THESIS

MANAGING RESOURCES IN A DYNAMIC LANDSCAPE: ANALYSIS OF INSTITUTIONS, SOCIETY AND THE ENVIRONMENT OF ELK MANAGEMENT IN NORTHERN COLORADO

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ABSTRACT

MANAGING RESOURCES IN A DYNAMIC LANDSCAPE: ANALYSIS OF INSTITUTIONS, SOCIETY AND THE ENVIRONMENT OF ELK MANAGEMENT IN NORTHERN COLORADO

When developing strategies to manage natural resources, it is important that actions are taken at the appropriate scale, particularly those that are mobile or cover and extensive area. This is complicated when there is a patchwork of institutions managing the resources. A complete understanding of the ecological and social systems and processes that drive change in the systems facilitates development of optimal management strategies. My goal is to understand how natural resources are managed at a landscape scale when there are multiple land management institutions and stakeholders. To answer this question, my research utilizes a qualitative case study approach to analyze elk management in Northern Colorado. In this case study, I assessed the capacity of formal institutions to perform inter-jurisdictional elk management in Northern Colorado. Drawing from climate vulnerability literature, I determined that this capacity to manage elk across the landscape, "Institutional Capacity", is measured as: the ability of multiple land management institutions to conceptualize or formulate policies, implement them, engage and build consensus among stakeholders, mobilize information, and monitor and evaluate. Through analysis of the missions, objectives, and priorities of each institution; the extent to which their jurisdiction is actually impacted by elk and their abilities to adapt management plans; and access to quality scientific information needed to develop elk management plans, I determine that the effectiveness of elk management is not a result of capacity of each individual institution, but is a result of collective management across many jurisdictions. Two features emerge as key elements that significantly contribute to successful elk

management: diversity in the elk management structure and extensive coordination between institutions to manage elk and their habitat. This case study provides useful insights that extend to broader landscape scale management. Resources that are mobile or extend across multiple management jurisdictions cannot be effectively managed by a single institution but are best managed by multiple agencies at different scales because this creates diversity the types of management actions undertaken. However, the coordination required for this type of complex governance involves collaboration of many agencies that is facilitated by organizations that connect others.

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INTRODUCTION

The impacts of human actions can be seen in all natural systems and have caused accelerated or unexpected changes to the world we live in. These shifts have led to research focused on the need to manage natural resources in a way that embraces changes and develop responses that do not lead to the loss of future options (Olsson et al. 2007). Management of resources that are changing rapidly and often across management boundaries requires coordination of multiple management organizations and many scales. This can be a difficult task for resource managers due to institutional differences such as mandates, cultures and tendencies to focus on internal issues. Development and implementation of appropriate resource management requires an understanding of processes from both inside and outside the organizations that make land management decisions. Researchers and resource managers alike have begun to recognize the need to manage resources at a landscape scale and include human institutions in systems analysis (Walker et al. 2006, Chapin et al. 2006, 2009, 2011a, Chapin 2009).

In this study I explore frameworks for analyzing management structures that enable resource management at a landscape scale when there are multiple land-owners and stakeholders. The study beings with a review of concepts that have been developed to understand management of social-ecological systems (SES). I then investigate elk (*Cervus elaphus*) management in Northern Colorado as a case study to develop a conceptual framework for analyzing how well management structures perform in dynamic systems.

ECOSYSTEM MANAGEMENT CONCEPTS

Resilience

Resilience, a term long used in ecological literature, was defined by Holling (1973) as the amount of disturbance a system can absorb before it shifts into an alternative state or regime with different controlling variables and processes (Holling 1973, Walker et al. 1981, 2006, Gunderson et al. 2002). Through analysis of predators and prey and their functional response in relation to ecological stability theory, Holling concluded that natural systems have multiple stability domains that were related to ecological processes, random events and spatial and temporal heterogeneity (Holling 1973, Folke 2006). His synthesis of existing experimental and analytical data described the processes leading to tipping points and demonstrated shifts from one state to another.

This was a departure from the traditional natural resource management paradigm (steady state resource management), where ecosystems have an equilibrium steady state and resilience (engineered resilience) is a measure of stability near the equilibrium state and its resistance to disturbance and speed of return to the equilibrium (Holling 1973, 1996, Pimm 1991, Folke 2006). The steady state model focuses on maintaining efficiency of function (Holling 1996) and attempts to reduce variability and prevent change (Chapin et al. 2009). It is derived from engineering traditions, where there is a need to optimize a system, or meet an objective state (Gunderson et al. 2002) and best applies to untouched ecological systems. Since it focuses on behavior near an equilibrium state, engineered resilience is estimated by the amount of time taken to return to equilibrium. Engineered resilience applies only to behavior of a linear system or a non-linear system in the immediate vicinity of a stable equilibrium (Ludwig et al. 1997,

Folke 2006). Therefore, resource management within a steady state paradigm aims to maintain constancy in the system and attempts to control and optimize resource flows (Folke 2006).

In contrast, emphasis on ecological resilience focuses on maintaining the existence of function. Because impacts are analyzed on a large scale, analysis and management are at the ecosystem scale (Holling 1996). It is believed that ecological resilience is strengthened by increasing the variability of critical variables that form and maintain the stability landscape (Gunderson et al. 2002), or functional diversity (Holling 1996). This concept embraces change as a basic feature of natural systems. Management strategies for ecological resilience are aimed to reduce loss of future management options (Folke 2003, Chapin et al. 2009).

Social-Ecological Systems

Until recently, social and ecological systems were studied separately, but recognized to have properties that interact with one another. Scholarly work on social resilience also has a long history, primarily in the sociological and physiological sciences (Stokols et al. 2013). It developed in parallel with studies of ecological resilience, but the two were not explicitly linked until Berkes and Folke (1998) analyzed multiple case studies of resource management to assess factors that lead to sustainability. Their analysis resulted in a framework for designing more sustainable resource management systems, and concluded that ecosystems are highly adapted systems and physical, ecological, and social changes are all interconnected (Gunderson et al. 2002, Folke 2003, Chapin et al. 2009). Until this point, resource management and environmental studies had been focused on ecosystems in their natural state with humans treated as external to the system. Similarly, studies on institutions and social systems treat the ecosystem as a "black box" and assume that if the social system is well organized and adaptive, the environmental resource will behave sustainably (Folke 2006, Folke et al. 2007). Chapin et al. (2006) assert that

ecological and social systems are interconnected and affect one another so strongly that they are best viewed as a coupled SES, particularly when trying to understand the linkages between changes in the earth systems and human-environmental interactions (Berkes and Folke 1998, Walker et al. 2004, Folke 2006, Chapin et al. 2009). Coupled SES are neither humans embedded in an ecological system nor ecosystems embedded in human systems (Westley et al. 2002, Walker et al. 2004, 2006). Ecosystems are highly adapted systems and physical, ecological, and social changes are all interconnected (Berkes and Folke 1998, Gunderson and Holling 2002, Gunderson et al. 2002, Folke 2003, Chapin et al. 2006, 2009).

Because of the interactions and interconnectedness within social-ecological systems, consideration of these as a single system in which people depend on ecosystem services and ecosystem dynamics are influenced by human activities (Chapin et al. 2009) provides a better management framework. Due to the inclusion of human intent, coupled SES display different dynamics than when looking at ecological or social components alone (Walker et al. 2006). The integrated management as a social-ecological system reduces the possibility that unintended consequences or inadvertent responses will occur relative to treatment of the ecological or social system independently (Chapin et al. 2009).

Multiple conceptual models have been developed to represent SES and can be defined at various scales. One such model, developed by Chapin et al. (2006) to analyze the vulnerability of Alaskan boreal forests to climate change (See Figure 1.2 for illustration of SES framework), captures the feedbacks between ecological processes and their relationships in time and space. This framework illustrates spatial and temporal variability in a system (essential for managing in an uncertain environment) through a set of exogenous controls, acting on different slow variables

and fast variables, and affecting ecological processes that cause changes in the state and sometimes structure of the system itself.

Exogenous controls are external drivers that govern the properties of the SES but are relatively constant over long periods of time (centuries and longer) and control the overall ecosystem structure but are not themselves influenced by the ecosystem. They cause change in the slow variables but are not directly altered by short-term or small-scale dynamics. Examples include climate, parent material, or regional biota. Slow variables influence ecosystems and may remain relatively constant over time (years to decades). They shape how fast variables respond to variation in exogenous controls. Fast variables operate at the same spatial scale as slow variables but change at daily, seasonal, or inter-annual timescales. They are typically the primary concern and focus of resource managers (Chapin et al. 2006, Walker et al. 2012). Feedbacks between fast and slow variables in the system are governed by ecological processes, social dynamics, or a mix of the two (Chapin et al. 2009).

Management of Social-Ecological Systems

One of the core elements of ecological resilience is that ecosystems are non-linear and always in a state of flux (Holling 1973, 1996). Therefore, resource managers deal with uncertainty and need to adapt to changing conditions (Olsson et al. 2004). Anticipation of disturbances and performing research of SES processes at a wide range of scales can reduce the uncertainty and allow management to respond flexibly to unanticipated changes (Chapin et al. 2009). Since management decisions must be made without complete understanding of system interactions, the benefit of ecological resilience is that it allows flexibility for resource managers to learn and adapt as the system changes (Gunderson et al. 2002). Approaching social and ecological systems as an interconnected complex adaptive system has generated the emergence

of new management frameworks such as adaptive co-management and adaptive governance (Olsson et al. 2007). These frameworks depart from traditional resource management because a fundamental tenant is the importance of collaboration among stakeholders at multiple scales to facilitate social learning. They emphasize the need to understand the role of people and social institutions as agents for driving social-ecological change (Kofinas 2009).

Adaptive co-management connects learning with policy implementation and is a systematic resource management approach that stresses learning from management outcomes (U.S. Department of Interior 2010). It combines dynamic learning characteristics with collaborative management across multiple scales to understand ecosystem conditions, learn from experience, and adapt actions so that social and natural assets are maintained while sustaining ecosystem services (Olsson et al. 2004, 2007, Folke et al. 2005, Kofinas 2009). Put simply:

> An adaptive approach involves exploring alternative ways to meet management objectives, predicting the outcomes of alternatives based on the current state of knowledge, implementing one or more of these alternatives, monitoring to learn about the impacts of management actions, and then using the results to update knowledge and adjust management actions (U.S. Department of Interior 2010)

A core principle of adaptive co-management is drawing from a combination of different knowledge systems (Olsson et al. 2004). Therefore, implementation of adaptive co-management requires collaborative practices of knowledge co-production and problem solving at multiple scales with a diversity of parties incorporating knowledge of ecosystem dynamics (Kofinas 2009).

Adaptive governance expands the focus from adaptive management of ecosystems to address broader social contexts and adapt to changing relationships between society and ecosystems (Chapin et al. 2009). This experimental form of governance fosters social

coordination among a diversity of institutions and stakeholders who differ in values, interests, perspectives, power, and information they bring to situations (Olsson et al. 2007). Effective governance requires an understanding of both ecosystems and social-ecological interactions. A key governance challenge is developing multi-level institutions and organizations that can address multi-scale ecosystem challenges that are in tune with incremental and abrupt system changes (Olsson et al. 2007).

Cross-scale linkages in SES make it important to study them at multiple spatial and temporal scales, because events that occur at each scale typically influence events at other scales (Berkes et al. 2003, Chapin et al. 2009). The mismatch of ecological and social dynamics is often referred to as the "problem of fit" (Folke et al. 2007, Olsson et al. 2007, Galaz et al. 2008). Effective governance largely depends on how well the governance fits the physical, ecological and social conditions (Kofinas 2009). Finding a good fit can be difficult because of the many dynamics of the system and requires co-evolution of institutional arrangements (Galaz et al. 2008). Ecologists stress the importance of variability in functional groups for promoting ecosystem resilience (Chapin et al. 1997). Similarly, institutional diversity can add to social ecological resilience and solve the "problem of fit" by providing an array of approaches to problem solving (Kofinas 2009).

CASE STUDY OF ELK MANAGEMENT IN NORTHERN COLORADO

To better understand how these concepts apply to a real world system, I analyzed a case study of elk management in Northern Colorado. The study began as part of ongoing discussions with the staff of Rocky Mountain National Park (RMNP) on engaging local scientists and resource managers to collaborate on resource management and climate change adaptation. A desire to develop a regional elk management plan, in collaboration with other land and resource

management institutions in the region, led to initiation of a study to gage interest of other agencies in collaborative elk management and assess their current management strategies.

Elk management in Northern Colorado is a logical case study for understanding landscape-scale resource management. Elk disperse widely throughout the region, are charismatic mega fauna that both generate revenue and cause economic harm in the region, and are a high priority management issue for several management entities. For this reason, the ungulates have been extensively studied by researchers at Colorado State University and local and federal land management agencies for decades. Due this wealth of information, I was able to focus on social factors affecting elk management and rely on previous work of others for ecological information. The elk population has significant influence on the ecosystem in the region (Johnson and Monello 2001, Peinetti et al. 2002, Weisberg and Coughenour 2003, Binkley et al. 2003, Schoenecker et al. 2004, Bradford and Hobbs 2008). Because elk are highly mobile they serve as a good focal point for looking at management aspects of a specific resource.

My study culminated with a workshop organized by the U.S. Geological Survey (USGS), RMNP, and the U.S. Forest Service (USFS) to facilitate a region-wide partnership for elk management. Held in Fort Collins, CO in May 2013, participants from eleven agencies discussed the state of knowledge on the environmental and social changes that will influence elk management over the next 10-20 years.

BACKGROUND

Study Area

Northern Colorado was chosen as a study area (Figure 1.1) because of the ecological and economic significance of elk to the region and extensive amount of public lands where they are

managed. The domain includes area to the east and west of RMNP to capture connections between resource management organizations on both sides of the continental divide. Since the study focuses on management aspects, the geographic extent of the study area is not as critical as the organizations involved (See Appendix A for list of participating institutions).

Three defining characteristics of the resource management throughout the region are: the landscape is managed by many different organizations with different goals (Figure 1.1); an apex predator is absent from the ecosystem; and natural resources in the region are highly managed.

The Rocky Mountains, particularly along the Front Range, saw dramatic conversion of private agricultural land to low-density residential development and infrastructure during the 1980s – 1990s (Theobald et al. 2000). These patterns of development, which have substantial impact on wildlife habitat directly and wildlife indirectly, are projected to accelerate throughout the coming decades and significantly alter the landscape (Riebsame et al. 1996, Theobald et al. 2000). One example is shifts in migration patterns and distribution changes due to fragmentation of migration corridors (Theobald et al. 1997). Greater habitat fragmentation for highly mobile species increases the potential for conflicts between humans and wildlife because it forces them to cross developed corridors seasonally (Riebsame et al. 1996).

Until recently, a defining characteristic of the Intermountain West was its lack of an apex predator, resulting in cascading ecosystem impacts. To rebuild a functional ecosystem, other regions (i.e. the greater Yellowstone ecosystem) have reintroduced wolves (Mao et al. 2005), an option unavailable in the RMNP ecosystem. Long ago, major predators of the system (wolves and grizzly bears) were eliminated (Singer and Zeigenfuss 2002). Effects of a missing animal functional group (discussed in more detail below) are still debated (Singer and Zeigenfuss 2002),

but generally extend to impacts on vegetation from over browsing by elk and competition for food with other species (Johnson and Monello 2001, Bradford and Hobbs 2008).

Resources in Northern Colorado are managed by federal, state, and local agencies, where much of the land is publicly owned (Riebsame et al. 1996, Theobald et al. 2000). There are efforts to manage mobile resources, such as elk, at a landscape scale, despite the number of institutions involved. Although most resource management activities occur within the borders of public lands, public land managers engage private stakeholders in the planning phase so the resources are managed at the appropriate scale. Although methods vary, local land management institutions manage elk by simulating predation (Huwer 2007, National Park Service 2007).

History of Elk Management

Since settlement of the region, humans have impacted the elk population of Northern Colorado. After the mid-19th century, the once abundant, large herbivore was extirpated by a period of intensive hunting (Guse 1966, Coughenour 2002). The SAVANNA ecosystem simulation model estimates that these historic elk populations fluctuated between 1,500-3,500, depending on weather, food resources, and predation (Coughenour 2002, National Park Service 2007). In 1913-1914, elk were reintroduced to the Estes Park Valley by the USFS and Estes Valley Improvement Association. Hunting prohibitions protected the species until 1939 which, along with creation of RMNP in 1915, caused the population to grow from 30 to about 350 animals by 1930 (Stevens 1980, National Park Service 2007).

Due to concern that elk were becoming overly abundant and causing damage to winter range areas, culling began in 1944. The elk and deer management plan of 1943 called for 300 elk to be removed in the winter of 1944-45 to reduce the grazing and browsing effects on vegetation (Guse 1966, National Park Service 2007). Annual removal of 60 elk continued until

1962, maintaining a steady winter population of about 350-800 (Stevens 1980, National Park Service 2007). In 1962, National Park Service researchers determined that vegetative communities had recovered enough that culling could cease. At this time, RMNP, Colorado Game and Fish (now Colorado Parks and Wildlife (CPW)), and USFS signed a memorandum of understanding for a cooperative program to study elk distribution and migration routes in the area. This study helped to determine when the elk were outside of the park boundaries to allow hunters to harvest populations, in place of park culling (Denney et al. 1967, National Park Service 2007).

The elk distribution study culminated in the development of a long-term management plan (1967) to control elk numbers with public harvest outside of the RMNP boundaries, marking the beginning of a management era within the park that became known as "natural regulation." From 1967 to 2008, the RMNP elk herd was only actively managed by sport hunting, administered by CPW, outside of the park boundary. Over this period, development in the Estes Park Valley decreased hunting opportunities, and elk increasingly became less migratory. They wintered just inside RMNP or in the town of Estes Park, where they are protected from hunting (Coughenour 2002, Lubow et al. 2002, National Park Service 2007). The increasing, sedentary population caused concern about their impacts on plant communities and the ecosystem in and around RMNP.

Research conducted in the 1980s-1990s concluded that elk were overabundant due to human activities (the creation of RMNP and land development in the region) and the absence of natural predators. The National Park Service assembled an interagency planning team in 2002 to prepare an Environmental Impact Statement (EIS) (required under the National Environmental Policy Act) and an Elk and Vegetation Management Plan. The planning team included the

National Park Service, Town of Estes Park, Estes Valley Recreation and Parks District, Colorado Division of Wildlife (now CPW), Grand County, Larimer County, Town of Grand Lake, U.S. Bureau of Reclamation, and U.S. Forest Service (National Park Service 2007) with the purpose of :

> "guiding management actions in RMNP and to achieve desired conditions by reducing the impacts of elk on vegetation and by restoring, to the extent possible, the natural range of variability in the elk population and affected plant communities" (National Park Service 2007).

The Record of Decision for the Final EIS was signed into effect on February 15, 2008, reestablishing active elk management in RMNP. The chosen alternative relies on fencing, redistribution, vegetation restoration, and lethal reduction of elk to achieve the desired conditions (National Park Service 2007). The twenty-year plan is evaluated and potentially revised every five years. Active elk management in RMNP created a nested approach to managing elk in the region. Ungulates are federally managed inside RMNP boundaries. The state of Colorado is responsible for the management of elk in all areas outside of RMNP. Since the elk regularly move across park boundaries, managing the ungulates requires considerable collaboration of all land managers in the region, particularly RMNP and CPW staff.

Ecological Impacts of Elk

The overabundant elk population caused significant ecological impacts, particularly in areas of high concentration (Johnson and Monello 2001, Peinetti et al. 2002, Weisberg and Coughenour 2003, Binkley et al. 2003, Schoenecker et al. 2004, Bradford and Hobbs 2008). As part of the EIS development, the USGS, in connection with the National Park Service, and the Natural Resource Ecology Laboratory at Colorado State University, completed an eight year study to document the influence elk had on the RMNP ecosystem (Singer and Zeigenfuss 2002).

The research effort addressed: 1) current status and trends of the population and distributions of winter ranges; 2) vegetation conditions and trends on the winter range; 3) relative effects of elk herbivory on vegetative conditions; 4) role of water availability and precipitation patterns; 5) long-term effects of grazing on soil fertility and system sustainability; and 6) effects resulting from different management scenarios (Singer and Zeigenfuss 2002). Although the research was extensive, relatively little of the follow-up monitoring research has been published within the past decade, but will be included in the 5-year evaluation of the Elk and Vegetation Management Plan.

ELK MANAGEMENT AS A SOCIAL-ECOLOGICAL SYSTEM

To abstract the RMNP SES, it is useful to look at fast and slow variables, but more importantly the social and ecological processes that control changes in these variables (Walker et al. 2012). Ecosystem components for this review are restricted to those that influence elk, their habitat, and management (See Figure 1.2).

Ecological Properties and Feedbacks

External drivers directly regulate elk vegetation and habitat and, therefore, indirectly influence elk. The three that have the biggest impact on elk are climate, parent material, and potential biota (Chapin et al. 2011b), because they control vegetation present in the ecosystem. Climate dictates temperature, precipitation, and extreme climate events such as floods, drought, and fire, which govern vegetation in a given area, making it the ultimate control of other variables in an ecosystem. Parent material determines soil type, which also influences regional vegetation distributions. The diversity of organisms that can occupy the ecosystem is limited by potential biota (Chapin et al. 2011b).

Parameters that strongly influence the ecosystem, yet remain relatively constant over time (slow variables) are: functional plant types; functional animal types; and disturbance regimes. Single species presence does not adequately determine the sustainability of an ecosystem (Levin 1998) and grouping species according to ecological function can help to better predict the dynamics of complex ecosystems by simplifying characteristics of the species diversity (Hader et al. 1999).

Fast variables that are of primary concern and most directly controlled by managers include: elk population size, distribution, disease, competition, and vegetation abundance. These variables are all closely related and changes in one cause shifts in the others. The elk population size is of primary concern for land managers because overabundance of the ungulates degrade vegetation (Hobbs 1996, Zeigenfuss et al. 1999, Weisberg and Coughenour 2003, Bradford and Hobbs 2008). Distribution of elk also influences vegetation health as well as human-elk conflicts (Hobbs et al. 1981, Zeigenfuss et al. 1999, Peinetti et al. 2002, Wang et al. 2002, Weisberg and Coughenour 2003, Mao et al. 2005). Both are controlled by but also influence, the abundance and distribution of vegetation across the landscape.

Processes Controlling Elk Ecological Properties

Knowing only the fast and slow variables of the ecological system is only marginally useful for land managers. Real value for management decisions comes from understanding the ecological processes that most strongly govern fluctuations in the fast and slow variables (represented by arrows between fast and slow variables in Figure 1.2). Ecosystem processes, an important concept in ecosystem ecology, are the losses of materials and energy to and from the ecosystem. They transfer biotic and abiotic materials to pools in the system (Chapin et al. 2011b). Although there are countless top-down and bottom-up feedbacks that control the states

of the ecosystem, in the case of elk in Northern Colorado, our focus is on the biotic ecosystem processes of predation and herbivory. These biological factors regulate the population dynamics and species interactions among communities in the region. These biotic ecosystem processes control population composition such as plant and animal densities and age structures as well as community dynamics such as species presence and rates of resource consumption (Chapin et al. 2011b).

Predation

The process of predation is controlled, top-down by the slow variable of functional animal types in the ecosystem. In the Northern Colorado ecosystem, a lack of top predators creates an absence of predation on large mammals, such as elk and their competitors, causing cascading impacts on the ecosystem. It drives fluctuations in the fast variables of elk distribution and elk population sizes.

In 1995, wolves were reintroduced to the Yellowstone National Park area, creating a case study demonstrating the before and after effects of a top predator on an ecosystem (Fortin et al. 2005, Mao et al. 2005). Similar to RMNP, prior to the reintroduction of wolves, elk were heavily concentrated in open areas at lower elevations in the winter and disbursed to higher elevations in the summer (Mao et al. 2005).

In the summer, elk avoided areas of high wolf density. In winter, they selected areas with moderate wolf density because both species use the same winter habitat. Rather than avoiding traveling in high-wolf-use areas, elk habitat preferences switched to burned forests rather than open meadows. Elk also clustered in groups as an anti-predator strategy (Fortin et al. 2005, Mao et al. 2005).

In the RMNP area, elk currently concentrate in open meadows for large portions of the year (Baker et al. 1997, 2005, Singer and Zeigenfuss 2002). If introduced, predators would disperse elk and prevent them from over-concentrating. Elk would be less sedentary and more wary, resulting in lower concentrations of elk on the elk range (National Park Service 2007). A switch in habitat preference could also prevent over-browsing willows in highly concentrated areas.

In addition to distribution changes, predation would alter elk population sizes within the boundaries of RMNP. It is difficult to determine how much it would alter populations outside of RMNP, as hunting is used to keep population sizes below carrying capacity (K). As of 2008, culling within the park began limiting population below K, but with different effects than natural predation would cause (National Park Service 2007).

Ever since Aldo Leopold's story of the Kaibab Plateau impacts of deer over-population, researchers have closely monitored predation, population levels, and habitat characteristics. In 1943, Leopold reported that reduction of predators caused an upsurge in the deer population that degraded the habitat and ultimately created a lower carrying capacity and near collapse in the deer population (Binkley et al. 2006).

Since elk are habitat generalists (Mao et al. 2005), the numbers that an ecosystem can support is much greater for elk than other species. In 1969, RMNP adopted a management plan of little or no intervention on elk population, resulting in a steady increase of herd sizes (Johnson and Monello 2001, Lubow et al. 2002, National Park Service 2007). The result was severe habitat degradation on elk winter ranges.

Herbivory

In the Northern Colorado ecosystem, the process of herbivory is a bottom-up control from the fast variables associated with elk population sizes, distributions, and vegetative abundance. Elk distribution is a spatial phenomenon that is influenced by predation, or lack thereof. Elk distribution also influences herbivory, which is a process that influences vegetation structure (which impacts other animals). Heavily concentrated herbivory causes variation in the slow variables plant and animal functional types.

Concentrated ungulate populations cause habitat degradation, particularly of preferred plant species, and potential shift in vegetation types. Degradation of willow and aspen on the heavily concentrated elk winter range serves as an example. Using 35-year-old exclosures on the primary elk winter range, studies show that willow size and growth in RMNP are principally determined by the intensity of elk browsing (Peinetti et al. 2001, Zeigenfuss et al. 2002), a result of elk concentration. Over the past 60 years, there has been about a 20% decline of riparian shrub cover (mostly willow) on the primary winter range (Johnson and Monello 2001). Peinetti et al. (2001) conclude that continuous elk browsing constrains plant growth and development by producing long-term changes in willow morphology, reducing the competitive ability and survivorship of willow.

Aspen stands have similarly declined due to over-browsing in the Kawuneeche Valley. They have not regenerated over the past three decades, and many stands have been eliminated or appear over-mature or degraded (Baker et al. 1997, Johnson and Monello 2001). Only when elk browsing was reduced did aspen regeneration occur on the primary winter range (Baker et al. 1997). There is little evidence of sucker maturation into trees outside of exclosures, leading to

the potential loss of aspen on elk winter ranges, where elk are concentrated and browse most heavily.

Losses of aspen and willow on the primary winter range, coupled with drier climate, could lead to more grasses and fewer trees and shrubs (Singer et al. 1998). Elk have a lower capacity to retain and digest fibrous food particles, making them better suited to feeding on grasses (Baker and Hansen 1985, Baker and Hobbs 1987), although they prefer willow and aspen due to higher nutritional content. Studies show willow are less competitive than grasses (Peinetti et al. 2001, 2002), and elk preference for them could lead to a vegetation shift if not properly managed.

Elk impacts on vegetation have cascading effects on other animal and plant interactions in the area as well. Elk, beaver and riparian willow interact in a complex way. In an intact ecosystem, beaver and elk would be competitors for willow herbivory (Baker et al. 2005, National Park Service 2007). However, beaver trapping caused a decline in the species in the 1940s (Baker et al. 1997, Singer et al. 1998, National Park Service 2007) and there has been a 90% reduction in the species since the mid-20th century (Peinetti et al. 2002, Zeigenfuss et al. 2002, National Park Service 2007). This has led to deterioration of willow and aspen that rely on the hydrologic conditions created by beaver dams. The 20% decrease in riparian shrub cover on elk winter ranges is at least partially attributed to reductions in stream sinuosity and length, as a result of beaver declines (Johnson and Monello 2001, Peinetti et al. 2001).

The reduction in willow and aspen has exacerbated the loss of beaver from the ecosystem and make its recovery unlikely under current conditions, as they rely on riparian willow communities as their primary food source (Baker et al. 2005). Increasing numbers and concentrations of elk on the core winter range causes further decline of willow and beaver.

Herbivory is also controlled by top down factors such as disturbance regimes. Controls in this direction impact fast variables on longer timescales, such as the distribution and abundance of vegetation. Two effects of changes in disturbance regimes in the Northern Colorado ecosystem are the outbreak of bark beetles and shifts in fire regimes. Both have been attributed to an exogenous control, climate change. Some research suggests the loss of aspen in parts of the region is caused by fire suppression because aspen regeneration increases following fires (Loope and Gruell 1973, Hessl 2002).

Alternatively, wildfire causes a reduction of woody-plants and increases grasses. Large disturbances (such as fire) creates large patches of deciduous plants that can be ingested by elk (Hobbs 1996). There is evidence that re-seeding grasses immediately following fire may help to reduce herbivore use of woody plants such as aspen during the earlier stages of re-growth (Biggs et al. 2010).

Similarly, the recent outbreak of bark beetle could increase browse availability and vegetation abundance for elk. There have been no studies linking the impacts of bark beetle to elk habitat. However, these large scale disturbances reduce the density of coniferous trees and create the potential for grasses or deciduous trees that elk can feed upon.

Social Properties

Mapping the SES and understanding how human interactions couple with the ecological properties requires understanding the social properties governing the system. Natural resource management is primarily directed by governmental institutions (local, state and federal). Due to the large amount of public lands in Northern Colorado, analysis of the social properties that govern institutional action and relationships to the ecological system provides insights on how elk are managed. In the SES framework for elk management in the Northern Colorado (Figure

1.2), I restricted my analysis of sociological components to those that influence decision-making and the capacity of institutions in the area to manage elk impacts.

In this context (See Figure 1.2), exogenous controls are regional governance systems (ie which institutions govern what in the area). They are relatively fixed, based on federal or state legislation and would change on decadal timescales to centuries. Institutional goals or objectives, jurisdictional boundaries, or social networks exemplify slow variables. Jantarasami et al. (2010) describes these as institutional norms that act as either barriers or enablers of action within public agencies. The scale of these variables is institution-wide and varies on inter-annual to decadal timescales. Fast variables can fluctuate yearly and have variance within an institution. These include staff priorities, annual goals (ie license numbers, visitation goals, etc.), or elk-human conflicts.

CONCLUSION

To achieve their goals, institutions alter the state of fast and sometimes slow variables through management actions that manipulate the ecosystem processes which control ecosystem conditions. Management actions typically focus on managing fast variables because they are most visible and easiest to influence. Examples in Northern Colorado elk management which controls fast variables include: CPW distribution of licenses to regulate population sizes (Huwer 2007); culling elk populations or enclosing riparian areas within RMNP to manage abundance of vegetation and population (National Park Service 2007); or zoning laws within cities to influence distributions of elk herds. Walker et al. (2012) describes these as control variables, or levers that can be pulled to achieve specific objectives.

Fast variables are the easiest to change to achieve institutional objectives because their dynamics are more visible. However, they are also the most susceptible to be altered by

"shocks" to the system (Walker et al. 2006). Regime shifts tend to change slowly, and slowly changing variables more strongly control ecological resilience (Walker et al. 2006). To achieve long-term sustainability of an ecosystem, management of slow variables is also critical (Walker et al. 2006, Chapin et al. 2009).

Management strategies tend to focus on controlling fast variables, because they are those that are typically of most concern to ecosystem users (Walker et al. 2012). Potential mismatches exist when the organizational structure and management planning process of an institution doesn't match the type of variable they seek to control. The management system becomes vulnerable to unintended consequences when there is either limited capacity to act on the priority or there is insufficient knowledge of the directionality of intervention or consequences to other factors.

Understanding these ecological processes and their interactions provides insight to the direction of change. As demonstrated in the analysis of processes in the ecological system, some act as top-down or bottom-up controls and impact the variables differently. Use of the SES framework to understand slow and fast variables and processes that regulate variance within the variables is useful for guiding appropriate, sustainable management decisions.

Chapter 2 uses this conceptual framework is used to investigate the governance dimensions that lead to effective elk management in Northern Colorado. Chapter 2 analyzes the institutional capacity to manage elk by addressing how elk are managed within each jurisdiction, the priorities and management objectives of the agencies that lead to the strategies they employ, and a network analysis of collaboration on elk management. This analysis provides a foundation for understanding the institutional management setting and speculating vulnerabilities that might be present if ecosystem dynamics change as well and lessons for managing other resources.

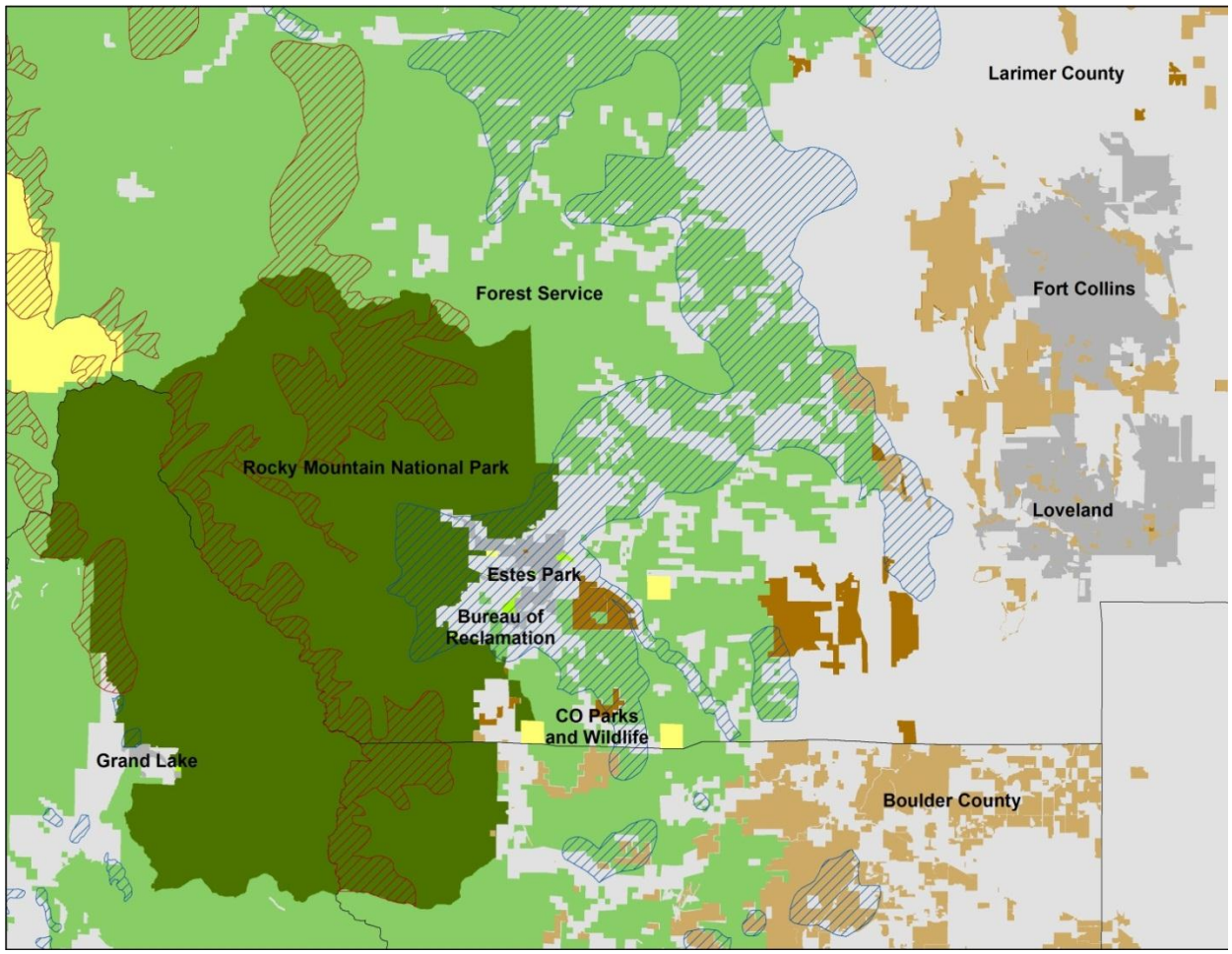

Figure 1.1: Study area. Green represents federal lands, yellow is state lands, brown represents county and city open spaces, grey is private land. Red shading is elk summer concentration areas and blue shading is elk winter concentration areas (Colorado Parks and Wildlife 2012).

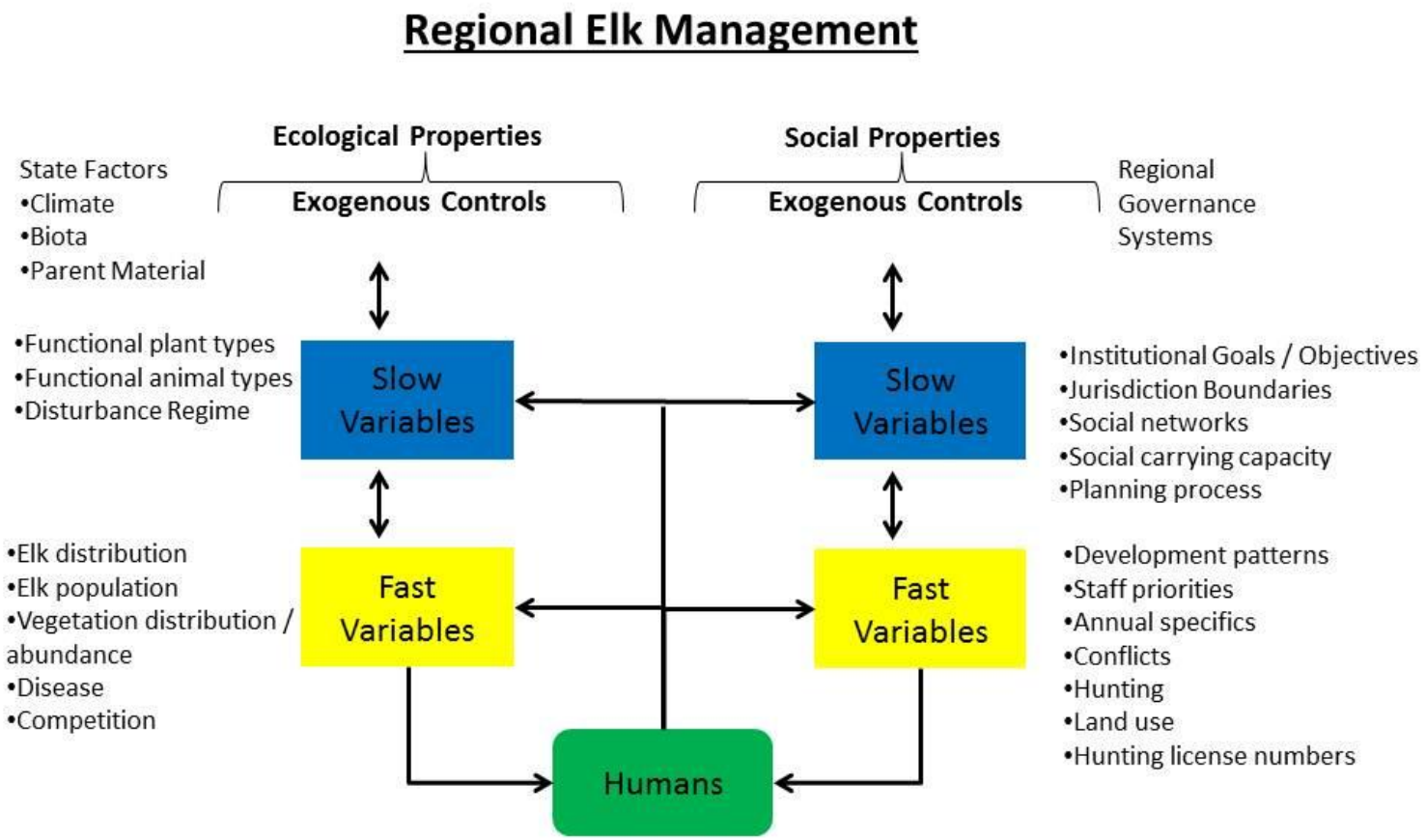

Figure 1.2: Socio Ecological System for Elk Management in the Rocky Mountain National Park Area. Adapted from (Chapin et al. 2006)

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CHAPTER 2: MANAGING RESOURCES IN A DYNAMIC LANDSCAPE: ANALYSIS OF INSTITUTIONS, SOCIETY AND THE ENVIRONMENT OF ELK MANAGEMENT IN NORTHERN COLORADO

INTRODUCTION

In a world with evolving ecosystems and shifting natural resources that transcend land management boundaries, attention has been drawn to the need to manage resources at their ecological scales, often requiring coordination of multiple land management organizations (Hessl 2002, Folke et al. 2007). Managing resources that are not constrained by management boundaries is a difficult task for land managers, particularly when there is a patchwork of management institutions and stakeholders. Development and implementation of appropriate resource management requires an understanding of processes that drive changes within ecosystems and the organizations that make land management decisions (Chapin et al. 2009).

Although resource management research traditionally focused on ecological properties of an ecosystem, human interactions with ecosystems has received more attention from the research community. It is recognized that, to manage resources at a landscape scale, human institutions need to be included in system dynamics (Berkes and Folke 1998, Gunderson et al. 2002, Berkes et al. 2003, Walker et al. 2006, Chapin et al. 2006, 2009a, 2011, Chapin 2009). In this study I seek to investigate management structures that enable resource management at a landscape scale when there are multiple landowners and stakeholders making management decisions.

Approaching social and ecological systems as an interconnected complex adaptive system has generated the emergence of new management frameworks such as adaptive co-management and adaptive governance (Olsson et al. 2004a, 2007, Folke et al. 2005, Chapin et al. 2009b, Kofinas 2009, Sandstrom and Rova 2010, U.S. Department of Interior 2010). A core

tenant of these frameworks is the importance of collaboration among stakeholders at multiple scales to facilitate social learning. They emphasize the need to understand the role of people and social institutions as agents for driving social-ecological change (Kofinas 2009).

Various scholars point out that a major challenge concerning adaptive governance lies in linking various scales of governance for communication, responsiveness, and accountability (Folke et al. 1998, Olsson et al. 2007, Kofinas 2009). A key governance challenge is developing multi-level institutions and organizations that can address multi-scale ecosystem challenges that are in tune with incremental and abrupt system changes (Olsson et al. 2007). Anderies et al. (2004) assert that it is assumed that necessary institutions and infrastructure is in place for designing and managing a robust social-ecological system but insufficient attention is paid to the institutional context.

Managing multiple complex issues requires integrating many issues and agendas to reach long-term goals. Usually the management decisions to reach those objectives focus on reaching short-term goals through immediate or targeted actions. A management challenge is to understand the different scales of resources and how management actions influence them. This will allow management strategies that meet short-term needs while still maintaining ecosystem function.

To further investigate the governance dimensions of ecosystem management, I analyzed a case study of elk (*Cervus* elaphus) management in Northern Colorado (See Figure 2.1). This serves as an example of a system where the study species has caused cascading ecological impacts and are heavily managed. Conveniently, scientific research has studied much of what is necessary for managing elk and their habitat in the region (see Chapter 1 for further background on historical elk management for the region), allowing me to focus this analysis on the social

system and management structure to gain a more complete picture of interactions between the social and ecological systems. Analysis of elk management in this region provides insights about institutional arrangements that enable landscape scale resource management across jurisdictional boundaries and scales. It demonstrates how goals of resource managers can focus on different spatial or temporal scales but still be complimentary for long-term regional management.

In 2012, RMNP expressed a desire to engage local scientists and resource managers to collaborate on resource management and climate change adaptation. To continue the regional elk management collaborative process that began with development of the EIS, RMNP staff engaged U.S. Geological Survey (USGS) researchers to initiate a study to gage interest of other agencies in collaborative elk management and an assessment of their current management strategies. The study culminated with a workshop organized by the USGS, RMNP, and the U.S. Forest Service (USFS) to facilitate a region-wide partnership for elk management. Held in Fort Collins, CO in May 2013, participants from eleven agencies discussed the state of knowledge on the environmental and social changes that will influence elk management over the next 10-20 years.

The study and workshop served three purposes. First, as RMNP nears the five-year evaluation of the Elk and Vegetation Management Plan, the information from the study and workshop will provide insights about how effective the management plan has been at achieving its intended goals regionally. Secondly, it provided a forum for resource managers to share experiences and lessons about elk management and develop a common vision moving forward. Lastly, it built a collegium of scientists and land managers that can work together on other resource management issues in the future and collectively adapt to changes within the region.

METHODS

To gain insight on how multiple institutions, with varying mandates and objectives manage elk across the region, I first investigated the capacity or ability of formal institutions to perform inter-jurisdictional elk management in Northern Colorado. Drawing from climate vulnerability literature, I determined that this capacity to manage elk across the landscape, "Institutional Capacity", would be measured as ability of multiple land management institutions to conceptualize or formulate policies, implement them, engage and build consensus among stakeholders, mobilize information, and monitor and evaluate (Haanpää 2007). To determine variation in the Institutional Capacity, I developed a survey instrument in collaboration with staff from RMNP and USGS (See Appendix B). Their experience determined that three factors (independent variables) would explain the variation in "Institutional Capacity" (dependent variable): the missions, objectives and institutional priorities of each institution; the extent to which their jurisdiction is actually impacted by elk and their abilities to adapt management plans; and access to quality scientific information needed to develop elk management plans.

Data Collection

Natural resource management is primarily directed by governmental agencies at various levels (local, state, federal). Due to the percentage of public lands in the study area, we simplified the study by using the agencies as cases and analyzing the attributes that govern their priorities and specific elk management actions.

To understand how the institutional arrangements contribute the effective management of elk across jurisdictional boundaries and scales, I relied upon interviews, document analysis and examination of the elk management workshop. Interviews served as the primary data source,

with the document evaluation and notes from the workshop serving as a validation of interview answers and providing additional background to fill in gaps.

I collaborated with staff at RMNP and CPW to develop an initial list of participants for the study. We employed non-random, purposive sampling techniques for the study in order to ensure that participants had an interest or involvement in elk management (Neuman 2011). The participant list was composed of scientists and resource managers from agencies in the area who manage elk either directly or indirectly. Upon recommendation by participants, additional individuals were added to the participant list, by means of snowball sampling (Neuman 2011), in order to better understand the scope of elk management of interested agencies or include agencies that were not initially contacted.

Individuals were contacted via email with an explanation of the study, goals and process. I requested that participants share their expertise on institutional resource management. Each participant was asked to sign a consent notifying them that there were minimal risks associated with the study and their names would not be released, however due to a small sample cluster, we could not assure confidentiality.

Staff at RMNP aided with development of the interview schedule (Appendix B) through an iterative process. Questions were written and organized by theme, trying to capture variation in the independent variables affecting Institutional Capacity. Questions were open ended and worded so variation could be determined both within and across institutions.

One-hour, semi-structured interviews (n=24) were scheduled and conducted in person between Sept 1, 2012 and January 9, 2013. They were recorded via digital audio recording and later transcribed for analysis.

Elk or natural resource management plans were examined to provide a baseline agency management actions and priorities and fill in the gaps from interviews. Collection of the management plans was conducted through internet searches of agency websites and suggestions by participants during interviews (See Appendix C for list of management plans analyzed).

I presented preliminary findings at the elk management workshop in May 2013. Many interview participants were present and provided feedback about the findings as well as additional insights. This served as an opportunity cross-check preliminary findings and augment them with further analysis of field notes taken during the workshop about the larger process of their collaboration on elk management.

Data Analysis

Qualitative data analysis was performed on transcribed interview responses and management plans, using an inductive approach (Thomas 2006, Olsson et al. 2007, Neuman 2011). Using NVivo10 analytical software, I went through an inductive coding and memoing process with the data, which converts volumes of text into categorical or nominal variables that can then be queried do investigate relationships or patterns. Inductive coding is used to analyze patterns, themes, and relationships in the data. During this process, interview transcripts and documents were analyzed together to understand the overall content.

The coding process helps to categorize data into themes or categories to better conceptualize, as theory develops. I began with 8 broad categories or nodes (Table 2.1) that represent different topics covered in the interviews. I then went through the nodes individually to identify more narrow categories or themes that emerged when the topic was investigated independently.

I also performed network analysis using NVivo10, where relationships between entities or concepts were coded to visualized their interactions and dynamics (Neuman 2011). The network analysis focused, primarily on which agencies collaborate on elk management or other natural resource management and their capacity to either directly or indirectly manage the elk population.

Elk or natural resource management plans were analyzed to understand the institutional setting for elk management. I specifically investigated which agencies manage elk, how elk are addressed by each agency, collaborate on elk management, and the extent to which they are impacted by elk. These documents were central to the analysis to fill in gaps where I was unable to speak to multiple individuals from a particular agency or they were unsure of the history or full context of elk management. By using management plans as a baseline and filling in the narrative with interview data, I was able to triangulate the analysis and gain a more complete understanding of the regional scope of elk management.

RESULTS

To investigate the Institutional Capacity of agencies to manage elk in Northern Colorado, I analyzed five questions: 1) What are the elk management priorities of each organization; 2) What actions do the institutions take to manage elk; 3) How flexible is the resource management planning process; 4) How do government agencies collaborate to manage elk; and 5) What scientific information is used for developing elk or habitat management plans? Analysis of these five questions provided insight about the spatial and temporal scales of specific elk management objectives and actions of institutions in the region.

What are the elk management priorities of each organization in the area?

I asked interview participants to describe the overall mission, resource management goals, and ideal elk management outcomes for the entity they represent. From this, I created an exhaustive list of resource and elk management priorities and grouped those priories into categories: minimizing human-elk conflict or damage caused by elk; enabling elk migration; elk distributions; attaining a herd population range; male: female sex ratio; maintaining or improving habitat or ecosystem function; or broadly maintaining plant community dynamics. Table 2.2 outlines the priorities of elk management for each institution, also grouped according to the spatial or temporal scales that the factors of concern fluctuate.

Table 2.2 is also grouped by level of government or jurisdictional scale, which I found to be a significant indicator for priorities and actions. Since the study aimed to investigate how institutions work together across scales to manage elk, the jurisdictional scale was a key element (illustrated in Figure 2.2). The organizations were originally separated as being either federal, state, county and municipal. However, we found that Fort Collins manages elk more similarly to the counties because it is larger in size and manages more open space than the other towns surveyed. Therefore, we grouped the organizations as being large (Federal and State), medium (Counties and Fort Collins) or small (other towns) (See Figure 2.2).

Small towns aim to minimize conflict or damages and enable elk migration. Because they manage larger amounts of open spaces, the medium sized entities had a greater focus on maintaining habitat, in addition to conflict minimization and migration facilitation. The large agencies were more diverse in their priorities, which can likely be attributed to the divergence of their missions and the amounts of land that they manage. The state wildlife agency is almost completely concerned with managing elk population dynamics and minimizing conflict. The

Bureau of Reclamation only manages a small amount of land so their priorities are more similar to the smaller towns included in the study. Since they provide habitat for the elk, but do not actively manage the population, the main focus of the forest service is maintaining habitat or ecosystem function. RMNP is unique because its mission and management plans direct it to maintain both the species and the integrity of the habitat. Therefore, I found that they have the broadest priorities for elk management.

With such broad extent of elk management interests represented, it was no surprise to find that elk are valued differently for each institution and that the priority given to elk management varies. I asked participants if elk or habitat management falls within their institutional goals, what their vision for ideal outcomes from elk management, and to describe key elements of elk management for their agency. Based on responses from the interviews and prevalence of elk management (or absence) in the agency resource management plans, I categorized the importance of elk management to each organization as low, medium, or high. I then asked each organization to describe the impacts that elk have on their jurisdiction. I looked at this, relative to elk concentration areas (Colorado Parks and Wildlife 2012), to determine which jurisdictions experience year-round (high), seasonal (medium), or little / no elk (low) impact (Figure 2.3).

Although all agencies in the area are concerned about elk management and want to see that they are well managed, I found that the interests and management actions of agencies varied significantly. I found that the extent that they are impacted by elk movement and the mission of the organizations most greatly determined emphasis placed on managing elk and management focus (Table 2.2). When compared to the importance of elk management of each jurisdiction, there is a correlation between level of impact and significance given to elk management,

represented in (Figure 2.3). Grand Lake, Estes Park, and Bureau of Reclamation are notable exceptions where the impacts of elk outweigh their viewed importance of elk management. This is likely attributable to two causes. First, since these areas are in migration corridors, they only experience seasonal impacts, so they would not need to implement year-round management actions. Second, and most importantly, they are responsible for managing land within the jurisdiction, but CPW is the entity charged with managing elk damage or mitigating the impacts of elk. For this reason, elk management becomes a lower management priority.

What actions do the institutions take to manage elk?

I found that the actions each entity takes with respect to elk management range anywhere from minimizing human/elk conflict or enabling migration corridors, to attaining a specific elk population size or maintaining a healthy habitat (See Table 2.2).

As previously stated, only RMNP and CPW have the mandate to directly manage elk through herd reductions, however other agencies have plans to cope with their impacts and indirectly manage the ungulates to achieve their elk management goals. Since they can't control population dynamics, manipulation of vegetation availability or mitigating negative impacts of elk are the methods used by most entities to control elk outside of RMNP. Strategies include habitat manipulations such as fencing or improving habitat in areas (See Table 2.2), or working with CPW to control the population.

How flexible is the resource management planning process?

Examination of the flexibility in developing elk and resource management plans revealed variation in the capacity of different institutions to respond to changes in the elk herd. I asked participants to describe the process for developing their current elk or related plans, the

management structure, and length of decision-making process to determine their ability to amend plans if needed. I found diversity in the management process that was most strongly associated with the level of governance. Table 2.3 illustrates the flexibility of management planning by categorizing the processes as either having low, moderate, or high flexibility. The longer management plan term length and planning processes means that the organization has less flexibility to respond to changes in elk distributions or environmental conditions. However, the ability to amend management plans adds flexibility to the management process. Results shown in Table 2.3 indicate that smaller entities actually have more flexibility to adapt management plans, due to less stringent planning processes or bureaucratic structure.

How do government agencies collaborate to manage elk?

To better understand the connections between agencies, a network analysis was conducted to investigate relationships and dynamics between entities or concepts. The primary focus of the network analysis was to determine which agencies collaborate on elk management or other natural resource management. Interview data was used to construct a network diagram of collaboration on elk management. Based on participant responses to questions asking the process for developing their management plans and descriptions of communication / collaboration with other agencies in the area, I developed four categories of collaboration that was developed into a diagram illustrating which agencies collaborate: 1) two entities collaborate on elk management; 2) entity A manages elk for entity B; 3) both entities manage other resources collaboratively; and 4) do not collaborate.

I divided collaboration on resource management by jurisdictional level to analyze how organizations communicate spatially and across scales, illustrated by Figure 2.4. The diagram illustrates that there is little collaboration between the towns on resource management. They all

collaborate with the county in which they are located. The towns that are adjacent to RMNP or Forest Service lands collaborate with those institutions. However, the main link between the towns is CPW because all towns collaborate with CPW on wildlife issues.

At the state and federal level I found extensive work across scales with multiple partners. The organizations that manage land collaborate with adjacent entities. Bureau of Reclamation has a concentrated land area, so it works almost exclusively with those directly around it. RMNP and the Forest Service manage larger areas of land with more neighbors who they collaborate with. Once again, since the main function of CPW is to manage wildlife across all the lands, they work with everyone.

RMNP and CPW are the only agencies directly managing the elk population dynamics of herds that moves across the park boundaries. They collaborate extensively with each other and other agencies in the region to manage the herd collaboratively.

What scientific information is used for developing elk or habitat management plans?

Because CPW manages the elk herd across the whole state (outside of RMNP), they provide a consistent base of scientific research for resource managers. As demonstrated in Figure 2.5, CPW, RMNP and USGS collaborate extensively on collecting and analyzing data on elk population dynamics and movement. Since there are no real differences in the quality or utilization of scientific knowledge for managing elk, the third factor is insignificant to understanding the institutional capacity for managing elk.

DISCUSSION

Analysis of the institutional capacity to manage elk in Northern Colorado reveal that the herd is not managed by each institution alone, but is a result of collective management across many jurisdictions. Key conclusions from the study come from using information about those organizations as elements of a whole system, rather than by looking at the ability each institution alone. These insights can be useful for managing other resources in the area.

It can be assumed that elk management in the region is effective at the present time because herd population numbers are back within objective and vegetation is recovering relative to the state in the early 2000s. When asked in interviews if they think elk management is effective, participants generally responded positively. In trying to understand what elements of the institutional system contribute to the effective management of elk in Northern Colorado, two key features emerged as significantly contributing: diversity in the elk management structure and extensive coordination between institutions to manage elk and their habitat. In the following sections I discuss both, focusing more attention on collaboration and the roles different institutions play in enabling it.

Diversity in elk management structure

Researchers attempting to link institutional diversity and redundancy (Low et al. 2003, Ostrom 2005) find that cross-scale diversity leads to effective, resilient management. Diversity in the institutions that manage resources and overlaps in authority can provide resilience through redundancy. The value placed on institutional diversity in ecosystem management stems from an ecological principle that a set of physical processes is essential in forming the structure and behavior of ecosystems. Functional species groups are an essential part of this structure and help sustain an ecosystem in a particular state or domain (Holling et al. 1995, Walker et al. 1999,

Folke 2006). Species have overlapping characteristics that may seem redundant, during some stages of ecosystem development, but could become critical for reorganization after a disturbance (Folke et al. 1996, Folke 2006). Therefore, diversity in species both within and across scales enables regeneration and renewal following a disturbance (Folke 2006).

Our findings from analysis of elk management in Northern Colorado demonstrate that this principle contributes to its effectiveness in the region. Because CPW has authority to manage the elk herd across the state, they see to the regulation of population dynamics in all areas outside of RMNP. Habitat management is conducted by other agencies outside of the park, illustrating the primary reason why elk are managed well in this area. Both elk and their habitat are managed on public lands, (making up most of the study area). There is continuity in the management of the elk population because CPW manages in all places. The elk also have a well-managed habitat because there is a large proportion of connected public lands that are also maintained. In RMNP, where CPW does not directly manage the elk herd, the park manages both.

This diversity in management strategies is important because population dynamics and elk distributions change relatively quickly when directly managed. However, many of the undesirable impacts of elk are due to over-browsing or vegetation damage. Habitat manipulations that affect the herd over longer time scales (See Table 2.2). Management of different ecosystem properties affects the state of the system at different timescales and a diversity of management options. When asked why elk management works, one participant responded,

> "When you look at the different land management agencies, you can see that it's a strength that one land is capable of doing certain manipulations and types of management that other landscapes are not… So if the animals move onto different lands, management

> is capable of doing things on some lands that it is not on others." (U.S. Geological Survey)

Elk management collaboration

Diverse elk management strategies would not be effective without coordination among institutions. Co-management across scales requires extensive communication and collaboration. Westley et al. (2002) and Cash et al. (2006) argue that the capacity for SES to deal with uncertainty and abrupt change requires networks of interacting individuals and organizations at multiple levels to develop connections around the right issues at the right time. Social networks that span different scales are essential for developing the knowledge of complex social-ecological interactions required for ecosystem management (Folke 2006). Olsson et al. (2004) investigate the role of social networks essential for ecosystem management and conclude that there is a need to understand and institutional arrangements for dealing with uncertainty and change in social-ecological systems.

Throughout this investigation of elk management, collaboration came up as a significant reason it works. When asked to list three key elements of successful landscape-scale resource management, all participants listed collaboration or communication in their response. A couple of the responses included:

> "I think a key is to have a very collaborative and open partnership…because you can only really influence a certain amount of the landscape." (City of Fort Collins)

> "We have a good, firm understanding of each resource agency's primary goals and outcomes that they're looking for. I think that we recognize that we do have to work together collaboratively to get stuff done." (Colorado Parks and Wildlife)

Historically, there has not always been as much cohesion behind managing elk and their habitat in this region. Prior to establishment of the RMNP Elk and Vegetation Management Plan, CPW was the only entity lethally reducing herd numbers and land managers had a more

passive policy towards elk management (National Park Service 2007). Through the process of collecting data for the Elk and Vegetation Management Plan, RMNP engaged local scientists at multiple research institutes and initiated public and inter-agency dialogue about elk and natural resource management in the region.

> "There were lots of problems in the 1960's and 1970's after RMNP stopped actively managing the herd and went to a bottom-up, carrying capacity approach to management…Once they started actively managing elk after the EIS there have been fewer problems and it has led to more collaboration between (the two) agencies since they are both actively managing the herd." (Colorado Parks and Wildlife)

Since elk are not restricted to the boundaries of a single jurisdiction, their management requires collaboration and constant communication of all of the agencies in the area. This is particularly true for smaller towns that lack the resources or experience to develop comprehensive management plans. A participant who manages open spaces for one of the small towns interviewed responded:

> "Because we're small staffed here, we don't have all of the information and resources required to make and implement management decisions. But they're available to us, so we'll definitely tap into other partners in the community." (City of Loveland)

In some cases assistance is provided in terms of managing resources for the organization (e.g. CPW manages elk across all boundaries). In other cases entities collaborate to co-manage elk or other resources. Examples would include CPW and RMNP sharing elk data or the City of Fort Collins and Larimer County sharing equipment and staff to control noxious weeds.

Social capital literature emphasizes that social networks can build resilience and aid in adaptation to unexpected environmental changes (Newman and Dale 2005), but not all types of connections are created equal. Newman and Dale (2005) highlight two kinds of networks, bonding, or strong ties, and bridging, or weaker links. They claim that through dense network structures, bonding ties can impose strict social norms and create strong, but localized trust. On

the other hand, bridges between different stakeholder groups allow actors to overcome social norms and are valuable for generating new knowledge or identifying opportunities (Granovetter 1973, Newman and Dale 2005, Olsson et al. 2007). Olsson et al. (2004) identifies bridging organizations as one set of actors in adaptive co-management networks because they coordinate interactions between actors at different scales. Newman and Dale (2005) conclude that the two types of social capital are complimentary and important for building proactive resilience and developing robust responses to uncertainty.

Although there is extensive collaboration on elk management, the organizations that stood out as having strong connections with others that enable collaboration are RMNP and CPW. These strong nodes in our network diagram operate at different scales of government with different mandates and goals regarding elk management. Through investigation of the roles that they play in enabling collaboration, we demonstrate that the linkages developed by CPW and RMNP are essential for effective elk management in Northern Colorado.

CPW manages elk continuously across most of the landscape and their mission is to "perpetuate wildlife resources of the state" (Huwer 2007). They work with other stakeholders to meet this end, primarily by promoting hunting as a tool. CPW provides guidance to stakeholders on wildlife issues and assists with all aspects of their management, including handling of game damage or animal conflicts. Because CPW manages elk across all jurisdictions (except within RMNP), there is consistency in the management throughout the region. They also have an institutional knowledge of the history of elk management and actions taken between jurisdictions. Because they are <u>the</u> wildlife management agency, they collaborate extensively with other agencies in the region on elk management, but have limited flexibility to types of management outside of hunter harvest to meet their objectives.

RMNP maintains federal authority within their jurisdiction and directly manages the elk herd within the park boundaries. RMNP staff work with CPW to communicate about elk data and objectives, but CPW has no authority over elk in the park. Because their mission is to provide "the freest use of the said park for recreation purposes by the public and for the preservation of the natural conditions and scenic beauties thereof" (National Park Service 2007), their goal is to maintain a functioning ecosystem. Through development of Environmental Impact Statements, RMNP regularly engages stakeholders throughout the region to identify major issues for consideration during the study. Because their boundaries are on both eastern and western sides of the continental divide, they provide a link between entities and facilitate sharing experiences where there is a geographic barrier.

When evaluating at the roles different agencies play in enabling collaboration on elk management, it is important to assess their different functions in promoting a shared vision for the region. Since it has a legal mandate to directly manage elk, CPW has strong formal ties to each of the institutions evaluated in the study (illustrated by solid lines in Figure 2.4). These formal ties make CPW analogous to a 'bonding' organization. They are trusted by other institutions to perform their role, but are less flexible to exploring novel management techniques. RMNP would be more akin to 'bridging' organizations. RMNP interacted with stakeholders at multiple levels to develop the EIS and continues to engage neighbors about forward-thinking elk management (illustrated by dashed lines in Figure 2.4). The presence of these different organizations that provide leadership and connect other agencies in the area on natural resource management issues confirms conclusions by Newman and Dale (2005) that diversity in types of networks increases the resilience of a system to adapt to unexpected changes. Bridging and bonding organizations are complimentary because bridging organizations bring in new and

potentially novel information, as RMNP has throughout this process, while bonding groups provide resilience and stability needed to adjust to changes (Newman and Dale 2005).

Vulnerabilities in future elk management

This study provides a snapshot of elk management at a particular time and it is beyond the scope of the study to evaluate how management has changed over time or could develop in the future. However, it is apparent that the management structure, as it exists today, is vulnerable to rapid changes in the elk herd.

Figure 2.3 illustrates that the extent to which jurisdictions are impacted by elk closely aligns with the significance placed upon elk management. Anecdotal evidence suggests that historic elk movement patterns and distributions have changed dramatically over the past decade. Although the survey instrument used in this study was designed to assess elk management goals and collaboration and did not directly evaluate constraints on elk management, these data suggest that if elk distributions continue to shift into areas that have not historically been impacted they could be adversely affected by the ungulates if they do not have management strategies in place to mitigate the impacts.

Additional vulnerabilities stem from structural constraints in the management planning process. Table 2.3 outlines the rigidity of the management plans and planning processes, which may serve as a structural impediment to adaptation if the elk herd or ecosystem change suddenly. Although the management planning of some agencies is rigid, other organizations with more flexibility may be able to adapt more easily.

CONCLUSIONS

This study explores frameworks for analyzing management structures that enable resource management at a landscape scale when there are multiple land-owners and stakeholders. The multi-scale, collaborative management of elk in Northern Colorado demonstrates an example of adaptive co-management that is centered around development of strong networks and a community of learning that is central to successfully respond to social-ecological changes.

Kofinas (2009) argues that social-ecological governance requires that institutions and organizations coordinate across scales and that understanding the cross-scale institutional interplay is critical for sustainable resource management. This case study provides useful insights that extend to broader landscape scale management. Resources that are mobile or extend across multiple management jurisdictions cannot be effectively managed by a single institution but are best managed by multiple agencies at different scales. This multi-scaled collaboration provides a more robust and diverse set of management options, which additional provides a regional framework for a more coordinated set of actions. However, the coordination required for this type of complex governance involves collaboration of many agencies that is facilitated by organizations that connect others.

Although this study provides useful insights about why elk management is effective throughout Northern Colorado, additional research is needed to properly assess implications that future changes will have on elk management. The current management is based upon absence of an apex predator and evaluation of how the return of wolves would impact elk management would be useful analysis. Additional research on the desired ecosystem states of the agencies involved would also help assess how well the current management strategies are achieving desired overall ecosystem states.

Table 2.1: Nodes used for coding interviews and resource management plans

Node	**Description**
ROLE	Information about own role within institution (responsibilities, priorities, dealings with elk, etc.)
INST_MISS	Information about mission of institution
INST_PRIOR	Information about priorities of institution
INST_STRUC	Information about structure of institution (inc. management structure, planning processes, flexibility)
MGMT_GEN	General management strategies (natural resource, other resources, or issues)
MGMT_ELK	Elk management strategies
INTERACT	Interactions with other institutions in the region (inc. Communication, planning, etc.)
ELK_MVMT	Movement patterns of elk and changes over time
ELK_SCIENCE	Science related to elk (inc. habitat, population size, disease, etc.)
ELK_IMPACTS	Impacts elk have on jurisdiction (inc. veg. for RMNP)

Table 2.2: Elk management priorities, focus and actions of public land management institutions in Northern Colorado

		Management Goals		Management Focus	Management Actions	
		Short-term	Long-term		Short-term	Long-term
Federal	RMNP [1,2]	Elk distribution Elk Population Size Elk Sex Ratio	Habitat / Ecosystem Function Plant Community Dynamics	Habitat Population Dynamics	Vegetation exclosures Harvest	Habitat improvement
	USFS [1,3]	Min Conflict / Damage	Habitat / Ecosystem Function Plant Community Dynamics	habitat	CPW reduce conflict Movement corridors Trail Closures	Habitat improvement
	BOR [1,4]	Min Conflict / Damage Enable Migration		Minimize Conflict	CPW reduce conflict Movement corridors Vegetation exclosures Trail Closures	
State	CPW [1,5,6,7]	Min Conflict / Damage Elk distribution Elk Population Size Elk Sex Ratio		Population Dynamics	Harvest elk hazing	Habitat improvement
County	LC [1,8,9,10]	Min Conflict / Damage Enable Migration	Habitat / Ecosystem Function Plant Community Dynamics	Habitat	CPW reduce conflict	Habitat improvement

Town				County
GL [1]	Estes Park [1,21]	LO [1,19,20]	FC [1,15,16,17,18]	BC [1,11,12,13,14]
Min Conflict / Damage	Min Conflict / Damage Enable Migration	Min Conflict / Damage Enable Migration	Min Conflict / Damage Enable Migration	Min Conflict / Damage Enable Migration Elk distribution
			Habitat / Ecosystem Function Plant Community Dynamics	Habitat / Ecosystem Function
Minimize Conflict	Minimize Conflict	Minimize Conflict	habitat	Habitat
CPW reduce conflict	CPW reduce conflict Movement corridors Vegetation exclosures Trail Closures	CPW reduce conflict Movement corridors	Movement corridors	CPW reduce conflict Movement corridors
Education	Education		Habitat improvement	Habitat improvement

Sources: [1]Interview transcriptions; [2]National Park Service 2007; [3]U.S. Forest Service 1997; [4]U.S. Bureau of Reclamation 2008; [5]Vieira 2009; [6]Oldham 2010; [7]Huwer 2007; [8]Larimer County 1997; [9]Larimer County 2001; [10]Larimer County 2007; [11]Boulder County 2010; [12]Boulder County 2011; [13]Boulder County 1984; [14]Boulder County 2004; [15]City of Fort Collins 2001; [16]City of Fort Collins 2004; [17]City of Fort Collins 2007; [18]City of Fort Collins 1992; [19]City of Loveland 2003; [20]City of Loveland 2005; [21]Town of Estes Park 1997.

Table 2.3: Flexibility of elk or natural resource planning process to respond to changes. Based upon level of governance, length of management plan, length of planning process and flexibility to amend management plans. Pink indicates low flexibility, orange indicates moderate flexibility, and green indicates most flexibility.

	Governance Level	**Management Plan Length**	**Planning Process Length**	**Amendment Process**
RMNP	Federal	20	>2 yrs	regular - less frequent
USFS	Federal	10	>2 yrs	regular and as needed
BOR	Federal	10	>2 yrs	ad-hoc
CPW	State	10	1-2 yrs	regular and as needed
Boulder Co	County	10	1-2 yrs	ad-hoc
Larimer Co	County	10	<1 yr	regular and as needed
Fort Collins	Town	10	>2 yrs	ad-hoc
Estes Park	Town	NA	1-2 yrs	ad-hoc
Grand Lake	Town	NA	<1 yr	ad-hoc
Loveland	Town	10	<1 yr	ad-hoc

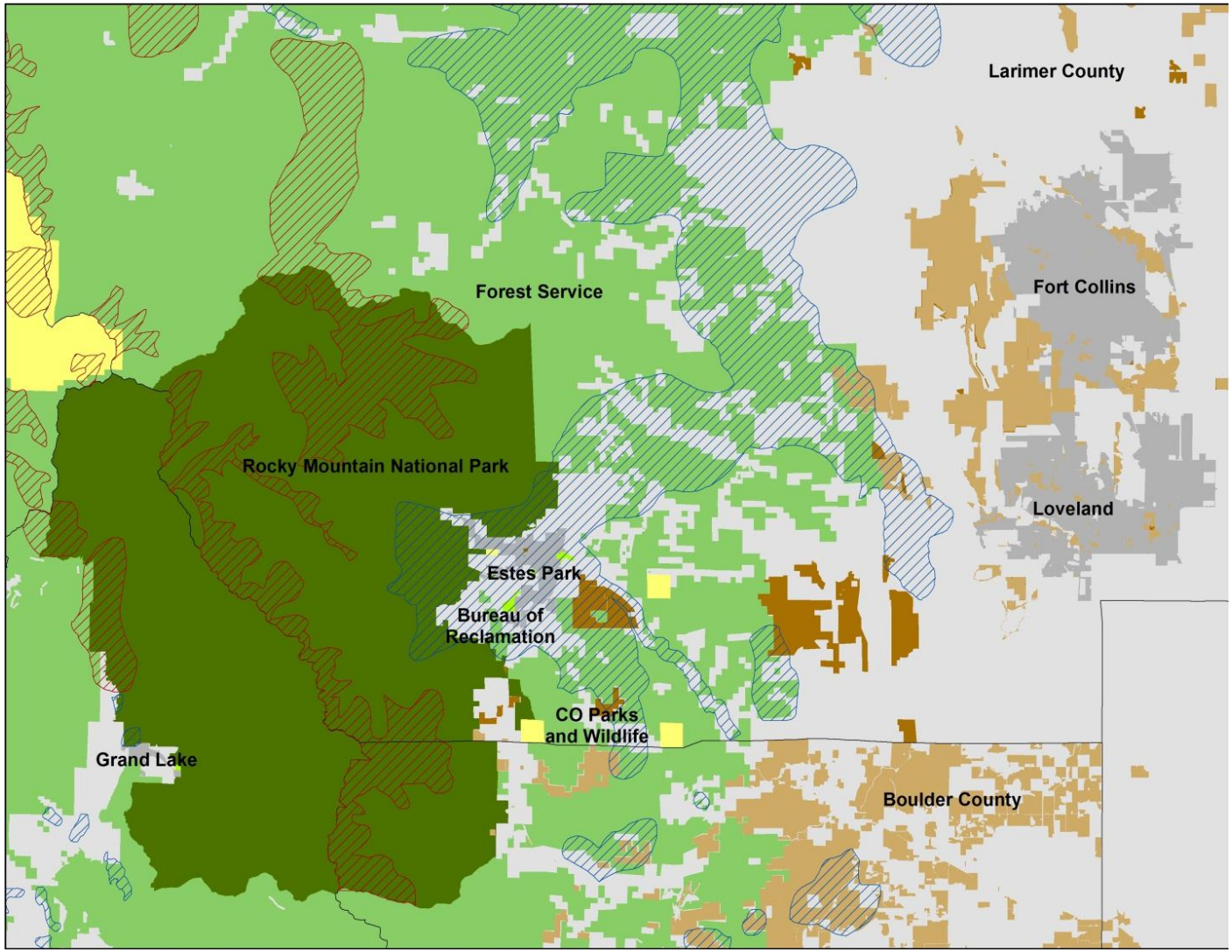

Figure 2.1: Study area. Green represents federal lands, yellow is state lands, brown represents county and city open spaces, grey is private land. Red shading is elk summer concentration areas and blue shading is elk winter concentration areas (Colorado Parks and Wildlife 2012).

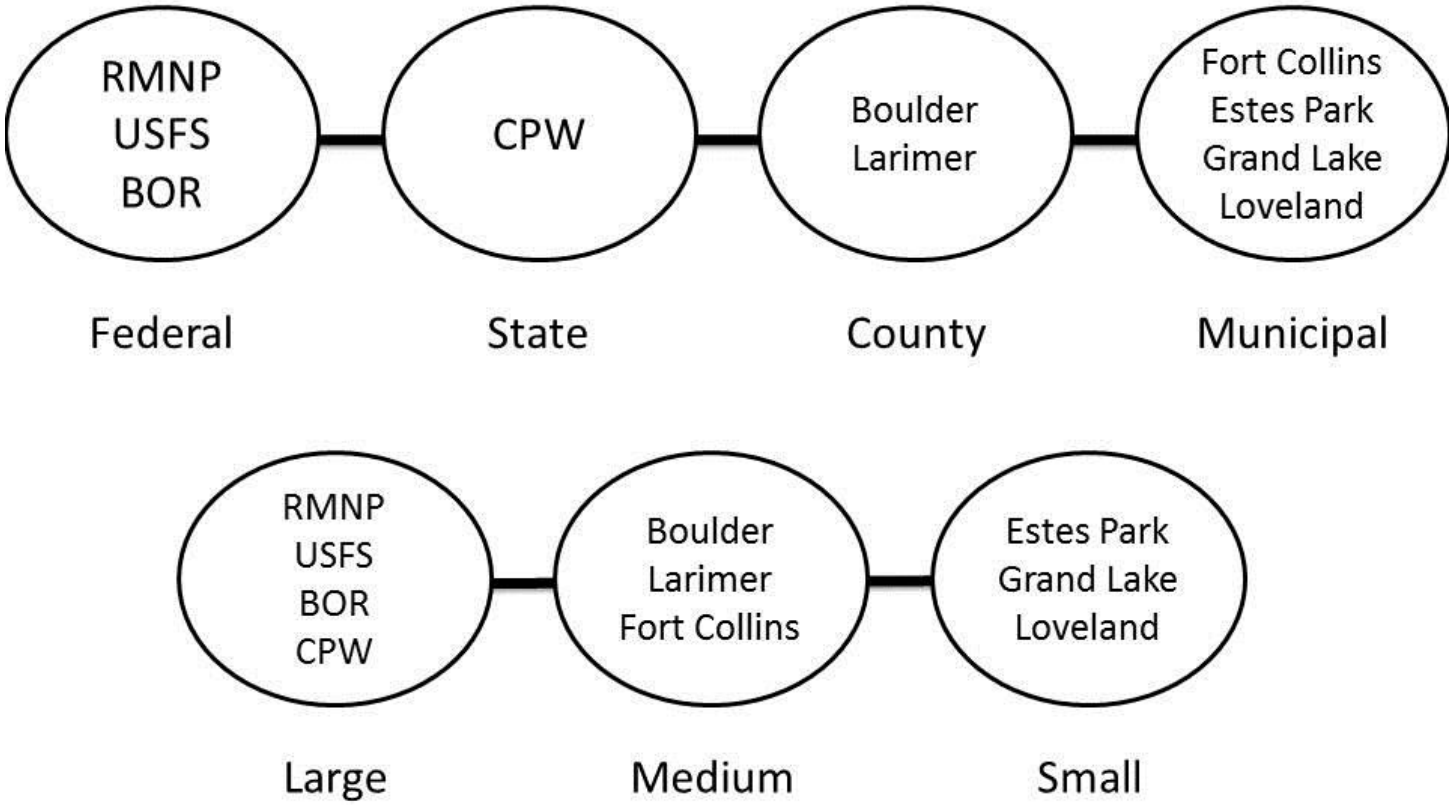

Figure 2.2: Organizations involved in the study arranged by levels of governance.

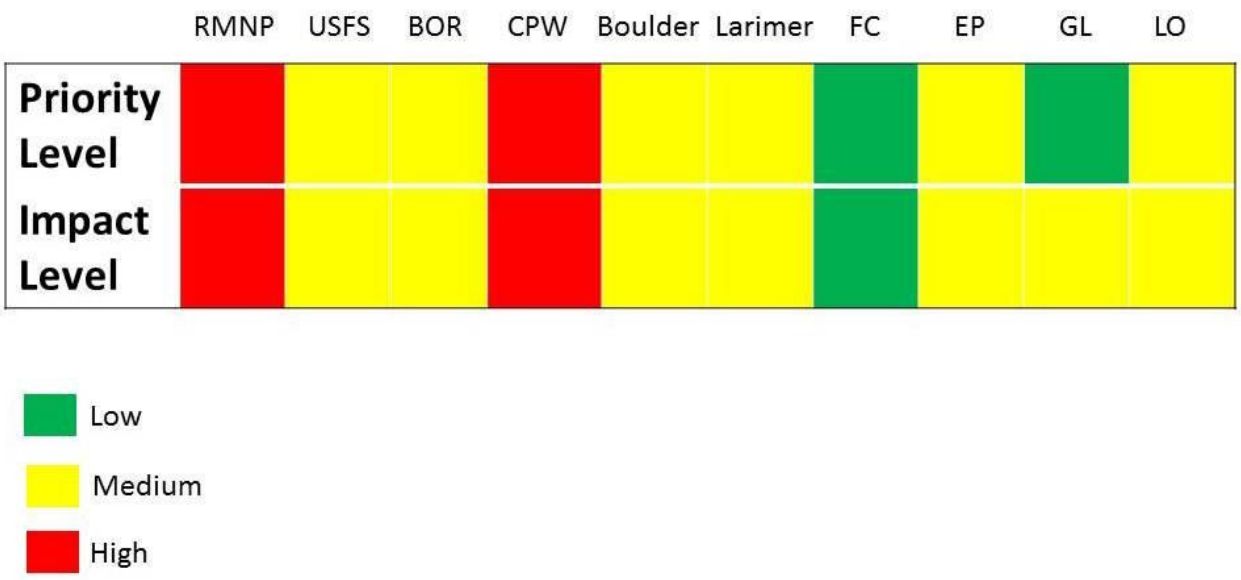

Figure 2.3: Impacts that elk have on the each jurisdiction are categorized as year-round, heavy seasonal, limited seasonal, or little or no impact. For most institutions, the priority of elk corresponds with their impact.

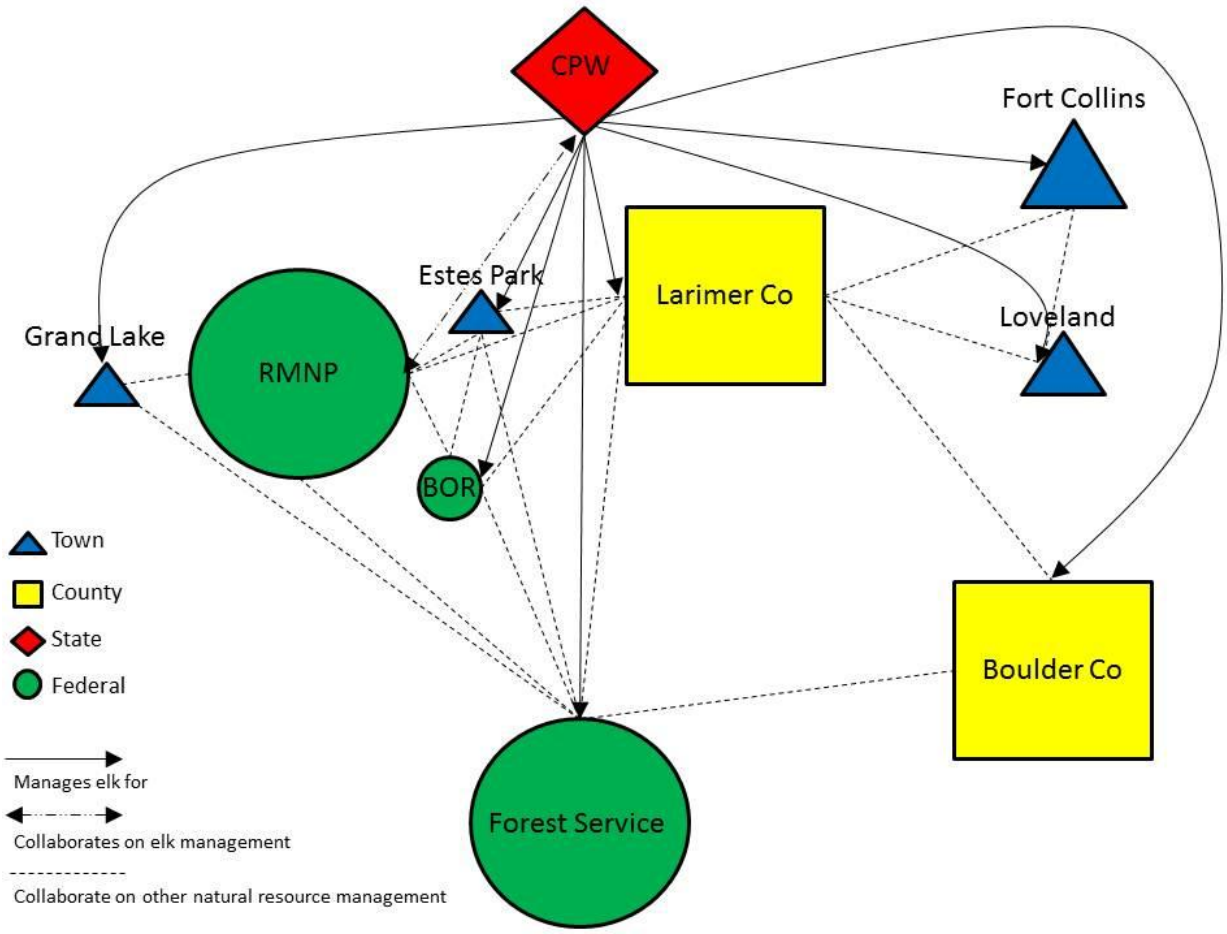

Figure 2.4 : Collaboration between entities on elk or other natural resource management. Nodes are plotted spatially (not to scale) to demonstrate the importance of geography in communication. The scale of entities are shown by shape / color and size to demonstrate their inter-scale collaboration.

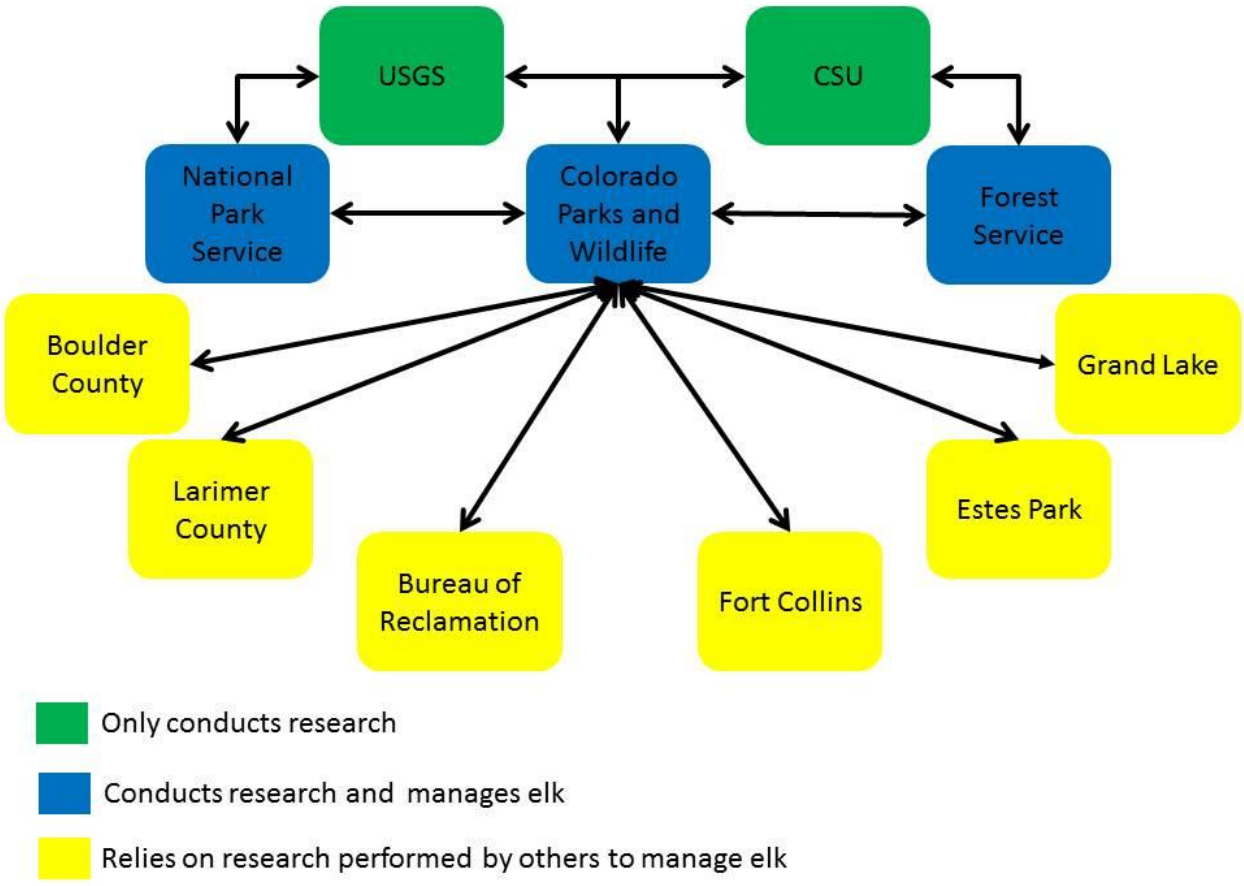

Figure 2.5: Scientific information used for managing elk and elk habitat. Agencies in green only conduct research and do not manage the herd. Those in blue conduct research and manage the herd. Yellow boxes represent agencies that do not conduct research, but rely on other agencies to disseminate data. Arrows illustrate that information flows two ways between the organizations.

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APPENDIX A: PARTICIPATING AGENCIES

Boulder County Parks and Open Space

Bureau of Reclamation

Colorado Parks and Wildlife

Colorado State University

Town of Estes Park

Estes Valley Recreation District

U.S. Forest Service

Town of Grand Lake

Larimer County Natural Resources

Town of Loveland

Rocky Mountain National Park

U.S. Geological Survey

APPENDIX B: INTERVIEW SCHEDULE AND JUSTIFICATION

I. Goals of Institution

1. What is your role at [INSTITUTION]?
2. As [role], what are your overall objectives?
3. What do you believe to be the objectives of [INSTITUTION]?
4. In your job, what are your top 3 priorities?
5. What, would you say, are the top 3 priorities of [INSTITUTION]?

The objective of this series of questions is to determine the mission, goals and priorities of each institution. Questions are also asked of the individual to normalize the data and determine if differences within institutions are due to institutional differences or personal interests of interviewee. An understanding of institutional missions and their differences will give insight to the role that institution does or can play in a regional elk management strategy.

II. Alignment / Adaptive Capacity

6. What are the resource management goals of [INSTITUTION]?
7. How do other institutions in the area think about resource management? [RMNP, FS, (BLM), CPW, Estes Park, Grand Lake, Loveland, Larimer County]
8. Do you think resource management can work at a landscape scale?
    a. If yes, 3 keys to success
    b. If no, 3 impediments
9. Do you think current communication between agencies are appropriate?

10. What was process of developing you current resource management (elk or other related) plans?
11. Who was involved in the process?
12. How does [INSTITUTION]ensure effectiveness of program (management plan)?
13. Is there flexibility in program development within [INSTITUTION]?
14. If a need arises or situation changes, what is the process for developing a new program?
15. What is the management structure of [INSTITUTION]?
16. What is the length of decision-making process within [INSTITUTION]?
17. How well do you understand the structure and planning process of other institutions in the region?

This section of questions aims to gain insight on the details of resource management of each institution, how closely they align or work with others, and organizational structure. This will help determine if there is flexibility to adapt management plans to include elk or work with others on managing elk, should the need arise.

III. Elk Impacts

18. Do elk have any effects on the jurisdiction of [INSTITUTION]? How?
19. Region then Jurisdiction Map
    a. Where elk are located, have been seen, are a problem - proximity of elk range to spatial jurisdiction
    b. Winter / Summer ranges – distribution of elk seasonally
    c. Elk movement patterns – What migration patterns have observed?
    d. Have you observed changes in migration patterns over time?

20. Why do you think these changes are the case?

This section of questions will determine the degree that elk impact the spatial jurisdiction of each institution and how that has changed over time. Information will lead to second phase of the project that models elk habitat and movement.

IV. State of Science

21. How have numbers and distributions of elk changed over time (historically and in past decade)?

22. What ecological factors control elk population sizes?

23. What are the appropriate elk population sizes (relate to K)?

24. What impacts do elk have on their habitat?

25. How might habitat change impact elk?

26. Are you familiar with any disease in this elk herd?

27. What do you know about this disease and how much of a problem is it?

28. In years with extreme weather variability (like past two years) how are elk impacted?

29. What are public perceptions about elk and managing them?

30. What is the greatest scientific need for managing elk and what do we know the most about?

Questions in this section address an important factor for elk management, the quality of science used in determining management plans and how each institution obtains that science. It will be useful to illustrate agreement or disconnects in scientific facts between institutions, that can serve as a starting off place if institutions do wish to consider a regional elk management plan.

APPENDIX C: MANAGEMENT PLANS ANALYZED

Agency	**Plan**	**Year**
Boulder County	Forest Management Policy	2010
	Niwot Trails Master Plan	2011
	Rabbit Mountain Management Plan	1984
	St. Vrain Creek Corridor Open Space Management Plan	2004
Bureau of Reclamation	Lake Estes, Marys Lake, East Portal and Common Point Resource Management Plan and Environmental Assessment Finding of No Significant Impact	2008
Colorado Parks and Wildlife	Elk Management Plan, Data Analysis Unit E-4	2009
	Elk Management Plan, Data Analysis Unit E-8	2010
	Elk Management Plan, Data Analysis Unit E-9	2007
Estes Park	Estes Valley Development Code	1997
Forest Service	1997 Revision of the Land and Resource Management Plan: Arapaho and Roosevelt National Forest and Pawnee National Grassland	1997
Fort Collins	General Management Guidelines for Natural Areas and Agricultural Lands Managed by the City of Fort Collins Natural Resources Department	2001
	Land Conservation and Stewardship Master Plan	2004
	Fort Collins Natural Areas Program Wildlife Management Guidelines	2007
	City of Fort Collins Natural Areas Policy Plan: An element of the Comprehensive Plan	1992
Larimer County	Larimer County Master Plan	1997
	Larimer County Open Lands Master Plan	2001
	Larimer County Parks Master Plan	2007
Loveland	Open Lands Plan	2003
	Comprehensive Plan	2005
RMNP	Elk and Vegetation Management Plan	2007

LIST OF ABBREVIATIONS

EIS	Environmental Impact Statement
SES	Social-ecological systems

Institutions

BC	Boulder County
BOR	U.S. Bureau of Reclamation
CPW	Colorado Parks and Wildlife
EP	Estes Park
FC	Fort Collins
GL	Grand Lake
LC	Larimer County
LO	Loveland
RMNP	Rocky Mountain National Park
USFS	U.S. Forest Service
USGS	U.S. Geological Survey