



Original Research

A Revised Adaptive Decision-Making Framework for Rangeland Management[☆]

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ABSTRACT

Rangelands across the world are facing rapid and unprecedented social and ecological change. In the US West, sustaining the ecological and economic integrity of rangelands across both public and private lands depends largely on ranchers who make adaptive decisions in the face of variability and uncertainty. In this study, we build on previous conceptualizations of adaptive decision making that situate individual-level decisions within complex rangeland social-ecological systems. We surveyed 450 (36% response rate) Montana ranchers to gain insight into how key factors influenced adaptive decision making, specifically in the context of ongoing drought and climate-related change affecting rangeland ecology and productivity. We predicted that ranchers' management goals, their use of information sources, and their use of monitoring would significantly influence the use of adaptive practices, with monitoring mediating the relationship between the explanatory and response variables. We tested these predictions using a path model analysis and found that management goals related to both stewardship and profit/production, the number of information sources used, and monitoring were all significantly and positively related to ranchers' use of adaptive management practices. Interestingly, we found that these factors were hierarchical with monitoring and the use of information was the strongest predictor while management goals were secondary. The significant, mediating effect of monitoring on the use of adaptive practices suggests that monitoring may be an important means for providing ranchers with useful and timely information about rangeland condition that is needed to adjust their actions, meet their management goals, and adapt to drought and climate-related change. We argue there is a need to better understand the efficacy of monitoring designs—of what, by whom, and how—for adaptive decision making, and we discuss other considerations related to the provision of useful drought and climate information for adaptive decision making based on our findings.

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Introduction

Rangelands cover approximately 50% of the world's terrestrial surface (Lund 2007) and make up the most extensive class of lands in the US West (Sayre et al. 2012; USFS 2012), of which grazing is a primary use (USDA-NRCS 2007; Bigelow and Borchers 2017).

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Today, ranchers and rangeland managers in the United States and across the globe face increasingly complex and widespread social and environmental challenges. Ecologically, climate change and its associated impacts introduce new dynamics and uncertainties for ranchers (Sayre et al. 2013; Briske et al. 2015; Cook et al. 2015; Kuwayama et al. 2019). In the US West, increased fluctuations of temperature and precipitation are likely to result in significant changes in land and water regimes that affect rangeland ecology and productivity, highlighting the need for rangeland managers to mitigate these risks and adapt to its challenges (Derner and Augustine 2016; Roche 2016; Kuwayama et al. 2019). Socially, ranch operations must respond and adapt to changing markets, the pressure of shifting land uses across the West (Gosnell and Travis 2005), and changes in ranch ownership and generational turnover (Hinrichs and Welsh 2003; Hoppe and Banker 2010). Sustaining rangelands, ranch livelihoods, and the suite of ecosystem goods

(e.g., livestock production) and services (e.g., wildlife habitat, plant diversity, watershed function) they provide hinges on not only understanding the ecological processes at play but also a greater understanding of the social processes within these changing systems (Sayre 2004; Briske et al. 2011).

Adaptive management has been well established as an effective and necessary means for managing rangeland social-ecological systems (SES) confronting change (Stafford Smith 1996; Derner et al. 2022; McCord and Pilliod 2022). In the US West, stewardship of rangelands across both public and private lands depends on ranchers and rangeland managers, who make adaptive decisions in the face of great variability and uncertainty. Ranchers make management decisions through nonlinear and complex consideration of social, ecological, and economic dynamics and through engagement with multiple ways of knowing (Roche et al. 2015; Wilmer & Fernández-Giménez 2015). Moreover, the suite of factors influencing ranchers' decisions is multiscalar; ranchers have unique knowledge, experience, and values that influence their individual goal setting and adaptive management strategies (Knapp and Fernández-Giménez 2009; Sorice et al. 2012; Roche et al. 2015; Wilmer & Fernández-Giménez 2015; Wilmer and Sturrock 2020) while, at the same time, their decisions are influenced by government policies, regulations, and other external factors (Sayre et al. 2013a; Wollstein et al. 2021). The need to understand how these cross-scale social processes drive ranchers' adaptive management has prompted a growing body of literature examining characteristics of ranchers and ranches that result in specific decisions or practices. As the US West faces unprecedented social and ecological change, there is a need for ongoing social science research that expands our understanding of factors driving adaptive decision making among ranchers.

This study complements and contributes to previous decision-making research by testing and building upon a widely used adaptive decision-making framework for rangeland management (Lubell et al. 2013), which conceptualizes adaptive decisions as dependent on a combination of social values, management goals and capacity, and management strategies and practices embedded within a ranching social and ecological system. Adopting this framework, we quantitatively analyzed survey responses ($n=450$) among Montana ranchers to better understand factors influencing the adaptive decision-making process, specifically in response to drought and climate-related events. Our research objectives were to 1) test the relationships among factors (e.g., operation/operator characteristics, management goals, information sources, practices) known to influence rancher decision making at a generalizable scale in the Montana SES context and 2) identify and quantitatively describe any new or distinct variables (e.g., monitoring) contributing to ranchers' decision-making processes. Given that ranchers' decision-making contexts in the West continue to undergo diverse and rapid changes, we argue that iteratively examining factors related to adaptive decision making across different rangeland SES is important to advance the ongoing dialogue around adaptive decision making.

Theoretical framework: adaptive decision making for rangeland management

Adaptive decision making is a key component to adaptive management in rangeland systems, which has been defined as the iterative process of learning from previous management actions and experiences, and using that information to plan future actions, facilitate decision making, and improve outcomes (Derner and Augustine 2016; Derner et al. 2022; McCord and Pilliod 2022). Adaptive management of rangelands involves complex and adaptive decision making across scales; ranchers are tasked with making numerous decisions to balance short-term and long-term man-

agement priorities, as well as local and landscape-level priorities. Adaptive decision making, then, we define as an individual, social-psychological process that involves iterative learning from experience, observation, and information to effectively respond to and improve outcomes while undergoing social and ecological change (Lubell et al. 2013; Roche et al. 2015; Wilmer et al. 2015; Derner et al. 2022; McCord and Pilliod 2022).

As the impacts of climate change manifest in the US West, ranchers make a wide range of adaptive decisions to achieve their management goals. For example, ranchers may move to dynamic grazing practices that are driven by forage availability rather than fixed dates, use conservative yet flexible stocking strategies that accounts for spatial heterogeneity in forage quality and quantity, improve the genetics of their herd for drought and heat tolerance, or establish contingency plans for extreme climatic events such as drought (Sayre et al. 2012; Joyce et al. 2013; Yung et al. 2015; Joyce and Marshall 2017; Haigh et al. 2021). A central tenant of adaptive management is that it involves flexibility and the use of feedback mechanisms, such as monitoring metrics/indicators, to adjust management actions (Derner and Augustine 2016). While the body of literature on adaptive management has grown rapidly in recent decades, it is also widely recognized that some ranchers, especially multigenerational ranching households, have extensive experience adaptively managing for ecological and climate-related change, including drought, through the use of trial-and-error learning and generational knowledge of management strategies (Roche et al. 2015; Yung et al. 2015; Wilmer et al. 2016).

Social scientists have taken various approaches to examining adaptive decision making in response to social and ecological change. Here, we build on the framework for adaptive decision making for rangeland management (Lubell et al. 2013; Fig. 1) that takes a complex systems perspective (Glaser et al. 2008), situating individual-level decisions within multiple scales of social and ecological interaction. Specifically, Lubell et al. (2013) hypothesized that four categories of variables affect decision making for rangeland management: 1) operation/operator characteristics; 2) time horizon (i.e., succession planning, generations in ranching); 3) social network connections/information sources; and 4) social values. Lubell et al. (2013) tested these proposed variables as they related to rancher decisions to participate in conservation programs. The authors estimated the impact of these variables on participation in conservation programs and found that access to conservation information sources was the most significant variable predicting program participation. Their findings also suggested that ranchers with larger amounts of land and an orientation toward the future, as well as those who were opinion leaders, were more likely to participate in conservation programs (Lubell et al. 2013). By integrating individual-level social theory (i.e., the theory of planned behavior) (Ajzen and Fishbein 1980) into their systems-level framework, Lubell et al. (2013) provided a foundational conceptualization of how ranchers' individual psychology interacts with other aspects of the SES. This framework has served as a helpful guide for subsequent studies on adaptive decision making among ranchers (e.g., Roche et al. 2015; Roche 2016; Wilmer et al. 2018; Munden-Dixon et al. 2019).

Research on rancher decision making in the US West has examined a suite of other ranch/rancher characteristics that best predict the use of specific conservation or production-related practices or programs (Kreuter et al. 2001; Didier and Brunson 2004; Kennedy and Brunson 2007; Roche et al. 2015; Haigh et al. 2019; Haigh et al. 2021). Characteristics predicting adoption of conservation and adaptation-related practices, such as size of ranch, dependence on ranch-based income, and risk orientation along with the use of social networks, place-based expertise, and education as key pathways for information sharing and increased knowledge about management practices, programs, and opportunities,

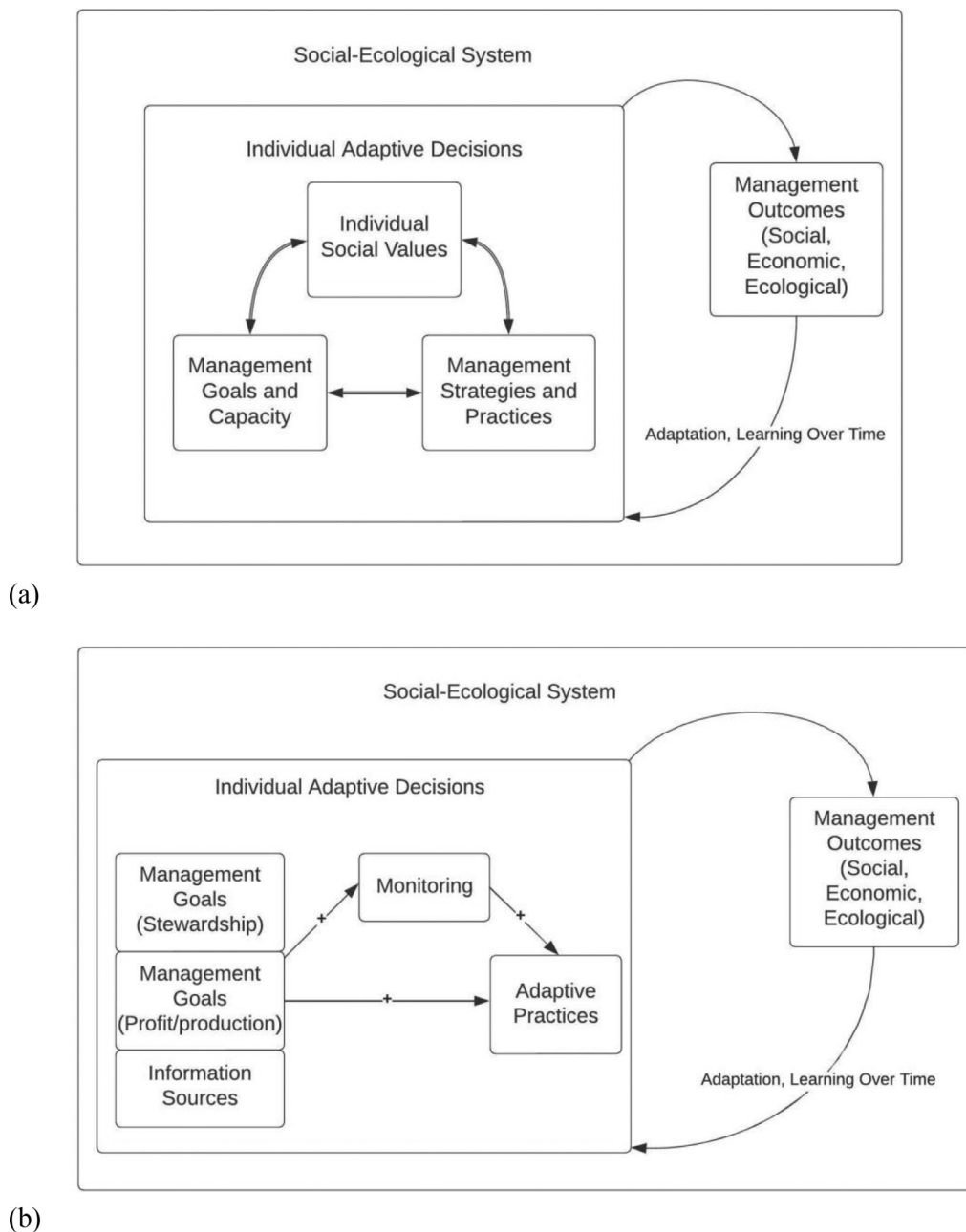


Figure 1. **a**, Adaptive decision making for rangeland management model conceptualized by Lubell et al. (2013). **b**, Adaptive decision making for rangeland management model showing the components of individual level adaptive decisions that we focus on here, including the hypothesized relationships between management goals (stewardship and profit/production), information sources, monitoring, and adaptive practices.

have been well described (Kreuter et al. 2001; Didier and Brunson 2004; Kennedy and Brunson 2007; Lubell and Fulton 2007; Marshall and Smajl 2013). For instance, building on the Lubell et al. (2013) framework in their analysis of drought-related decision making among California ranchers, Roche (2016) found that information resource networks, goal setting for sustainable natural resources, and management capacity all acted to enhance individual drought adaptation. In a study on the adoption of drought contingency plans, Haigh et al. (2021) found that larger ranch operations were more likely than others to have drought contingency plans and that ranchers with a plan were more likely to destock pastures more than usual through culling, early weaning, ending grazing contracts, sending to feedlot, etc., compared with those without a plan, controlling for drought severity and size of operation. Evaluations of barriers to adaptation and innovation adoption

have also repeatedly highlighted the importance of building trust among ranchers, researchers, and government agencies to accomplish desired research, conservation-related management practices, and livelihood outcomes in rangeland SESs in the West (Lien et al. 2017; Wilmer et al. 2018).

Rangeland monitoring and adaptive decision making

In the field of rangeland management, rangeland monitoring has been widely accepted as a critical component of adaptive management as it offers a system for collecting information about rangeland resource condition and change across scales to support decision making (Herrick et al. 2006; McCord and Pilliod 2022). By providing ranchers and rangeland managers with information on ecosystem structure, function, and condition, monitoring can

empower managers with useful information to adjust their actions to meet their management goals and objectives (Stephenson et al. 2017; Germino et al. 2022; McCord and Pilliod 2022). In this way, rangeland monitoring can enhance the iterative or “loop” learning process inherent to adaptive decision making by providing ranchers with timely and relevant feedback about the effectiveness (or ineffectiveness) of past management actions that they can then use to adapt and improve outcomes (Derner and Augustine 2016; Derner et al. 2022; McCord and Pilliod 2022). Moreover, in a time of an increasingly complex social and ecological change on rangelands at multiple temporal and spatial scales, monitoring has been encouraged to facilitate faster development of local environmental knowledge when traditional experiential learning modes cannot always keep up (Lynam and Smith 2004; McCollum et al. 2017). However, while rangeland monitoring has long been central to the theory and practice of adaptive management, how monitoring influences the use of adaptive management practices and contributes to improved social and ecological outcomes is limited.

As the management objectives across public and private rangelands in the United States have become more diverse, the technologies, methods, and indicators used by the rangeland community have also expanded (McCord and Pilliod 2022). In recent decades, progress has been made in rangeland monitoring approaches to track rangeland condition and change across scales, in the context of climate variability, and in light of shifts in land uses across the US West (Booth and Tueller 2003; Jones et al. 2018; McCord and Pilliod 2022; Newingham et al. 2022). There have been efforts to standardize monitoring methods to better aggregate data and understand larger-scale (i.e., regional) conditions and change across landownerships (i.e., public and private) while also creating cohesiveness and shared understandings among monitoring participants (Toevs et al. 2011; Kachergis et al. 2021). For instance, monitoring methods described in Herrick et al. (2018) have been adopted and used widely by members of the rangeland community, including ranchers, land management agencies, conservation organizations, research networks, and local researchers (Toevs et al. 2011; Herrick et al. 2017; Herrick et al. 2018). Additionally, technological developments such as the Land-Potential Knowledge System (LandPKS) platform paired with mobile apps, or the Rangelands Analysis Platform, have allowed users to share and compare their data with others (Herrick et al. 2017). On public lands, efforts such as the BLM Assessment, Inventory, and Monitoring (AIM) Strategy described by Toevs et al. (2011) have been made to standardize monitoring methods and indicators so that local and national data sets can be combined to understand change at regional and national scales.

Despite these advancements in monitoring systems and technologies intended to provide useful feedback for adaptive management, designing useful management-relevant monitoring systems has remained a challenge and formal monitoring is often weak or missing in practice (Sayre et al. 2013; Newingham et al. 2022). In other words, while rangeland monitoring has been discussed as a method for improving decisions in a “virtuous feedback loop of ‘learning by doing’” (Walters and Holling 1990; Sayre et al. 2013), empirical evidence of this relationship is largely undocumented. Thus, there is a need to better understand the social dimensions of monitoring—if and how monitoring is used and what its influence might be on adaptive decision making—which, compared with technical issues and advancements, have received relatively little scholarly attention.

Research Questions

Although research across a variety of disciplines has demonstrated the important roles of management goals, monitoring, and the use of information networks and resources for adaptive man-

agement among ranchers, their combined effects on the adoption of adaptive practices among ranchers using generalizable social science research have been largely undocumented. In this context, the goal of this paper is to examine the contribution of these factors to adaptive decision making among Montana ranchers. In this study, we aimed to test and extend the Lubell et al. (2013) framework of adaptive decision making for rangeland management. We asked:

- 1) What variables drive adaptive decision making for Montana ranchers? Specifically, is there a statistically significant relationship among operation/operator characteristics, management goals, and/or the use of information sources and the use of adaptive practices?
- 2) Does the use of monitoring by ranchers mediate the relationships between these variables, and if so, to what extent?

Hypotheses and Predictions

By asking these questions, we sought to understand the individual-level factors driving Montana ranchers' adaptive decision making. Specifically, we focused on the role of management goals, information sources, and monitoring as they related to ranchers' decisions to use a suite of adaptive practices ranchers might use to plan for and respond to drought and climate-related events. We hypothesized that:

- H1: Adaptive decision making is driven by ranchers' management goals, their use of information sources, and their use of monitoring data; monitoring directly affects the use of adaptive practices, whereas ranchers' management goals and their use of information sources affect the use of adaptive practices both directly and indirectly through monitoring.

On the basis of this hypothesis, we predicted the following (see Fig. 1):

- Prediction 1 (P_1): Management goals and information sources will have a significant positive effect on the use of adaptive practices
 P_2 : Management goals and information sources will have a significant positive effect on the use of monitoring.
 P_3 : Monitoring will have a significant positive effect on the use of adaptive practices.
 P_4 : Monitoring will mediate the relationship between management goals and information sources and adaptive practices.

These predictions were developed from existing literature that suggests the importance of monitoring as a key element influencing the iterative learning process involved in adaptive decision making. We expected that ranchers who use more information sources and who place importance on management goals related to stewardship and profit/production would be more likely to use adaptive practices. However, we also expected that without the use of monitoring to gather data about rangeland resources, ranchers would be less likely to engage in adaptive management practices. We anticipated the greatest use of adaptive management practices when ranchers had management goals that aligned with the outcomes of adaptive practices, used a variety of information sources, and used monitoring to track rangeland resource change over time. Figure 3 shows the hypothesized relationships among management goals (stewardship), management goals (profitability), information sources, monitoring, and adaptive practices.

Study Area

This study was conducted in Montana, where ranching plays a large role in the state's land use and economy. In Montana, nearly

40 million acres (43% of the state's 94 million acres) are pasture and rangelands, used primarily for livestock grazing for native rangeland beef cattle cow-calf operations (USDA Census of Agriculture 2017). Socioeconomically, livestock production is a key agricultural industry in Montana. The market value of cattle and calves (\$1 715 741 000) exceeds the sales of all crops in the state (\$1 585 015 000). Ranching takes place on predominately native rangeland, interspersed with some irrigated pasture (on average 14.2% of land for ranchers is irrigated, see Results) and Montana ranchers manage livestock across both public (e.g., Forest Service, Bureau of Land Management, State) and private lands, resulting in a complex mosaic of land tenure and management priorities. Montana is unique in that it has extensive tracts of public land; approximately 30 million acres, or roughly one third of the state (MT FWP 2022). Interestingly, while public rangelands in the United States have been a dominant focus and priority of rangeland conservation (Charnley et al. 2014), the productivity of private rangelands in the West has been found to be more than twice that of public rangelands (Robinson et al. 2019), speaking to the importance of management decisions on private lands alongside public lands. Thus, the extent of privately owned rangeland managed for livestock in Montana offers a unique study area to examine how ranchers are sustaining both the ecological and economic integrity of US rangeland systems in the context of drought and climate change.

For ranchers in Montana, increased drought frequency and other impacts of climate change have and will continue to present new challenges and uncertainties. During this study, Montana experienced more than 2 yr of drought conditions that predominately fell into the US Drought Monitor categories of severe (D2) to exceptional (D4) in 2020–21. The pattern of weather extremes that characterized the fall of 2020 and all of 2021 persisted through the first 6 mo of 2022 (DNRC 2022). According to the Montana Climate Assessment (Whitlock et al. 2017), more extreme and variable conditions are predicted to continue. Montana is projected to continue to warm in all geographic locations, seasons, and under all emission scenarios throughout the 21st century. By midcentury, there is predicted to be an average increase in temperature of 4.5–6.0°F (2.5–3.3°C), shifted timing of precipitation, and a declining snowpack that will put additional stress on Montana's water supply (Whitlock et al. 2017). These state-level changes are larger than the average changes projected globally and nationally (Whitlock et al. 2017). Thus, Montana provides a unique and important climatological context and rangeland SES context in the United States for understanding how ranchers, who both use and steward Montana's land and water resources, are making adaptive decisions toward positive social-ecological outcomes.

Methods

Sampling

We obtained data for this study using a survey of randomly selected agricultural producers in Montana conducted as part of the Montana Drought and Climate (MTDC) project, a US Department of Agriculture-funded project of the Montana Climate Office (MCO) at the W. A. Franke College of Forestry & Conservation at the University of Montana, in collaboration with the Montana State University Extension Service. We identified the population of agricultural producers in Montana and draw our sample following a five-step process using the following three datasets from the Montana State Library (Base Map Service Center Montana State Library 2022):

- The 2018 Montana Cadastral dataset;
- The 2017 Final Land Unit classification (FLU) data from the Montana Department of Revenue;

- The 2017 Montana Landcover dataset

In Step 1, we standardized owner addresses in the Montana Cadastral (parcel ownership) dataset treating landowners who received their tax bills at the same address as the same, recognizing there may be cases of multiple landowners living at each address. From this reduced dataset, we retained only the landuse acreage, owner, and address attributes. We also standardized owner addresses; for instance, we removed the last four digits of nine-digit ZIP codes and attempted to standardize idiosyncratically applied street-naming conventions, such as abbreviations of "highway" (hwy) and "route" (rte). The Montana Cadastral dataset from January 2018 contained 932 986 individual parcel ownership records. In Step 2, we aggregated and validated the owner addresses of parcels. Specifically, we aggregated parcel records for which the owner address were identical, concatenating owner names into a list and spatially merging associated parcels. This process resulted in 339 325 unique tax addresses. We further cleaned and validated the addresses using the UPS Address Validation–Street Level API. After validation, we once again aggregated parcels with identical addresses. In Step 3, we identified the agricultural acreage for each landowner using the 2017 FLU and MT Landcover datasets. For the FLU data, we selected all regions not categorized as "T—forest land," "N—noncommercial forest land," "X—other commercial nonagricultural land," and then calculated the acreage of retained FLU agricultural lands within each landholding. For the Montana Landcover data, we calculated the acreage of land classified as under cultivation (i.e., cropland). In Step 4, we applied final inclusion criteria to identify working agricultural lands. First, we excluded parcels whose owners listed mailing addresses outside of Montana. This reduced the number of landowners to 292 992. Second, we excluded land owned by federal, state, county, tribal, or municipal entities, as well as large nonprofit landholders. This further reduced the count of landowners to 292 470. Finally, to filter out "amenity" owners (i.e., those who own large parcels taxed as agricultural land but unlikely to self-identify as "agricultural producers" and/or rely on agricultural production for a substantial portion of their income), we applied two heuristic requirements for inclusion in the final population:

- 1) Must own at least 1 000 acres identified as FLU agricultural land and at least 50 acres classified as cropland per the Montana Landcover dataset. This proxies ranch operations with a minimal amount of cultivated land for hay/feed; or
- 2) Must own at least 160 acres classified as cropland per the Montana Landcover dataset. This proxied other agricultural producers.

Figure 2a shows the distribution of private landholdings of agricultural producers (as defined in this study) in Montana identified using the FLU, Montana Cadastral, NASS, and MT Landcover datasets and the proportion of private landholdings in Montana classified as grazing acreage. The criteria we applied resulted in the final eligible population of 11 155 agricultural producers from which our sample was drawn.

Finally, in Step 5, we used a stratified, random sampling method to draw our sample of 2 999 agricultural producers across the three strata. This sample size was selected to achieve approximately 900 total responses based on the overall population, funding available, and an anticipated completion rate of 30% (Dillman et al. 2014). Figure 2b shows the distribution of MTDC survey sample ($n = 2 999$) across Montana counties.

Survey development and dissemination

We administered the survey in spring 2021 using a Tailored Design Method (Dillman et al. 2014), including a presurvey letter, an



Figure 2. Map showing the distribution of private landholdings of agricultural producers in Montana (in color) identified using the FLU, Montana Cadastral, NASS, and MT Landcover datasets. **b.** Distribution of MTDC survey sample ($n=2\,999$) across Montana counties.

initial cover letter, hardcopy questionnaire, postage-paid return envelope, and two replacement packets to nonrespondents. Research questions and methods were approved by the University of Montana Institutional Review Board (IRB 31-21) before survey administration.

To understand factors related to adaptive decision making among ranchers, we asked survey respondents about themselves and their operations, replicating previous authors' measures where possible and employing new measures developed from adaptive decision-making literature where existing measures were unavailable or inapplicable.

Management goals were measured with 14 items reflecting potential management goals with importance ranks using a 1–5 scale from “Very unimportant” to “Extremely important.” To identify the “Stewardship” and “Profit/Production” dimensions of the 14 items (Table 1), we conducted an exploratory factor analysis with varimax rotation paired to reliability analyses using a cutoff of Cronbach alpha of .70 (Cronbach 1951).

To measure use of various information, we provided respondents with a list of 29 information resources adapted to our specific study area and context and asked respondents to indicate if they use each resource to make management decisions using a scale where 0 = No and 1 = Yes. For this study, composite scores were calculated as the sum of the top 10 most used information sources (see Table 1).

To understand adaptive behavior among ranchers, we provided a list of adaptive management practices that have been cited as strategies for producing desirable social and ecological outcomes during drought/climate events (Table 2). Practices were separated into categories on vegetation, soil and water management, diversification, monitoring, insurance and contracts, landscape enhancements, and grazing and livestock management. We asked respondents to indicate the extent to which they used each practice using the options “Not at all,” on a “portion of farm/ranch,” or on their “entire farm/ranch,” and for how long they had been using the practice using a scale of “less than 3 years,” “more than 3 years,” or

Table 1
Item means, standard deviations, factor loadings, and Cronbach α for all variables.

Variables ¹	Mean estimate (SE)	Cronbach α	n	Nested items	Factor loading ²	Mean estimate (SE)	n
Management Goals (Stewardship) ²	4.05 (.056)	0.894	441	To take care of the land for the future	.784	4.29 (.061)	429
			441	To support habitat health for all species	.761	3.83 (.060)	425
				To protect water and soil resources	.801	4.18 (.062)	429
				To ensure land does not become fragmented	.789	4.02 (.064)	420
Management Goals (Profit/production)	4.02 (.057)	0.878	441	To increase livestock/crop production	.824	3.80 (.058)	429
			441	To maximize profit through production	.812	4.11 (.062)	418
				To earn a living	.670	4.19 (.067)	429
				To produce food	.677	4.14 (.059)	433
Information Sources (Top 10)	3.82 (.146)		450	In person with other farmers/ranchers			324
				MSU Extension Agents			224
				Conservation District			206
				Montana Dept of Agriculture			186
				Natural Resources Conservation Service (NRCS)			144
				Montana Stockgrowers Association			141
				Agricultural Research Centers			128
				MT DNRC (including MGCC)			127
				National Oceanic and Atmospheric Administration (NOAA)			120
				Through social media with other farmers/ranchers			117
			417	Established soil and vegetation/range monitoring program to track and respond to change			
				Intensive rotational grazing		.59 (.029)	400
Adaptive Practices ³	4.53 (.110)	0.648	439	Planned grazing for weed and invasive species management		.64 (.028)	398
				Timing grazing for improved pastures		.91 (.018)	401
				Strategic placement of water for livestock and better forage utilization (infrastructure upgrades, piping systems, water tanks)		.85 (.021)	408
				Drought plan (e.g., reduce stocking rates, lease pasture, use additional hay)		.84 (.022)	403
				Managing for wildlife habitat		.61 (.028)	421
				Established riparian buffers		.46 (.029)	413

¹ Item wordings are presented here verbatim.

² Factor loadings on Management Goals (Stewardship) and Management Goals (Profit/production) components extracted using principal component analysis with Varimax rotation and Kaiser normalization. Respondents were asked to indicate how important each of these statements were to them using a five-point Likert scale where 1 = Very unimportant; 2 = Unimportant; 3 = Neither Important nor Unimportant; 4 = Important; 5 = Extremely important.

³ Question wording: "Please review the list below, indicating which practices you use and don't use. For those that you use, please let us know at what scale and for how long you have been using them." Temporal and spatial scale aspects of responses were excluded for this study and recoded as 0 = No and 1 = Yes.

Table 2
Path analysis results.

Regression model	n	R ² (adj)	F	Unstandardized coefficients - β (SE)	Standardized path coefficients	P value
Relationship between X (MGS, MGP, IS) and Y (AP), Y = B1(X)						
AP = MGS	432	.012 (.010)	5.174	0.229 (.101)	.109	.023
AP = MGP	432	.009 (.007)	3.888	0.0195 (.099)	.095	.049
AP = IS	438	.083 (.081)	39.717	0.223 (.035)	.289	.000
Relationship between X (MGS, MGP, IS) and M (M), M = B1(X)						
M = MGS	414	.018 (.015)	7.405	0.074 (.027)	.133	0.007
M = MGP	412	.016 (.014)	6.804	0.072 (.028)	.128	0.009
M = IS	416	.055 (.053)	24.273	0.047 (.009)	.235	.000
Full model						
Y = B1(X) + B2(M)						
AP = MGS + M	412	.139 (.135)	33.190	MGS: 0.130 (.099)	.061	.188
				M: 1.376 (.177)	.360	.000
AP = MGP + M	410	.138 (.134)	32.777	MGP: 0.009 (.100)	.004	.930
				M: 1.422 (.177)	.372	.000
AP = IS + M	414	.180 (.176)	45.328	IS: 0.162 (.035)	.215	.000
				M: 1.217 (.175)	.319	.000

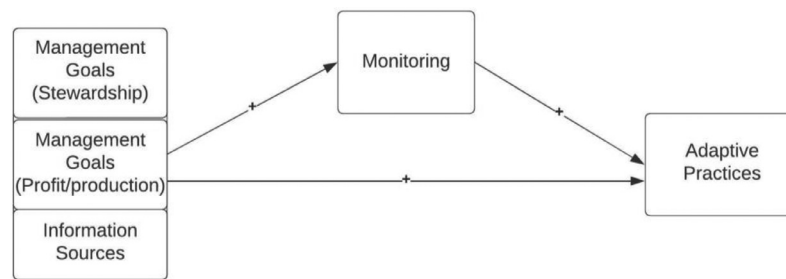


Figure 3. Conceptual diagrams showing hypothesized relationships among management goals (stewardship), management goals (profitability), information sources, monitoring, and adaptive practices.

“experimenting.” For this study, we recoded the adaptive practice variables to yes/no where 0 = No, and 1 = Yes. Composite scores for the Adaptive Practice variable were calculated as the sum of the individual items. See Table 1 for the list of behaviors included as part of the “Adaptive Practice” composite variable.

We included monitoring in the list of potential management practices and asked respondents to indicate whether they “Established soil and vegetation/range monitoring program to track and respond to change.” For this variable, we also recoded responses to yes/no where 0 = No, and 1 = Yes.

Data from questionnaires were codified and entered using appropriate data labels to facilitate analysis. Weights for the survey were calculated using a three-step process that is widely accepted in survey research literature and accounts for the study design (design weight) and nonresponse (nonresponse weight), and it calibrates the weights to population totals (Valliant et al. 2013; Battaglia et al. 2016; Haziza and Lesage 2016; Lavalley and Beaumont 2016; Haziza and Beaumont 2017). Although we found no evidence of nonresponse bias in our sample, survey weights were applied in this analysis to improve the accuracy of estimates and ensure estimates were representative of the study population. In Step 1, a base weight was calculated to account for the probability of selection of each individual in the sample. The population control total was the 11 155 agricultural producers. In Step 2, the base weight was modified to adjust for nonresponse (Brick 2013; Kreuter and Olson 2013; Olson 2013; Valliant et al. 2013; Battaglia et al. 2016; Haziza and Lesage 2016). In Step 3, the nonresponse-adjusted weight was calibrated to sampling control totals derived from the number of farms or ranches in each sampling strata (Kalton and Flores-Cervantes 2003; Sarndal 2007; Valliant et al. 2013; Lavalley and Beaumont 2016; Haziza and Beaumont 2017). Survey weight calibration was conducted using the Gest_Calibration module of Generalized Estimation System version 2.003 (January 2019) developed by Statistics Canada.

We analyzed data using three statistical software packages, including IBM SPSS Statistics version 28 (2021), SAS Version 9.5 (2021), and Statistics Canada's G-EST Version 2.03 (2019) to conduct descriptive statistics, linear regression, and path model analysis.

To determine whether monitoring partially or fully mediated the relationship among management goals (stewardship), management goals (profit/production), and information sources and the use of adaptive practices, we conducted a path analysis of our hypothesized relationship by sequentially testing 1) explanatory variables (management goals—stewardship, management goals—profit/production, and use of information sources) effect on adaptive practices, 2) explanatory variables (management goals—stewardship, management goals—profit/production, and use of information sources) effect on monitoring, and 3) combined effects of explanatory variables (management goals—stewardship, management goals—profit/production, and use of information sources) and monitoring on adaptive practices (see Fig. 1). We used a

P value of 0.05 to determine significance (Baron and Kenny 1986; Vaske 2008) and the Sobel (1982) test to further examine the indirect effect of the explanatory variables on adaptive practices when the mediator variable (*M*) is included in the model (Abu-Bader and Jones 2021).

Results

Respondent characteristics

Of the initial sample of 2 999 addresses, there were 412 ineligible addresses (i.e., undeliverable, not a farm/ranch, etc.), resulting in 2 588 eligible addresses. We received 706 useable surveys, an American Association of Public Opinion Research Response Rate 3 (The American Association of Public Opinion Research 2023) of 36.7%. Among the survey respondents, 450 self-identified as ranchers or both ranchers and farmers and were included in analysis. Cronbach alpha scores for management goals composite variables were well above the 0.65 cutoff (Vaske 2008) and right at the cutoff for adaptive practices (see Table 1).

Mean age of respondents was 66 ($n=430$), and the majority were male (77.4%; $n=437$). Only 10% ($n=47$) reported having a professional degree (MS, DDS, DVM, LLB, JD, DD) or beyond (doctorate), with 43.7% ($n=191$) reporting having an associate or bachelor's degree and 46.3% (194) reporting having high school/GED equivalent or below. Most respondents come from families with three or more generations in ranching ($M=3.57$ generations, $n=447$). More than 86% ($n=384$) of respondents had a succession plan in place and an additional 9.8% ($n=40$) had a plan to keep their land in ranching. Respondents also relied on ranching as a critical source of income—on average, 73.3% ($n=426$) of respondents' total household income came from their ranching operation.

Respondents tended to operate on land they owned ($M=76.9\%$ of acres owned, $n=434$), but private ($M=31.2\%$ of acres private leased, $n=188$) and public land (State or Federal) leases ($M=20.7\%$ acres public leased, $n=193$) also comprised significant portions of operations. Consistent with production across Montana, ranchers in our sample indicated they operated on predominately nonirrigated land, with an average of 14.2% irrigated acres across all land tenure types. The majority of respondents included cow-calf enterprises (89.9%, $n=398$), but other types of operations were represented as secondary or primary enterprises. Just under 15% (14.7%, $n=69$) of respondents said they had a stocker or yearling operation, 6.1% ($n=26$) raised sheep, 43% ($n=3$) have dairy operations, and 18.3% ($n=77$) raised other types of animals (bison, goats, horses, swine, poultry). Many ranchers indicated they grew crops, with the majority (84.2%, $n=384$) reporting hay, 41.2% ($n=183$) wheat, 37.3% ($n=162$) barley, 16.9% ($n=71$) pulses (e.g., beans, peas, lentils), and 17.3% ($n=71$) oats. All other types of crops/products we asked about (i.e., buckwheat, grain/silage corn, sugar beets, fall potatoes, oil seeds, mixed vegetable/market farm) represented < 10% of the sample.

Management goals and information sources

Respondents' management goals fell into two observable categories: 1) agricultural/livestock production and 2) land stewardship and conservation-related (see Table 1). Management goals related to lifestyle, the continuation of family traditions, and helping to maintain the vitality of rural Montana were deemed important to ranchers as well but were not a distinct category and were excluded from our analysis. Lower-level management priorities included providing opportunities for recreation, to provide good jobs, and to sequester carbon through farming/ranching practices.

Among respondents, the most highly used source of information was in-person interactions with other farmers/ranchers (72.3%, $n = 324$). Montana State University Cooperative Extension Agents (49.1%, $n = 224$), Conservation Districts (45.0%, $n = 206$), and Montana Dept. of Agriculture (41.6%, $n = 186$) information resources were used by nearly half of the respondents. Following those primary sources of information, ranchers indicated they used Montana Stockgrowers Association (33.4%, $n = 141$), Natural Resources Conservation Service (NRCS) (30.6%, $n = 144$), Agricultural Research Centers (28.8%, $n = 128$), MT DNRC (including MGCC) (28.6%, $n = 127$), social media with other farmers/ranchers (26.6%, $n = 117$), and National Oceanic and Atmospheric Administration (NOAA) (26.3%, $n = 120$). All other information resources included on our list were used by < 25% of respondents.

Monitoring and adaptive management practices

Survey respondents ($n = 450$) used a variety of practices to achieve their goals. Adaptive livestock and grazing management practices used by most ranchers were timing grazing for improved pastures (80.6%, $n = 366$), strategic placement of water for livestock and better forage utilization (infrastructure upgrades, piping systems, water tanks) (76.6%, $n = 346$), and a drought plan (e.g., reduce stocking rates, lease pasture, use additional hay) (74.3%, $n = 337$). Following those practices, more than half of respondents used planned grazing for weed and invasive species management (56.1%, $n = 247$) and intensive rotational grazing (53.1%, $n = 228$). In addition to livestock and grazing practices, just over half of respondents managed land for wildlife habitat (56.3%, $n = 251$) and two-fifths of respondents had established riparian buffers (41.8%, $n = 181$). Finally, 42.9% ($n = 193$) of ranchers reported establishing a soil and vegetation/range monitoring program to track and respond to change.

Path analysis

We found that each of the explanatory variables (management goals—stewardship; management goals—profit; and information sources) had a significant and positive effect on adaptive practices used ($\beta = .109$, $P < .05$; $\beta = .095$, $P < .01$; $\beta = .289$, $P < .001$) when monitoring was not included in the model (Table 2). Each of the explanatory variables (management goals—stewardship; management goals—profit; and information sources) also had a significant and positive effect on monitoring ($\beta = .133$, $P < .01$; $\beta = .128$, $P < .01$; $\beta = .235$, $P < .001$). However, when management goals—stewardship and management goals—profit and monitoring were both included in the model, only monitoring had a significant, positive effect on adaptive practices ($\beta = .360$, $P < .001$; $\beta = .372$, $P < .001$). When information sources and monitoring were both included in the model, both variables had a significant, positive effect on adaptive practices ($\beta = .215$, $P < .001$; $\beta = .319$, $P < .001$) (see Table 2).

Sobel test results showed the indirect effect of the management goals (MGS and MGP) variables on adaptive practices was significantly different than 0 ($z = 2.59492049$, $P < .01$; $z = 2.44985556$,

$P < .05$), as the indirect effect of information sources was significant ($z = 4.38316209$, $P < .001$) (Table 3). Thus, in the final models with the explanatory variables and monitoring included, monitoring partially mediated the relationship between management goals (MGS and MGP) and the use of adaptive practices. Monitoring also partially mediated the relationship between information sources and the use of adaptive practices (see Tables 2 and 3). No covariates were significantly related to use of adaptive practices; we excluded these variables from the final models.

These results provided evidence of a mediation among the variables in their relationship to adaptive decision making where monitoring is the strongest predictor of the use of adaptive practices and management goals, and use of information are secondary. In other words, the partial mediation we observe in our model suggests that when ranchers use monitoring, their management goals and use of information sources become less influential factors in their decision making.

Discussion

A revised adaptive decision-making-for-rangeland-management framework

This study contributes to the theory of how ranchers manage for and adapt to social and ecological change and uncertainty on rangelands in the United States. Specifically, we built upon existing knowledge of adaptive decision making within ranching systems. Recognizing that adaptive decision making among ranchers involves a suite of factors and interactions, we present a revised adaptive decision-making framework (see Fig. 1) based on the evidence from this study. Our conceptual framework illustrates three empirically grounded extensions of earlier work (Lubell et al. 2013) (see Fig. 1). First, we made the distinction between ranchers' management goals related to stewardship versus profit/production and found that both were related to ranchers' use of adaptive practices. Second, we found that monitoring and the use of information sources were the strongest predictors of adaptive decisions, which suggests that the role of loop-learning—or taking in new information and applying it in iterative fashion to adaptive decision-making processes—may be more important than previously assumed. Third, our path model analyses showed that ranchers use of monitoring mediates the influence of the other factors (i.e., use of information and management goals) on adaptive management practices.

In the context of rapid social and environmental change in the US West, these revisions to the adaptive decision making for rangeland management framework highlight two key needs: 1) increased use of monitoring among ranchers by identifying and facilitating the negotiation of key constraints to adoption; and 2) facilitated access to and use of other sources of information for rapid and effective loop-learning inherent in adaptive decision making.

Monitoring for adaptive decision making: of what, by whom, and how?

In this study, we demonstrate through empirical research that monitoring influences adaptive decision making among Montana ranchers. However, despite technological advancements that have increased the scale, accelerated the pace, and diversified the methods for rangeland monitoring—and extensive resources allocated toward education and outreach efforts through university, federal and state agencies (Stephenson et al. 2017)—monitoring has not been widely adopted for adaptive management by ranchers and rangeland managers in the United States (Fernandez-Gimenez et al. 2005; Peterson 2010; Sayre et al. 2013). Our results were consistent with these studies, showing that formal monitoring is used

Table 3
Sobel test results.

Model	A	SE _A	B	SE _B	Sobel test statistic (z)	SE	P value
AP = MGS + M	.074	.027	1.411	.175	2.5949	.0402	.00946
AP = MGP + M	.072	.028	1.411	.175	2.4499	.0415	.01429
AP = IS + M	.047	.009	1.411	.175	4.3831	.0151	.00001

by less than half of Montana ranchers. Documented constraints to the adoption of formal monitoring among ranchers include the time, labor, and associated cost involved, as well as a lack of ample training for end-users on how to collect, interpret, and apply monitoring data for management decision making (Fernandez-Gimenez et al. 2005; Stephenson et al. 2017; Newingham et al. 2022). These constraints exist for ranchers managing private lands, but empirical evidence also suggests the use of long-term monitoring programs among US public lands agencies often fail for similar reasons despite widespread institutional commitments to monitoring as part of an adaptive management strategy (Bricker and Ruggiero 1998; Sayre et al. 2013; US Forest Service 2006; Williams et al. 2007). For agencies managing grazing on public rangelands, constraints include a lack of adequate funding, human capacity, collaboration between researchers and practitioners, and flexibility in the approaches to monitoring itself (Danielsen et al. 2008; Koontz and Bodine 2008; Sayre et al. 2013).

In contrast to the lack of formal monitoring used by ranchers in the United States, a smaller number of studies have documented how informal monitoring techniques are widely used by ranchers, highlighting the need to better understand how informal methods contribute to, and could be compatible with, formal methods for effective rangeland management (Sayre 2004; Knapp and Fernandez-Gimenez 2008, 2009; Woods and Ruyle 2015). Informal monitoring is defined as nonstandardized monitoring that relies on personal practice and experience and is typically rooted in local cultural and natural environments (Raymond et al. 2010; Woods and Ruyle 2015). These techniques might include visual estimates of forage abundance and condition or precipitation and its effects on vegetation or informal photographs of their ranch from 20 or more yr previously, which they compare with current conditions. For ranchers, Woods and Ruyle (2015) found that informal monitoring can have higher spatial coverage and temporal resolution while also providing assessments faster than formal monitoring. Moreover, informal rangeland monitoring in Woods and Ruyle's (2015) study area generally appeared compatible with natural science and with formal monitoring practices. At the same time, informal monitoring was perceived by ranchers as more relevant than formal monitoring for formulating yearly grazing plans and responding rapidly to unpredictable changes in the natural environment (Woods and Ruyle 2015).

In Montana, there is an innovative pilot project under way called the Rangeland Monitoring Group (RMG) that provides an example of how ranchers, scientists, and nonprofit conservation groups are working together to understand how rangeland monitoring and collective knowledge can inform and improve land management. Through virtual and in-person meetings, the RMG team has engaged in dialogue addressing some of the barriers to implementing and using monitoring in management decisions. For instance, RMG members have discussed how training local technicians would save on expenses given that most monitoring costs are for travel and logistics for third-party consultants (RMG 2022). In addition, local technicians would likely be more available, including availability at shorter time frames, when a follow-up or clarification visit is needed. Regarding what and how to monitor, a goal of RMG is to identify key indicators for their local ecosystems (in the Northern Great Plains) based on both existing literature and ranchers' on-the-ground experiences. Central tenants of the

project include group learning, training younger participants, sharing monitoring data, discussing management decisions, and documenting outcomes. The RMG project presents an example of how researchers and ranchers can work together to jointly understand, test, and develop monitoring techniques that can be effectively integrated into adaptive decision making toward desired social and ecological outcomes.

On the basis of the results of this study, we argue that there is a need for additional research that examines social dimensions of—and constraints to—the adoption of monitoring by ranchers, which have received relatively little scholarly attention in comparison with research addressing technological limitations. Specifically, the questions arise: monitoring of what, by whom, and how is most effective for adaptive decision making? Future research might endeavor to ask questions, such as “What characteristics of monitoring systems are most relevant and useful to ranchers for rapidly developing knowledge that supports decision making, particularly in light of the pace at which rangeland SESs are changing? How can the well-documented barriers of time, cost, and technical expertise be reduced for ranchers? and How could support from government agencies (e.g., Extension, NRCS) help address these challenges?” Future research is also needed to examine the efficacy of strategies such as those RMG is currently employing (e.g., increasing local involvement in monitoring, group learning, and negotiating constraints associated with cost) to increase the efficacy of monitoring for rangeland management. In addition, future research is needed to understand the advantages and disadvantages associated with informal monitoring techniques and how, in combination with formal monitoring, they might enhance adaptive decision making on US rangelands. In contrast to the exclusively quantitative methods used in this study, we suggest that these questions lend themselves to qualitative, interdisciplinary, and collaborative research that centers the experiences and ranchers and other rangeland decision makers with regard to monitoring as it influences adaptive management in light of change.

Other information sources to enable effective loop-learning for adaptive decision making

We found that the use of information sources, including in-person networks among Montana ranchers, was a significant predictor of the use of adaptive practices, consistent with previous research (Prokopy et al. 2008; Kachergis et al. 2013; Lubell et al. 2013; Roche et al. 2015; Fernández-Giménez et al. 2019; Prokopy et al. 2019). Ranchers who used a greater number of information sources were more likely to use adaptive management practices. Montana ranchers in our study used information from a diversity of sources, including their community/peers, industry organizations, and extension agencies leaders. The source of information most used by Montana ranchers, however, is their own network of other farmers and ranchers (72% of ranchers). This finding echoes research highlighting the positive influence that social learning, or peer-to-peer learning, can have on conservation and climate-related decision-making practices among agricultural producers (Lubell et al. 2013; Marshall and Stokes 2014; Roche et al. 2015; Roche 2016; Wilmer et al. 2021). On the basis of these results, it seems likely that Montana ranchers would benefit from institutional and financial support for peer-to-peer learning opportunities

where ranchers can set their own agendas and discuss their own experiences, knowledge, and experimentation with adaptive management practices in response to drought and climate events. For instance, in Montana, where ranchers often have to travel long distances to attend meetings and gatherings, funding could cover travel expenses associated with rancher groups/networks in each of Montana's seven climate zones who want to share and learn from one another in the midst of current drought conditions.

Aside from other agricultural producers, MSU Extension, Conservation Districts, NRCS, Montana Dept of Agriculture, and Montana Stockgrowers Association were the most used sources of information, making them well positioned to link producer knowledge and goals with climate information and adaptive management strategies. Research investigating the influence of similar types of in-person sources of information—conservation agencies, attendance at workshops, and agricultural advisors (Nowak 1987; McBride and Daberkow, 2003; Gillespie et al. 2007; Singh et al., 2018; Eanes et al., 2017)—has generally found a positive relationship between agricultural producers who actively sought out these sources and their adoption of conservation practices (Prokopy et al. 2019). Thus, it is important that information on current and projected impacts of drought and climate events, along with information on adaptive management strategies in responses to these changes is available to ranchers seeking it through these channels. Moreover, as others have suggested (Briske 2012; Smith et al. 2021; Wilmer et al. 2021), building cooperation among these diverse entities for communicating information and other learning opportunities for ranchers could potentially bring new ideas and opportunities to the table for adaptive rangeland management.

Beyond providing Montana ranchers with more opportunities to access information from trusted information sources, there is a need for the right type of climate-related information that is specifically designed to aid decision making. Numerous studies have shown that climate-related information is especially underutilized in decisions made by agricultural producers (Dilling and Lemos 2011; Lemos et al. 2012; Mase and Prokopy 2014; Smith et al. 2021). For Montana farmer and ranchers, Smith et al. (2021) found that the underuse of climate information is due to mismatches in the temporal and spatial scale affecting the utility of that information for decision making, as well as other factors interacting with scale, such as producers' perceptions of uncertainty or low accuracy of information, negative perceptions of source credibility, and a lack of trust in information providers (Smith et al. 2021). Specifically, producers preferred climate information at smaller spatial scales (i.e., ranch or pasture-level) and short-term weather forecasts and seasonal climate forecasts were more useful than long-term projections (e.g., midcentury), in part because shorter timeframes were perceived to be more accurate. These findings are consistent with other studies (McCrea et al. 2005; Cash et al. 2006; Ash et al. 2007; Dong et al. 2018). Following Smith et al. (2021) and others, we suggest that trusted information providers in Montana work with ranchers to align the spatial and temporal scales of climate information, format of dissemination, and content with ranchers' decision-making needs, to the extent possible given the limits of climate forecasts and projections. The improvement of drought and climate-related resources, we posit, will involve mechanisms for iterative feedback and meaningful engagement between information providers and ranchers.

Changing landscapes, changing management goals and decisions?

Our results showed that Montana ranchers' top management priorities included both sustaining a profitable operation while also achieving stewardship-related goals, which is consistent with past work documenting management goals among ranchers in the US West (Kachergis et al. 2013; Roche et al. 2015). This suggests

that efforts to support the ranching community in the adoption of more adaptive practices will be most effective if they highlight how these practices contribute to ranchers' ecological and economic goals in tandem, address tradeoffs between these goals, and provide resources specific to ranchers' operations and environmental contexts. However, in contrast to Roche et al. (2015) and Kachergis et al. (2013), who both found that ranchers' highest priorities were production related followed by environmental, the two goals that ranked highest in importance for Montana ranchers in our study were “to take care of the land for the future” and “to protect water and soil resources.” The prominence of stewardship-related goals among respondents raises a number of questions for further consideration. First, research has shown that ranchers in the US West tend to share a common concern for the land, or “land ethic” regardless of viewpoints on other issues such as government involvement in land management (Lien et al. 2017). Our results suggest that Montana ranchers, too, place importance on land stewardship and conservation. At the same time, management goals were not found to be the dominant factors influencing decision making. Future research might endeavor to understand ranchers' environment-related values in greater detail, examining how they influence rangeland management and decision making. Second, these results prompt questions around how climate and other environmental changes on rangelands have potentially influenced ranchers' management priorities. Have recent ecological threats brought conservation-related goals to the forefront of ranchers' minds or “mental models” (Wilmer and Sturrock 2020) for managing resources they rely on for livelihood? Finally, could Montana ranchers' indication of stewardship-related goals be reflective of broader shifts in land management priorities related to land ownership transitions in the West? Currently in the US West, significant landownership transitions are under way where “traditional” working ranches are being sold to amenity buyers, whose focus is on providing land “amenities” rather than livestock production as their dominant goal (Gosnell and Travis 2005; Brunson and Huntsinger 2008). Although we attempted to exclude amenity owners from our sample, what characterizes amenity owners from working ranchers in Montana is largely undocumented. Given that amenity owners are becoming more important as stewards of US rangelands, understanding who they are and how they are managing rangelands alongside working ranchers in light of drought and climate change may be a worthwhile research endeavor.

Limitations

A few limitations of this study should be noted. First, we recognize that adaptive decision making among ranchers involves a complex and broad suite of factors and interactions at both the individual level and at scales beyond the individual beyond what this study was able to capture. Second, there are considerations regarding the relationships among variables in our model that we do not examine. For example, while our findings align with the well-established body of literature that has found the use of information to be positively correlated with the adoption of conservation-related practices among agricultural producers described earlier, there could be more to this relationship. Do ranchers use adaptive practices *because* they use more information, or does the use of information reflect other qualities ranchers possess, such as an affinity for science-based management or an openness to change and experimentation? Or, as Lubell et al. (2013) point out in their study, could a strong relationship between use of information and practices be indicative of a positive feedback loop or a case of reciprocal causality, where ranchers continue to invest in learning about practices in ways that reinforce their decisions use those practices? Using a quantitative survey approach limited our ability to ask these kinds of follow-up questions. Despite these limita-

tions, our findings have both theoretical contributions and practical implications for improving future outreach, extension and research on adaptive decision making for rangeland management.

Conclusion

In this paper, we examined factors that influence Montana ranchers' adaptive decision making in light of drought and climate change. Building on previous conceptualizations of adaptive decision making for rangeland management, we examined the role of management goals, information sources, and the role of monitoring as they influenced ranchers' decisions to use a suite of adaptive management practices. Our findings highlight that monitoring has a significant, positive impact on adaptive decision making—an assertion that has been made in the rangeland management literature but has lacked empirical evidence. More specifically, our path model analysis showed that monitoring partially mediated the relationship between management goals and information sources on adaptive practices. In our revised framework for adaptive decision making, we show this hierarchical relationship among management goals, information sources, and monitoring on the use of adaptive practices, adding to earlier models. Our findings point to the need for future research to better understand how to develop monitoring programs and providing information resources that not only appear useful—but are also used—by ranchers to both achieve management objectives and engage in adaptive decision making toward desirable social and ecological outcomes. Our research explored these concepts in the context of ranchers' adaptations to drought and climate-related change in Montana, but additional research in diverse rangeland SESs will aid in assessing and expanding on our results.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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