance to ocean	
	Presence of access to ocean	
	Presence of ocean	
	Presence of view of ocean	
278	Diversity of odors	Odors
	Presence of pleasant odor	
	Strength of pleasant odor	
	Strength of unpleasant odor	
279	Amount of abandoned gas wells	Oil and gas exploitation
	Distance to gas well	
	Level of oil and gas development	
280	Ability to see horizon	Open landscapes
	Ability to see long distances	
	Amount of open space	
	Level of openness of landscape	
281	Amount of economic options	Opportunities to increase income
282	Ability to experience rural lifestyle	Opportunity to experience rural lifestyle
	Opportunity to experience rural lifestyle	
283	Opportunity to see beavers	Opportunity to see beavers
	Opportunity to see beavers	
	Opportunity to see beavers working	
284	Amount of organic material	Organic material
	Amount of organic material	
	Amount of organic material in water	
285	Amount of material deposited	Organic/mineral material deposited
	Amount of seashells incorporated into soil	
	Presence of volcanic deposits	
286	Presence of ownership of minerals on one's own land	Ownership of mineral rights
287	Amount of oxygen in the soil	Oxygen level in water/soil
	Concentration of oxygen in water	
	Level of oxygenation	
	Location in an anaerobic environment	
288	Presence of ozone hole	Ozone hole
	Size of hole in ozone layer	

289	Abundance of parasites	Parasites
	Presence of parasites in water	
290	Abundance of parasitic lichens	Parasitic lichens
291	Level of patience of fisherman or woman	Patience
292	Ability to exploit peat bogs	Peat bog exploitation
	Level of exploitation of peat bogs	
	Level of peat bog exploitation	
293	Amount of peat bogs	Peat bogs
294	Level of pest control	Pest control
295	Use of pesticides	Pesticides
296	Presence of pet drinking water	Pet drinking water
297	Presence of petrified forests	Petrified forests
298	Presence of the cave of hands	Petroglyphs
299	Presence of appropriate pH for fish	pH of water
	Level of acidity of water	
300	Opportunity to take unique photographs	Photography opportunities
301	Use of pipeline from water source	Pipeline from water source
302	Amount of planes	Planes
303	Amount of plant roots	Plant roots
	Depth of plant roots	
	Strength of plant roots	
304	Level of pollination	Pollination
305	Amount of rain	Precipitation
	Amount of snow	
	Amount of snowmelt	
	Gradual melting of snow	
306	Amount of predators adapted to hunt spawning fish	Predation
	Level of predation	
	Presence of predators	
307	Level of individual preference for cold climates	Preference for cold climates
308	Price of wood	Price of wood
309	Level of demand for products	Price/Demand for agricultural products
	Level of market demand for products	
	Level of market demand for wool	
	Price of wool	
310	Level of demand for beaver pelts	Price/demand for beaver pelts
311	Price of gold	Price/demand for gold
	Value of gold on land	
312	Level of demand for peat moss	Price/demand for peat moss
	Price of peat moss	
313	Level of protection from predators	Protection from predators
314	Amount of protein in plant	Protein in plants
315	Ability to relieve stress	Psychological well-being

	Feeling of anger	
	Feeling of frustration	
	Feeling of increased happiness	
	Feeling of nervousness	
	Feeling of personal enjoyment	
	Feeling of relaxation	
316	Quality of beaver habitat	Quality of beaver habitat
317	Quality of bird habitat	Quality of bird habitat
	Quality of location for migratory bird stopovers	
318	Quality of vegetation	Quality of forage
	Amount of calories in grass	
	Amount of nutrients in grass	
	Level of tenderness of forage	
	Level of tenderness of grass	
	Quality of forage	
319	Amount of problems for participant	Quality of life
	Difficulty of domestic tasks	
	Frequency of disturbances to human system	
	Level of difficulty of one's life	
	Quality of life for employees	
	Quality of life for participant	
	Quality of lifestyle	
320	Quality of meat produced	Quality of meat
321	Quality of place for camping	Quality of place for camping
322	Quality of place for building ranch house	Quality of place for living
	Quality of place for living	
323	Quality of place for picnicking	Quality of place for picnicking
324	Quality of place for planting trees	Quality of place for planting trees
325	Quality of place for relaxation	Quality of place for relaxation
326	Quality of place for sport fishing	Quality of place for sport fishing
	Quality of place for sport fishing	
	Quality of place for sportfishing	
327	Quality of place for tourism	Quality of place for tourism
328	Ability to produce healthy products	Quality of produce
	Quality of produce	
329	Presence of appropriately-sized trees for forest exploitation	Quality of timber
	Quality of forest for wood exploitation	
	Quality of trees for building fenceposts	
330	Quality of wildlife habitat	Quality of wildlife habitat
331	Amount of dust trapped in sheeps' wool	Quality of wool
	Amount of organic material trapped in sheeps' wool	
	Quality of wool	

	Quality of wool produced	
332	Abundance of rabbits	Rabbits
333	Amount of rainwater collected	Rainwater collected
334	Decision to raise cattle instead of sheep	Raising cattle versus sheep
	Decision to raise sheep	
335	Abundance of condors	Raptors/Condors
	Abundance of raptors	
336	Rate of decomposition	Rate of decomposition
337	Rate of snow melting	Rate of snowmelt
338	Amount of rats	Rats
339	Amount of recreational activities for participant's family	Recreational opportunities
	Amount of recreational opportunities	
	Amount of recreational opportunities for participant's family	
340	Level of community development	Regional economic development
	Level of regional economic development	
341	Ability to get fish that are adapted to the zone	Regionally-adapted fish
342	Selection of livestock breeds able to adapt to TDF climate	Regionally-adapted livestock breed
343	Level of privacy	Remoteness
	Level of remoteness	
344	Ability to make decisions that support ecosystem health	Responsible livestock management strategy
	Level of consideration of consequences of any actions taken on the land	
	Presence of responsible landowner	
	Use of holistic management style	
	Use of responsible livestock management strategy	
	Use of responsible livestock management style	
	Use of rotational livestock management strategy	
Variety of livestock management options		
345	Ability to retain water like a sponge	Retention of water in soil
	Amount of water that runs off the land	
	Level of soil sponginess	
	Rate of water retention	
346	Amount of riparian forest	Riparian forest
	Location of forest within a certain distance of surface water bodies	
347	Amount of river banks	River banks
348	Relocation of sewer systems	Road construction
	Ability to construct roads	
	Amount of paved roads	

	Construction of new roads	
	Level of road construction activities	
349	Amount of rocks in soil	Rocks in soil
	Presence of rocks in subsurface geology	
	Presence of sand in subsurface geology	
350	Level of safety for sport fishing	Safety for sport fishing
351	Level of risk for well-being of livestock	Safety for walking
	Level of safety for walking	
	Likelihood of livestock getting stuck	
352	Amount of salt in soil	Salt in soil
353	Concentration of salt in water	Salt in water
354	Presence of sand dunes	Sand dunes
355	Presence of sand in surface geology	Sand in soil
356	Presence of schools and colleges	Schools/Colleges
357	Abundance of scuds	Scuds
358	Abundance of sea lions	Sea lions
359	Presence of rainy season	Season
	Spring season	
	Summer of season	
	Summer season	
	Winter season	
360	Amount of seeds transported to new locations	Seed dispersal
	Rate of seed dispersal	
	Rate of vegetation reseeding	
361	Amount of seedlings	Seedlings
	Amount of seedlings eaten by livestock	
	Rate of seedling consumption	
362	Amount of seeds planted	Seeds planted
363	Ability to supply water to a nearby city	Sell water to city
364	Presence of water for industrial uses	Sell water to industrial developers
365	Ability to sell firewood	Selling firewood
	Amount of firewood sold to other people	
366	Male livestock	Sex of livestock
367	Amount of sharp stumps	Sharp stumps left by beavers
368	Amount of shelters for livestock with water stored in them	Shelter/protected places for livestock
	Presence of protected places for livestock	
	Presence of protected spaces for livestock	
	Presence of shelter from predators	
	Quality of place for livestock to sleep	
369	Opportunity to experience silence	Silence/Solitude
	Opportunity to experience solitude	
370	Presence of curves in river	Sinuosity of rivers
	Presence of curves in rivers	

371	Size of area impacted by beavers	Size of beaver impact zone
	Size of area occupied by beavers	
372	Size of fish	Size of fish
373	Size of nearby city	Size of nearby city
374	Size of pasture	Size of pastures
375	Size of planted trees	Size of planted trees
376	Size of dead zone	Size/intensity of flooding
	Size of flooded area	
	Level of flooding	
377	Opportunity to go skiing	Skiing opportunities
378	Slope of land	Slope of land
379	Opportunity for socialization	Socialization
380	Level of soil fertility	Soil fertility
381	Level of soil health	Soil health
382	Presence of healthy soil pH	Soil pH
383	Presence of healthy soil structure	Soil structure
384	Temperature of soil	Soil temperature
385	Use of solar power	Solar power
386	Ability to access spawning habitat	Spawning habitat
	Access to spawning habitat	
	Access to spawning habitat	
	Presence of access to spawning habitat	
	Quality of spawning habitat	
387	Presence of special clay	Special clay
388	Presence of RAMSAR site	Special ecological protections
	Use of protected status	
389	Quality of sport fishing	Sport fishing experience
	Quality of sport fishing experience	
390	Ability to go fishing	Sport fishing opportunities
	Opportunity for sport fishing	
	Opportunity to go fishing	
	Opportunity to go sport fishing	
391	Level of steepness of banks	Steepness of banks
392	Amount of rocks in substrate of water bodies	Substrate of water body
	Amount of sand in substrate of water bodies	
	Level of muddiness of substrate	
	Presence of shells in stream bed	
	Presence of small gravel in stream bed	
	Presence of rocks in streambed	
393	Level of exposure to sunlight	Sunlight
	Number of hours of daylight per day	
394	Amount of surface water available	Surface water availability
	Level of permanence of water source	
	Presence of consistently available water source	

395	Level of swampiness	Swampiness
396	Opportunity to go swimming	Swimming opportunities
397	Feeling of sympathy	Sympathy for beavers
398	Level of harmoniousness	System health/Ecological balance
	Level of stability of the system	
	Level of system health	
	Sense of balance on land	
399	Strength of bitter flavor	Taste
	Strength of natural gas flavor	
	Strength of pleasant taste	
	Strength of unpleasant taste	
400	Amount of taxes charged	Taxes
	Use of taxes on water usage	
401	Level of technological advancement	Technological advancement
402	Level of tidiness of property	Tidiness of property
403	Use of tilling the land	Tilling the land
404	Ability to exploit forest	Timber exploitation
	Amount of forest cut by forest companies	
	Level of forest exploitat	
	Level of forest exploitation	
405	Evening time	Time of day
406	Number of days	Time passed
	Number of years	
407	Ability to promote rural territories	Tourism
	Ability to run an agrotourism operation	
	Amount of tourism	
	Amount of toursim	
408	Presence of tourism infrastructure	Tourism infrastructure
	Quality of tourism infrafstructure	
409	Concentration of arsenic in water	Toxic minerals
	Presence of toxic minerals	
410	Amount of traffic	Traffic
	Amount of trucks	
411	Presence of trails and pathways	Trails and pathways
412	Amount of interruptions	Tranquility
	Level of tranquility	
413	Amount of trash	Trash/Waste
	Amount of trash in water	
	Amount of waste in water supply	
	Amount of waste in water supply	
414	Rate of growth of planted trees	Tree growth
415	Height of trees in forest	Tree height
416	Amount of tree roots	Tree roots
417	Diversity of trees	Trees

418	Amount of trees in water	Trees in water
419	Amount of people engaging in illegal behavior	Trespassers/illegal behavior
	Amount of trespassers	
420	Ability to see substrate of streams	Turbidity
	Amount of sediment	
	Amount of sediment in water	
	Level of heaviness of water	
	Level of turbidity	
421	Presence of a turbine	Turbines
	Presence of turbine	
	Use of a turbine	
	Use of turbine	
422	Amount of lenga forest	Type of forest
	Amount of nire forest	
423	Presence of unique bird species	Unique/rare wildlife
	Presence of unique fish species	
	Presence of unique wildlife species	
424	Use of corrals	Use of fences/corrals
	Use of electric fences	
	Use of fences	
425	Use of machinery	Use of machinery
426	Use of a boat	Use of vehicles
	Use of a tractor	
	Use of a truck	
	Use of truck to transport livestock	
427	Ability to irrigate	Use water for irrigation
	Amount of water used for irrigation	
	Amount of water used to irrigate	
	Amount of water used to irrigate garden	
	Use of water for irrigation	
428	Use of water to operate a wool-washing plant	Use water for wool-washing plant
429	Location in valley	Valley
	Location in valleys	
	Presence of valleys	
430	Ability to sell value-added products	Value-added products
431	Rate of photosynthesis	Vegetation growth/regeneration
	Rate of vegetation growth	
	Rate of vegetation regeneration	
432	Presence of running water	Velocity of water
	Velocity of water	
433	Velocity of wind	Velocity of wind
434	Amount of germs in water	Viruses/Germs/Diseases
	Concentration of viruses in water	
	Presence of diseases	

	Presence of giardia	
435	Amount of visitors	Visitors
436	Level of enjoyment of visitors	Visitors/public enjoyment
	Level of public enjoyment	
437	Amount of vitamin E in forage	Vitamin E in plants
438	Amount of water available downstream	Water available downstream
	Amount of water available downstream	
	Amount of water available to downstream neighbors	
439	Depth of water body	Water depth
	Presence of deep pools	
440	Ability to bathe	Water for domestic uses
	Ability to cook	
	Ability to wash clothes	
	Amount of water used for domestic uses	
	Presence of water for domestic uses	
441	Amount of water in reserves for future use	Water in reserves/storage
	Amount of water stored in retention ponds	
	Quality of place for maintaining reserves of water	
442	Presence of water pumps	Water pumps/generators
	Use of generator	
	Use of generators	
	Use of water pumps	
443	Level of water quality	Water quality
444	Level of water quality for bathing animals	Water quality for bathing animals
445	Level of water quality for domestic uses	Water quality for domestic uses
446	Level of water quality for drinking	Water quality for drinking
	Potability of water	
447	Level of water quality for irrigation	Water quality for irrigation
448	Amount of water retained in peat bogs	Water retained in peat bogs
449	Ability to get ownership rights to water on your property	Water rights
450	Presence of water tanks	Water tanks
	Use of water storage tank	
	Use of water storage tanks	
451	Presence of appropriate water temperature for scuds	Water temperature
	Temperature of water	
	Temperature of water	
452	Presence of water treatment plant	Water treatment plant
453	Amount of water brought to ranch	Water trucked to ranch
454	Amount of constructed water wells	Water wells
	Presence of constructed water well	
455	Width of water body	Water width

456	Magnitude of drop in altitude	Waterfalls
	Presence of waterfalls	
457	Abundance of waterfowl	Waterfowl
458	Amount of wetlands	Wetlands/Vegas
	Presence of wetlands	
459	Abundance of food for wildlife	Wildlife food
	Abundance of food for wildlife	
460	Amount of wildlife hunted	Wildlife Hunted
461	Ability to generate wind power	Wind power
	Use of wind power	
462	Presence of windblocks	Windblocks
463	Use of wind mills	Windmills
	Use of windmills	
464	Level of winds hitting each other from opposite directions	Winds hitting each other from opposite directions
465	Use of wood for fenceposts	Wood for building
466	Use of wood for firewood	Wood for heating
	Use of wood for heating ranch	
467	Ability for workers to live on ranch	Workers living on ranch
468	Level of worldwide environmental degradation	Worldwide environmental degradation
469	Level of demand for fresh water	Worldwide natural resource scarcity
	Level of worldwide scarcity of food	
	Level of worldwide scarcity of freshwater	
	Level of worldwide scarcity of land	
470	Abundance of worms	Worms
471	Access to fish habitat	Quality of fish habitat
	Quality of fish habitat	

Appendix D. Exploring Spatial Analyses of Social Data Using ArcGIS: Lessons Learned

INTRODUCTION

Representing human subjects data spatially can violate research participants' right to confidentiality. Introducing ambiguity into maps can protect participants' rights.

OBJECTIVE: Identify effective GIS tools for maintaining confidentiality while spatially representing private landowners' opinions about an invasive species.

BACKGROUND

Beavers were introduced to Tierra del Fuego (TDF) in 1946. They have caused the greatest landscape-level change to the ecoregion in 10,000 years. In 2008, Argentina and Chile signed a binational treaty calling for eradication.

Landowners hold disparate opinions about beavers' impacts, but their participation is necessary for eradication.

We examine whether TDF landowner opinions about beavers exhibit spatial patterns.



Figures 1,2. Beavers have destroyed 16 million hectares of TDF forests (Fig. 1). They damage fences, forage, and create ponds that can be used for recreation, irrigation, or to increase landscape beauty (Fig. 2).

METHODS

1) We used 2014 survey data about whether landowners believe beavers are: a) good/bad, b) beneficial/damaging, c) likable/not likable for their property and the region. Responses were on a 7-pt. likert scale.

2) We linked survey responses to map parcels.

3) We explored visualization tools (e.g., kernel density, trend interpolation, inverse distance weighting (IDW)) and settings to see if maps protected confidentiality.

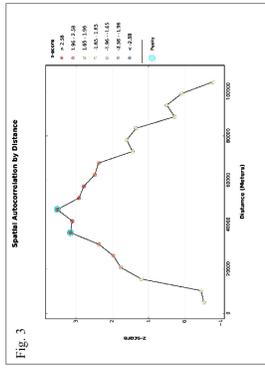
4) We used incremental spatial autocorrelation, hotspot analysis, and IDW interpolation to identify significant clustering of responses and to visualize "heat" maps.

RESULTS

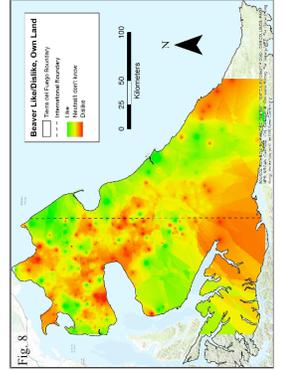
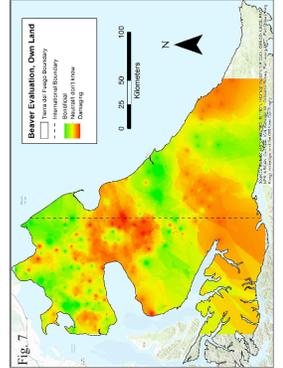
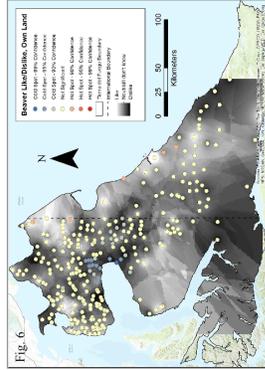
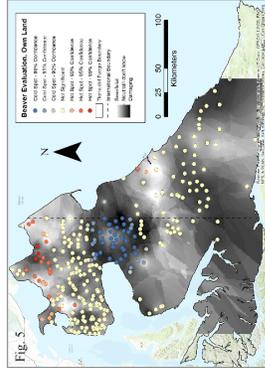
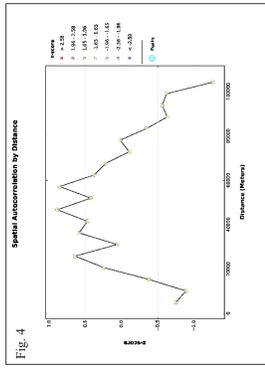
- We had 134 usable surveys (Chile = 97; Argentina = 37), a 74% response rate. Non-response did not exhibit any spatial patterns.
- The good/bad and beneficial/damaging beaver measures were spatially autocorrelated; like/dislike beavers was not.
- IDW interpolation was our preferred visualization tool (Fig. 7,8) because it maintained confidentiality and produced interpretable heat maps.

Figures 3-8. Incremental spatial autocorrelation graphs (Fig. 3,4), maps of hotspot analyses (Fig. 5,6), and IDW interpolation surfaces (Fig. 7,8) for two survey variables. Spatial autocorrelation and hotspot analysis establish the statistical significance of response clustering that allowed for subsequent interpolations.

Landowners' Evaluation (Good/Bad) of Beavers on Their Own Land

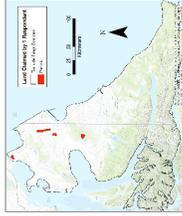


Landowners' Like/Dislike of Beavers on Their Own Land



COMPLICATIONS

Single landowner, multiple parcels
Figure 9. This is an example of a single respondent claiming multiple parcels, some in the water-limited, northern grasslands, and some in the forested center of the island.

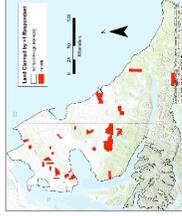


Some landowners owned multiple parcels, and may have had different opinions about beavers in each context. But, we did not collect parcel-specific opinion data. This led to:

- Possible misrepresentation of beliefs in some contexts
- Possible false significance in spatial autocorrelation (i.e., if one landowner owns several parcels in close proximity)

Single parcel, multiple landowners

Figure 10. All parcels that were claimed by two or more respondents. In some cases, up to five individuals claimed a single piece of land.



Some parcels were claimed by multiple landowners. Redundancy may be due to shared ownership, or misidentification of parcels, which could obfuscate results.

Additional possible sources of error:

- incomplete and outdated parcel data
- error unique to social science (i.e., respondents' variable reactions and interpretations)
- potential loss of meaning during language translation
- differences in average parcel size between countries

LESSONS LEARNED

- 1) If respondents own multiple parcels, evaluations should be collected for each parcel to account for landowners' variable opinions in different contexts.
- 2) Correct parcel identification is key; landowners may be unable to accurately identify their parcels on a map. Simplify parcel ID process and incorporate quality controls.
- 3) The choice of visualization tool, and options within that tool, can dramatically affect interpretation. IDW interpolation provided useful and interpretable heat maps that effectively protected participant confidentiality.

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