RANCHERS' AND FEDERAL LAND MANAGERS' PERCEPTIONS OF RANGELAND MANAGEMENT ACROSS AN ENVIRONMENTAL GRADIENT

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Calandria Puntenney

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of the thesis submitted by

Calandria Puntenney

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The following individuals read and discussed the thesis submitted by student Calandria Puntenney, and they evaluated the student's presentation and response to questions during the final oral examination. They found that the student passed the final oral examination.

Kelly Hopping, Ph.D.	Chair, Supervisory Committee
Marie-Anne de Graaff, Ph.D.	Member, Supervisory Committee
April Hulet, Ph.D.	Member, Supervisory Committee
Amy Ulappa, Ph.D.	Member, Supervisory Committee

The final reading approval of the thesis was granted by Kelly Hopping, Ph.D., Chair of the Supervisory Committee. The thesis was approved by the Graduate College.

DEDICATION

This thesis is dedicated to the rangelands of Idaho

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ABSTRACT

Managing semi-arid rangelands to meet social-ecological goals requires monitoring of key ecological indicators that will inform management responses. These goals and monitoring objectives are in turn grounded in land managers' understandings, or "mental models," of how the rangeland system operates. Rangeland managers' mental models are often highly place-specific, which can enable management actions to be matched to local conditions. In the western United States, ranchers and federal agency resource specialists, like those in the Bureau of Land Management (BLM), are two of the primary groups involved in rangeland management. We compared ranchers' and BLM agency specialists' rangeland mental models in two regions of southern Idaho, along a climatic and elevational gradient. We conducted semi-structured interviews about their land management goals and objectives, as well as important rangeland system dynamics, from their perspectives. We used a mixed-methods approach, including network analysis metrics, to elucidate similarities and differences in their mental models, and in the ecological indicators that they use to assess rangeland health and to trigger management actions in service of their goals and objectives. We also investigated self-assessed constraints on ranchers' and agency specialists' ability to take the actions necessary to make progress towards their goals. We found that their overarching goals differed more between social groups than by geographic regions, whereas specific management objectives differed more by region. Ranchers' and agency specialists' mental models indicated divergent perspectives on the seasonal impacts of livestock on soils and vegetation and about the use of grazing to maintain processes in the ecosystem. There were also geographic differences in the mental models related to the reliability of plant growth and the prioritization of managing for invasive annual grasses and fire. Similarities between ranchers' and agency specialists' mental models included ways in which they viewed plant species diversity and abundance as indicators of rangeland health and the use of plant height as an indicator for management actions, such as moving livestock. These findings indicate that ranchers and agency specialists have place-specific knowledge, but that their mental models are often more similar to others in their social group than to those outside their social group in the same region. Differences in their conceptions of rangeland management suggest areas for increased communication between ranchers and agency specialists, as well as potential opportunities for collaboration where complementary perspectives could better enable both groups to reach their management goals.

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LIST OF ABBREVIATIONS

BLM	Bureau of Land Management
EA	Environmental Action
LEK	Local Ecological Knowledge
MLRA	Major Land Resource Area
NE	Northeast
NEPA	National Environmental Policy Act
SW	Southwest

CHAPTER ONE: RANCHERS' AND FEDERAL LAND MANAGERS' PERCEPTIONS OF RANGELAND MANAGEMENT ACROSS AN ENVIRONMENTAL GRADIENT

Introduction

Rangeland management mediates the relationship between livestock production-based livelihoods and the ecological components and processes of rangeland ecosystems. A social-ecological approach to rangeland management must thus sustain both the viability of the human community and the health of the landscape (Muñoz-Erickson et al., 2007), despite often challenging environmental conditions. Many rangelands are semi-arid ecosystems defined by seasonally or interannually variable precipitation and high annual evapotranspiration (Illius and O'Connor, 1999; Ullah et al., 2022). The semi-arid climate coupled with variation in soil types and topography creates spatially and temporally heterogenous vegetation that can make identifying causal relationships in semi-arid rangelands difficult (Bestelmeyer and Briske, 2012; Hruska et al., 2017; Sayre et al., 2013b). In addition, equilibrium dynamics—in which livestock grazing plays a more dominant role in influencing patterns of vegetation change—and nonequilibrium dynamics—in which climate largely influences vegetation patterns—may both occur in semi-arid rangelands, depending on the spatial and temporal scale of observation (Briske et al., 2003; Ellis and Swift, 1988; Illius and O'Connor, 1999). It is therefore not always clear when climate or livestock grazing have a greater effect on vegetation, which can complicate effective, place-specific management (Briske et al., 2003; Illius and O'Connor, 1999).

The complex relationships in the ecosystem that span spatial and temporal scales complicate evaluating changes and patterns in ecological processes. In order to monitor the processes and components of the ecosystem, land managers use observable or measurable characteristics of the system, called ecological indicators (Karl et al., 2017). Federal land managers and scientists use formal monitoring protocols to collect scientific data about ecological indicators to track change in ecological processes or attributes and assess the effects of management (Herrick et al., 2017; Karl et al., 2017; Pellant et al., 2020). To identify appropriate indicators to monitor for rangeland management, monitoring manuals and research recommend selecting management goals and objectives to guide the management process (Dale and Beyeler, 2001; Derner et al., 2022; Fischman and Ruhl, 2016; Swanson et al., 2018; West, 2003a). Management "goals" are broad statements about the desired result from management (e.g., sustained use) and "objectives" are the desired outcomes from successful management that support the management goal (e.g., 50% more grass) (Swanson et al., 2018). The management goals and objectives guide decision-making and managers' responses to change in the system. Selected indicator metrics should help identify how weather, disturbance, and management influence progress towards objectives and goals (Derner et al., 2022).

Selecting indicators that adequately encompass the complexity of the rangeland system and account for variation in ecological processes can be difficult (Karl et al., 2017; Toevs et al., 2011). Individual indicators may not adequately represent system complexity, and many indicators are either too sensitive or not sensitive enough to be able to analyze change in an ecological process or detect management effects (Dale and Beyeler, 2001; Karl et al., 2017). Once indicators are selected, they must be compared to a known range or metric in order to determine the condition or status of the system (Toevs et al., 2011). The range of variation for ecological indicators depend on the physical, hydrologic, and biological characteristics of the site where the indicator is monitored (Pyke et al., 2002). Indicators should thus be selected to fit the local site where monitoring will occur and match the goals and objectives of management for that site. Aligning the scales at which management, monitoring, and ecological processes occur can prevent generalizations that were applied at mismatched scales in rangeland management in the past (Cumming et al., 2006; Sayre, 2017; West, 2003b).

Local ecological knowledge (LEK), defined as knowledge built from observation and experience in a landscape, can enrich and improve formal monitoring and management practices for social-ecological systems like rangelands (Hruska et al., 2017; Jamsranjav et al., 2019; Thompson et al., 2020). LEK of rangelands has been used as a source of knowledge about herd and livestock management, forage and medicinal plants, landscapes, wildlife, and climate change (Fernández-Giménez and Estaque, 2012; Hopping et al., 2016; Molnár, 2017; Sharifian et al., 2022). Ecological observations by social groups with local ecological knowledge equate to a form of qualitative monitoring that is complementary to the formal monitoring developed and documented via western scientific knowledge (Jamsranjav et al., 2019; Lepak et al., 2022; Woods and Ruyle, 2015). In studies that compared western scientific and local ecological knowledge, LEK was validated as accurate and of comparable breadth to scientific knowledge (Felt, 2008; Gagnon and Berteaux, 2009; Jamsranjav et al., 2019; Woods and Ruyle, 2015), or the apparent tensions between them ultimately led to greater ecological understanding (Klein et al., 2014). Studies have therefore investigated the potential integration of LEK of ecological indicators into formal monitoring (Herrick et al., 2010; Jamsranjav et al., 2019; Knapp and Fernandez-Gimenez, 2009; Reed et al., 2008; Thompson et al., 2020). Integration of multiple knowledge types in management has been found to improve complex problem-solving and provide a more complete understanding of natural resource systems (Aminpour et al., 2021, 2020). A more complete understanding of the system enables managers to better align monitoring with ecosystem processes and anticipate how the system will respond to management (Aminpour et al., 2020).

However, monitoring alone does not create effective management. For monitoring to influence management, it needs to be understood and acted upon by involved parties (Sayre et al., 2013a). Selecting ecological indicators rooted in local ecological knowledge can help, but for formal monitoring to influence management, the ecological indicators, objectives, and goals that structure monitoring must also be relevant to and understood by all parties (Friedel et al., 2004). For those conducting observational monitoring rooted in LEK, the ecological indicators they observe are innately tied to their objectives and goals (Abel et al., 1998). Integrating indicators from LEK without a full understanding of the ecological processes they represent and the goals and objectives they guide dilutes the intended benefits of bringing together diverse knowledge in management.

Mental models, a constructivist psychology concept, can be used to understand how land managers perceive the system surrounding their ecological indicators (Jones et al. 2014). Constructivist psychologies posit that individuals construct knowledge through experience and interaction with their environment, just as local ecological knowledge is constructed through observations and experience in an ecosystem (Davis and Wagner, 2003; Raskin, 2002). Mental models are composed of the concepts people perceive as relevant or important in a system and the relationships between the concepts (Jones et al., 2011). These simplified representations of how the world works helps a person understand, predict, and react to stimuli in their external environment (Abel et al., 1998). When eliciting a mental model, there can be discrepancies between what a person says is their mental model versus what they actually do in management, so when using mental models to understand management, it is also necessary to consider constraints on a person's capacity to act in accordance with their mental model (Jones et al., 2014; Moon et al., 2019).

Both experience and socialization influence shared knowledge and the construction of a person's mental model (Jones et al., 2011). The regionally grounded experience associated with local ecological knowledge may mean that people who share a geographic region also share knowledge and have similar mental models (Davis and Wagner, 2003; Jamsranjav et al., 2019). Socially related groups of individuals with similar interests, values, or norms, like those in the same profession, also tend to accumulate shared knowledge and may have similar mental models (Aminpour et al., 2021, 2020). Because mental models can vary depending on the characteristics of a person's experiences and interactions, they can be used to understand the perspectives of different parties in rangeland management (Abel et al., 1998; Wilmer and Sturrock, 2020).

The parties participating in rangeland management often involve persons representing a centralized governing body whose policies define rangeland management and pastoralists or ranchers responsible for on-the-ground implementation of those policies (Hruska et al., 2017; Lien et al., 2017; Sayre, 2017). In the western U.S., federal land management agencies, such as the Bureau of Land Management (BLM), and ranchers participate in management of rangelands in the public domain. Agency specialists in the BLM manage for sustained rangeland health, diversity, and productivity, with a mandated directive to manage the land for multiple uses (Bureau of Land Management, n.d.). Ranchers also have a common concern for the land and manage both for their economic livelihood and the stewardship of the land (Roche et al., 2015; Weeks and Packard, 1997; Woods and Ruyle, 2015).

Both agency specialists and ranchers develop a body of local knowledge by engaging with the land through experience and observation (Knapp and Fernandez-Gimenez, 2009; Woods and Ruyle, 2015). The unique characteristics of their professional social group and their different experiences and observations on local rangelands could influence their mental models of the rangeland system (Aoyama and Huntsinger, 2019). Mental models are also dynamic, so the accumulation of shared experiences through the public policy processes that mediate public lands grazing in the U.S. could change how ranchers and agency specialists structure their mental models (Abel et al., 1998).

Bridging the knowledge gaps between ranchers and agency specialists and identifying shared and divergent knowledge opens opportunities for more robust, local rangeland management. Previous research has compared ranchers and agency personnel by looking at their informal monitoring practices and attitudes to monitoring approaches in Arizona (Fernandez-Gimenez et al., 2005; Woods and Ruyle, 2015), grazing of invasive species in California (Shapero et al., 2018), and perspectives on conservation in

California (Aoyama and Huntsinger, 2019). To build on this research, we use a mental model approach to compare BLM agency specialists' and ranchers' local knowledge of ecological indicators in Idaho, a state that has more than 11.5 million acres of public rangeland that support over 1,600 livestock operators (Bureau of Land Management, n.d.).

We identified agency specialists' and ranchers' local knowledge of ecological indicators, which we examine in the broader context of their goals, objectives, and mental models of the rangeland management system. In doing so, we identify shared knowledge and patterns in ecological processes at the local scale. The comparison of indicators in this manner allows us to discern opportunities for collaboration, communication, and integration of diverse knowledge in rangeland management. Our objective is to compare ranchers' and agency specialists' ecological indicators in the semi-arid rangelands of Idaho. To meet our objective, we ask the following questions:

1) What are ranchers and agency specialists managing for, and how do their goals and objectives differ between social groups and geographic regions?
2) What components of the rangeland ecosystem do ranchers and agency specialists pay the most attention to, how do the components connect, and what components do they use to guide management towards their goals and objectives?
3) What limitations constrain ranchers' and agency specialists' capacity to achieve their management goals and objectives?

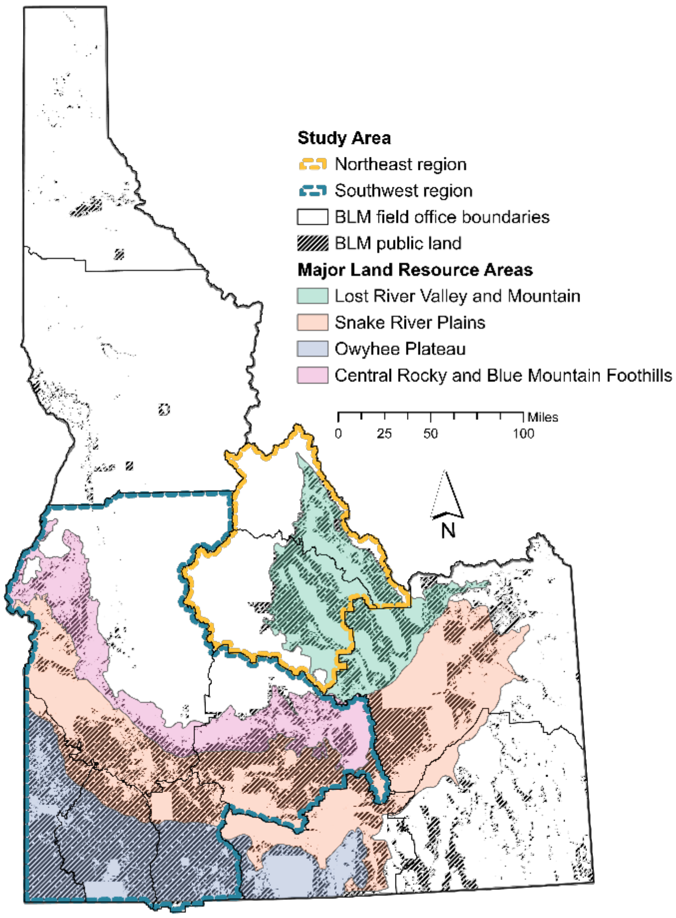
We hypothesize that social group identity creates fundamental differences in agency specialists' and ranchers' goals for management and mental models of the system. We also hypothesize that shared experiences in the local environment results in shared knowledge among agency specialists and ranchers within geographic regions, though the exchange of knowledge in the regulatory processes of public lands grazing in the U.S. could also contribute to shared knowledge.

In this case study, we first compare agency specialists' and ranchers' goals and objectives for rangeland management in two regions of Idaho. Next, we compare the rangeland mental models of agency specialists and ranchers from each subregion through a discussion of important components, perceived processes, and ecological indicators. We then examine common constraints on ranchers' and agency specialists' capacity to achieve their management goals and objectives. The study concludes with a discussion of emergent themes in agency specialists' and ranchers' rangeland management, placement of the results in the larger body of rangeland LEK research, and the study's implications for a social-ecological approach to rangeland management.

Methods

Biophysical Study Area

We selected semi-arid regions of Idaho with BLM-managed public lands for the study area. The public lands of interest fall within four Major Land Resource Areas (MLRA): the Owyhee High Plateau, Lost River Valleys and Mountains, the Central Rocky and Blue Mountain Foothills, and the Snake River Plains (United States Department of Agriculture and Natural Resources Conservation Service, 2006) (Table A.1). According to MLRA descriptions, mean annual precipitation in the study area ranges from 180-635 mm, though mountain crests in the region can receive more than 1145 mm. The area experiences strongly seasonal precipitation and temperature, with winters largely receiving precipitation as snow and summers usually with very low precipitation. Mean annual temperatures range from 2-13 °C. A typical average growing season length is 110-165 days (range of 60-220 days), decreasing with elevation. Soils are mostly aridisols and mollisols with xeric to aridic soil moisture regimes. Elevations range from 395-2300 m a.s.l., with mountain peaks up to 3660 m in the Lost River Valleys and Mountains MLRA. More than 50% of the Lost River Valley and Mountains MLRA is mountainous. The higher elevation, colder temperatures, and higher precipitation of the Lost River Valley and Mountains MLRA creates a suite of environmental conditions that distinguish it from the rest of the study region (Table A.1). To characterize local knowledge across such a range of environmental conditions, we therefore separated the study region into a subregion designated “the northeast” (NE), which includes the Lost River Valley and Mountains MLRA, and a subregion designated “the southwest” (SW), which encompasses the Owyhee Plateau MLRA and areas in the Snake River Plains and Central Rocky and Blue Mountain Foothills MLRA (Map 1).



Map 1. Map of the study area. The blue and yellow dashed outlined areas constitute the southwest and northeast subregions of the study area, encompassing seven BLM field offices. Different colors indicate the Major Land Resource Area designations, and the shaded portions indicate land managed by the BLM.

<u>Institutional Context</u>

The study area is located within three BLM districts. Each BLM district is delineated into three to four sections managed by field offices. The study area encompasses seven field offices comprising 75% of the total land area managed by these three districts (Map 1) (Bureau of Land Management (BLM), 2020). Livestock producers graze on public lands through a permitting process with the BLM that is regulated by national laws like the National Environmental Policy Act of 1969 and the Federal Land Policy and Management Act of 1976, and guided by BLM manuals, handbooks and directives (Bureau of Land Management, 2009; West, 2003b). The permits set the maximum duration, location, and number of livestock that livestock producers may run each year. The permits are mandated to be reviewed before renewal every 10 years, and the terms are maintained annually through grazing plans and monitoring (43 CFR Part 4100, 1978).

Interview Procedure

We conducted 30 semi-structured interviews with BLM resource specialists and ranchers between August and November 2020. Semi-structured interviews allowed for predefined comparisons across interviews, while still providing opportunities to probe participants on otherwise tacit topics that emerged organically in the course of the interview (Bernard, 2006).

Due to the COVID-19 pandemic, we modified our protocols to accommodate in-person, phone, and video-conferencing interviews. We conducted five interviews by phone, three by video, and 22 in-person at the location of the participant's choice. We were outside for 19 of the 22 in-person interviews. Each participant gave verbal or written consent to participate in the research per the procedures approved by Boise State University Institutional Review Board protocol 090-SB20-123. Interviews ranged from one to four hours, with agency interviews lasting a mean of 1.4 hours and rancher interviews a mean of 2 hours.

Participants were selected using a non-probabilistic, purposive sampling method suitable to an intensive case study (Bernard, 2006). We identified 13 Bureau of Land Management specialist participants through lists of contacts provided by BLM state and district managers. The agency specialists were all field office specialists located throughout six of the seven BLM field offices in the study area. We used their primary field office association as a proxy for their location.

We identified 17 rancher participants through contacts in rancher cooperatives and recommendations from institutions involved with rangeland management in Idaho. The ranchers we interviewed were located throughout all seven BLM field offices in the study area. Due to their ranching operation history, several rancher interviewees had experience with multiple BLM field offices. In those situations, we used the rancher's residence as a proxy for their primary field office association.

We developed interview questions for ranchers and for agency specialists that were designed to capture participants' perspectives and practices that have developed from their lived experience as land managers (Tracy, 2013) (Appendix B, C). We asked interviewees how they approach land management, what observations of the rangeland they use to inform their decision-making, and how they assess the health or condition of the land. Questions were designed to prompt discussion about recurrent themes in rangeland monitoring and management literature and suggested topics from rangeland experts (Pyke et al., 2002; Swanson et al., 2018; Toevs et al., 2011; Woods and Ruyle, 2015). Open-ended questions allowed us to probe interviewees' experiential knowledge of the local ecosystem. We refined the interview questions through preliminary interviews with ranchers and agency staff who were not included in the final study sample. We did not include any questions or prompt discussion specific to riparian areas, as riparian system dynamics and management differ from that of upland grazing areas and were thus outside the scope of this study.

We recorded each interview and transcribed the audio recordings. We transcribed one interview using "Landmark Associates" transcription service and transcribed the other 29 using "Otter.ai" and "Transcribe by Wreally LLC" transcription tools.

Participant Demographics

We interviewed eight female participants (two ranchers, six agency specialists) and twenty-two males (fifteen ranchers, seven agency specialists). Thirteen of the seventeen ranchers had post-secondary education, with ten ranchers having a Bachelor's degree, three of which had a rangeland focus and four of which were in business. The thirteen agency specialists interviewed had a Bachelor's degree, with ten having a rangeland focus and the remaining three having biology or natural resource degrees.

The seventeen rancher interviewees represented sixteen different operations: fourteen cattle operations and two that raised both sheep and cattle. Not everyone specified what type of cattle operation they managed, but ranchers from thirteen operations reported having a cow-calf operation, five of which also reported having yearling cattle. Several ranchers ran specialty operations (e.g., steers).

Ranchers had a mean age of 52 years (median 54 years), with much of that time spent ranching professionally (mean 32 years, median 36 years). Ranchers had spent a mean of 46 years in Idaho (median 54.5 years), with a mean of 29 years operating in the same location (median 22 years; Fig. 1). Of the fifteen ranchers who answered how much ranching contributed to their income, the contribution ranged from 0 to 100%, with eight of the ranchers reporting that 100% of their income came from ranching and another five ranchers reporting that more than 50% of their income came from ranching. Ranchers mentioned managing their livestock on anywhere from 8,000 to 130,000 acres of public land (median 55,000 acres) and spending a mean of 6.0 days a week outside on the land (median 7 days, range 1-7 days).

Of the 13 agency specialists, 11 were rangeland specialists or had previous experience as rangeland specialists, but participants' position titles at the time of the interview included "rangeland", "ecology", "wildlife", and "monitoring" specialists. The agency specialists were a mean age of 38 years (median 35 years), with a mean of 10.5 years spent in Idaho (median 9 years) and a mean of 6.5 years of that time spent in the same location (median 5 years; Fig. 1). Agency specialists reported working a mean of 7.1 years as an agency specialist (median 4.5 years). The self-reported number of acres under the purview of a specialist's workload ranged from 250,000 to 1,200,000 acres (n=8, median 500,000 acres). For those directly responsible for grazing allotments, they each had responsibility for 13 to 125 allotments of varying sizes (n=6, median 42 allotments). Agency specialists spent a mean of 2.7 days per week outside on the land (median 2.5 days, range 0.5-4.5 days).

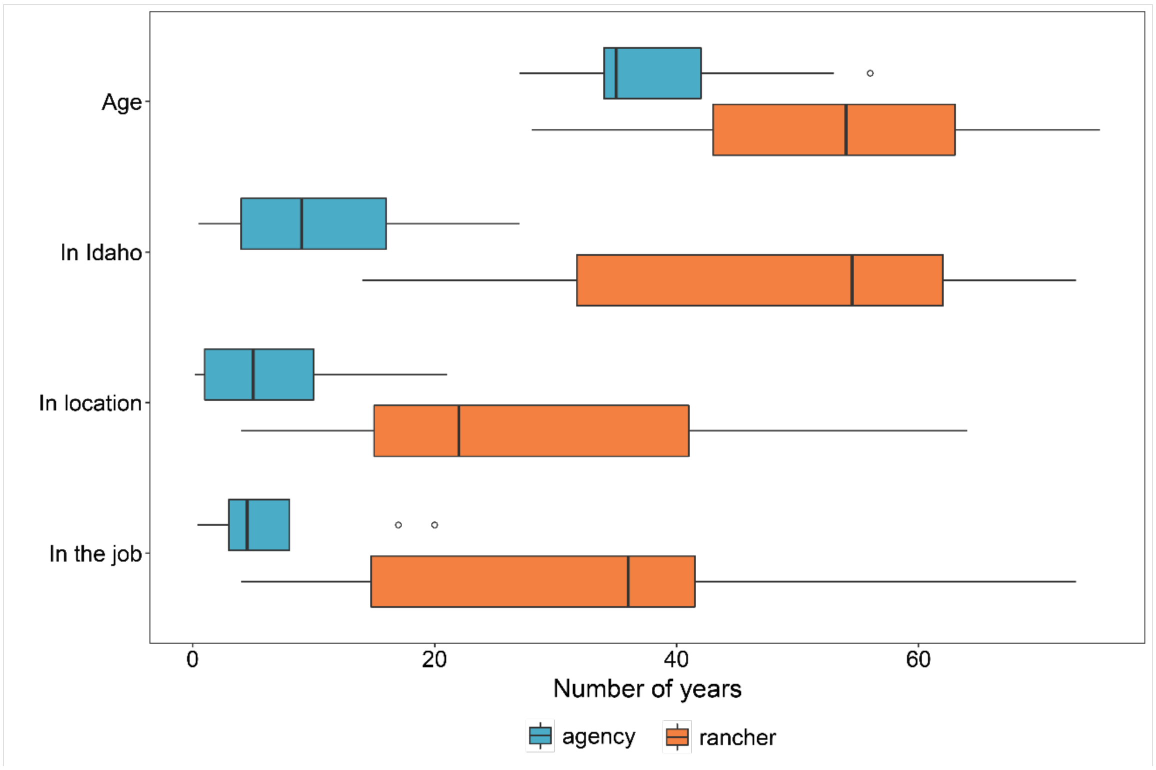


Figure 1. Participant demographic profile. The distribution of rancher and agency participants' age, the number of years they have lived in Idaho, the number of years they have lived or worked in their current location, and the number of years they have been in their job. The vertical black line represents the median. Ranchers tended to be older and to have lived in Idaho, in the same location, working in their profession longer than agency specialists.

Data Analysis

Interview Coding

We used the qualitative data analysis and research software Atlas.ti 9 Windows to code the interviews in an iterative process using a priori codes from the interview questions and subsequent emergent codes from concepts mentioned by multiple interviewees (Atlas.ti 9, 2020; Bernard, 2006; Tracy, 2013).

For the first research question, to understand ranchers' and agency specialists' *goals* for land management, we asked each participant about their land management philosophy. When speaking about their land management philosophy, participants broadly described what they are seeking to achieve through their work. We extracted and coded the key phrases in each quote to identify their goals for management and classified them by emergent themes (Table D.1). The goals are not mutually exclusive, so one interviewee could have multiple goals. We iteratively defined and refined the list of possible goals by reflexively reviewing the extracted quotes from each interviewee multiple times and crosschecking responses to confirm presence or absence of each goal in the list. Each participant was recorded as having a particular goal if it was mentioned at least once in the coded interview passages.

Also for the first research question, to understand ranchers' and agency specialists' ecological *objectives*, we coded participants' responses to interview questions about their management priorities, as well as instances throughout the interview in which they expressed a desire to see a certain outcome in the system, often signaled by terms like "want", "should", or "would like," or the antithesis of those terms, such as "don't want," "shouldn't", or "wouldn't like." Ranchers and agency specialists expressed a wide range of objectives related to what they would like to see in the social, operational, institutional, and ecological arenas of working rangelands, but for this study, we focused on ecological objectives for land management. We coded passages mentioning a desired outcome for ecological aspects of the system and created a list of the objectives in an iterative process that involved revisiting passages multiple times to classify the extracted ecological objectives into common categories based on their subject matter (Table E.1). For example, the presence of plants or the number of plants were both categorized as "plant amount." We removed duplicates wherever an interviewee mentioned an objective category more than once.

For the second research question about how ranchers and agency specialists perceive and connect components of the ecosystem, we coded the responses to the interview questions about what they look at for landscape health and what components of the system they use to inform management decisions. We iteratively coded emergent themes common to multiple interviews (e.g., views on fire or how livestock affect the system). We then coded passages in which interviewees described relationships between the components of the system, often using connecting terms like "drives," "because," "if – then," or "in order to," or a progression of statements about how one aspect of the system yields a result in another aspect of the system; for example, descriptions of relationships between water and plant growth or how weather influences management actions. We revisited the coded passages multiple times to refine a list of all connected components.

In preparation for creating networks of the system components, we labeled all components that acted upon, indicated, or influenced another component as source nodes and their respective related components as the target nodes. Source nodes were then designated as a "driver" influencing the target node, a "landscape health indicator" telling the interviewee about the condition or state of the rangeland, or a "management indicator" informing the interviewee about where or when to take a certain management action. If source nodes connected to more than one target node, they often had more than one driver or indicator designation. We then classified the source and target components into categories, employing the same categories that were used to classify participants' ecological objectives wherever appropriate (e.g., the presence of plants or the number of plants were labeled "plant amount"). We iteratively refined the list of categories, revisiting coded passages multiple times to understand the original context for each component, to create a final list of 55 categories (Table E.1).

For the third research question about capacity constraints on ranchers' and specialists' rangeland management, we coded participants' responses to an interview question in which we asked whether capacity, like funding and personnel, affected their management. We iteratively coded emergent themes within their responses.

Group-level Differences

To understand if social group identity or the local environment shape different conceptualizations of rangeland management, we ran a fisher's exact test of independence (two-sided) using R (v4.1.2) to test for significant differences between the proportion of participants in each social group (rancher or agency) and each subregion (NE or SW) who mentioned an objective or goal (Agresti, 2002; R Core Team, 2021).

Mental Models of the System

The mental models in this study focus on management in the context of landscape health and ecological sustainability. However, it must be noted that ranchers and agency specialists have additional management responsibilities not fully represented by the scope of this analysis. Ranchers often have other management tasks related to farming and the maintenance and care of their livestock. Agency specialists often address a wide range of concerns including recreation, riparian area condition, and endangered species. While those aspects of the management system are present in the mental models, they are referenced broadly, such as "ranching operation" or "threatened species," and are represented in connection to other ecological components of the system. If participants brought up unprompted references to riparian areas in terms comparable to those used for upland management (e.g. riparian area "health"), we included it as part of their mental model of rangeland management.

We used the connections between components of the system to build network graphs representing the participants' mental models of rangeland management for each social group and subregion (Knoke and Yang, 2008; Moon et al., 2019). We removed duplicate connections wherever an interviewee mentioned the same source-target connection multiple times, but retained the information about whether the source node was designated as a "landscape health indicator," a "management indicator," and/or a "driver" for subsequent analysis. We then calculated the proportion of rancher or agency interviewees for each subregion that mentioned each source-target connection and assigned that value as the weight of the edge connecting each pair of nodes.

The directional relationship between the source-target connections and the weights on the connection edges enabled us to create a directed, weighted network in R using the tidyverse (v1.3.1) and igraph (v1.2.11) packages (Csardi and Nepusz, 2006; Wickham et al., 2019).

To determine which components of the system are most closely connected in each network, we ran the leiden community detection algorithm in R using the leiden package (v0.3.9) (Kelly, 2021; Traag et al., 2019). The leiden community detection algorithm creates communities, or what we will refer to as "clusters", of nodes, in which there are more connecting edges within each cluster than there are between clusters. The algorithm assesses the quality of the cluster detection using a function called modularity (Blondel et al., 2008). We included edge weights and directionality in the cluster detection calculation and assigned the resolution parameter for modularity to be one (Traag et al., 2019). The resolution parameter determines whether there are more, or fewer, clusters detected. The algorithm repetitively moves nodes to different clusters to identify which grouping maximizes within-group connectivity and increases the modularity value.

To understand the most important components of agency specialists' and ranchers' mental models, we used weighted degree centrality as a proxy for importance (Barrat et al., 2004). Degree centrality calculates the number of connections a node has to other nodes in a network. Weighted degree includes the weight of the edges to account for the proportion of participants who connected that node to other nodes. In a directed network, total weighted degree equals the sum of the number of connections going into a node and the number of connections leaving a node (Knoke and Yang, 2008). We calculated weighted degree for all nodes in each network using the igraph package in R (Csardi and Nepusz, 2006). The most connected nodes in each network provided a basis for comparisons of the importance of components in participants' mental models.

To understand what components are central to processes in the system, we calculated betweenness centrality for the nodes in each network using igraph in R (Brandes, 2001; Freeman, 1978). Betweenness centrality calculates which nodes lie along the pathway between other nodes in the network, acting as a connecting node (Knoke and Yang, 2008). Nodes that are critical to multi-step relationships in the network, like the steps in an ecological process, have higher betweenness calculations (e.g., if cheatgrass connects to litter, and litter connects to fire in the network, litter would have a higher betweenness score). We modified the parameter inputs for the betweenness function to include network directionality and edge weights in the calculations. The nodes with the highest betweenness centrality in each network provided a basis for understanding the components most central to processes within the system.

We created visual representations of the mental models using the graphlayouts (v0.8.0) and ggraph (v2.0.5) packages in R (Lin Pedersen, 2021; Schoch, 2022). The total weighted degree of each node determined its size in the graph, with the bigger nodes having a higher total weighted degree. We used a customized layout combined with a radial centrality layout to group nodes by their leiden cluster and position nodes with the highest betweenness centrality value toward the center of the graph and nodes of decreasing betweenness positioned radially outward. Nodes at the very periphery of the graph thus would likely have connections coming in from other nodes but not many connections directed back out. We colored each leiden cluster based on the node with the highest total weighted degree in the cluster. We colored the edge links to match their source node color and scaled their size by their weight, with larger proportions of people that mentioned a connection represented by thicker edge links.

To identify what components ranchers and agency specialists use to evaluate the health of the land and inform management decisions, we extracted lists of all the source nodes designated as “landscape health indicators” and “management indicators,” respectively. We then calculated the number of ranchers and agency specialists in each subregion that mentioned each landscape health or management indicator. For the management indicators, we wanted to know what components are most often used for decision-making, regardless of the resulting decision, so we calculated the number of ranchers and agency specialists in each subregion that mentioned each management indicator at least once. If three or more people mentioned an indicator of landscape health or a management indicator, we regarded that as shared local knowledge (Davis and Wagner, 2003).

Unless otherwise mentioned, we performed all calculations using R (v4.1.2) (R Core Team, 2021).

Capacity Code Co-occurrence

We used coding frequencies from Atlas.ti 9 Windows to determine ranchers' and agency specialists' commonly mentioned themes when asked about constraints on their management (Atlas.ti 9, 2020). Our question specifically prompted whether they had funding or personnel constraints, so responses centered around those themes. We then used the frequencies of co-occurring themes to understand how the constraints modified, or related to, each other for each social group.

Results

Management Goals

We identified land management goals for all 17 interviewed ranchers and 12 of the 13 agency specialists. Most interviewees had a multi-faceted approach to land management that encompassed from one to five stated goals. We did not find any significant differences between the proportion of participants in the southwest and the proportion of participants in the northeast that mentioned each goal ($p > 0.05$). We did, however, find significant differences between the social groups (Fig. 2).

Agency specialists mentioned goals regarding multiple use ($p = 0.001$) and formal monitoring ($p = 0.0005$) as part of their land management goals significantly more often than ranchers did (Fig. 2). Of the nine agency specialists that mentioned “multiple use” as a goal, six described this in terms of keeping a balance, or as one agency specialist put it, “managing the resource in balance with all other uses.” The formal monitoring goals were primarily instances in which agency specialists described the importance of adhering to the standards and regulations that guide BLM management and the importance of using monitoring data to support decision-making.

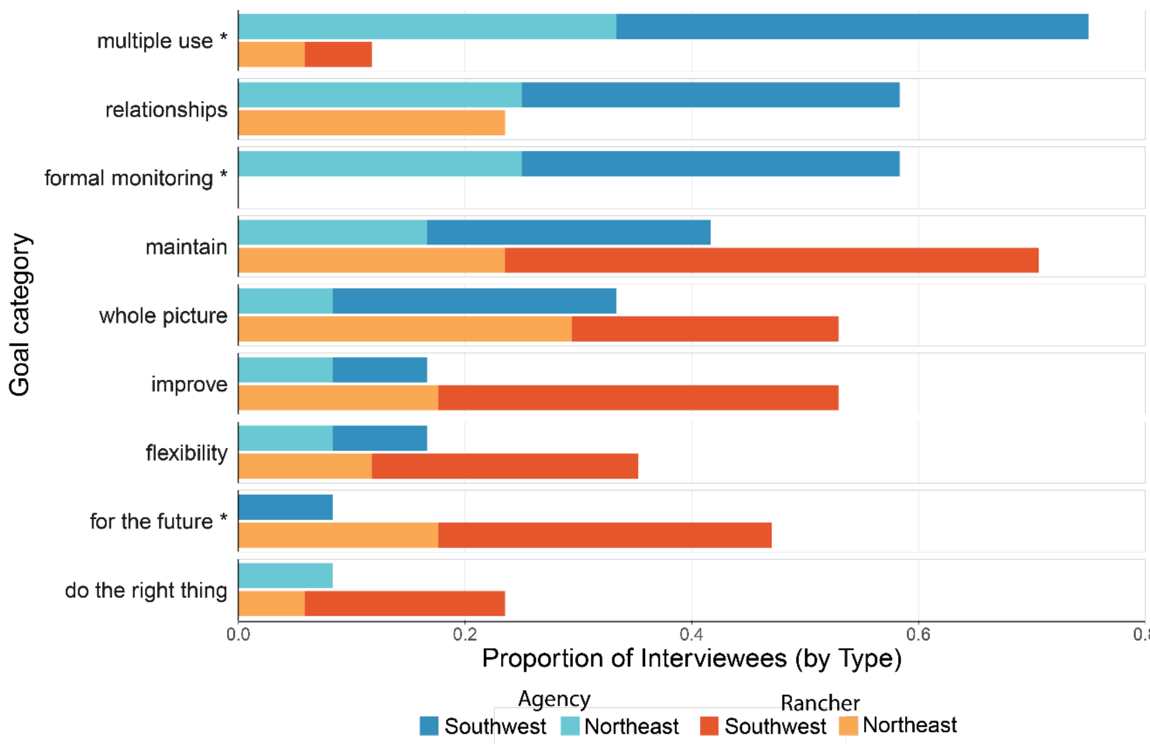


Figure 2. Participants' land management goals. Proportion of rancher (n=17) and agency specialist (n=12) interviewees that described each goal category as part of their land management philosophy. Asterisks indicate goals with a significant difference between agency specialists and ranchers ($p < 0.05$).

While 23.5% of ranchers mentioned goals related to relationships with their agency or rangeland user counterparts, typically in reference to the communication that supports such relationships, 58.3% of agency specialists mentioned "relationships" as an integral part of their management approach. As one agency specialist put it:

> *"Communication is key, and you need really good people skills… It's just being able to keep in touch with [permittees] and keep those communication lines open."*

Ranchers and agency specialists both described managing in a way that maintains the ecological condition of the rangeland (Fig. 2). Half of the ranchers who had a goal to "maintain" the land described it in terms of "taking care" of the land; for example, as one rancher said:

> *"We try and use it and take care of it, I guess, all at the same time. If you don't take care of it, you're just shooting yourself in the foot down the road."*

The "take care" description of maintaining the land is a similar sentiment to the goal of "doing the right thing" for the resource that was mentioned by four ranchers and one agency specialist. Indeed, three of the four ranchers and the agency specialist who cited wanting to "do the right thing" also had the goal to "maintain" the land. Like goals to "do the right thing", goals to "improve" the land were mentioned more often by ranchers than agency specialists (52.9% of ranchers and 16.6% of agency specialists; Fig. 2). Nine ranchers had a goal to "improve" the land, six of whom also had goals to "maintain" the land.

Ranchers' goals included descriptions of managing for the future, specifically for future generations, significantly more than agency specialists did ($p = 0.043$; Fig. 2). Of the eight ranchers with goals for the future, five ranchers described a goal of managing "for the future" in combination with goals to "maintain" or "improve" the land; for example, one rancher said:

> *"But the point is, is to keep pace or advance. And to do that, you know, we need to take care of it. So it's not just about me, it's for the next generation and the one after that."*

Participants who had goals to maintain or improve the land and to manage for the future sometimes used the terms "sustainable" and "sustainability" to describe their goals, such as one rancher who said:

> *"Sustainability is the main word… For the long term, for the future. So maybe there's a big die-off of antelope from heavy snows. Maybe in another year or two, there'll be more antelope come back. I want that grass there for them too. I want the grass and the range for the future of people."*

When ranchers expressed a broad view for management inclusive of many aspects of the system, their goal was considered a "whole-picture" goal. More than half of the ranchers (52.9%) described the importance of viewing land management through a "whole picture" or wide-view lens, with one rancher describing this aim as "holistic" (Fig. 2). He said:

> *"I try to be a holistic-type manager, so meaning that I try to take everything into account when I go to manage the lands."*

One-third of the agency specialists also had "whole-picture" goals (Fig. 2). "Whole-picture" goals are similar to "multiple-use" goals, as both goals imply a multiplicity of priorities in management. Four participants (three agency specialists, one rancher) held both "whole-picture" and "multiple-use" goals, but "whole-picture" goals were marked by qualifying statements about needing to "think about the bigger picture" or "manage for everything"

Flexibility goals expressed by six ranchers and two agency specialists included adapting management to meet the needs of the ecosystem (Fig. 2). As one rancher said:

> *"There's one thing very simple in our grazing management, is to not be in the same pasture two years in a row during the growing season. That pretty much sums it up... every year is different."*

Management Objectives

From the 30 interviews, we recorded 287 ecological objectives that fit into 25 broad categories. We only analyzed the categories mentioned by two or more people, which excluded five categories from analysis: "roots," "threatened species," "insects," "carbon storage," and "plant litter."

We did not find any significant differences between the proportion of ranchers and the proportion of agency specialists that mentioned each ecological objective ($p > 0.05$). We did, however, find significant differences between subregions (Fig. 3).

Land managers in the southwest (n=18), particularly ranchers, expressed desires to see certain outcomes regarding forbs ($p=0.024$) and fire ($p=0.024$), whereas these were not mentioned in the northeast (n=12; Fig. 3). Objectives regarding fire management were further supported by fine fuel objectives that were mentioned by 22.2% of the ranchers in the southwest. Ranchers in the southwest largely expressed wanting to reduce fine fuels and not have "devastating" or "catastrophic" wildfires, nor frequent burning in the same areas.

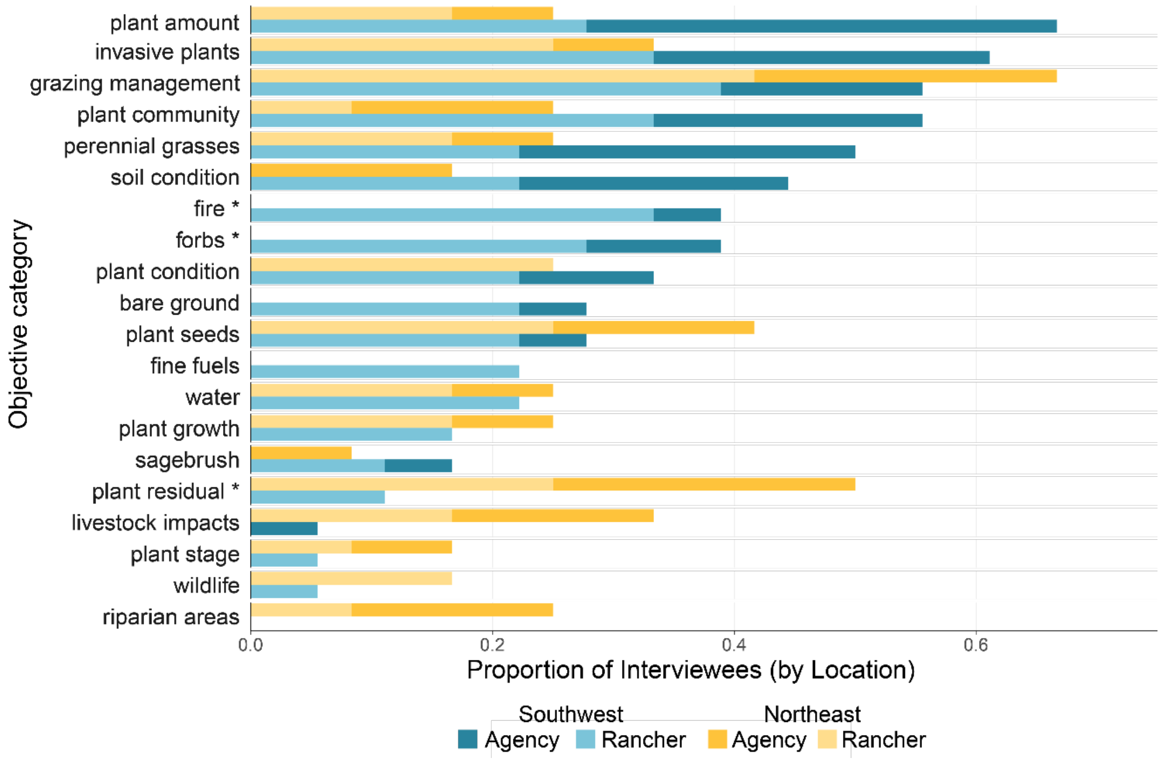


Figure 3. Participants' land management objectives. The proportion of participants (ranchers and agency specialists) in each subregion with stated objectives in each thematic category. "Fire," "forbs," and "plant residual" are significantly different between the southwest (n=18) and northeast (n=12) subregions ($p < 0.05$).

Thirty-nine percent of the managers in the southwest mentioned an objective specific to forbs (Fig. 3). Their objectives for forbs and the amount of plants are related, since managers most often described their desired forb state as the *presence* or *amount* of forbs they would like to see. The situation is similar for perennial grass objectives, mentioned by 50% of managers in the southwest, where more than half of their specific objectives for perennial grasses related to a desired *presence* or *amount* of native perennial bunchgrasses. Ranchers and agency specialists in the southwest also cited not wanting to graze perennial grasses too often or too much. In addition to the presence of forbs and perennial grasses, the twelve managers in the southwest who mentioned objectives related to the amount of plants described the importance of having plant cover on the ground. In the northeast, where objectives for the amount of plants and perennial grasses were mentioned less often, three managers mentioned objectives to see an upward trend in the amount of plants ("plant amount") and three managers mentioned objectives to have diverse and healthy perennial grasses ("perennial grasses").

The five managers (one agency specialist, four ranchers), all in the southwest, who mentioned objectives related to the amount of bare ground also had related objectives for good water retention, more perennial plants, recruitment of forbs, good spacing between plants in the plant community, and fewer invasive plants (Fig. 3). Four managers cited *not wanting* bare ground because it provides opportunities for invasive plant establishment or reduces water retention. The fifth manager, a rancher, *wanted* bare ground in amounts appropriate to native perennial bunchgrass communities, saying "that's where the forbs come in."

Managers in the southwest mentioned objectives for the plant community more often than those in the northeast (51.5% in the southwest and 25% in the northeast, Fig. 3). Managers in both regions described wanting to see diverse plant communities and a certain community composition, with many specific references to perennial grasses in the southwest. Agency specialists and ranchers in the southwest also mentioned the spacing of plants as a consideration for the plant community, expressing desires to have perennial grasses in interspaces between shrubs like big sagebrush (*Artemisia tridentata)*.

In the southwest, 61.1% of managers mentioned objectives about reducing or controlling invasive plants, mostly in reference to invasive annual grasses, with eight referring to the non-native annual grass, cheatgrass (*Bromus tectorum*), and four referring to another non-native annual grass, medusahead (*Taeniatherum caput-medusae*). In the northeast, 33.3% of managers also mentioned objectives about reducing or controlling invasive plants, typically using the broad term “weeds” to refer to undesirable plants, with only one manager (a rancher) mentioning an objective specifically related to cheatgrass.

Significantly more managers in the northeast expressed objectives about residual plant matter (p=0.034, Fig. 3). This objective was often a reference to leaving plant matter to hold down the soil, ensure there is enough forage for wildlife, or to provide the plant with the best opportunity to regrow after grazing. The plant residual objectives were similar to grazing management objectives that referenced not wanting to graze too much of a plant. Seven managers in the northeast (two agency specialists, five ranchers) and six in the southwest (two agency specialists, four ranchers) described objectives to manage grazing such that plants are not bitten twice or over-grazed, and a certain amount of the plant is left behind. Other grazing management objectives expressed in both subregions included not grazing in the same area year after year and distributing the grazing so that not all plants are grazed the same amount.

Objectives regarding reducing livestock impacts and managing riparian areas were also more commonly mentioned as objectives for managers in the northeast (Fig. 3). Ranchers and agency specialists both expressed a desire to improve or maintain riparian areas, and several of the livestock impact objectives included avoiding impacts on streams, creeks, and water sources. Other objectives about livestock impacts in the northeast related to reducing impacts on soil, like impacts on thin ridgeline soils (rancher) or wet soils (agency specialists).

All social groups (ranchers and agency specialists) and subregions (northeast and southwest) mentioned objectives about seeing grasses produce seed heads, the amount or presence of plants, the presence or condition of perennial grasses, invasive plant management, grazing management, and the plant community's composition or diversity (Fig. 3).

Mental Models of Management

Network characteristics

The convergence and divergence of managers' goals and objectives indicate complex views of rangeland management that differ by social group and subregion. To capture the complexity and highlight similarities and differences more comprehensively, we made separate networks for ranchers and agency specialists in each subregion (four networks total; Fig. 4). The networks in the northeast had 52 nodes for both agency specialists and ranchers, with 264 and 259 edges, respectively. The networks in the southwest had 54 nodes for agency specialists and 55 nodes for ranchers, with 404 and 431 edges, respectively.

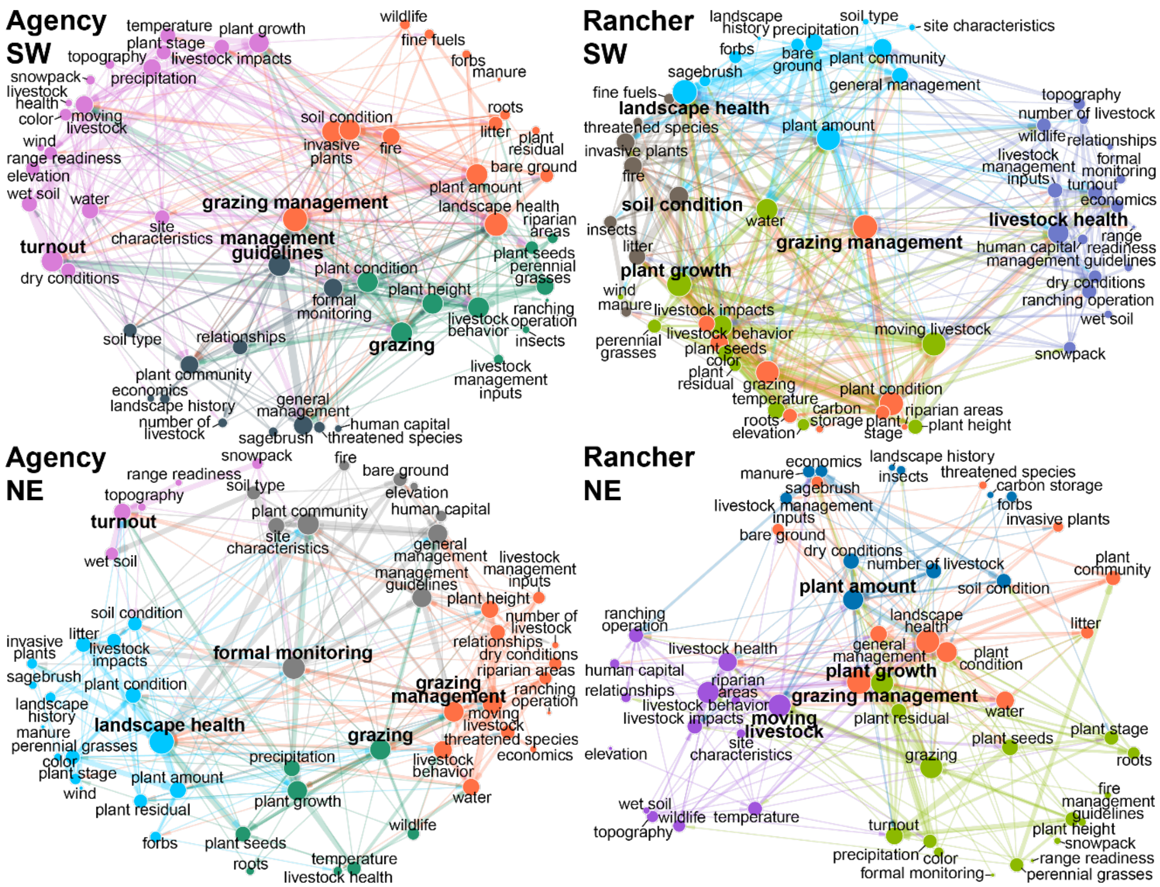


Figure 4. Mental models of rangeland management. Directed, weighted network representations of mental models of rangeland management in the southwest (top) and northeast (bottom) for agency specialists (left) and ranchers (right). Nodes towards the center of each network have higher betweenness centrality. The size of the nodes and edges represent their weighted degree and weight, respectively. Node and edge sizes are scaled so that minimum and maximum values for each network are the same size. Nodes with the highest weighted degree within each leiden cluster are labeled in bold text, and their color determines the color of all other nodes in the cluster. Edges are colored according to their source node color.

Using the leiden algorithm to detect clusters within each network, agency specialists in the southwest and ranchers in the northeast had four clusters of nodes (topics) in their mental models, and agency specialists in the northeast and ranchers in the southwest had five clusters of nodes (18 total clusters across four networks). Each cluster contained 5-18 nodes. Eleven different nodes were the nodes with the highest weighted degree in the 18 clusters, meaning that these nodes were some of the most frequently mentioned topics across the interviews.

Landscape health, grazing, grazing management, monitoring, management guidelines, moving livestock, and beginning grazing in the spring (or "turnout") were each the subject of interview questions, but how participants chose to elaborate on those topics and connect them to other nodes varied.

Management Guidelines and Formal Monitoring

"Formal monitoring" and "management guidelines" had high weighted degree and betweenness centrality scores for agency specialists in both subregions (Table 1, 2). The high weighted degree indicates that "formal monitoring" and "management guidelines" are frequently connected to other components in the mental model. The high betweenness score indicates that "formal monitoring" and "management guidelines" are also integral to the processes or pathways between other components in the mental models, bridging otherwise unconnected nodes. Agency specialists' grazing management and general rangeland management are mediated by management guidelines, such as policies prescribed in management plans and grazing permits, which are in turn informed by formal monitoring data, as explained by an agency specialist in the northeast:

> *"We're also tied into the regulations. Like, you know, when we say we're going to manage for late-seral…, you look up what that is. So, that means we want these plants here at this site. And so that's what we're managing for. So, if we go in there and we monitor and all we're getting is early-seral. That-, "well, okay. What are we doing wrong? Or was there a fire recently?" Like, "why is this all early-seral?" And then*

> *you look at the data, and maybe it hasn't been-, it's always been early-to-mid-seral. It's just not getting past that point. Maybe that's all that site can do or, you know, whatever. Maybe it's not management. Maybe it is. Maybe we-, you know, maybe we need to change the grazing or maybe it's wild horses, you know, so we pinpoint that…So it's like public information what we're managing for right? It's in our RMP-range management plan, like we're managing for late-seral, that's what we want to be. We do our monitoring saying this is what it is right now based on our current management…"*

Management guidelines, such as ecological site descriptions, also help agency specialists determine the reference plant community for the areas they manage. Agency specialists use the plant community as a management indicator to inform turnout of livestock and to guide adjustments to management in the long-term (Table 3). Trends in the plant community might cue changes to the grazing plan when permits are set to be renewed, and the plants that are present in the plant community might affect turnout decisions. In agency specialists' mental models, the "formal monitoring," "management guidelines," "general management," and "plant community" nodes are in the same leiden cluster, indicating strong connections to each other (Fig. 4).

Table 1. Nodes with the highest weighted degree centrality. The nodes with the ten highest weighted degrees for ranchers' and agency specialists' mental models in each subregion, listed in descending order. Circles denote nodes that are also considered indicators in participants' mental models of management (filled circles represent landscape health indicators, open circles represent management indicators).

Agency				**Rancher**			
Southwest (n=8)		Northeast (n=5)		Southwest (n=10)		Northeast (n=7)	
node	degree	node	degree	node	degree	node	degree
grazing management	8.9	landscape health	9.8	landscape health	7.4	grazing management	6.9
landscape health	8.0	formal monitoring ○	8.2	grazing management	7.3	landscape health	6.3
management guidelines	6.9	plant community ●○	7.4	plant growth	7.3	plant growth	5.7
invasive plants ●○	6.8	grazing ○	6.6	plant condition ●○	6.9	grazing ○	5.6
grazing ○	6.5	grazing management	6.2	plant amount ●○	6.8	moving livestock	5.6
turnout	6.5	moving livestock	6.0	moving livestock	6.8	livestock behavior ○	5.1
plant amount ●○	6.4	plant growth	6.0	grazing ○	6.4	plant amount ●○	4.6
livestock behavior ○	6.3	management guidelines	5.8	water ○	5.4	plant condition ●	4.6
plant condition ○	6.0	general management	5.8	livestock health ●○	5.2	livestock health	3.7
plant height ○	6.0	livestock behavior	5.0	livestock behavior ○	5.0	water	3.4
soil condition ●	6.0						

Table 2. Nodes with the highest betweenness centrality. The nodes with the ten highest betweenness scores for ranchers' and agency specialists' mental models in each subregion. Nodes are listed in descending order of betweenness centrality. Circles denote nodes that are also considered indicators in participants' mental models of management (filled circles represent landscape health indicators, open circles represent management indicators).

Agency				**Rancher**			
Southwest (n=8)		Northeast (n=5)		Southwest (n=10)		Northeast (n=7)	
node	score	node	score	node	score	node	score
grazing management	377.8	formal monitoring ○	426.2	grazing management	522.3	grazing management	305.3
management guidelines	293.5	precipitation	218.6	water ○	326.0	plant growth	303.9
formal monitoring	244.9	grazing ○	205.9	plant amount ●○	285.7	plant residual	253.4
plant condition ○	227.3	plant growth	171.9	moving livestock	196.2	general management	236.8
invasive plants ●○	210.4	management guidelines	171.8	soil condition	151.3	landscape health	220.3
soil condition ●	201.9	landscape health	162.3	livestock health ●○	146.2	plant condition ●	211.7
site characteristics	191.8	plant condition ●	158.6	livestock behavior ○	146.1	moving livestock	200.6
fire	179.2	livestock impacts	152.0	livestock management inputs	141.3	plant amount ●○	186.9
relationships	138.7	grazing management	150.0	livestock impacts	133.2	grazing ○	166.9
plant height ○	134.2	site characteristics	131.3	plant growth	132.2	riparian areas	156.1

<u>Relationships</u>

For agency specialists in both subregions, the node "relationships" also connected to "grazing management" (Fig. 4). Relationships in which agency specialists could communicate and coordinate with permittees helped agency specialists to adjust pasture rotations or grazing timing. For agency specialists in the northeast, "relationships" was in the same leiden cluster as "grazing management," with 60% of agency specialists making the connection (Fig. 4). "Relationships" had a high betweenness score for agency specialists in the southwest, where a variety of situations like the height of the plants, dry conditions, or amount of grazing could prompt having conversations with permittees to adjust management or address issues, as an agency specialist in the southwest described:

> *"If I see something going on utilization-wise, I'll have the conversation with the permittees that, you know, "here's what's going on phenologically and morphologically with these plants. It can handle it once in a while or maybe once every few years, but long term, this is gonna start to stress things out and kill things off."*

<u>Grazing</u>

"Grazing" was frequently connected to other components in all mental models and often informed management decisions, particularly grazing management (Table 1, 3). For example, where and when cattle grazed last year helped managers to adjust pasture rotations or timing in grazing management (Fig. 4).

Grazing and grazing management was also associated with plant growth and plant condition, though the connection was mentioned more often by ranchers than for agency specialists — with the "grazing management" and "plant condition" nodes grouped together in the same leiden cluster for ranchers, but not for agency specialists (Fig. 4). Ranchers often described how grazing dead plant material on dormant plants and grazing a managed amount at the right time helps maintain healthy plants and encourages plant regrowth, as a rancher in the southwest described:

> *"I try to find the right amount of use. Like the basal health on all of these plants: Graze [the plants] off at the right season [and] let them*

> *get to reproductive stage. I think if you ever graze them after they get to the reproduction stage, they've got a chance at maximum root growth; [The plants] go into dormancy [and you] leave enough energy in the basal plant where they're gonna come back good. But you've taken off the old feed, so when new feed grows, you're gonna get more root growth which then helps porosity…in the soil.*"

For both ranchers and agency specialists, grazing and grazing management were associated with impacts on plant condition more often in the southwest, where "grazing" and *"*plant *condition"* were in the same leiden cluster in their mental models. In the northeast, ranchers and agency specialists more often associated grazing with impacts on plant growth, with "grazing" and *"*plant *growth"* in the same leiden cluster (Fig. 4). Plant condition referred to the health, robustness, and palatability of plants, while plant growth referred to a plant adding biomass to itself through the act of growing or regrowing (Table E.1).

<u>Vegetation</u>

Agency specialists and ranchers in both subregions considered the plant community to be an indicator of landscape health (Table 3). The features of the plant community that indicated landscape health for each social group were similar in that both ranchers and agency specialists looked at the diversity of the plant community, but differed in that agency specialists more often referenced the *composition* of the plant community, while ranchers more often referenced the *spacing* of plants within the community.

Table 3. Landscape health and management indicators. Indicators of landscape health and of management decisions mentioned by three or more agency specialist or rancher interviewees in the southwest and northeast subregions. Indicators are listed in descending order of use as a management or landscape health indicator across social groups and subregions. Filled circles represent landscape health indicators, open circles represent management indicators.

● - landscape health indicator ○ - management indicator	Agency		Rancher	
Category	Southwest (n=8)	Northeast (n=5)	Southwest (n=10)	Northeast (n=7)
plant amount	● ○	●	● ○	● ○
bare ground	● ○	● ○	● ○	
plant community	● ○	● ○	●	●
plant condition	○	●	● ○	●
grazing	○	○	○	○
invasive plants	● ○	●	○	
plant height	○	○	○	○
plant seeds		●	● ○	○
plant stage	● ○		● ○	
livestock behavior	○		○	○
litter		●	●	
livestock health			● ○	
water		○	○	
wet soil	○	○		
dry conditions				○
formal monitoring		○		
plant growth	○			
precipitation	○			
range readiness	○			
wildlife			○	
soil condition	●			

Plant growth and plant condition had high weighted degree and betweenness scores for most mental models, evidencing their centrality in participants' rangeland management (Table 1, Table 2). Plant condition was a common indicator of landscape health for managers in both social groups and subregions (Table 3). Managers recognized the condition of plants in a healthy landscape to be robust and healthy, typically referring to perennial bunchgrasses. In the southwest, plant condition also acted as a management indicator for both social groups for actions such as turnout, grazing, and moving livestock, but was used most often by ranchers to inform adjustments to grazing management (Table 3).

Plant amount was one of the most common indicators of landscape health, with more than 50% of ranchers and agency specialists mentioning it in each subregion (Table 3). The amount of plants was used to cue management decisions in several mental models, particularly for managers in the southwest, where it primarily informed decisions about the timing and duration of grazing, turnout, and moving livestock (Table 3, Fig. 4). Plant height was also used to inform decisions about turnout and moving livestock for all social groups and subregions (Table 3, Fig. 4).

For ranchers and agency specialists alike, the maturity of plants, such that they flower and set seed—represented by the nodes “plant seeds” and “plant stage”—played an important role in their mental models. Though mentioned at least once by all social groups, for ranchers in both subregions, seed production was a management indicator cueing the opportunity to graze (Table 3). “Plant seeds” and “grazing” were in the same leiden cluster for ranchers in both subregions. Over one-third of ranchers (35.3%) also connected livestock impacts to seeds, though the connection was most prominent in ranchers’ mental model in the southwest, where “plant seeds” and “livestock impacts” were in the same leiden cluster. As one rancher in the southwest explained:

> *"There are certain times that that ground needs to be manipulated such that it's reseeded i.e., you know, rest, so that it goes to a seed head. The livestock then, when they come in, knock the seed head off to the ground and help plant that seed with the hoof action and help, you know, create better ground cover."*

For agency specialists in the northeast, seed production was an indicator of a healthy landscape (Table 3). For agency specialists in the southwest, plant stage, defined as the phenology, timing of maturity, and dormancy of plants, was more commonly referred to than seed production. In the southwest, ranchers and agency specialists used plant stage, and particularly flowering, as a management indicator and an indicator of landscape health (Table 3). Plant stage cued different management decisions for ranchers and agency specialists in the southwest, with ranchers using plant dormancy, usually in the fall, to cue an opportunity to graze, while agency specialists used plant phenology, usually in the spring, as a cue to turn out or move livestock (Fig. 4).

"Invasive plants" and "landscape health" were in the same leiden cluster for agency specialists in both subregions (Fig. 4), as invasive plants evidenced poor landscape health or changing conditions (Table 3). For agency specialists in the southwest, "invasive plants" had a high betweenness score (Table 2). In their mental model, twelve different components of the system could influence the presence and amount of invasive annual grasses, while invasive annual grasses, in turn, connected out to 18 components, largely influencing grazing management, litter, fire, and landscape health. Ranchers in the southwest also described a relationship between invasive annual grasses, litter, and fire (Fig. 4). Managers in the southwest expressed concerns about the amount of fine fuels and litter created by these annual grasses. Managers also described the role fire can have on soil condition, either adding nutrients or sterilizing the soil, depending on the fire severity. “Invasive plants,” “litter,” “fire,” and “soil condition” were all part of the same leiden cluster for both social groups in the southwest (Fig. 4).

Both ranchers and agency specialists in the southwest mentioned using invasive plants as a management indicator most often to cue grazing management decisions, but also to inform the amount of grazing, the timing of turnout, moving livestock, or other management actions, like applying herbicide (Table 3). Ranchers and agency specialists in the southwest held divergent views of the effects of grazing on invasive annual grasses. Agency specialists in the southwest more often described how grazing increased invasive annual grasses by opening up new areas to invasion. They also mentioned how an increase in invasive grasses might require reduced spring grazing or an adjusted grazing approach. Ranchers in the southwest, on the other hand, more often described grazing as decreasing invasive annual grasses, and they used invasive plants as a cue to alter the timing and intensity of grazing so that they could graze invasive annual grasses in the spring or at other times when livestock are most likely to eat them.

Livestock

“Livestock behavior” was important for all social groups and subregions and had a high weighted degree in all mental models. Managers used livestock behavior (e.g., what they are eating, how they are distributed, and if they lie down contentedly in the morning or not), as a cue to move livestock to a different area (Table 3). As a node with one of the highest betweenness scores, moving livestock is an important part of maintaining processes in ranchers’ rangeland management system for both subregions

(Table 2, Fig. 4). The use of livestock behavior as a cue to move livestock was mentioned more often by ranchers than agency specialists, with 52.9% of ranchers connecting "livestock behavior" to "moving livestock," compared to 30.8% of agency specialists. Ranchers explained that livestock behavior was a sign of what is happening on the ground, like the amount or condition of plants and water, as explained by a rancher in the southwest:

Rancher: "You look at the plant and the body condition on the cows. You need to be there by 8:30 in the morning and see what the cattle are doing for behavior."

Researcher: "Why 8:30?"

Rancher: "Because a cow will eat from daylight and if she's full, she'll lay down at 9:00 or 9:30, her energy requirements are still met. And if not, she'll still be eating. And if she's not getting any of that done, she's traveling, she's walking."

Researcher: "And that tells you something about the food that's out there?"

Rancher: "It tells you everything about what's going on, on the ground."

Ranchers in both subregions also made strong connections between livestock behavior and livestock health, describing how what the cattle eat and how they are distributed leads to healthier, happier cattle, as one rancher detailed:

Researcher: "Is distribution of livestock something that you're looking at when you go out?"

Rancher: "Oh, absolutely, yeah."

Researcher: "Okay. And it tells you kind of-, what is it telling you?"

Rancher: "It's telling me that the cows are happy and that there's plenty of forage and we're leaving plenty of forage left for the wildlife."

Researcher: "Okay."

Rancher: "Space [in their distribution] is good."

Livestock health was an indicator of landscape health for 40% of ranchers in the southwest (Table 3).

Agency specialists also used livestock behaviors like what the livestock were eating as an indication of which plant species to monitor and how the livestock were distributed (e.g. congregated or bunched) as an indication to adjust management in order to avoid concentrated grazing or prevent livestock impacts (Table 3).

Soil

Wet soils acted as a management indicator, informing the timing of livestock turnout, for 12 of the 13 agency specialists (Table 3). Agency specialists often considered wet soils to be a concern for turnout. The impact of wet soils on turnout was related to snow in the northeast, where 60% of agency specialists referred to how snowpack influences turnout decisions (Fig. 4). Three agency specialists in the northeast also expressed that the soil type (i.e., clay soil) exacerbates concerns about wet soil. As one agency specialist in the northeast explained:

> *"Maybe if it's like really cold and snowier. Some places if it's really wet and you have that bentonite clay… It gets compacted easier and it's just more erodible. And so, if it's really wet, that can kind of, cause problems… So [wet soil] depends on where we're at and what the soil is. But sometimes we think about that, for sure".*

The agency specialists expressed concerns about livestock damaging soils with their hooves when the soils are very wet, as described by an agency specialist in the southwest:

> *"So if it's like a really, really wet spring, we have withheld turnout to later until the soils dry out. Usually only takes a couple days, so [the ranchers are] pretty patient, because also in the spring when the rains came, the wind comes as well… it's kind of like a blow dryer. So it rains, we withhold turnout for a couple days, and then when the soils are more able to withstand that hoof impact, then we allow them to go out."*

This concern over livestock impacts on soils is particularly true for agency specialists in the southwest, where soil compaction, biological soil crusts, and soil stability are considered indicators of landscape health (Table 3). "Wet soil" and "turnout" were in the same leiden cluster as "snowpack" for agency specialists in the northeast and in the same cluster as "livestock impacts" for agency specialists in the southwest (Fig. 4).

In the southwest, soil condition had high betweenness scores (Table 2), indicating its centrality in ranchers' and agency specialists' mental models. They most frequently linked the condition of the soil to landscape health as both an indicator (agency specialists) and driver through its promotion of plant growth (ranchers). While agency specialists in the southwest more often expressed concerns about livestock impacts on soil condition, primarily in the spring, ranchers in the southwest spoke more often about how livestock integrate litter into the soil with their hooves to improve the soil condition, primarily in the fall, as one rancher in the southwest explained:

> *You have to have that litter and you have to have some way to let it get broke down and reintroduced back into the soil, because that's what makes our soil. So, it's a life cycle. And at the end of that life cycle, you have to have some way to be able to reintroduce the dead plants and litter back into the soil. And we do it with hoof action. That's our mentality – is more hoof action we can get on that dead stuff, the more it gets churned into the soil, the faster it decomposes, and the faster it becomes nutrients in the soil for the next plants. So we're constantly looking at that. Soil….and dead plants, the litter reintroduction into the soil, and the soil, you know, they go hand in hand…You've got lots of dead plants that have grown up, whether it be grass or whatever, mostly grass, that have grown up and died and produced seed, and now they're ready to be, with hoof action, reintroduced back into the soil. And so, winter does it, we get a heavy snowpack so that helps and it*

helps break those plants down, but it doesn't help as fast as hoof action. So we try to do that with hoof action.

Both social groups mentioned bare ground as an indicator of landscape health, with 53.8% of agency specialists, split across both subregions, and 35.2% of ranchers, mainly in the southwest, mentioning it (Table 3). Participants observed the amount and trend of bare ground as an indicator of changing landscape health. The mere presence of bare ground was not as much of a concern, as several participants explained that bare ground naturally occurs in certain native bunchgrass communities, and the trend and amount were therefore dependent on location, as one agency specialist in the southwest said:

"Now how much bareground that is determined by, again, maybe looking at the ecological side to understand how much should be out there…versus what you see…"

Water

As expected for semi-arid rangelands, all four mental models referred to the effect of precipitation on plant growth. "Precipitation" was in the same leiden cluster as "plant growth" for all but the ranchers in the southwest, who instead had it in the same cluster as "plant amount." That distinction may be largely due to semantics, as participants from each social group and subregion described precipitation's positive effect on plant growth and recovery, but an equal number of ranchers in the southwest described precipitation's effect in terms of the amount of forage produced. Related to precipitation, "water", defined as the availability of water in the system, had an overall high weighted degree for ranchers in both subregions (Table 1). Water is also an important driver of livestock behavior and a cue to move livestock in several mental models (Fig. 4, Table 3). One rancher in the northeast explained:

> *"Water availability is huge. An old guy told me you can keep cows on a mountain, when there's no feed, but you can't when there's no water. Water is big."*

This is particularly true in the northeast for both social groups, where water was described to influence the distribution of livestock and thus their impacts, particularly on riparian areas (Fig. 4). In the northeast, "water" was frequently connected to "landscape health" (Fig. 4). As one agency specialist in the northeast described:

> *"Water is probably one of the best tools we have for properly distributing cows. And if you're low on water, and you can't distribute cows across the landscape, you're going to concentrate impacts."*

Constraints on Capacity

A subset of ranchers and agency specialists responded to the questions about constraints on their capacity to reach their management objectives and goals. Fourteen ranchers and ten agency specialists answered the question. Two of the fourteen ranchers said they did not have capacity constraints, and one of the ten agency specialists felt that he could not speak adequately to the question at the time of the interview.

Agency Specialists' Constraints

Agency specialists in the subset in both subregions most often spoke about the amount of work and personnel constraints, with 90% of the subset who responded mentioning too much work, and 70% mentioning lack of personnel (Fig. 5). Descriptions of the amount of work included the pressure to complete monitoring within a limited seasonal window, procedural data analysis and writing associated with NEPA (National Environmental Policy Act of 1970), and two mentions of the sheer scale of acreage in agency specialists' jurisdictions. Of the quotes about having too much work, 33.3% referenced NEPA, 77.7% of the quotes mentioned monitoring, and 33.3% of agency specialists described the amount of work in terms of just not having time for everything.

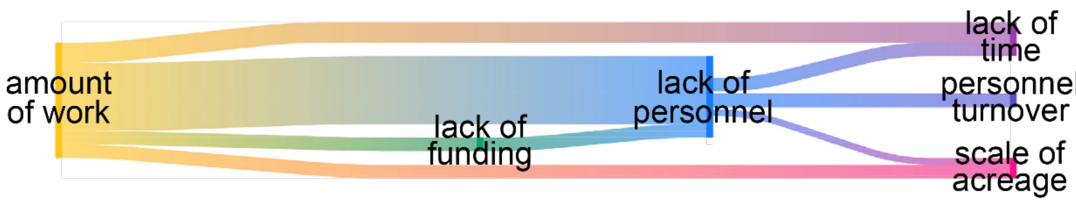


Figure 5. Co-occurrence of capacity constraints for agency specialists (n=10). Among 10 agency specialists that answered the question, the amount of work was mentioned as a constraint by 90% of them, and lack of personnel was mentioned by 70% of them. Line thickness represents the frequency with which each type of constraint was mentioned, colors represent different constraints, and connections between constraints indicate the frequency with which those constraints were mentioned together.

Having too much work was closely related to personnel constraints, with 66.6% of agency specialists in the subset who responded mentioning these constraints in relation to each other (Fig. 5). This relationship between a lack of personnel and the amount of work was described by one agency specialist as:

"We have had so many openings in our field office. So, we've kind of gotten really good at wearing more than two, three, hats which has actually become a detriment to us. So, you know, the more you do, the more they give you. And they keep saying to do less with less, but that's

not it. They really do want us to do… more with less. So when we do have an opening, we're really good at just absorbing that. We just absorb it all the time. Till that little sponge can't soak up any more, we're gonna do it."

Agency specialists also emphasized the importance of seasonal staff to be able to collect all their monitoring data. At the time of the interviews, agency specialists in the northeast said they had seasonal staff to collect the monitoring data and expressed the significance of that contribution:

"The fieldwork-, we have a really good monitoring crew and they come back every year. So, that's how that gets done. So, I think we're pretty much able to get all the fieldwork we want to get done done."

In contrast, at the time of the interviews, agency specialists in the southwest emphasized how much they needed seasonal employees. For example, agency specialists in the southwest said:

"All of that monitoring takes a lot of time, a lot of effort, and a lot of staff. And we've been so cut back and cut down on seasonal staff, we haven't even had seasonals to do any of that [trend and utilization] monitoring in the last year or two, at least not consistently."

"I just feel like there's so much more I could do if… it was either split amongst more resource specialists, or if we had like more field technicians to help with monitoring and getting all the data collected."

Capacity constraints were also related to personnel turnover. While four ranchers mentioned turnover in agency staff as a frustration, supporting other research describing ranchers' concerns (Weeks and Packard, 1997), four agency specialists cited turnover as a constraint on management capacity, expressing concerns over a lack of continuity or consistency in data management and project priorities. As one agency specialist in the northeast explained:

> *"The biggest thing is like, having the personnel to not only collect the data, but then to actually use it in the future. Um, you know, especially because there tends to be so much turnover in federal agencies… When I was in my last office, I wrote an EA [Environmental Action related to NEPA], and put in all these, you know, nice grazing standards and developed monitoring. Well, I'm gone now. And if that position sits vacant for another year, it's going to get forgotten about. So we need like, some way to be more cohesive, like either keep people or have enough people to make that data, like, really easily accessible."*

Four agency specialists mentioned lack of funding as a constraint, describing how funding is needed for rangeland restoration or improvement projects and how low funding requires careful reconsideration of top priorities.

<u>Ranchers' Constraints</u>

Funding was a larger capacity constraint for ranchers who answered the capacity question (n=14) than it was for agency specialists, expressed similarly in both subregions, with 57.1% of ranchers in the subset mentioning a lack of funding (Fig. 6). Lack of funding overlapped with lack of personnel 62.5% of the time, with ranchers most often mentioning the expense of labor (Fig. 6). Three ranchers further qualified their funding constraints by describing the influence of the economics of livestock markets (Fig. 6). Of the ranchers with funding constraints, 37.5% described how a lack of funding can impact rangeland improvement projects, like replacing fences and reseeding areas with native seeds. If it is not funding, a lack of time (mentioned by two ranchers) constrains the ability to do projects. One rancher in the southwest said:

> *"I've got a lot a lot of projects that are on my list that I continue to want to accomplish before I check out of this game, but my two limiting factors are time and money."*

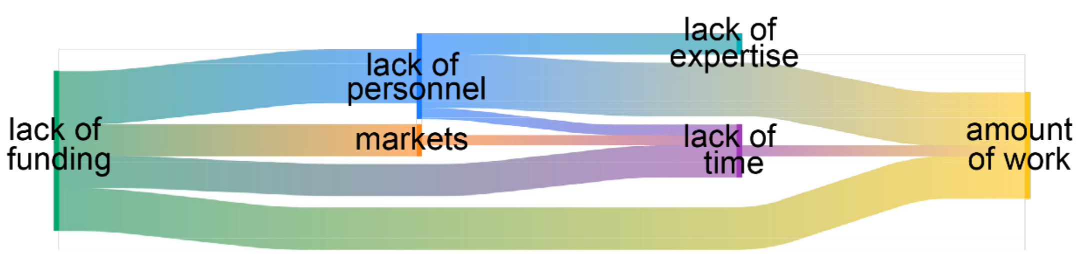


Figure 6. Co-occurrence of capacity constraints for ranchers (n=14). The co-occurrence of capacity constraints in quotes from 14 rancher interviews. Funding and lack of personnel were mentioned by 57.1% of the 14 ranchers. Line thickness represents the frequency with which each type of constraint was mentioned, colors represent different constraints, and connections between constraints indicate the frequency with which those constraints were mentioned together.

Personnel constraints was also mentioned by 57.1% of ranchers in the subset (Fig. 6). Half of the ranchers with personnel constraints referred to the challenge of finding labor, and particularly experienced labor. As one rancher put it:

> *"You can't hardly hire a person that's a big cow person. The availability isn't there. If you can hire somebody that's truly a cow*

person, I would pay them whatever, if they knew how to manage deserts and cows, but they aren't available...There's very few people that will go look and see what's going on on the ground with the livestock and the grass and then do something about it."

Four ranchers also mentioned that having sufficient personnel alleviates the time constraints and the amount of work in their management (Fig. 6).

Four ranchers described how family is an important part of the capacity of the ranch. They described this in terms of how they maintain the capacity of the ranch at a level they know they can handle as a family, how family members provide experienced labor, and how family members can get a job off the ranch if the market "stumbles." One rancher summarized these dynamics in the following way:

"We're just so used to running everything on a shoestring budget… These kids…, they have to be willing to come back and resist the urge to go out and make big money somewhere else. They have to be willing to come back and continue this process for not a lot of money, for not a lot of monetary compensation. This business isn't about that. It's rich in a lot of other kinds of compensation – the lifestyle. I can't even imagine raising kids and not being able to spend the kind of time with them that I've had to spend with these kids. And, you know, I can't even imagine a different lifestyle. So, there's some very positive things that we get out of this. But when it all comes down to it, it's the monetary part of it that drives young people away and drives them to a different industry… As far as personnel goes, it's a shoestring and you always work

> *undermanned, and your personnel is always not what it ought to be to get the job done. And so, it's a lifestyle you grow up with. And we really don't know any different… If we couldn't do it with our kids, we couldn't do it."*

Recognition of other groups' constraints was commonly mentioned throughout all agency specialists' (n=13) and ranchers' (n=17) interviews, with 76.9% of agency specialists and 70.6% of ranchers acknowledging the pressures on their counterparts' management. Nearly all (96.7%) interviewees (n=30) described the intent, benefit, or practice of working together with their agency or rancher counterparts, with two specifically citing how working together helped them with their management goals.

Discussion

Identifying Local Ecological Knowledge

Rangeland managers accumulate local ecological knowledge through experiences and observations over their lifetimes (Davis and Wagner, 2003; Hopping et al., 2016). In our study, ranchers are on average older than their agency counterparts, and they have spent a mean of more than 30 years ranching and living in Idaho. Not only have they ranched in the same areas for many years, but ranchers in our study population also spent a great deal of time on the land, with a mean of 6 days per week. Agency specialists in our study area, on average, spend less time out on the land each week than ranchers and have had fewer years of accumulated local experience. They still build local ecological knowledge through their experiences, but the centrality of management guidelines and formal monitoring in their mental models supports a hybridization of local ecological knowledge with bureaucratic knowledge about federal administration and policy (Edelenbos et al., 2011). Their knowledge may also hybridize with scientific knowledge from post-secondary education, as all agency specialists in our study population possessed a bachelor's degree or higher in a natural resources subject. Contrary to Fleischman and Briske, who proposed that federal land managers have a non-hybridized knowledge domain they termed "professional ecological knowledge," the educational background of agency specialists, their goals for policy and monitoring, and the emphasis on site characteristics in their mental models supports that agency specialists' knowledge is likely a hybridization of bureaucratic, scientific, and local ecological knowledge (Edelenbos et al., 2011; Fleischman and Briske, 2016).

Local knowledge was likely not uniformly distributed in our study population, as younger ranchers and agency specialists may not have had as much experience from which to make connections in their mental model (Hopping et al., 2016). The small sample size in the northeast, particularly for agency specialists (n=5), may have skewed findings towards the knowledge of a few knowledge-holders that were better able to articulate tacit knowledge and describe connections in the system. Elicitation of the tacit knowledge of LEK can also be challenging (Jones et al., 2014). The location where interviews were conducted could have affected the number of topics discussed and the number of connections made between components (Jones et al., 2014). Several of the interviews in our research were conducted outside on the rangeland, and as such may have resulted in richer models from some participants.

Agency specialists and ranchers were also heterogeneous groups. Several agency specialists had a ranching background, and several ranchers had post-secondary degrees in natural resources. Heterogeneous study populations can make discerning differences and similarities between groups difficult. Although we found that social groups' and subregion groups' perspectives overlapped, several key differences were evident.

Emergent Themes in Ranchers' and Agency Specialists' Rangeland Management

Differences in Management Goals

Both ranchers and agency specialists described intentions to manage for multiple priorities, which is supportive of an ecosystem approach to management (Fuhlendorf et al., 2012). An ecosystem approach considers multiple components of the ecosystem to maintain patterns and processes, and when social components are included in the patterns and processes, supports a robust social-ecological approach to management (Fuhlendorf et al., 2012; Hruska et al., 2017). Despite similar intentions, ranchers and agency specialists expressed their goals for management differently. Agency specialists used the terminology “multiple-use” to describe managing for multiple priorities and refenced the need to manage according to policy and permits of the BLM. These goals are in accordance with the mandates of their profession (Bureau of Land Management, n.d.). Contrary to other studies that describe federal land managers as divorced from evidence-based and scientific knowledge in management, agency specialists in our study centered their management around formal monitoring and expressed goals to have land management supported by monitoring data (Cook et al., 2010; Fleischman and Briske, 2016). Agency specialists used formal monitoring to evaluate livestock impacts and management effects and referenced scientific information or local knowledge about site characteristics (ecological site descriptions) to provide context for their data.

The key to agency specialists’ management approach was described as communicative and effective relationships with rancher permittees and other rangeland users. These relationships help bridge between federal agencies, which plan and implement management policies, and ranchers, who are responsible for on-the-ground implementation of the policies (Lien et al., 2017). The high betweenness centrality of “relationships” in agency specialists’ mental model in the southwest supports that agency-rancher relationships are integral to management processes, similar to findings from other research in Idaho (Wollstein et al., 2021). The centrality of relationships to agency specialists’ management goals supports assertions that social relationships may be just as important as formal monitoring for successful rangeland management (Sayre et al., 2013a). However, for agency specialists to effectively translate information and concerns in their communication, they need to understand the social context of the social-ecological system and ensure the message will be compatible with ranchers' mental models of the system (Abel et al., 1998; Weeks and Packard, 1997).

Ranchers described managing for multiple priorities as having goals to attend to many aspects of the ecosystem and to look at the "whole picture." Most ranchers desired to improve the land through their management and ensure the longevity of the resource for the future, which some described as managing for sustainability. This view is similar to ranchers in Colorado and Wyoming who chose grazing strategies that allowed them to maintain their ranching operation, ecologically and economically, over their lifetime and beyond (Wilmer et al., 2018). A subset of ranchers cited "flexibility" to adapt to changing conditions as critical to achieving sustainable management, which is a common strategy for pastoralists globally, including other ranchers in the American West (Derner et al., 2022; Galvin, 2009; Wilmer et al., 2018).

Ranchers said they want to "take care" of the resource. This terminology was also found among ranchers in California, who used the term "take care" to define conservation (Aoyama and Huntsinger, 2019). Idaho ranchers' desire to care for the land complements findings of a common land ethic among ranchers in New Mexico and Arizona and nearly universal agreement among surveyed ranchers in California that they try to conserve natural resources (Lien et al., 2017; Roche et al., 2015). Our rancher interviewees were selected through recommendations from parties involved in rangeland conservation and monitoring, which could mean they are more conservation-focused than typical ranchers in Idaho (Davis and Wagner, 2003). However, when rancher interviewees were asked if they held different goals or views from other ranchers, they felt they were generally representative of the ranching community.

Differences in Mental Models

Divergent Views on Management

An emergent theme in ranchers' mental model of rangelands was an action-oriented approach to management that they viewed as a form of conservation (Aoyama and Huntsinger, 2019). As has been found in other pastoral regions (Klein et al., 2014), livestock are a medium through which ranchers interpreted the health and condition of the land, using livestock behavior and health as ecological indicators. Ranchers' views of how livestock indicate landscape health, coupled with their goals for managing the "whole picture," evidence that ranchers perceive livestock as part of the processes in the ecosystem (Fleischman and Briske, 2016). As such, ranchers tended to view livestock and their impacts as an implementable disturbance that, if carefully managed, can aid progress towards rangeland goals. This view is illustrated by the way that ranchers connected grazing and grazing management to plant growth and plant condition in their mental models, explaining that grazing helps encourage perennial grass growth and plant recruitment. Ranchers also mentioned that grazing off the dead material on perennial grasses keeps them healthy and that grazing invasive grasses keeps them at bay. These findings are similar to research in Arizona that found almost all public lands ranching permittees surveyed believed that grazing was required to maintain vigorous rangelands (Fernandez-Gimenez et al., 2005).

Ranchers' connection between livestock impacts and plant seeds also supports a positive view of the ecological impact of livestock grazing. Ranchers reported using livestock to maintain landscape health in a way that some described as akin to a farmer planting seeds and helping plants grow. This motivation to grow more plants is likely influenced by the importance of forage production as a crucial rangeland ecosystem service for ranching communities (Roche et al., 2015; York et al., 2019). In ranchers' mental models, livestock knock down plants after they are dormant and have gone to seed, push the seeds into the ground with their hooves, and then improve the soil to help the seed grow by churning plant litter into the soil and leaving behind manure as fertilizer. Ranchers thus often look at plant seed production and the stage of the plant, particularly dormancy in fall, as indicators of when to graze. The seed-planting approach to grazing management and maintenance of grasses through grazing aligns with ranchers' goals to not only maintain the rangeland, but also "improve" it.

In contrast, agency specialists tended to express a perspective that livestock grazing is a disturbance to be mitigated, and that livestock must be closely managed to prevent negative effects to the ecosystem. Agency specialists' use of wet soils to cue turnout, plant stage to cue turnout or move livestock, and soil condition to indicate landscape health supports a perspective focused on preventative management (Aoyama and Huntsinger, 2019). The spring tended to be a time when the prevention of impacts was particularly important, with agency specialists in the southwest taking cues from plants' phenology to determine when grazing would least effect perennial grasses, and agency specialists in both subregions expressing concerns about trampling impacts on wet soils. We found that agency specialists' approach to management is similar to their counterparts in California, who tended to use terms like "preserve," "protect," and "keep" to define rangeland conservation (Aoyama and Huntsinger, 2019).

Divergent Views Across Environmental Gradients

Despite divergent management goals between social groups, ecological objectives did not differ significantly by social group, but rather by subregion. The differences between subregions suggest that elevational and climatic gradients effect management priorities and local ecological knowledge in rangeland management. The importance of place-specific indicators of landscape health has also been found in Mongolia, where pastoralists' ecological indicators varied along a climatic gradient (Jamsranjav et al., 2019). Because ecological indicators are selected to monitor towards objectives, the two are closely related, and ranchers' and agency specialists' objectives are integrated into the emergent themes from their mental models.

Semi-arid rangelands often exhibit nonequilibrium dynamics, where stochastic abiotic factors create variable plant growing conditions (Ellis and Swift, 1988; Illius and O'Connor, 1999). The way managers across both social groups and subregions described the effect of variable precipitation on plant growth supports a nonequilibrium view of system dynamics in our study area. In alignment with other research though, equilibrium and nonequilibrium dynamics in the study area may depend on the region and scale (Briske et al., 2003). In the wetter, more mountainous conditions of the northeast, managers tended to connect grazing management directly to plant growth and described objectives to maintain residual plant matter to help regrowth. In the southwest, grazing connected to the condition of the plant, and managers described objectives to have more forbs, which are largely precipitation and temperature dependent (Kitchen, 1994). The different connections in the northeast and southwest evidence that plant growth may be coupled more closely with grazing in the northeast, and that management of the plant's condition may be the most manageable step to encourage plant growth with variable precipitation in the southwest.

Additional differences between the mental models in the northeast and southwest also evidence effects of an environmental gradient on mental models of management. Managers in the northeast had more objectives for riparian areas and more emphasis on the use of water to control the distribution of livestock and their impacts. This emphasis on water likely reflects concerns for the riparian areas and rivers in the higher-elevation northeast, where anadromous fish species are a conservation concern (Idaho Department of Fish and Game, 2019). Managers in the southwest, meanwhile, emphasized the condition of the soil and the use of plants' stage of maturity as both a management indicator and an indicator of landscape health. The emphasis on plant stage, such as phenology and dormancy, may be a result of the mixed invasive annual and perennial grass plant community in the southwest. Invasive annual grasses and perennial grasses reach phenological stages and dormancy at different times and rates, which can complicate the timing and duration of grazing (Davies et al., 2021).

While invasive plants indicated poor landscape health and were cited as a management priority in both subregions, in the southwest, invasive annual grasses, such as cheatgrass and medusahead, dominated land managers' concerns. Ranchers' and agency specialists' mental models in the southwest connected the effects of annual invasive grasses to grazing management, the amount of litter, and wildfire. Their views diverged, however, according to their understandings of livestock disturbance as having either primarily desirable or undesirable ecological effects. Agency specialists saw invasive plants as a landscape health indicator, similar to agency specialists in California, who viewed invasive annual grasses as an indicator of poor rangeland health (Shapero et al., 2018) and prioritized the control of invasive plants and promotion of native perennial grasses (Aoyama and Huntsinger, 2019). Contrary to managers in California who wanted livestock to graze invasive annuals (Condon and Pyke, 2018; Shapero et al., 2018), agency specialists in Idaho have expressed concerns over this approach (Wollstein et al., 2021). Indeed, we found that agency specialists in Idaho viewed invasive annual grasses as a consequence of livestock disturbance, which should thus be mitigated by managing the disturbance. Ranchers, on the other hand, saw invasive annual grasses as a management indicator signaling a need to graze in a way that dampens invasive plant reproduction and growth, thereby using livestock disturbance as an active management tool.

Shared Knowledge in Rangeland Ecosystems

Although pastoralists' knowledge is context-based, common elements of their LEK often occur across regions (Sharifian et al., 2022). Idaho rangelands differ from many other pastoral systems politically, ecologically, and economically, but similarities can be traced between the LEK of ranchers in Idaho to pastoralists and ranchers in other rangeland systems in the U.S. and globally (Sayre et al., 2013b).

The amount of plants, plant community diversity and composition, plant condition, plant stage, and seed production were all used as indicators by both the ranchers in Idaho and other pastoral communities around the world (Jamsranjav et al., 2019; Knapp and Fernandez-Gimenez, 2009; Molnár, 2017; Reed et al., 2008; Woods and Ruyle, 2015). Specific to the western U.S., Idaho ranchers shared similarities with ranchers in Colorado and Arizona through the use of plant species diversity, condition (palatability and vigor), and abundance as indicators of landscape health (Knapp and Fernandez-Gimenez, 2009; Woods and Ruyle, 2015). Ranchers in southwestern Idaho also aligned with those in Colorado and Arizona in their use of invasive species and the growth stage of plants (e.g., seed production) as indicators for the timing of grazing (Knapp and Fernandez-Gimenez, 2009; Woods and Ruyle, 2015).

As with pastoralists globally, ranchers in our study adapted to seasonal dynamics and variable forage availability by moving livestock to more suitable areas (Galvin, 2009; Jamsranjav et al., 2019). Moving livestock had a central role in processes in the system, as evidenced by a high betweenness score in ranchers' mental models. The use of moving livestock as a connecting element between components in the system supports that it is an adaptive practice done in response to stimuli in order to effect outcomes (Galvin, 2009). Moving livestock could be considered a tool ranchers use to make progress towards their goal of maintaining or improving the land. Like herders in Spain and Mongolia, ranchers in Idaho used livestock behavior (e.g., contentedness) and livestock health as landscape health and management indicators (Fernández-Giménez and Estaque, 2012; Jamsranjav et al., 2019).

Bare ground was not as common of an indicator of landscape health as vegetation indicators were in our study, which differs from how prominent bare ground is as an indicator in other rangeland research (Jamsranjav et al., 2019; Knapp and Fernandez-Gimenez, 2009; Reed et al., 2008; Veblen et al., 2014). For agency specialists, the importance of the amount of plants and its use as an indicator is similar to research that found federal agency personnel in the western U.S. most often cited ground cover as a top priority for monitoring rangeland condition and livestock effects (Veblen et al., 2014).

Similarities between ranchers' and agency specialists' perspectives in the study were also evident. Priorities for vegetation management were shared between both groups (Aoyama and Huntsinger, 2019), with the amount of plants, diversity of the plant community, and plant height each serving as important characteristics for interpreting the rangeland and making management decisions. Grazing management was central for all mental models and aided managers in their objectives to promote perennial grasses (Condon and Pyke, 2018). Though ranchers and agency specialists may differ in their view of the positive and negative impacts of grazing disturbance, both groups recognized the importance of managing livestock grazing as a disturbance to maintain the rangeland. Landscape health was important for all groups and, for ranchers, directly related to livestock health (Aoyama and Huntsinger, 2019; Hopping et al., 2016).

Overlaps in indicators and perspectives in ranchers' and agency specialists' mental models may indicate that shared experiences occur in the system (Abel et al., 1998), either due to geographic proximity, through the grazing permitting processes, or by a method not evaluated in this study, like workshops and trainings. The hybridization of scientific and bureaucratic knowledge with local ecological knowledge may also contribute to mental model overlaps (Jones et al., 2011).

Limitations and Implications

The mental models of rangeland management that we created do not include an explicit temporal dimension. Yet, in order to untangle effects of livestock grazing from the effects of climate, monitoring must be conducted for long timespans, sometimes for more than 20-25 years (Briske et al., 2003; West, 2003a). Many indicators, like the amount of bare ground or the composition of the plant community, change slowly, while others such as plant height and condition respond more quickly (Derner et al., 2022). Formal monitoring protocols suggest that qualitative assessment should be supplemented by formal quantitative monitoring as quantitative data can be used to detect long-term trends that may be harder to observe qualitatively (Lepak et al., 2022; Pyke et al., 2002; West, 2003a; Woods and Ruyle, 2015). However, formal quantitative data is often lacking, and in its absence, qualitative assessments are used to make management decisions (Veblen et al., 2014; Woods and Ruyle, 2015). In addition, we found that limitations in agency specialists' ability to maintain data due to turnover or a lack of personnel affects their ability to act on the results of monitoring data.

LEK accumulated over many years, such as by ranchers in our study, contains observations of the ecosystem that can provide insights into the fluctuations and dynamics of longer-term changes (Hopping et al., 2018; Reyes-García et al., 2016). While some research proposes that this continual observation of fluctuations masks ranchers' ability to see trends in the ecosystem (Knapp and Fernandez-Gimenez, 2009), other research finds that local ecological knowledge-holders are attuned to long-term changes in ecosystem patterns and processes (Fernández-Giménez and Estaque, 2012; Hopping et al., 2016, 2018; Klein et al., 2014). LEK-holders' ability to see patterns and identify processes in the system facilitates an ecosystem approach to management that can help match monitoring to the scale of ecological processes, including both short-term adjustments and identification of long-term trends (Cumming, 2011; Fuhlendorf et al., 2012). Moreover, collaborative management that integrates LEK is also more likely to monitor a more holistic suite of indicators that includes both ecological and social-ecological components (Reed et al., 2008; Thompson et al., 2020). The management practices of ranchers and agency specialists are thus complementary, where observational assessments by ranchers can aid in detecting long-term shifts, identify the need for short-term adaptive management, and enhance social-ecological management, and agency specialists' formal monitoring can quantitatively monitor long-term trends to help untangle climate and grazing effects (Aminpour et al., 2021; Gagnon and Berteaux, 2009; Lepak et al., 2022).

Lack of workforce capacity may also impede agency specialists' and ranchers' progress toward management objectives and goals. The amount of work under an agency specialist's purview and the lack of personnel to distribute the work means that balancing multiple uses and monitoring the system may be hindered. Other research also suggested that lack of time, money, and personnel prevent consistent monitoring (Veblen et al., 2014). For ranchers, a lack of financial capital (funding) and a lack of personnel with the expertise to manage livestock may hinder the ability to improve the rangeland or limit their ability to manage for future generations. These constraints, coupled with potential communication issues and frequent staff turnover, have been identified as barriers for the implementation of conservation practices for ranchers and managers (Aoyama and Huntsinger, 2019).

Social-ecological systems approaches require that people, such as livestock producers, are an integral part of the management process to properly manage the system (Felt, 2008; Hruska et al., 2017). Communication and relationships are important to effective management (Sayre et al., 2013a; Weeks and Packard, 1997). Agency specialists acknowledged the importance of relationships in their management goals and mental models. Recognition of the similarities and differences in their land management counterparts' mental models could help communication between ranchers and agency specialists, if they adjust their communication to fit the contexts of their counterpart's mental model (Abel et al., 1998; Friedel et al., 2004).

Most interviewees mentioned the practice or benefit of working together and recognized capacity limitations of their rangeland management counterpart. Working together to manage rangelands can help alleviate capacity constraints and create a more robust understanding of the social-ecological system (Aminpour et al., 2020). Similar research in Arizona described how ranchers and agency personnel agreed that collaboration has useful outcomes (Fernandez-Gimenez et al., 2005). A robust understanding of the system that incorporates LEK may allow managers to better match management to the ecological processes occurring at the local scale (Cumming, 2011).

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APPENDIX A

Major Land Resource Area Site Descriptions

Table A.1. Major Land Resource Area site descriptions. Site descriptions of the Major Land Resource Areas in the research study area. (United States Department of Agriculture and Natural Resources Conservation Service, 2006)

	Owyhee High Plateau	**Central Rocky and Blue Mountain Foothills**	**Snake River Plains**	**Lost River Valley and Mountains**
Elevation	3000-7550 ft (915-2300 m)	1300-6600 ft (395-2010 m)	2100-5000 ft (640-1525 m)	4000-12000 ft (1220-3660 m)
Average annual precipitation	7-16 in (180-40 mm) >50 in (1270mm) mountain crests	8-16 in (205-405 mm)	7-12 in (180-305 mm)	7-25 in (180-635 mm) >45 in (1145mm) mountain crests
Timing of precipitation	Evenly: spring, fall, winter Lowest: midsummer to early autumn	Evenly: spring, fall, winter Lowest: summer	Mostly: spring, fall, winter Lowest: summer	Mostly: spring, fall, winter
Type of precipitation	spring, sporadically summer = rain winter = snow	winter = snow	spring, fall, winter = rain winter = snow	winter = snow spring, fall, winter = rain & snow
Average annual temperature	35-53°F (2-12°C)	36-53°F (2-12°C)	41-55°F (5-13°C)	35-45°F (2-7°C)
Freeze-free period	130 days avg. range = 65-190	140 days avg. range= 60-220	165 days avg. range = 110-220	110 days avg. range = 65-150
Dominant soils	Aridisols, mollisols	Mollisols, some aridisols	Aridisols	Mollisols, aridisols, some histosols

	Owyhee High Plateau	**Central Rocky and Blue Mountain Foothills**	**Snake River Plains**	**Lost River Valley and Mountains**
Soil moisture regime	Aridic	Xeric or aridic	Aridic	Xeric or aridic
Dominant vegetation	Wyoming sagebrush, bluebunch wheatgrass, western wheatgrass, Idaho fescue, Sandberg bluegrass, foxtail wheatgrass, penstemon, phlox	Big sagebrush, bluebunch wheatgrass, Idaho fescue, stiff sagebrush, low sagebrush, Sandberg bluegrass	Big sagebrush, winter fat, Indian ricegrass, needle and thread, Thurber's needlegrass, Sandberg bluegrass, bluebunch wheatgrass, arrowleaf balsamroot	Indian ricegrass, needle and thread, shad scale, junegrass, Indian paintbrush, scarlet globemallow, Gardner's saltbush, bluebunch wheatgrass, onion grass, lupine, Sandberg bluegrass, winterfat, black, Wyoming, and low sagebrush, rabbitbrush

APPENDIX B

Agency Specialist Interview Questions

Interview questions used to interview Agency Specialists. Not all questions were analyzed as part of this thesis.

Section 1: Demographics

Record gender and race, or ask if it seems more appropriate

"I want to be able to describe the general demographics of who I am interviewing so, may I ask:"

1. For the recording, could you please state your field office and position?
2. How long have you been in your current position?
3. What is your age?

I am interested in your background in agricultural education,

4. Did you participate in FFA in high school?
5. Do you have post-secondary education? *Prompt College*
   a. What field(s) of study?
   b. What years were you in your post-secondary program(s)?

"Those are all the demographic questions, so now we will jump into the interview:"

Section 2: Background

6. How many years have you been in Idaho?
7. How many years have you worked for the BLM? Were all of those years in the same location? *If not, how long have you been at this current location? prompt what other ecology/natural resource positions if appropriate)*
8. How would you describe what you do in your position to a lay person?
9. How many grazing allotments do you manage?
   a. Does that number change? When does it change?
10. About how many acres is the total area that you manage?
11. Could you describe your land management philosophy to me? *Prompt what that means to them in their position.*
12. What documents primarily guide your management? (RMPS, biological opinions, 6840 special status species, allotment management plans)
13. Can you describe what tools you currently using most often to assess and interpret resource conditions? (state and transition models, interpreting indicators of rangeland health, ecological site descriptions, trend data)
14. Can you talk me through a year of management tasks for your position?
    a. Would you be willing to sketch it out with me on this timeline? (*See supplement, Prompt list of common management tasks, prompt to indicate if things don't happen every year)*
       i. *Conduct upland range monitoring*
       ii. *Visit certain areas*
       iii. *Train monitoring teams*
       iv. *Contact ranchers about moving livestock*
       v. *Evaluate allotment leases/permits*
       vi. *Coordinate/write NEPA documents*

15. What helps you determine when to -Insert management task from the question above-? Are there any ecological indicators you look at?
16. Did you have specific management priorities for this year? For next year? Long term? (*Prompt in general or commonly across allotments. "Goals"- if not ecological, can probe. Prompt how long is "long term")*

Section 3: Time and Indicators

17. In your position, what months of the year require your attention the most outside on the range?
    a. Can you explain a little about why that is?
    b. During that time are you out there about 7 days a week (Everyday), 3-6 days a week (Regularly), 1-2 days a week (Often)?
    c. How does that compare to how much are you out on the range in the other months of the year?
    d. Does that stay the same from year to year? (prompt: is it consistent?)
18. Do you go out and look at the ground before cows are turned out into spring pastures?
19. In your position, what months of the year require your attention the most administratively? (e.g. spent inside taking care of business)
20. What do you look at to tell you how the land management is doing? (Landscape health)
    a. I would like to run through a list to get your thoughts about how any of these indicator categories inform your land management. You don't have to add anything to any of these if it doesn't apply to you. Do you also look at anything about: (*probe at what part, what management does it relate to, and when is it used)*
        - Plant community
            - *diversity (different species)*
            - *composition (what types of species)*
            - *quantity (how much of each species)*
        - Specific plant species
        - Plant life stage/Phenology (*seeds, flowers*)
        - Dead plants/Litter
        - Soil
        - Bare Ground
        - Precipitation
        - Livestock
        - Wildlife
        - Colors (*soil, plants, flowers*)
21. On a scale of 1-7, How important do you think each of these aspects is in determining when would be the best time to **start grazing** on a pasture in the spring? 1 is not at all important and 7 is extremely important
    a. The height of the grass
    b. The amount of ground surface covered by plants
    c. When cows grazed there last year
    d. Previous months precipitation

  e. Previous months temperature
  f. How wet the soil is
  g. Is there an aspect (that I mentioned or didn't) that is most important in determining when to turnout onto spring pastures?

22. On a scale of 1-7, How important do you think each of these aspects is in determining when it is important to **remove cows** from an area? 1 is not at all important and 7 is extremely important
    a. The height of the grass
    b. The amount of bare ground
    c. The amount of litter
    d. Water availability
    e. What the cows are eating
    f. When cows grazed there last year
    g. Is there an aspect (that I mentioned or didn't) that is most important in determining when to remove the cows from an area?
23. On a scale of 1-7, How important do you think each of these aspects is in determining how to **adjust management** for the next year? 1 is not at all important and 7 is extremely important
    a. The height of the grass
    b. How much a certain species was eaten
    c. The amount of bare ground
    d. The composition of the plant community
    e. The amount of precipitation throughout the year
    f. Where cows grazed this year
    g. Is there an aspect (that I mentioned or didn't) that would be most important in determining how to adjust management for the next year?
24. How much do you use predetermined management schedules versus responding to environmental cues? *Prompt, how much flexibility their schedules allow response to cues, could be a percentage of allotments.*

Section 4: Monitoring Relationship

The interview is confidential, but you don't have to answer if you don't want to:

25. May I ask what your relationship is like with the ranchers that have permits in your district?
26. Do you discuss the results of your monitoring with the ranchers?
27. Have you had a specific monitoring practice you used often in the past that you don't anymore? Is there a specific practice you plan to use more in the future?

Section 5: Flexibility and Constraints

28. How much is your management impacted by capacity, like availability of personnel and funding?
29. Are there any recommendations from your perspective that you would give to improve permitting?
30. When people talk about flexibility in public grazing, what would that look like to you?

31. Are there any recommendations you would give to improve rangeland monitoring?

Section 6: Additional Information

32. Is there anything else I should know about being a BLM specialist in Idaho, socially, ecologically, or economically?
33. Is there anything else you would like to share about your experience or what we have talked about so far?
34. May I share direct quotations from any or all of our interview when reporting the results of this study?
    a. Are there any topics we talked about that you would prefer I not directly quote?
    b. I am not intending to use any identifying information, but would you prefer I do and have any quotes I use from this interview cited directly to your name?
35. Is there another employee that work with rangeland monitoring in your field office who you would recommend I talk to? If so, would you be willing to share their contact information or may I email you an invitation to participate to share with them?

APPENDIX C

Rancher Interview Questions

Interview questions used to interview ranchers. Not all questions were analyzed as part of this thesis.

Section 1: Demographics

Record gender and race, or ask if it seems more appropriate

"I want to be able to describe the general demographics of who I am interviewing so, may I ask:"

1. What is your age?
2. About what percent of your household's yearly income is derived from ranching?
   --All of it 100% --More than 75% --Between 25-75% --Less than 25%

   I am interested in your background in agricultural education,
3. Did you participate in FFA in high school?
4. Do you have post-secondary education? *Prompt College*
   a. What field(s) of study?
   b. What years were you in your post-secondary program(s)?

"Those are all the demographic questions, so now we will jump into the interview:"

Section 2: Background

5. How many years have you lived in Idaho?
6. How many years have you been ranching? Were all of those years in the same location? *If not, how long have you been at this current location?*
7. Do you have grazing leases or permits with the BLM? *May I ask how many leases and permits? (probe if they are in multiple states for the Idaho amount)*
8. Could you please tell me a little about the ranch? (*prompt history (generational), the size of the ranch-acres, herd size, herd make up (cows/sheep/horses))*
9. Could you describe your land management philosophy to me?
10. Are there specific management practices or particular guidelines you are currently using most often, such as: holistic grazing, rotational grazing, rest and rotation, "take half/leave half", short duration-high intensity, pulse grazing?
11. Can you talk me through a year of management tasks for your operation?
    a. Would you be willing to sketch it out with me on this timeline? (*See supplement, Prompt list of common ranching management tasks*)
       i. *Move calves to pasture*
       ii. *Move herd on/off areas (spring/winter pasture)*
       iii. *Market cows/calves/yearlings*
       iv. *Breeding heifers/cows*
       v. *Calving*
       vi. *Wean calves*
       vii. *Provide nutrients/minerals*
       viii. *Feed hay/corn or haul water*
12. What helps you determine when to -Insert management task from previous question-? Are there any ecological indicators you look at?
13. Did you have specific management priorities for this year? For next year? Long term? (*a year is a calendar year*, *"Goals"- if they say about breaking even, could probe about ecological. Prompt how long is "long term")*

Section 3: Time and Indicators

14. For your operation, what months of the year require your attention the most out on the range?
    a. Can you explain a little about why that is? *(see if they are talking about non-irrigated pastures where animals don't receive supplemental feed- not private holding pastures for calving and branding)*
    b. During that time are you out there about 7 days a week (Everyday), 3-6 days a week (Regularly), 1-2 days a week (Often)?
    c. How does that compare to how much are you out on the range in the other months of the year?
    d. Does that stay the same from year to year? (prompt: is it consistent?)
15. Do you go out and look at the ground before cows are turned out into spring pastures?
16. For your operation, what months of the year require your attention the most administratively? (e.g. spent inside taking care of business)
17. What do you look at to tell you how your land management is doing? *(healthy Landscape)*
    a. I would like to run through a list to get your thoughts about how any of these indicator categories inform your land management. You don't have to add anything to any of these if it doesn't apply to you. Do you also look at anything about: (*probe at what part, what management does it relate to, and when is it used)*
        - Plant community
            - *diversity (different species)*
            - *composition (what types of species)*
            - *quantity (how much of each species)*
        - Specific plant species
        - Plant life stage/Phenology (*seeds, flowers*)
        - Dead plants/Litter
        - Soil
        - Bare Ground
        - Precipitation
        - Livestock
        - Wildlife
        - Colors (*soil, plants, flowers*)
18. On a scale of 1-7, How important do you think each of these aspects is in determining when would be the best time to **start grazing** on a pasture in the spring? 1 is not at all important and 7 is extremely important
    a. The height of the grass
    b. The amount of ground surface covered by plants
    c. Previous months precipitation
    d. Previous months temperature
    e. How wet the soil is
    f. When cows grazed there last year
    g. Is there an aspect (that I mentioned or didn't) that is most important in determining when to turnout onto spring pastures?

19. On a scale of 1-7, How important do you think each of these aspects is in determining when it is important to **remove cows** from an area? 1 is not at all important and 7 is extremely important
    a. The height of the grass
    b. The amount of bare ground
    c. The amount of litter
    d. Water availability
    e. What the cows are eating
    f. When the cows grazed there last year
    g. Is there an aspect (that I mentioned or didn't) that is most important in determining when to remove the cows from an area?
20. On a scale of 1-7, How important do you think each of these aspects is in determining how to **adjust management** for the next year? 1 is not at all important and 7 is extremely important
    a. The height of the grass
    b. The amount of bare ground
    c. How much a certain species was eaten
    d. The composition of the plant community
    e. The amount of precipitation throughout the year
    f. Where cows grazed this year
    g. Is there an aspect (that I mentioned or didn't) that would be most important in determining how to adjust management for the next year?

Section 4: Monitoring Relationship

21. Can you tell me about any monitoring records you collect on the range, like plant cover or photo monitoring?
    a. Is that on the deeded or leased land or both?
    b. Who does that monitoring? *(prompt consultant, yourself)*
22. Do you discuss the results of your monitoring with BLM specialists?

The interview is confidential, but you do not have to answer if you prefer not to:

23. May I ask how you would describe your relationship with your rangeland specialist for the BLM? *What is it like?*
24. Are there any recommendations from your perspective that you would give to improve permitting with the BLM? (*prompt their understanding of what BLM is monitoring and managing for)*
25. On a scale of 1-5, 1 being "not at all" to 5 being "extremely influential", How influential would you rate these sources to your land management practices? Again 1 is not at all, 5 is extremely
    a. Personal Experience
    b. Family Members
    c. Community Members
    d. Prominent figures (Allan Savory, Gus Hormay)
    e. Extension Educators
    f. Consultants
    g. BLM
    h. NRCS

i. Any others you would like to mention?

Section 5: Flexibility and Constraints

26. How much is your management impacted by capacity, like availability of personnel and funding?
27. How much do you use predetermined schedules based on market and permit dates versus responding to environmental cues? *Prompt, how much flexibility their schedules allow response to cues*
28. What does flexibility in your operation mean to you?
29. When people talk about flexibility in public grazing, what would that look like to you?
30. Do you manage anything differently on your leased/permitted and deeded land?
31. If you could manage the leased/permitted land differently, what would you want to do?

Section 6: Additional Information

32. Is there anything else I should know about being a rancher in Idaho, socially, ecologically, or economically?
33. Is there anything else you would like to share about your experience or what we have talked about so far?
34. May I share direct quotations from any or all of our interview when reporting the results of this study?
    a. Are there any topics we talked about that you would prefer I not directly quote?
    b. I am not intending to use any identifying information, but would you prefer I do and have any quotes I use from this interview cited directly to your name?
35. Is there another rancher in the community who you would recommend that I should talk to? If so, would you be willing to share their contact information or may I email you an invitation to participate to share with them?

APPENDIX D

Goal Categories

Table D.1. Goal categories. The nine categories used to classify participants' goals.

Category	Definition	Key Phrases	Exemplary Quote
do the right thing	Specific use of the phrase "do the right thing," or its variants, to describe wanting to "do the right thing" when managing the land	do right	"I want to **do what's right** for people. What's **right** for the environment. What's **right** for the future."
flexibility	References to the adaptation or adjustment of land management to match changing conditions in the ecosystem	adaptive, adjust, year, change, timing	"We do everything not by what the capacity is, we do it by what the land at **that year** can handle."
for the future	Managing the land for the use and enjoyment by future generations of people	future, generation, for children or grandchildren, sustain, sustainability	"The point is, is to keep pace or advance. And to do that, you know, we need to take care of it. So it's not just about me, it's for the **next generation** and the one after that."
formal monitoring	References to the use and prominence of policy, regulations, standards, formal monitoring, or protocols in land management	policy, rules, standards, evaluating, track, data	"My job is all about the resource and making sure that we adhere to our **standards** so that we properly manage that resource."
improve	Managing to improve or change the land	improve, add, leave it better, make it the best	"Simply, my land management philosophy has been the same that my grandfather and my father had, and that is that we truly want to leave the resource **better** than we found it."
maintain	Keeping the land in a certain state by doing, or not doing, management actions or by managing in a way that mimics the	maintain, keep, sustain, take care, preserve	"What we do is we **maintain** the landscape… I try to **maintain** habitat."

	perceived natural ecology		
Category	**Definition**	**Key Phrases**	**Exemplary Quote**
multiple use	Use of the term "multiple use" or references to considerations for the human uses of a shared resource in management	multiple use, multi use, many uses, using the resource, share the resource, balance use	"The way I've always looked at it as is... the land, especially public land, is **multi-use**."
relationships	Managing human-to-human relationships in order to manage the land, including communicating, listening, building trust, collaborating or working together	communication, working with people, respect, listen	"It really comes down to **working with people**."
whole picture	Managing for multiple aspects of the ecosystem or describing a broad view of land management that includes connections between social, ecological, and economic aspects of the system	all the parts, whole picture, broad view, manage for everything, not just cows	"It's kind of like... "how can we do this to keep **all the parts**?" You know, all the wild parts, and then **all the parts of the system**: the water, the soil, everything working, all the plants, and then, all the people around."

APPENDIX E

Network and Objective Categories

Table E.1. Network and objective categories. The 55 categories used to classify participants' objectives and components of the mental models.

Category	Definition	Key phrases	Exemplary quote
bare ground	An area, ground, or soil without vegetation	bare soil, bare ground, bare area	"…when it comes to **bare ground**, again, that one is going to vary on where you're at."
carbon storage	Plants removing carbon from the atmosphere or releasing it, or carbon stored in the ground and plant material	store carbon, carbon from the atmosphere, carbon sequestration	"I mean it pulls some **carbon** from the **atmosphere carbon**, but it's getting fed nutrients from the soil through the roots…"
color	The color of plants or soil. Does not include "green plants" when green is used as an adjective to describe the growth condition or palatability of the plant (that situation is coded as "plant condition")	green, red, yellow or brown plants or patches of color	"Yeah, the **brown** look is pretty much native community and then the deep **yellow** is mostly Medusa."
dry conditions	A state or condition of dryness. drought, dry year, dry or dried soils	drought, dry year, dry or drying or dried soils	"If you're in a **drought**, you're going to notice the plants didn't grow very much."
economics	References to markets, costs, money, and finances	market cycles, costs, financial security	"You're constantly weighing your **input costs**, because that's where your profit margin is, or that's where your break-even point is. It's all about your **input costs.**"
elevation	Use of the term elevation or references to "up" and "down" implying change in elevation	elevation, up, down, high country, low areas	"So our **elevations** are getting drier and drier and it just keeps going up the mountain."

Category	Definition	Key phrases	Exemplary quote
fine fuels	Plants or litter, or the absence of, affecting the severity, occurrence, or probability of fire	litter, fine fuels, fuel, fire breaks	"…if you have a lot of cheatgrass, you have a lot of litter and it's kind of a surrogate for the **amount of fuel**."
fire	The history, occurrence, and frequency of fires or burns	fire, burns, burning	"And we look at wet springs as "oh great. We're not going to have a **fire** season. Its putting it off." But the more grass grows, the more stuff there is to **burn.**
forbs	Forbs or specific references to species of non-invasive forbs, flowers, or wildflowers	forbs, flowers, or species of forbs (e.g. lupine, sunflowers, etc.)	"If you've got a decadent sagebrush stand, then you don't have **forbs.**"
formal monitoring	Monitoring techniques and practices or general reference to the practice of "monitoring" that involves data collection or measurement (e.g. utilization monitoring, nested frequency)	monitoring, transects, data, interpreting indicators of rangeland health, specific monitoring types (e.g. MIMs, nested frequency)	"Usually, I'm just looking at the long-term vegetation **data** and what it says, and then in relation to the grazing and how it's changed, if it's changed, that kind of thing."
general management	Management not specific to how grazing is manipulated. Includes "adjusting management" and general rangeland management tasks like mowing or seeding	adjusting, altering, adapting or changing management, strategy, decision making, finding solutions, mechanically planting seed, taking care of ground	"Being out there on the ground and having actual data is essential and really the only way you can do **adaptive management** or make **adjustments in management**."

Category	Definition	Key phrases	Exemplary quote
grazing	The past or current act of grazing or taking of a plant, grazing disturbance used as a noun, and grazing as an action or condition of the rangeland. Does not include future planning of grazing actions	presence/absence of grazing, the act of grazing, grazing disturbance, AUMS, take, or utilization as an act	"Height of the grass, you know, is gonna determine if-, from my experience, is going to help determine if the plant is going to be able to survive **grazing**."
grazing management	The state or practice of grazing management including intensity, duration, and timing of grazing	grazing timing, duration, intensity, graze with rest, rotations, overgrazing (as a state of management), actual use report	"I think on a small scale, on an allotment, you can build flexibility that addresses your resource needs. And the flexibility would be just adjusting the **timing, intensity, and duration** of livestock use."
human capital	Human resources used for management	work load, labor, riders, experience	"Another part of the decision was we began to look at, you know, kind of our **workload**."
insects	References to beetles, ants, flies, or other insects, either beneficial or not	beetles, insects, flies, ants, bugs	"Those **insects** come predominantly because of the manure from the livestock."
invasive plants	Invasive plants including weeds and invasive forbs, annual grasses, and specific species of annual grass or weeds	annual grasses, weeds, invasive plants, or specific plant species (e.g. cheatgrass, medusahead, rush skeleton weed)	"If it's **cheatgrass** we can graze it really early before it goes to seed,"
landscape health	The state or condition of the rangeland	Landscape/rangeland health or condition, looks bad/good, good for range, pasture lasting a long time	"So I'm walking through areas and I see a lot of invasive annual grasses, you just know the health of the **rangeland isn't that great**."

Category	Definition	Key phrases	Exemplary quote
landscape history	References to historical effects of grazing or processes affecting the land in the past	history of grazing, historical records or information, Oregon Trail, in the past	"Like the **historical information**, I'm big on finding as far back as I can and looking at it as a continuum."
litter	Dead material from plants	litter, knocked over plants, dead plant material on the ground	"The amount of **litter** on the ground, in my opinion, is essential to have--To help keep your soil there, to keep your topsoil."
livestock behavior	Livestock behavior including how they act, how they are distributed on the landscape, and what they eat	livestock distribution, what livestock eat, grazing of certain plants, lying down, bunching up	"The key to it… is placing these cattle where they're happy. If they're happy, **they'll graze the grass** and **use it more uniform** and not take as much labor than if you're fighting them."
livestock health	Descriptions of the health, state, or condition of livestock	livestock health, body condition, weight gain, herd health, calf health, pregnancy status, conception rates, nutritional needs	"We want our cows to have the optimal feed and have good **body scores**, and you can only do that by taking care of your ground."
livestock impacts	Effects on the land from the physical presence of livestock	livestock disturbance (hooves), impact, hummocking, pugging, hoof action	"I like to keep my cows off of ridges because I feel like that's where they do the most **impact.**"
livestock management inputs	Human-added inputs into the grazing system to aid in the production of livestock	salt, fences, supplemental feed, mineral supplements, hay	"Now we had some really bad drought years that we didn't raise **hay** and we had to buy a lot of **hay**. And it really hurt our bottom-line."

Category	Definition	Key phrases	Exemplary quote
management guidelines	Policies and procedures, typically written or published, associated with rangeland management	permits, ecological site descriptions (ESD), State and Transition models, range management plans, land management plan, grazing management plans	"…if we want to do a project that isn't explicitly covered in our **Land Use Plan** or in the **Resource Management Plan**, then we would have to do **NEPA**."
manure	Livestock patties, scat, or "left behind fertilizer"	manure, organic matter from cows, cow patties/pats	"…dump a lot of nutrients in with bringing the cow's **manure** and urine and everything…"
moving livestock	Removing, taking off, or moving livestock from an area. Does not include the manner in which livestock are moved (e.g. herding, riders, gentle herding)	moving livestock, removing livestock, taking livestock off, moving livestock to a new area, get them out, put them in	"…if you grazed it in the spring last year, and you're grazing it kind of early again this year, and you're kind of getting short, you might want to **move them** a little quicker than you would normally."
number of livestock	References to the quantity of livestock	the number of livestock, stocking rate, amount of livestock	"That's why we dropped the **number of cows**."
perennial grasses	References to perennial grasses (typically native perennial bunchgrasses) or specific perennial grass species (e.g. bluebunch wheatgrass, Sandberg's bluegrass)	key species, bunchgrasses, specific perennial grass species, "perennials" in a context that implies grass	"…if there are deep-rooted **perennials** then, well after the rainy season, they're still green because they can still access that water."
plant amount	The quantity or presence of plants on the land	presence/absence or amount of plants, number of bunchgrasses, amount to eat, foliage or ground cover, biomass or production	"…if we're getting more bare ground, we're losing litter, we're losing that **ground cover**, then we know that we've got a problem."

Category	Definition	Key phrases	Exemplary quote
plant community	The characteristics and state of the assemblage of plants in an area	plant community, community composition, community diversity, plant spacing	"**Composition** of **plant community**, that's something that kind of takes more, like long term trend data to look at."
plant condition	The health, state, or condition of plants including mortality, palatability, and robustness	plant health, softer feed, nutrients in plants, palatability, decadence, dead/dying plant center, plant hurt or not, "green grass" as a condition of the grass, lushness, plant ability to withstand grazing	"All these plants, look at the size of the basal structure, those are **healthy plants**."
plant growth	The growth, regrowth, or emergence of plants	photosynthesis, pushing up leaves, leaf stage, plant regrowth, plant regeneration, grass established, growing season, green up starts happening	"I want some residual left on that plant… It'll be ready next spring to **grow** again. It'll have some to **photosynthesize** with and something to protect it."
plant height	Specific descriptions of plant height including plants growing to a certain height or being grazed down to a certain height	plant height, tall, short, specific measurements	"…we like at least 6 **inches** of new growth."
plant residual	Plant material left behind after grazing	residual, residual cover, residual stubble height, remaining vegetation, left cover on the ground, leaving vegetation/feed behind	"Uplands, I want to see **residual** like, you know, I want to see grass left."

Category	Definition	Key phrases	Exemplary quote
plant seeds	Production of seeds by plants	seeds, seed heads, seed production	You need to let it get to **seed head** on these native plants out here.
plant stage	The process of maturing and stages in a plant's life cycle. Excludes specific references to the production of seeds.	plant stage, phenology, dormancy, maturity, flowering, biological potential	"If it's in the Fall or something when the perennials are already **dormant**, then it probably can't do a whole lot of damage."
precipitation	Precipitation, typically as rain or snowfall	wet spring, rains, amount of precipitation, rain/snow precipitation, moisture	"And then we got about two months of **rain** and cool weather and all the perennial species just boomed."
ranching operation	References to the ranching profession, operation, and related activities	calving timing/process, replacement heifer selection, ranching as a profession, livelihood, weaning calves	"It really depends on **calving season** for our operators just because that's such a busy time of year for them…"
range readiness	A set of guidelines called "range readiness" that indicate when the range is "ready" and turnout of livestock can occur	"range readiness"	"We have a monitoring. It's called **range readiness**. It's a monitoring form that we have, it has all these criteria for early Spring."
relationships	Descriptions of communication and interaction with parties involved in range management (ranchers or agency specialists)	relationships, communication, rural communities, shared allotments, public interest, meetings	"And **communicate with the permittees** that that's what you're trying to keep healthy…"
riparian areas	References to areas characterized by mesic hydrological conditions and associated vegetation	riparian health, riparian areas, steams, creeks	"…your bottoms is where your **riparian areas**, those sensitive areas are and the more you keep the cows out of those bottoms, the better."

Category	Definition	Key phrases	Exemplary quote
roots	The roots of plants and grasses	roots	"And then compaction is a big deal because if the **roots** aren't able to expand as far as they want to, the plant just can't get as much water and stuff."
sagebrush	The shrub, sagebrush (*Artemisia tridentata*) and its subspecies	sagebrush, brush, sage	"So then you just kind of see what's happening under your **sagebrush** is kind of your indicator of kind of what's going on."
site characteristics	Variation in ecological characteristics caused by location	site conditions, site capabilities, where you are, it depends on location	"**It depends** on where you're at really. You can't say one specific thing for one **specific area**, in my opinion."
snowpack	The amount, trend, or presence of snow on the ground	snowpack, amount of snow, melting snow, snow on ground	"So at the same time, usually those areas, since they're so hot and dry, means there's **less snow** in the winter."
soil condition	The condition or health of the soil including characteristics that affect the condition like erosion or biological soil crusts	soil health or condition, top soil, nutrients/fertilizer in soil, biological soil crusts, alkali soil, erosion, pedestalling and terracets	"And litter becomes humus, which is vegetable matter in the ground and helps create **healthier soils**…"
soil type	General or specific references to the type of soil	slick spots, soil type, sandy soil, bentonite clay	"…depending on the **soil type**, the amount of precipitation is gonna affect how wet the soil is in general."
temperature	The temperature of the soil, air, or other ecological components	hot, cold, temperature, frost (frost heaving), soil temperature, warm, cool	"So there's kind of a **temperature** cut off where… cheatgrass survival isn't like a thing."

Category	Definition	Key phrases	Exemplary quote
threatened species	Federally listed endangered or threatened plant and animal species and greater sage-grouse	ESD species, endangered or threatened fish species, sage-grouse, slick spot pepper grass	"Usually, good **sage-grouse** habitat is good habitat for other wildlife, not always…"
topography	Descriptions of topography including slope and aspect	aspect, ridges, canyons, slopes, hillsides	"South **slope** versus north **slope**, you're going to have a-, certainly a division, you know, as far as temperature and moisture."
turnout	References to beginning grazing at the start of a season, usually spring. Typically described using the term "turnout"	starting grazing, turnout timing, going out to graze, turning out	"And you don't necessarily want to **turn them out** too early because then they'll mow everything down and then you won't get seed production…"
water	The availability and presence of water on the landscape	water sources, water availability, flow patterns, run off, water quality, haul water, infiltrated water, soil moisture availability (for plants)	"**Water availability** is huge, because that's your concentration of livestock."
wet soil	A saturated or wet state of the soil	wet soil, soil too wet, saturated soil, wetness of the soil	"The idea behind the **wet soil** is not so much that the soil's going to be wet, it could be wet anytime out there, the idea is they're moving and they're trailing cattle to the allotment"
wildlife	References to wildlife and wildlife species that are not threatened or endangered species	wildlife, elk, antelope, wolves	"These are all little forbs through here, these are forbs coming up and those are very important for **wildlife** and stuff."

Category	Definition	Key phrases	Exemplary quote
wind	Descriptions of wind	wind, windy	"…it doesn't matter what happened last month because a lot of times it will rain, but then it just, the **wind** takes it all out of the soil."