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ADAPTATION IN RANGELAND SOCIAL-ECOLOGICAL SYSTEMS: A MIXED-METHODS, CROSS-SCALE EXAMINATION OF FACTORS INFLUENCING RANCHERS’ ADAPTATION TO DROUGHT AND CLIMATE CHANGE

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ADAPTATION IN RANGELAND SOCIAL-ECOLOGICAL SYSTEMS: A MIXED-METHODS, CROSS-SCALE EXAMINATION OF FACTORS INFLUENCING RANCHERS' ADAPTATION TO DROUGHT AND CLIMATE CHANGE

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ABSTRACT

Rangeland social-ecological systems (SESs), which make up vast tracts of land on Earth, are critical for safeguarding ecosystem services, producing food and fiber, protecting open space, contributing to local and regional economies, and maintaining cultures and knowledges. Sustaining rangelands, the ranching livelihoods that depend on them, and the suite of ecosystem goods and services they provide hinges on a greater understanding of the social processes that influence ranchers' ability to adapt within these changing systems. In this study, I used a mixed-methods approach to examine factors influencing ranchers' adaptation to drought and climate change across scales.

In Chapter 3, I systematically reviewed social science studies examining adaptation in rangeland SESs, finding that this research is theoretically and conceptually fragmented, yet geographically concentrated. For this body of research to provide important insights into climate change adaptation policy and practice, I suggest there is a need for more transdisciplinary and translational approaches to evaluating adaptation in rangeland SESs, particularly in understudied rangeland systems.

In Chapter 4, I used a quantitative approach to examine factors that influence Montana ranchers' (n= 450) adaptive decision-making in light of drought and climate change. Consistent with existing theory of adaptive decision-making in rangeland systems, I demonstrated the significant role of ranchers' management goals and use of information on their use of adaptive practices. Unlike previous conceptualizations, I found that ranchers' use of rangeland monitoring is also a significant, positive predictor of adaptive decision-making and mediates the influence of other factors — an assertion that has been made in the rangeland management literature but has lacked empirical evidence. These findings demonstrate that the role of loop-learning — or taking in new information and applying it in an iterative fashion to adaptive decision-making processes — may be more important to adaptive decision-making than earlier conceptualizations suggest.

In Chapter 5, I used a mixed-methods approach to examine how 'structures' — specifically government programs and grazing permits administered by public lands agencies — influence Montana ranchers' ability to adapt to drought and other climate-related events. Through an analysis of survey data (n= 450) and in-depth interviews (n= 34), three key themes emerged: 1) the need for increased flexibility within government programs to allow ranchers to achieve desired outcomes in ways that fit their operations and local conditions; 2) the need for participatory design approaches when developing programs intended to assist ranchers in adaptive management and; 3) the need for collaborative, working relationships between ranchers and government representatives in order to navigate the 'gray zones' of program and policy implementation on-the-ground. Based on these findings, I discuss how government programs and permits might more effectively enable ranchers' ability to adapt to complex and changing conditions. As a whole, this dissertation reflects a commitment to research that uses and develops methodological approaches for conducting meaningful social science research with ranchers in the U.S., expands upon theory and concepts related to climate change adaptation, informs policy and practices for management, and illuminates future research directions.

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Chapter 1: Introduction

Rangelands cover nearly half of all land on Earth and are home to millions of people who derive their livelihoods predominately from livestock grazing (Asner et al., 2004; Reid et al., 2014; Sayre et al., 2013). In the U.S., rangelands make up the most extensive class of lands in the U.S. West (Sayre 2012; USFS 2012), of which grazing is a primary use (Nickerson et al. 2011; USDA-NRCS 2007). Rangelands, often described as “social-ecological systems” (SESs) because of the interconnectedness of humans (and their values, organizations, and institutions) with ecological processes (Hruska et al., 2017; Roche, 2021), are critical for safeguarding ecosystem services, producing food and fiber, protecting open space, contributing to local and regional economies, and maintaining cultures and knowledges (Brunson & Huntsinger, 2008; Sayre et al., 2012).

Today, ranchers and rangeland managers, who use and steward rangelands, are facing unprecedented social and environmental change. Specifically, climate change and its associated impacts introduce new dynamics and uncertainties that affect rangeland ecology and productivity (Briske et al., 2015; Cook et al., 2015; Derner & Augustine, 2016; Joyce et al., 2013; Kuwayama et al., 2019; Sayre et al., 2013). At the same time, ranchers must adapt to changing markets, the pressures of shifting land use across the West (Gosnell & Travis 2005), and changes in ranch ownership and generational turnover (Hinrichs & Welsh 2003; Hoppe & Banker, 2010) among other dynamics. While ranchers are seasoned to adapting their management goals and practices to reduce their risks in the face of increased complexity and uncertainty (Sayre et al. 2012), the pace and extent of social and ecological change today will require ranchers to adapt in new ways (Briske et al., 2015; Joyce et al., 2013; Joyce & Marshall, 2017; Roche, 2021).

In Montana, the current and anticipated impacts of drought and climate change present new challenges for ranchers, who manage vast tracts of land across the state. Nearly 40 million acres (of Montana’s 94 million acres) are pasture and rangelands, used primarily for livestock grazing for native rangeland beef cattle cow-calf operations (USDA, 2019). Montana ranchers manage livestock across both public (i.e. Forest Service, Bureau of Land Management, State) and private lands, resulting in a complex mosaic of land tenure and management priorities. While Montana ranchers have always faced variability in weather and climate conditions, Montana ranchers are currently experiencing some of its worst drought conditions in recent decades (NIDIS, 2022), a trend that is expected to continue. According to the Montana Climate Assessment, by mid-century, there is predicted to be an average increase in temperature of 4.5–6.0°F (2.5–3.3°C), an increased variability in precipitation, and a declining snowpack, which will put additional stress on Montana's water supply and the rangeland ecosystems that depend on it (Whitlock et al., 2017). Thus, stewardship of rangelands in Montana depends on ranchers and rangeland managers who are able to adapt in the face of great variability and uncertainty.

Understanding the adaptation context and strategies of Montana ranchers in light of drought and climate change is the focus of this research. Adaptation is recognized as a vital approach for reducing vulnerability and building resilience in rangeland SESs (Adger, 2006; Adger et al., 2007; Briske et al., 2015; Karimi, 2018) and involves structural and behavioral actions of adjusting to the threats of climate change to sustain activities or transform the state of the social-ecological system (Adger et al. 2007; Berrang-Ford et al., 2011; Folke, 2006; Gallopin, 2006). Adaptation is influenced by adaptive capacity, or the preconditions that determine peoples' ability to anticipate and adapt to change, which can include factors related to actors, social networks, and institutions (Cinner, 2015). For example, institutions such as government policies, programs and regulations have been cited as critical variables affecting adaptive capacity, recognizing that they can either enable or constrain agency of actors within the system (Engle 2011; Gupta, 2010; Sayre et al., 2013a; Wollstein et al, 2021). In addition, adaptation involves adaptive management and decision-making among individuals, which involves ranchers' unique knowledge, experience, and values (Knapp & Fernandez-Gimenez, 2009; Roche et al., 2015; Sorice et al., 2012; Wilmer & Fernández-Giménez, 2015; Wilmer & Sturrock, 2020) as well as iterative learning to effectively respond to and improve outcomes in light of social and ecological change (Derner et al., 2022;

Derner & Augustine, 2016; McCord & Pilliod, 2022; Roche, 2016). Thus, adaptation involves both individual choice or 'agency' as well as agency that exists within a context of structures, governance, and institutions.

As the impacts of climate change manifest in the U.S. West, ranchers adapt in numerous ways to achieve their management goals, improve rangeland ecosystems, and reduce economic risks for their ranching operation. 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 (Haigh et al., 2021; Joyce & Marshall, 2017; Sayre 2012; Yung et al., 2015). Ranchers may also utilize incentive-based programs developed by federal and state governments to mitigate risk and/or help support ecosystem function (e.g. watershed health, biodiversity, and wildlife habitat) in light of drought and other climate events. There are also well-documented barriers to the adaptive capacity and decision-making of ranchers in the U.S., including the lack of adequate policies to certify and support smaller processing facilities that would help more ranchers diversify genetics of their herd for drought or heat tolerance or sell directly to local consumers when needed. In addition, for ranchers who graze on public lands, the uncertainties of renewal and terms of grazing permits leases has been found to inhibit adaptive management (Sayre et al., 2012; Wollstein et al., 2021). Indeed, in rangeland SESs, the suite of factors influencing ranchers' adaptation strategies is complex and multiscalar. For ranchers in Montana, considerable gaps remain in our understanding of what adaptation strategies ranchers are utilizing to plan for and respond to drought and climate change — and what factors enable and constrain those strategies.

The need to understand how people who depend on rangelands for their livelihoods are adapting to change has prompted a growing body of literature examining factors influencing adaptive capacity and adaptation practices among ranchers. In Chapter 3, I systematically review this literature using a combination of qualitative, quantitative, and bibliometric analysis to understand how the social dimensions of adaptation processes in rangeland SESs have been studied. Specifically, I examine scholarship that uses climate adaptation, adaptive capacity, and adaptive decision-making frameworks. Broadly, I am interested in understanding how each of these three concepts are employed in research. I discuss their theoretical foundations, disciplinary origins, and methodological differences, highlighting the strengths and weaknesses of different research approaches. By synthesizing past research, my goal is to help identify how we can use existing knowledge in this rapidly growing body of scholarship in ways that advance current and future lines of research.

In Chapter 4, I build on previous conceptualizations of adaptive decision-making that situate individual-level decisions within complex rangeland social-ecological systems. Specifically, I use a quantitative modelling approach to understand the most influential factors enabling and constraining Montana ranchers' adaptive decision-making process in the context of ongoing drought and climate related change. I test and build 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 SES. Adopting this framework, I analyze survey responses (n=450) among Montana ranchers using linear regression and path model analysis techniques to quantitatively test the relationships among factors known to drive rancher decision-making at a generalizable scale and to identify and describe new, significant, variables contributing to ranchers' adaptive decision-making. Through this analysis, I advance adaptive decision-making theory and contribute social science perspectives to the dialogue on adaptive management that has existed predominately in the natural science-oriented field of rangeland management.

In Chapter 5, I "zoom out" and look at external factors shaping adaptation for ranchers. I examine how institutions — specifically government programs and grazing permits administered by public lands agencies (i.e. Forest Service, Bureau of Land Management) — influence Montana ranchers' ability to adapt to drought and other climate-related events. Using both quantitative survey data (n=450) and in-depth interviews (n= 34), I examine ranchers' participation in a suite of conservation-related government programs in Montana. I use qualitative interviews to gain a more detailed understanding of how ranchers' perceptions of and experiences participating in various programs have enabled or constrained their ability to plan for and respond to drought and climate-related events. I discuss four themes that emerged across interviews and survey data that highlight institutional factors enabling and constraining ranchers adaptation processes. In this Chapter, I also provide recommendations for future research and policy efforts aimed at developing government programs and permits that enhance ranchers' ability to adapt to complex and changing conditions.

Sustaining rangeland landscapes, the ranching livelihoods that depend on them, and the suite of ecosystem goods and services they provide (Briske et al. 2011; Sayre, 2012) hinges on a greater understanding of the social factors and processes that influence the ability of ranchers to adapt within these changing systems (Reid, 2014; Roche, 2021). Montana offers a unique and important social and ecological context to examine adaptation given the current and anticipated effects of drought and climate change as well as the dominant role ranching plays in the state's land use, economy, and culture. The following chapters reflect my attempt to respond to the need for advancing rangeland science and management through greater attention to social dimensions of adaptation among ranchers across scales (Reid et al, 2014; Reid et al., 2021; Roche, 2021). By using a mixed-methods approach, I also address recent calls in the field for using methods that move toward translational rangeland science that informs and catalyzes management to meet multiple social, economic and ecological objectives in light of change (Reid et al., 2021; Wilmer et al., 2019; Wilmer et al., 2021). This study is simply the beginning of future research, conversations, and collaborations. Undoubtedly, bolstering adaptive capacity and enabling adaptive action will require cross-scale solutions and synergies among people — from ranchers to conservation and extension agencies, information-providers, and others — to bring about positive social-ecological outcomes now and into the future.

References

Adger, W.N., Agrawala, S., Mirza, M.M.Q., Conde, C., O'Brien, K., Pulhin, J., Pulwarty, R., Smit, B., & Takahashi, K. (2007). Assessment of adaptation practices, options, constraints and capacity. In M.L. Parry, O.F. Canziani,J.P. Palutikof,P.J. van der Linden,& C.E. Hanson (Eds*.), Climate change 2007: Impacts, adaptation and vulnerability.* Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, England, pp. 717–743.

Asner, G.P., Elmore, A.J., Olander, L.P., Martin, R.E., & Harris, A.T. (2004). Grazing systems, ecosystem responses, and global change. *Annual Review of Environment and Resources 29*(1), 261-299.

Berrang-Ford, L., Ford, J.D., & Paterson, J. (2011). Are we adapting to climate change? *Global Environmental Change, 21*, 25–33.

Briske, D. D., Joyce, L. A., Polley, H. W., Brown, J. R., Wolter, K., Morgan, J. A., … Bailey, D. W. (2015). Climate-change adaptation on rangelands: Linking regional exposure with diverse adaptive capacity. *Frontiers in Ecology and the Environment*, *13*(5), 249–256. https://doi.org/10.1890/140266

Brunson, M. W., & Huntsinger, L. (2008). Ranching as a conservation strategy: Can old ranchers save the new west? *Rangeland Ecology and Management, 61*, 137-147. https://doi.org/10.2111/07-063.1

Cinner, J. E., Huchery, C., Hicks, C. C., Daw, T. M., Marshall, N., Wamukota, A., & Allison, E. H. (2015). Changes in adaptive capacity of Kenyan fishing communities. *Nature Climate Change*, *5*(9), 872–876. https://doi.org/10.1038/nclimate2690

Cook, B. I., Ault, T. R., & Smerdon, J. E. (2015). Unprecedented 21st century drought risk in the American Southwest and Central Plains. Sci. Adv. 1:e1400082. https://doi.org/10.1126/sciadv.1400082

Derner, J. D., Budd, B., Grissom, G., Kachergis, E. J., Augustine, D. J., Wilmer, H., … Ritten, J. P. (2022). Adaptive grazing management in semiarid rangelands: An outcome-driven focus. *Rangelands*, *44*(1), 111–118. https://doi.org/10.1016/j.rala.2021.02.004

Derner, J. D., & Augustine, D. J. (2016). Adaptive management for drought on rangelands. *Rangelands*, *38*(4), 211–215. https://doi.org/10.1016/j.rala.2016.05.002

Engle, N. L. (2011). Adaptive capacity and its assessment. *Global Environmental Change*, *21*(2), 647–656. https://doi.org/10.1016/j.gloenvcha.2011.01.019

Folke, C. (2006). Resilience: The emergence of a perspective for social-ecological systems analyses. *Global Environmental Change,* 1, 253–267.

Gallopin, G.C. (2006). Linkages between vulnerability, resilience, and adaptive capacity. *Global Environmental Change, 16*(3), 235–316.

Gosnell, H., & Travis, W. R. (2005). Ranchland ownership dynamics in the Rocky Mountain West. *Society for Range Management*, *58*(2), 191–198.

Gupta, J., Termeer, C., Klostermann, J., Meijerink, S., van den Brink, M., Jong, P., … Bergsma, E. (2010). The Adaptive Capacity Wheel: A method to assess the inherent characteristics of institutions to enable the adaptive capacity of society. *Environmental Science and Policy*, *13*(6), 459–471. https://doi.org/10.1016/j.envsci.2010.05.006

Haigh, T., Hayes, M., Smyth, J., Prokopy, L., Francis, C., & Burbach, M. (2021). Ranchers' use of drought contingency plans in protective action decision making. *Rangeland Ecology & Management*, *74*(1), 50–62. https://doi.org/10.1016/j.rama.2020.09.007

Hinrichs, C. C., & Welsh, R. (2003). The effects of the industrialization of US livestock agriculture on promoting sustainable production practices. *Agriculture and Human Values, 20*, 125–141. https://doi.org/10.1023/ A:1024061425531

Hoppe, R. A., & Banker, D. E. (2010). *Structure and finances of US farms: Family farm report.* Economic Information Bulletin, USDA Economic Research Service. http://ssrn.com/abstract= 923592 (accessed 23 October 2015).

Hruska, Tracy, Lynn Huntsinger, Mark Brunson, Wenjun Li, Nadine Marshall, José L. Oviedo, & Hilary Whitcomb. (2017). Rangelands as social-ecological systems. In D. D. Briske (Ed.), *Rangeland Systems*, (pp. 263– 302). Cham, Switzerland: Springer

Joyce, L. A., Briske, D. D., Brown, J. R., Polley, H. W., McCarl, B. A., & Bailey, D. W. (2013). Climate change and North American rangelands: Assessment of mitigation and adaptation strategies. *Rangeland Ecology and Management*, *66*(5), 512–528. https://doi.org/10.2111/REM-D-12-00142.1

Joyce, L. A., & Marshall, N. A. (2017). Managing climate change risks in rangeland systems. In D. D. Briske (Ed.), *Rangeland systems: Processes, management and challenges* (pp. 491–526). Springer Cham. https://doi.org/10.1007/978-3-319-46709-2_15

Knapp, C. N., & Fernandez-Gimenez, M.E. (2009). Knowledge in practice: Documenting rancher local knowledge in northwest Colorado. *Rangeland Ecology and Management, 62*, 500–509.

Kuwayama, Y., Thompson, A., Bernknopf, R., Zaitchik, B., & Vail, P. (2019). Estimating the impact of drought on agriculture using the U.S. drought monitor. *Am. J. Agric. Econ. 101*, 193–210. https://doi.org/10.1093/ajae/aay037

Lubell, M. N., Cutts, B. B., Roche, L. M., Hamilton, M., Derner, J. D., Kachergis, E., & Tate, K. W. (2013). Conservation program participation and adaptive rangeland decision-making. *Rangeland Ecology & Management*, *66*, 609–620.

McCord, S. E., & Pilliod, D. S. (2022). Adaptive monitoring in support of adaptive management in rangelands. *Rangelands*, *44*(1), 1–7. https://doi.org/10.1016/j.rala.2021.07.003

Nickerson, C., Ebel, R., Borchers, A., & Carriazo, F. (2011). Major uses of land in the United States, 2007. U.S. Department of Agriculture Economic Research Service. http://www.ers.usda.gov/Publications/ EIB89/EIB89.pdf

National Integrated Drought Information System (NIDIS). (2022). https://www.drought.gov/historical-information?state=montana&dataset=0&selectedDateUSDM=20211019

Reid, R. S., Fernández-Giménez, M. E., & Galvin, K. A. (2014). Dynamics and resilience of rangelands and pastoral peoples around the globe. *Annual Review of Environment and Resources*, *39*(1), 217–242. https://doi.org/10.1146/annurev-environ-020713-163329

Reid, R. S., Fernández-giménez, M. E., Wilmer, H., Pickering, T., Kassam, K. S., Yasin, A., … Reid, R. S. (2021). Using research to support transformative impacts on complex, "wicked problems" with pastoral peoples in rangelands. *Frontiers in Sustainable Food Systems, 4*. https://doi.org/10.3389/fsufs.2020.600689

Roche, L. M. (2016). Adaptive rangeland decision-making and coping with drought. *Sustainability*, *8*(12), 1–13. https://doi.org/10.3390/su8121334

Roche, L. M. (2021). Grand challenges and transformative solutions for rangeland social-ecological systems – emphasizing the human dimensions. *Rangelands*, 1–8. https://doi.org/10.1016/j.rala.2021.03.006

Sorice, M. G., Conner, J. R.,Kreuter, LI. P. &Wilkins, R. M. (2012). Centrality of the ranching lifestyle and attitudes toward a voluntary incentive program to protect endangered species. *Rangeland Ecology & Management, 65*, 144-152.

Sayre, N. F., Carlisle, L., Huntsinger, L., Fisher, G., & Shattuck, A. (2012). The role of rangelands in diversified farming systems: Innovations, obstacles, and opportunities in the USA. *Ecology and Society*, *17*(4). https://doi.org/10.5751/ES-04790-170443

Sayre, N. F., McAllister, R. R., Bestelmeyer, B. T., Moritz, M., & Turner, M. D. (2013). Earth Stewardship of rangelands: coping with ecological, economic, and political marginality. *Frontiers in Ecology and the Environment*, *11*(7), 348–354. https://doi.org/10.1890/120333

United States Department of Agriculture Natural Resources Conservation Service (USDA-NRCS). (2007). *Summary report: 2007 natural resources inventory.* http://www.nrcs. usda.gov/Internet/FSE_DOCUMENTS//stelprdb1041379.pdf. http://dx.doi.org/10.2172/910936

United States Forest Service (USFS). (2012). *About rangelands.* http://www.fs.fed.us/rangelands/whoweare/index.shtml

United States Department of Agriculture. (2019). Montana agricultural facts 2018. https://www.nass.usda.gov/Statistics_by_State/Montana/Publications/Special_Interest_Reports/agfacts.pdf

Whitlock, C., Cross, W., Maxwell, B., Silverman, N., & Wade A. A. (2017). *2017 Montana climate asssessment.* Montana State University; University of Montana, Montana Institute on Ecosystems. doi:10.15788/m2ww8w.

Wilmer, H., & Fernández-Giménez, M. E. (2015). Rethinking rancher decision-making: A grounded theory of ranching approaches to drought and succession management. *Rangeland Journal*, *37*(5), 517–528. https://doi.org/10.1071/RJ15017

Wilmer, H., & Sturrock, J. (2020). "Humbled by nature": A rancher's mental model of adaptation in the great plains. *Great Plains Research*, *30*(1), 15–33. https://doi.org/10.1353/gpr.2020.0001

Wilmer, H., Porensky, L., Fernandez-Gimenez, M., Derner, J., Augustine, D., Ritten, J., & Peck, D. (2019). Community-engaged research builds a nature-culture of hope on North American Great Plains Rangelands. *Social Sciences*, *8*(1). https://doi.org/10.3390/socsci8010022

Wilmer, H., Schulz, T., Fernández-Giménez, M. E., Derner, J. D., Porensky, L. M., Augustine, D. J., … Meade, R. (2021). Social learning lessons from collaborative adaptive rangeland management. *Rangelands*, 1–11. https://doi.org/10.1016/j.rala.2021.02.002

Wollstein, K., Wardropper, C. B., & Becker, D. R. (2021). Outcome-based approaches for managing wildfire risk: Institutional interactions and implementation within the "Gray Zone." *Rangeland Ecology & Management*, *77*(1), 101–111. https://doi.org/10.1016/j.rama.2021.04.007

Yung, L., Phear, N., Dupont, A., Montag, J., & Murphy, D. (2015). Drought adaptation and climate change beliefs among working ranchers in Montana. *Weather, Climate, and Society*, *7*(4), 281–293. https://doi.org/10.1175/WCAS-D-14-00039.1

Positionality

Situating the Author: 'The place from which I speak'

This research emerged, first and foremost, out of my interest, experiences, and connections to ranching in Montana — which, for me, has been an ongoing journey of learning from my own family and from countless ranchers about their histories, knowledge, and ways of managing, stewarding and producing food on Montana's rangelands. During the interviews I conducted with over 30 ranchers for this research, I was, without exception, asked, "Where are you from?" or "Did you grow up here?" and in answering these questions, I had over thirty opportunities to reflect upon my own identity and relationship to this work, which I discuss here.

In all research, but especially in relational and qualitative social science research, it is critical for researchers to locate themselves — to answer the question, from what "place" do you speak? (Absolon & Willett, 2005). In the social sciences, this is known as acknowledging your positionality — or, 'where you're coming from' — your views and positions, and how these might influence the design, execution, and interpretation of your research and data findings (Holmes, 2020; May & Perry, 2017; Rowe, 2014; Savin-Baden & Major, 2013). Self-reflection and reflexivity are necessary prerequisites — and ongoing processes — for identifying, constructing, and critiquing one's positionality (Smith, 1999). In this section, I address the question: how do I understand the impact of my identity and relationships to my work? By doing so, I attempt to make my own views and subjectivity transparent to others, and in the process, to gain clarity for myself.

An Insider or an Outsider View?

I didn't grow up in Montana and I didn't grow up a ranch kid. Simply put, I am not, in many ways an "insider" to the Montana ranching community and culture. At the same time, I'm not entirely "outside" of it either.

A long-standing definition of insiders and outsiders in social science research is, "insiders are the members of specified groups and collectives or occupants of specified social statuses;

outsiders are non-members" (Merton, 1972). One area of debate regarding researchers' positionality is whether or not being an "insider" or an "outsider" to the culture or people who are the focus of research is advantageous or not; some question the ability of outsider scholars to competently understand the experiences of those inside the culture, while others question if insider scholars are too close, or too embedded within a culture or community to be able to sufficiently study it (Kusow, 2003).

Growing up, I spent summers in Montana on my grandparent's land, much of which had been working ranchland in years past. While my visits were after my family was actively ranching, I grew up hearing stories about the days my (step-)Grandpa Ralph and his brother Bruce had a thriving sheep and then cow-calf operation at the far reaches of Ninemile Valley before he married my grandma (in their 70s) — and about the years my Grandpa Jim, a physician, had a small herd of cattle in same valley, too. Some of my most impressionable childhood memories revolved around my summer horse friends (Fella and Lou to be specific), the smell of leather in the tack shed, and our annual visit with our good friends the Zentz's at Zig Zag Ranch just outside of Billings. I will never forget when I was 7 or 8 and my sisters and I got to "help" with a day-long cattle move — I can still picture the sea of cows and calves around us and my Dad showing us skills that we never knew he had from his days working at the Zentz's. When we were not in Montana, we were back home on our small farmstead in southern Wisconsin, where my parents had set up shop on an old farmstead on three and a half acres. There we had a garden large enough to enjoy the harvest almost year-round. My parents chose this lifestyle intentionally — out of a desire to steward the place we called "home" and to cultivate an intimate knowledge of it. For my sisters and me, the combination of our Wisconsin home and our Montana summer home provided fertile ground for learning — about food, wildlife, and the environment.

Reflecting on my past, it seems clear now that, in many ways, my life (and my identity) has been (to make up my own term), solidly "ranch adjacent" — neither fully in it nor fully outside of it, and that there have always been aspects of ranching and Montana that have kept drawing me back to it. I adopt the view of Mercer (2007) and others that the insider-outsider dichotomy is, in reality, a continuum with multiple dimensions and that researchers are constantly navigating and negotiating in our every-day interactions and with communities that are changing, too.

As I've gotten older, my position as an insider-outsider has shifted with my academic interests. From an academic perspective, I am, and have always been, deeply curious about people who choose to live rooted in places and derive their livelihoods from the land. There is a saying that goes, "What does the sagebrush know that the tumbleweed doesn't?" When I left home, I was quite like the tumbleweed — taking seed in certain place, growing for a time, and then when the wind was right, breaking off where the trunk meets the soil, and then moving with the next big gust. But even while tumbling along, my focus was learning from people and communities who have stayed rooted, like the sagebrush. My thesis in Anthropology and Environmental Studies at Wellesley College focused on the survivance of Vieques islanders and their foodways in light of multiple waves of colonial rule — and my Master's research focused on understanding Indigenous food sovereignty with the Gitxaala community in northern coastal British Columbia. During the last year of my Masters, my Grandpa Ralph passed away, and I came back to Montana for his celebration. During that trip back to Montana, I had the overwhelming feeling that I no longer wanted to live like the tumbleweed— I wanted to stay, rooted, like the sagebrush. I felt, as author Bryce Andrews has expressed, "at the center of my heart's geography" (Andrews, 2014). I had a desire not only to continue studying and working with people who were rooted in place — but I wanted to *be* rooted — and to start navigating my way back to Montana and, in my work, toward an insider view.

Since I have been in Montana, my insider-outsider position has continued to evolve as I've had the privilege to work with ranchers here as a researcher — and also as a friend, an intern, and a community member. I am very grateful for the opportunity I had during the summer of 2019 to work on the Mannix's ranch — to get "back in the saddle" and to learn about ranching by "doing." I have been welcomed into other networks — Women in Ranching, the Ranchers Stewardship Alliance, the Rangeland Monitoring Group, and MSU Extension workshops — where I've learned more about rangeland management and met mentors and friends. Still, I have never spent cold nights up calving or relied on rainfall or favorable cattle markets for my livelihood — or experienced the reward of training a cow dog or being in sync with my own horse. Although there are lots of things I will never know or fully understand about ranching, I hope that my continued interest and involvement in ranching systems can continue to help me connect with my research participants and better interpret my data. Moreover, I aspire to do what so many ranchers here in Montana do every day — steward and sustain Montana's rangelands and forests. For me, it is a privilege to carry on my family's legacy of protecting the integrity of upper Ninemile Valley — the land, the water, and the wildlife — through partnerships with others who share the vision of stewardship in the valley.

Situating this Research in Place and Time: COVID-19 and Drought in Montana

Another important aspect of acknowledging positionality in social science research is describing research-project context and an explanation as to how, where, when and in what way these might, may, or have influenced the research process (Savin-Baden & Major, 2013). During this research, which took place from 2018 through 2022, Montana was experiencing both the COVID-19 pandemic and severe drought. Below I describe the extent of these social and ecological phenomena and important considerations for this research.

COVID-19

In this study, my focus was on adaptation in the context of drought and climate change, but ranchers are constantly adapting to a suite of social and ecological factors — market change, demographic change, land use change, and so on. The COVID-19 pandemic presented a significant social disruption for Montana ranchers and the U.S. cattle industry before and during the data collection phases of this study. Indeed, the effects are COVID-19 are ongoing. During April and May of 2020, livestock cattle prices plummeted, and meat processing and packing plants slowed and/or shut down across the U.S. in response to COVID-19 outbreaks among workers and the incorporation of personal protective equipment at cattle processing plants (Dyal et al. 2020; Reuters 2020; USDA, 2020). At the same time, demand for beef faced a sharp decline in the food service sector and a boom in the grocery store setting (Lusk et al., 2020; Martinez et al., 2021). Beef prices at U.S. grocery stores nearly doubled, and meat processers and packers, not producers, saw their profit margins reach historic highs (Fu, 2020; Held, 2021). An economic damage report in early April 2020 estimated the total effect of COVID-19 on the beef cattle industry to be $13.6 billion, noting that there would likely be additional impacts in the future (Peel et al., 2020).

In Montana, cattle production is a key agricultural industry, with the market value of cattle and calves ($1,715,741,000) exceeding the sale of all other crops combined ($1,585,015,000) (USDA Census of Ag, 2017). Cow-calf enterprises are the most common among Montana ranchers, where calves are sold directly into the conventional feedlot system before they go into the secondary aspects of the supply chain (USDA Census of Ag, 2017). During the COVID-19 pandemic, Montana ranchers, like cattle producers across the U.S., navigated the effects of the national and regional shutdowns, slowdowns, and overall uncertainty. Not only were ranchers affected by the disruptions associated with COVID-19, but the Montana Drought & Climate project team also had to make several adjustments. For instance, MTDC survey dissemination timeline was delayed until Spring 2021, after the height of the pandemic and as the project team was able to meet more regularly. As a result, I was unable to collect and analyze responses to the survey before developing interview guides and beginning the interview process. The questions I asked during interviews, then, were not informed by survey data as initially anticipated. In addition to delays in survey dissemination, I waited until restrictions on conducting in-person interviews were lifted by the University of Montana Institutional Review Board. While there can be benefits to virtual interviews, my decision to conduct in-person interviews was based on ranchers’ preferences for in-person visits as well as my experience with in-person conversations facilitating richer dialogue. Moreover, traveling to ranchers’ homes offered me the opportunity to gain experiential knowledge of the diverse landscapes ranchers manage across Montana. It should be noted that while recruiting interview participants, COVID-19 was not an apparent factor influencing whether or not ranchers agreed to participate. In addition, COVID-19 was not central to interview conversations, which may have been because I did not ask about it specifically or because it was not viewed as the most relevant topic in response to the questions I asked. While I don't attempt to assess exactly how the pandemic influenced data collected in the quantitative survey and in-depth qualitative interviews conducted for this research, COVID-19 undoubtedly shaped the social-ecological system that ranchers' adaptive capacity and adaptive decision-making context are situated within.

Drought in Montana

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 had experienced more than two years of drought conditions that predominately fell into the US Drought Monitor categories of Moderate (D1) to Exceptional Drought (D4) conditions in 2020 and 2021. The U.S. Drought Monitor interactive map with historical drought information on the National Integrated Drought Information System (NIDIS) website (www.drought.gov) shows that, in Montana, starting in the fall of 2020, almost the entire state was experiencing some level of drought from Abnormally Dry (D0) conditions to Extreme Drought (D3) (see Figure 1.0, Figure 1.1, and Figure 1.2). Drought conditions worsened through 2020 and into 2021. By late summer and fall of 2021, the entire state was experiencing at least Moderate Drought (D1) conditions, with large portions of the state in Severe, Extreme, and Exceptional Drought. Figure 1.1 shows drought conditions during the week of May 25, 2021, just after the second mailing of the MTDC survey. At that time, 85.52% of Montana was experiencing at least Abnormally Dry conditions, if not greater (D0–D4) and 30.69% of the state was experiencing Severe Drought (D2) or worse (D2–D4). Figure 1.2 shows drought conditions during the middle of in-depth interviews, conducted in the fall of 2021. During the week of October 18, 2021, the entire state was experiencing Severe Drought or higher (D2–D4); 78.7% of the state was in Extreme or Exceptional Drought (D3–D4) and 18.05% was experiencing Exceptional Drought conditions (NIDIS, 2022). The pattern of weather extremes that characterized the fall of 2020 and all of 2021 persisted through the first six months of 2022 (DNRC, 2022).

According to the Montana Climate Assessment, more extreme and variable conditions are predicted to continue in Montana. Throughout the 21st Century, Montana is projected to continue to warm in all geographic locations, seasons, and under all emission scenarios. In addition, the predicted increase in variability in precipitation suggests the potential for more severe droughts, particularly in connection with climate oscillations (Whitlock et al., 2017). These state-level changes are larger than the average changes projected globally and nationally (Whitlock et al., 2017). Thus, for this study and for future research, Montana is a unique and important climatological context for understanding how ranchers, who both use and steward Montana's land and water resources, are making adaptive decisions toward positive social-ecological outcomes.

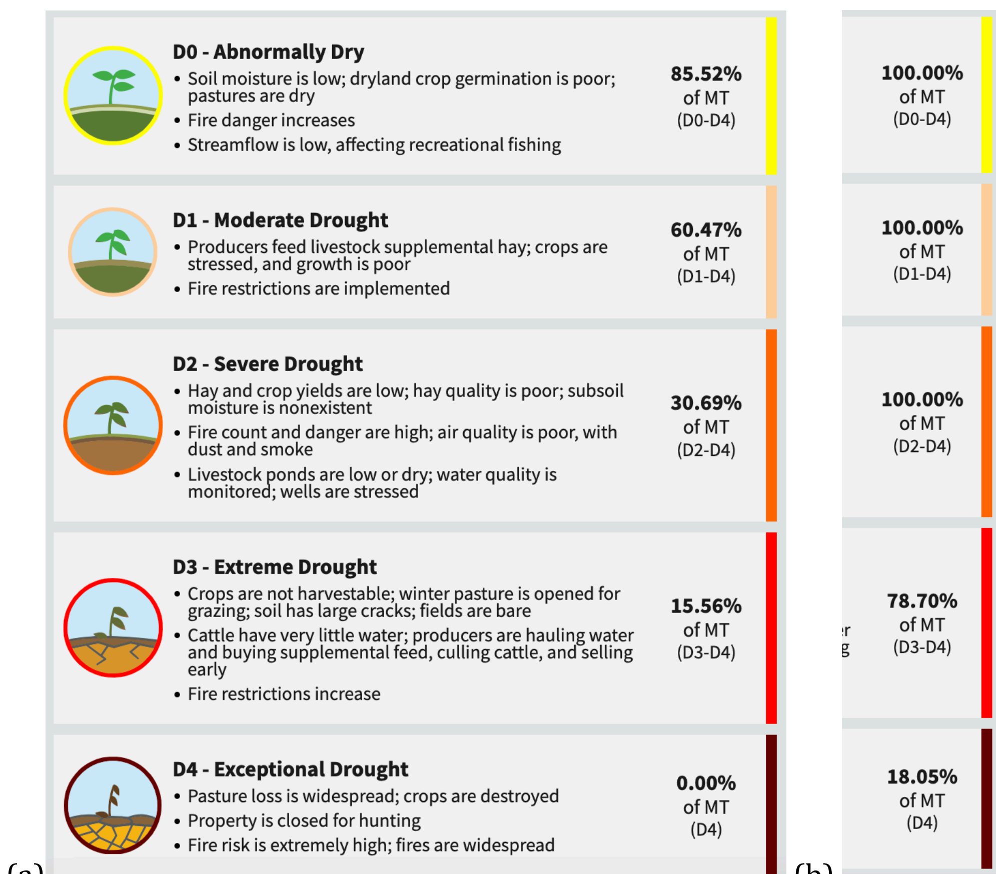


Figure 1.0. U.S. Drought Monitor levels, definitions, and percent of Montana at each level during the weeks of (a) May 25, 2021 and (b) October 18, 2021.

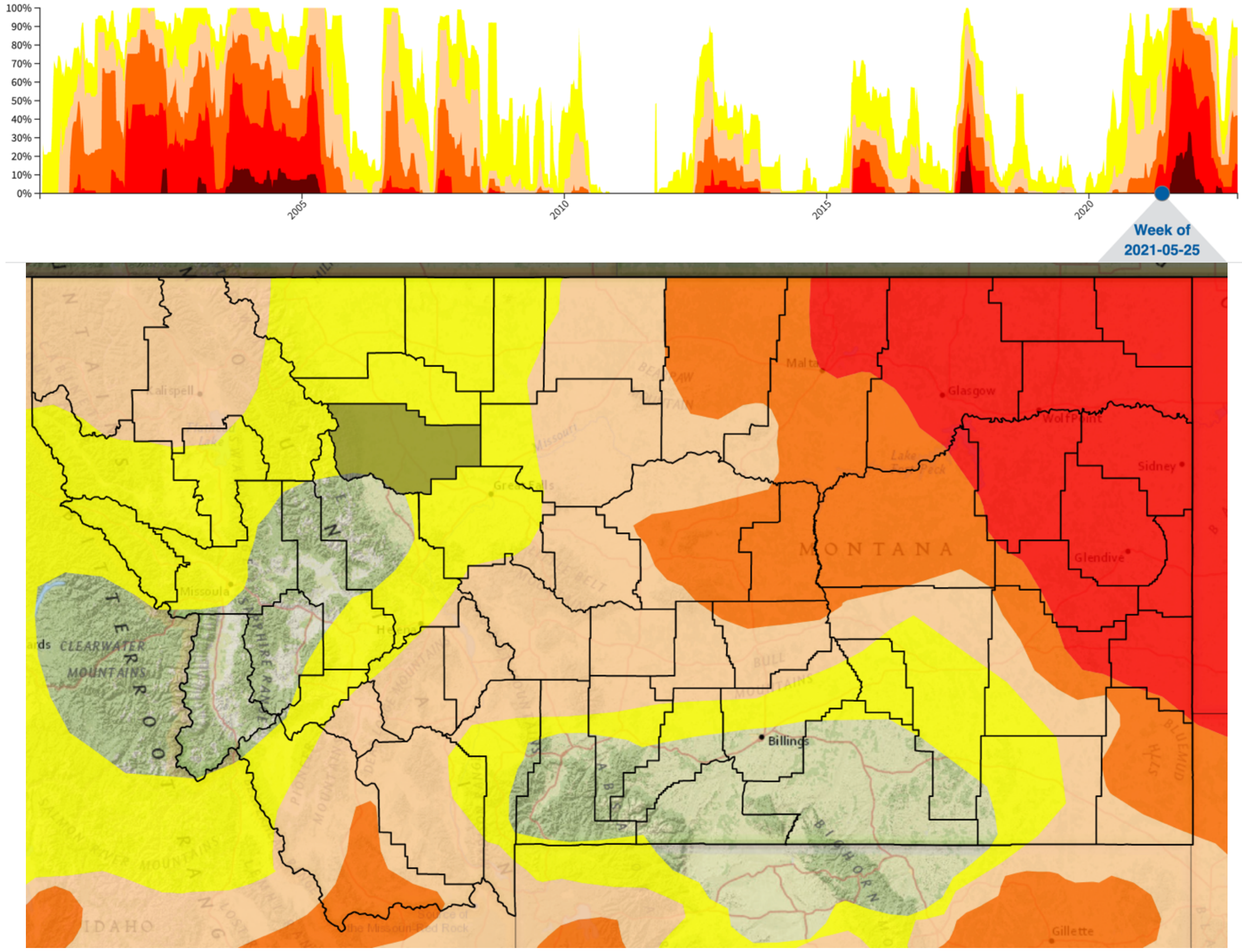


Figure 1.1. U.S. Drought Monitor historical drought conditions map for Montana showing the extent and intensity of drought during the week of May 25, 2021.

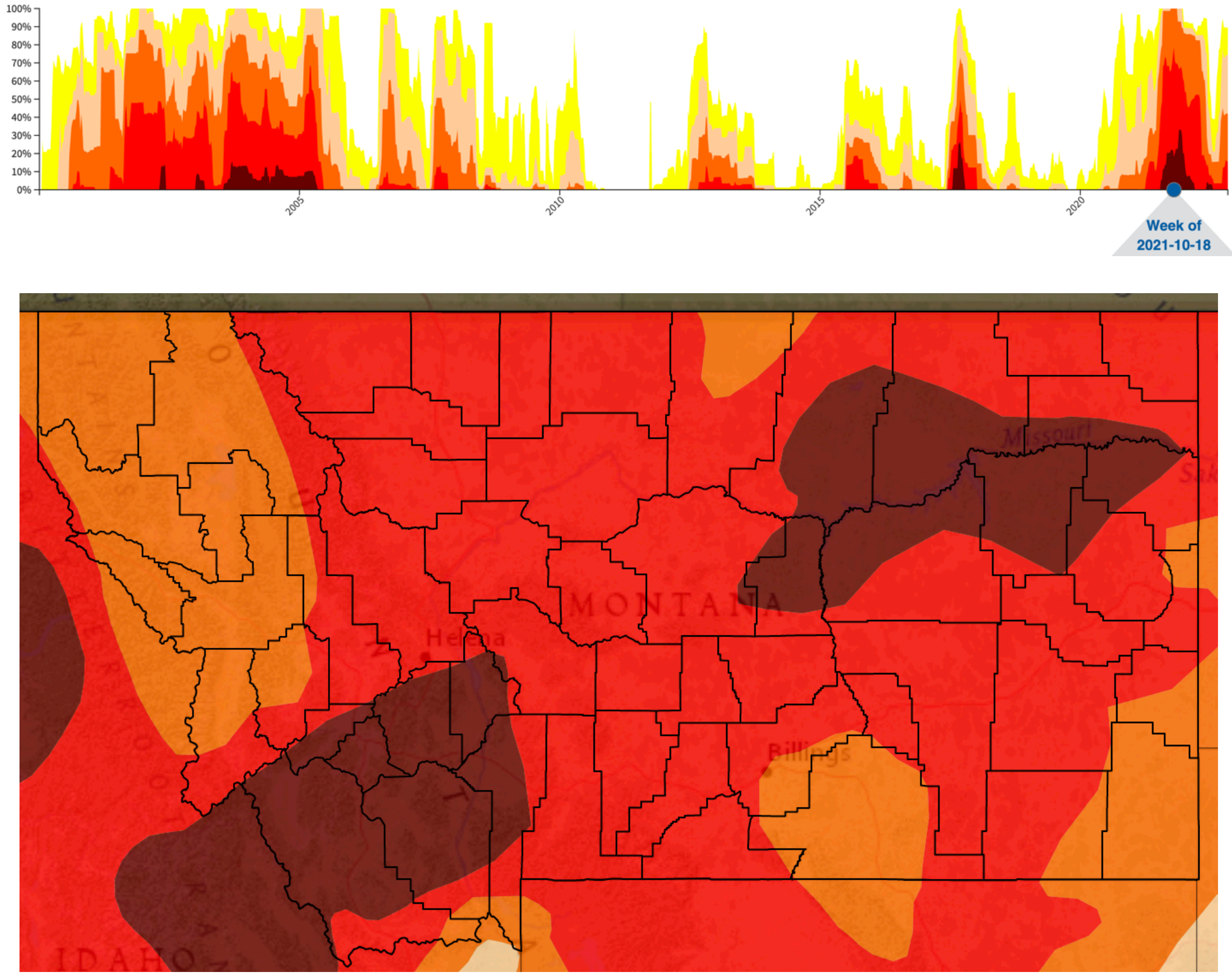


Figure 1.2. U.S. Drought Monitor historical drought conditions map for Montana showing the extent and intensity of drought during the week of October 18, 2021.

References

Absolon, K., & Willett, C. (2005). Putting ourselves forward: Location in Aboriginal research. In L. Brown & S. Strega (Eds.), *Research as resistance: Critical, indigenous and anti-oppressive Approaches* (pp. 97–126). Toronto: Canadian Scholars Press.

Andrews, B. (2014). *Badluck Way: A year on the ragged edge of the West.* Atria Books.

Montana DNRC on behalf of the Governor's Drought & Water Supply Advisory Committee. (2022). *Montana drought outlook report – summer 2022.* http://dnrc.mt.gov/divisions/water/drought-management/drought-documents/drought-outlook-report-summer-2022.pdf

Dyal, Jonathan W., Michael P. Grant, Kendra Broadwater, Adam Bjork, Michelle A. Waltenburg, John D. Gibbins, Christa Hale, et al. (2020). COVID-19 among workers in meat and poultry processing facilities—19 States, April 2020. MMWR. *Morbidity and Mortality Weekly Report, 69*, 557–561. https://doi.org/10.15585/mmwr. mm6918e3externalicon.

Fu, J. (2020, July, 24). *Beef packers' profit margins reached historic levels during the height of Covid-19 plant shutdowns*. The Counter. https://thecounter.org/beef-packers-profit-margins-reached-historic-levels-covid-19-plant-shutdowns/

Held, L. (2021, July, 14). *Civil Eats: Just a Few Companies Control the Meat Industry. Can a New Approach to Monopolies Level the Playing Field?* Civil Eats. https://civileats.com/2021/07/14/just-a-few-companies-control-the-meat-industry-can-a-new-approach-to-monopolies-level-the-playing-field/

Holmes, A. G. D. (2020). Researcher positionality - A consideration of its influence and place in qualitative research - A new researcher guide. *Shanlax International Journal of Education*, *8*(4), 1–10.

Lusk, J. L., Tonsor, G. T., & Schulz, L. L. (2020). Beef and pork marketing margins and price spreads during COVID-19. *Applied Economic Perspectives and Policy*, *43*(1). https://doi.org/10.1002/aepp.13101

Martinez, C. C., Maples, J. G., & Benavidez, J. (2021). Beef cattle markets and COVID-19. *Applied Economic Perspectives and Policy*, *43*(1), 304–314. https://doi.org/10.1002/aepp.13080

May, T., & Perry, B. (2017) *Reflexivity: The Essential Guide*. Sage.

Mercer, J. (2007). The challenges of insider research in educational institutions: Wielding a double-edged wword and resolving delicate dilemmas. *Oxford Review of Education, 33*(1), 1-17.

Merton, R. K. (1972). Insiders and outsiders: A chapter in the sociology of knowledge. *American Journal of Sociology*, *78*(1), 9-47.

National Integrated Drought Information System (NIDIS). (2022, November, 5). Historical Data and Conditions. Drought.gov. https://www.drought.gov/historical-information?state=montana&dataset=0&selectedDateUSDM=20211019

Peel, D. S., Aherin, D., Blach, R., Burdine, K., Close, D., Hagerman, A., Maples, J., Robb, J., & Tonsor, G. (2020). *Economic damages to the U.S. beef cattle industry due to COVID-19.* Oklahoma Cooperative Extension Service/National Cattlemen's Beef Association Center for Public Policy. https:// www.ncba.org/CMDocs/BeefUSA/Publications/OSU%20NCBA%20Beef_ COVID_Impacts_Exec.pdf.

Reuters. (2020). *Factbox: Spread of Coronavirus Closes North American Meat Plants*. https://www.reuters.com/article/us-health-coronavirus-meat-factbox/spread-of-coronavirus-closes-north-american-meat-plants-idUSKCN21V09W

Rowe, W. E. (2014). Positionality. In D. Coughlan & M. Brydon-Miller (Eds.). *The Sage Encyclopedia of Action Research*. Sage.

Savin-Baden, M., & Major, C. H. (2013). *Qualitative research: The essential guide to theory and practice*. Routledge.

Smith, L. T. (1999). *Decolonizing methodologies: Research and indigenous peoples*. Zed Books. https://doi.org /10 .1097/NAQ .0b013e318258ba14

USDA. (2021, July 29). *America's farmers: Resilient throughout the COVID pandemic*. https://www.usda.gov/media/blog/2020/09/24/americas-farmers-resilient-throughout-covid-pandemic

USDA. (2020). *Boxed beef and fed cattle price spread investigation report.* https://www.ams.usda.gov/reports/boxed-beef-and-fed-cattle-price-spread-investigation-report

Whitlock, C., Cross, W., Maxwell, B., Silverman, N., & Wade, A. A. (2017). *2017 Montana climate assessment.* Montana State University; University of Montana, Montana Institute on Ecosystems. https://doi.org /10.15788/m2ww8w.

Chapter 2: Methods

Methodology

> *A mixed methods way of thinking is an orientation toward social inquiry that actively invites us to participate in dialogue about multiple ways of seeing and hearing, multiple ways of making sense of the social world, and multiple standpoints on what is important and to be valued and cherished (Greene, 2008, p. 20).*

When we think of rangeland science, we often imagine that it involves transects, tape measures, and clip boards for ecological monitoring and that, for the most part, work gets done in library-like offices with papers piled high as a haystack. At the same time, when we think of ranching, popular media has engrained images of a cowboy swinging his rope high in the air as he rides across arid rangelands, sunset ablaze in the distance. While rangeland science and rangeland management can involve very different and distinct ways of knowing (Provenza, 1991), and the development of meaningful, policy and practice-oriented knowledge has been a daunting challenge (Roche, 2021), there has been a growing interest in methods that promote mutual learning through collaboration between scientists and managers in order to catalyze management that meets multiple social, economic, and ecological objectives in light of change (Reid et al., 2021; Wilmer et al., 2019; Wilmer et al., 2021).

Interdisciplinary and mixed methods research has been gaining traction as an approach for moving toward more translational rangeland science. Sometimes referred to as constituting a "third methodological movement" which includes both quantitative and qualitative approaches (Teddlie & Tashakkori, 2003), mixed methods research is integrative and pragmatic, where the focus is on the problem or research question in its social and historical context rather than on the method. In other words, from a mixed methods approach, research questions drive what methods are used to collect relevant forms of data instead of research methods determining what questions are asked (Creswell, 2007). Pragmatism in mixed methods research also involves the consideration of how our values and ethics, our politics and epistemologies, and our worldviews as researchers directly influence our actions and our methodologies (Morgan, 2007).

In this study, I took a mixed methods research approach by using a combination of participatory research methods, survey data collection, and in-depth interviews to understand Montana ranchers adaptation processes. Using a mixed methods design allowed for the collection of a robust amount of both quantitative and qualitative data that, together, lead to a thorough understanding of the research context. Triangulating multiple streams of evidence from ranchers (participatory research, survey, and interviews) provided valuable insights into trends around adaptive practices, participation in government programs, and other characteristics related to adaptation among ranchers. While the quantitative survey provided data at a statistically generalizable scale, the qualitative interviews allowed me to ask more detailed questions that addressed the "why" of factors both enabling and constraining ranchers' adaptive decision-making processes — and also to hear ranchers' perspectives that emerged organically from conversation. In combination, the interviews and survey also created multiple mechanisms for engagement between our research team and the Montana ranching community.

Science from the Saddle: Participatory Research Methods

In the summer of 2019, during the exploratory phase of this study, I worked on the Mannix Ranch in Montana's Blackfoot Valley in attempt to more closely link management and science through the process of learning by doing (Knapp et al., 2011), which can, in my view, lead to the development of more meaningful research questions. Through the integration of local knowledge and application of research to relevant local management scales (Cornwall & Jewkes, 1995), participatory research facilitates genuine and meaningful engagement of stakeholders, engages community members and others in the research process, and considers questions around who benefits from knowledge that is produced and how research might be translated into action (Cornwall, 2003; Cornwall & Jewkes, 1995).

As an intern at the Mannix Ranch for three months (May through August), I began learning about everything from the art and science of stockmanship and rangeland monitoring to the intricacies of fixing fence and irrigating. This opportunity — with boots on the ground, hands on the reins, and ready to say 'yes' to try my luck at just about any task — was the beginning of my research process. While this may diverge from more traditional views of the scientific method, learning by doing equipped me with experiential knowledge that no amount of reading or data could replace. Over the course of the summer, I learned that ranching is not only a complex science, but also an art. Ranching involves the management of a colorful palate of resources — water, soil, timber, grasses, native plants, wildlife, and cattle — that demands attention to both the 'big picture' and the finest details. And my favorite task, moving cows, is like a dance — requiring the right move at the right time, a balance of leading and following, and knowing when 'good motion creates good motion.' Every decision, big and small, is rooted in knowledge from years — generations even — of experience, as well as values, relationships, and creativity. I gained new perspectives — from the saddle, behind the wheel, on the fence, and in the field — on what ranching entails, the critical role ranchers play in stewarding Western rangelands, and the deep knowledge ranchers have of these places they call home. It is from this grounded perspective that I began to develop research questions as well as a keener ear for listening to answers that emerged from multiple forms of data to provide insight toward sustaining people and places in the West in light of change.

Montana Drought & Climate (MTDC)

This study was conducted as part of Montana Drought and Climate (MTDC) project, a USDA-funded project of the W.A. Franke College of Forestry & Conservation at the University of Montana, in collaboration with the Montana Climate Office (MCO) and the Montana State University Extension Service. The main objective of MTDC was to improve the utility and impact of climate information (e.g. existing forecasts and projections) in order to meet the needs of agricultural producers in Montana. MTDC brought together an interdisciplinary research team which included social scientists and climatologists at MCO to gain a detailed understanding of how climate information produced by MCO is utilized in agricultural producer decisions about adaptation to drought and climate variability with the long-term goal of developing ongoing climate information resources for producers. While the goal of my dissertation was to understand factors related to adaptation beyond the use of climate information — and the MTDC project had research objectives related to climate information and agricultural decision-making outside the scope of my dissertation — our team designed survey and interview questions to meet the objectives of both projects.

Sampling

For this study and MTDC, we needed to identify the population of agricultural producers in Montana to draw our sample. For MTDC, seasonal newsletters detailing climate impacts on Montana agriculture were mailed over the course of two years (fall 2018 – fall 2020) to our sample, which included one thousand farmers and stock growers throughout Montana (T2); 999 other producers were mailed postcards directing them to an online version of the newsletter (T1); and one thousand producers were pre-selected to be a part of a control group that received neither the newsletter nor the postcard (C). In the spring of 2021, an in-print survey was sent to the sample of Montana producers and used to understand differences between treatment groups regarding the use of climate information in decision-making while also including questions to meet the objectives of this study looking at adaptation processes among producers more broadly.

Identifying the population of agricultural producers in Montana and drawing our sample for this study followed a five-step process (Figure 2.0). The analysis to determine a candidate pool of producers used the following three datasets:

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

These datasets are available from the Montana State Library as part of the Montana Spatial Data Infrastructure (http://geoinfo.msl.mt.gov/msdi.aspx).

In Step 1, we standardized owner addresses in the Montana Cadastral (parcel ownership) dataset. By using the Montana Cadastral dataset, we treated landowners who received their tax bills at the same address as the same, recognizing that there are in many cases multiple people living at each address. From this dataset, we retained only the landuse acreage, owner, and address columns. We also standardized owner addresses; for instance, we removed the last four digits of nine-digit zip codes, and we 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 addresses were identical, concatenating owner names into a list and taking the spatial union of owner parcels. In other words, if addresses were the same they collapsed into one landowner with summed landuse acreage. Grouping parcels by owner addresses (street number, street, city, state, and zip) 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. Unfortunately, at the time of this writing, the UPS Address Validation service is no longer available for bulk address validation in the way we used it. Other services, such as those provided by the US Postal Service, may be useful for validating addresses for research purposes in the future.

In Step 3, we identified the agricultural acreage for each landowner. We produced two estimates for the agricultural acreage of each landholding using the 2017 FLU and MT Landcover datasets. For the FLU data, we selected all regions not categorized as "T — forest land", "N — non-commercial forest land", "X — other commercial non-agricultural 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 bein under cultivation (cropland). In Step 4, we applied final inclusion and exclusion criteria to identify working agricultural lands. First, we excluded parcels whose owners listed mailing addresses outside of the state of Montana in the Cadastral database. 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 non-profit landholders such as the Nature Conservancy and the American Prairie Foundation. This further reduced the count of landowners to 292,470. Finally, in order to filter out "amenity" owners (i.e. those who own large parcels taxed as agricultural land but are 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 to be included in the final population. Landowners had to meet at least one of the following criteria:

1) At least 1000 acres identified as FLU agricultural land and at least 50 acres classified as being under cultivation per the Montana Landcover dataset. This proxies ranch operations with a minimal amount of cultivated land for hay/feed.
2) At least 160 acres classified as being under cultivation per the Montana Landcover dataset. This proxies other agricultural producers.

Figure 2.1 shows the distribution of landholdings of the population of agricultural producers in Montana we identified using these criteria. By examining this map, we were able to visually see where we might expect our sample of agricultural producers to be located in the state. The criteria we applied resulted in the final eligible population of 11,155 agricultural producers from which our sample was drawn.

In Step 5, we used a stratified, random sampling method to draw our final sample of 2,999 agricultural producers across the three strata (Table 2.2). 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 percent (Dillman et al., 2014). The final sample was selected by randomly assigning unique integers to the landholder records and processing them sequentially such that the first 1000 records are the "newsletter" group (T2), the second 999 are the "postcard" group (T1), and the third 1000 are the "control" group (C). One producer was accidentally omitted from the postcard group, hence its smaller sample size (Table 2.2). Following this method allowed for subsequent records to be added to each group should other records have to be removed. Lastly, we manually reviewed names and addresses for quality control prior to a mail-merge for the newsletter and postcards. We exported the sample to a Google Sheets spreadsheet, manually checked each address, and generated the mailing names. For landholders registered to a business, we attempted to find other contact information with a personal name. In lieu of a personal name, we simply addressed the newsletter/postcard to "Farm/Ranch Manager." It should be noted that, despite our best efforts to design this sampling process for reproducibility, some of the original datasets have changed. For example, there are subtle differences in the MT Landcover Dataset and with the the way the UPS Validation—Street Level API validates addresses that present limitations. A detailed description of sampling with R code can be found at an open-access R Markdown file. The maps below show the geographic distribution of the MTDC survey sample (n= 2,999) across Montana counties (Figure 2.2), Montana climate divisions (Figure 2.3), and Major Land Resource Areas (Figure 2.4).

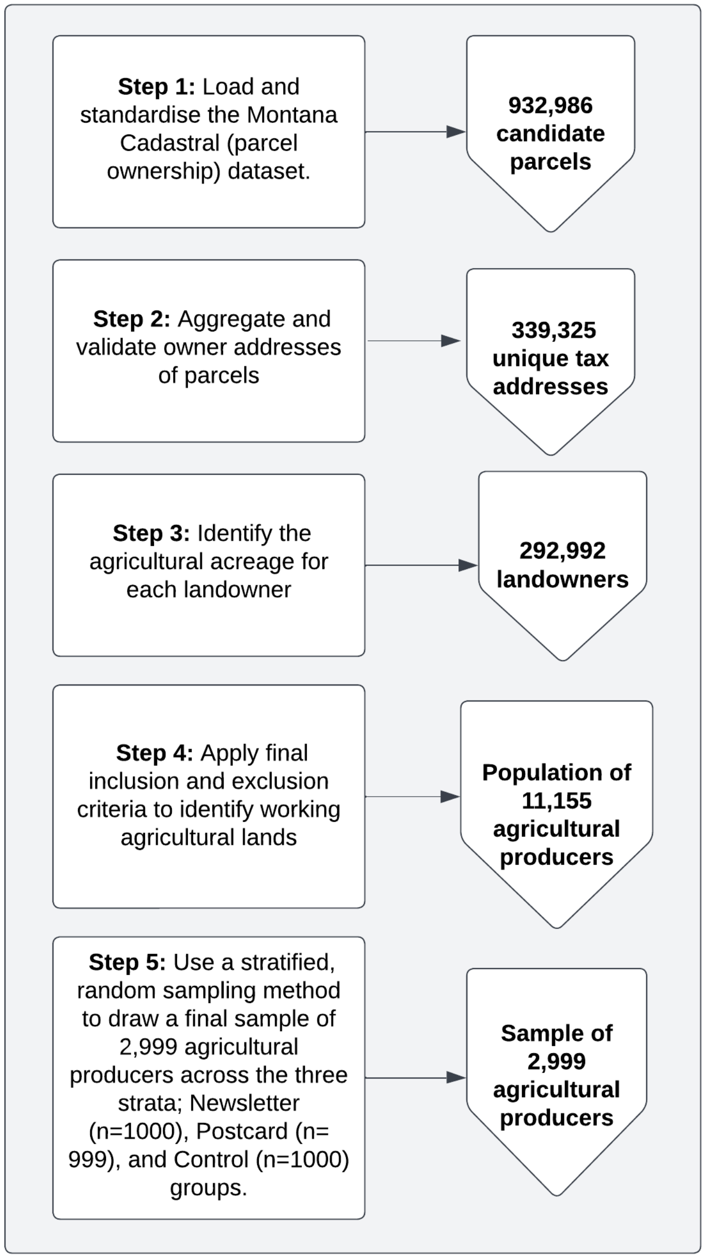


Figure 2.0. A flowchart depicting the five-step MTDC sampling process for identifying and drawing a sample of agricultural producers in Montana using geospatial landcover datasets.

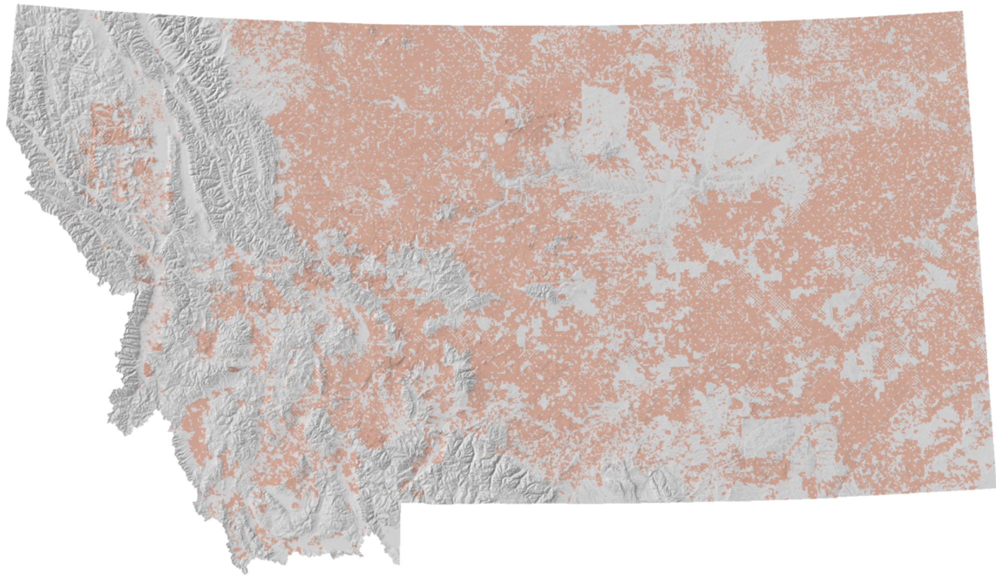


Figure 2.1. Total landholdings of agricultural producers in Montana identified using the FLU, Montana Cadastral and MT Landcover datasets.

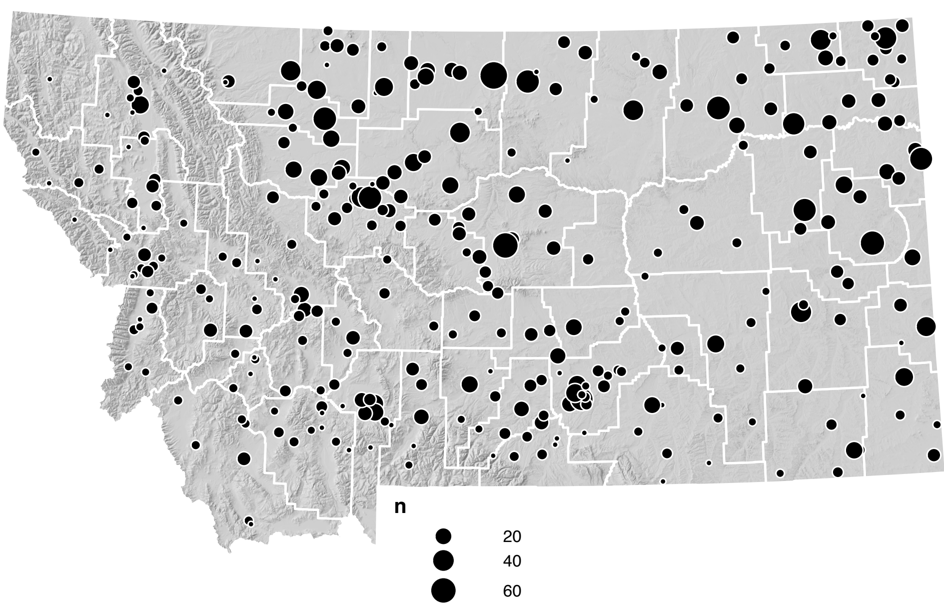


Figure 2.2. MTDC survey sample distribution across Montana counties. Locations of points are roughly centers of ZIP codes associated with each mailing address in the sample.

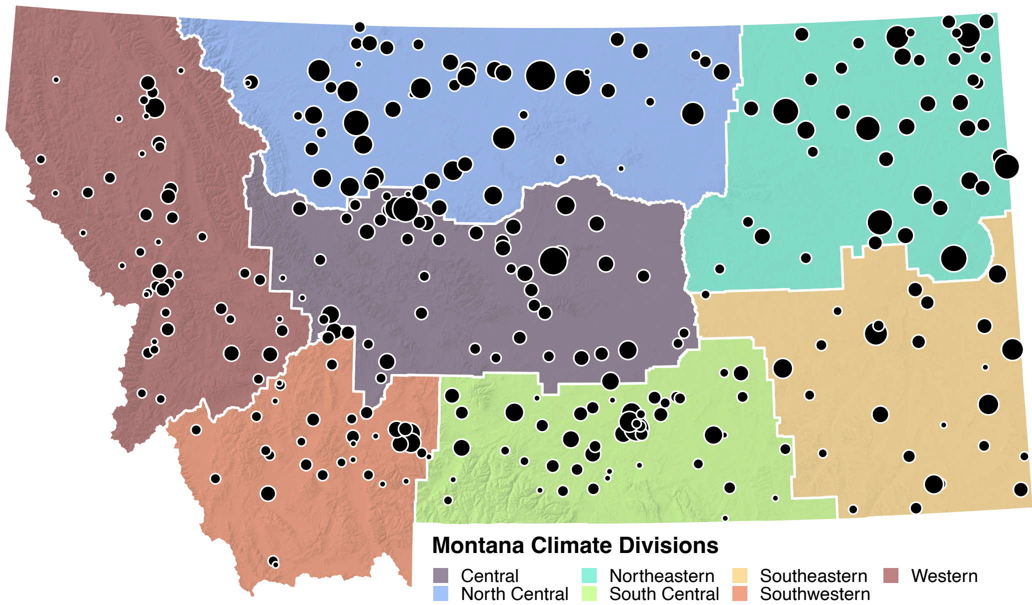


Figure 2.3. MTDC survey sample distribution by Montana climate divisions.

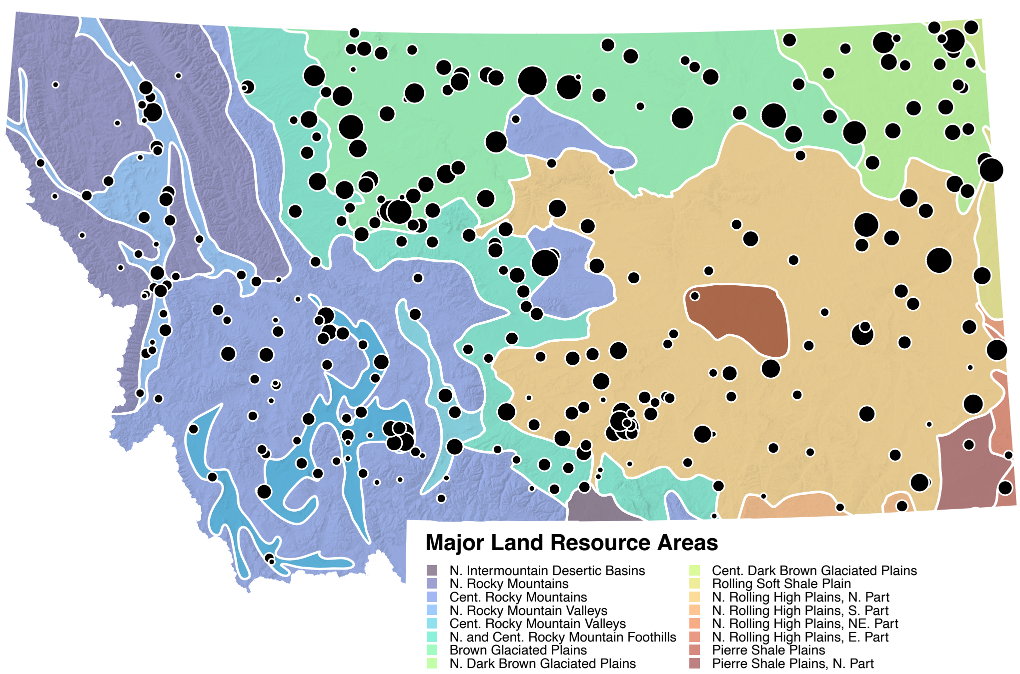


Figure 2.4. MTDC survey sample distribution across Major Land Resource Areas.

Montana Drought & Climate Survey

Design & Development

The survey was designed in line with objectives of this study and the overall goals of the Montana Drought & Climate Project. For this study, the survey was used to understand how ranchers perceive drought and climate impacts, how they view and use climate information resources, what strategies they are using to adapt to drought and other climate events, and to gain insights into key factors shaping adaptive decision-making. The survey included sections on operator and operation characteristics, management goals and barriers, views on three-month forecasts, views on climate projections for 2050, use of information for management decisions, management practices, participation in conservation-related programs, experiences with drought and other climate events, views on climate change, views related to government programs, and demographic information. In addition, for groups T1 and T2 (who received either an in-print MTDC newsletter or postcards with a link to the online version of the newsletter) we included questions asking about the relevance and utility of climate information resources for making management decisions. Survey questions were informed by scholarship on adaptive capacity in rangeland social-ecological systems, agricultural decision-making, and rangeland management. Table 2.0 includes survey questions used in this study, measurement scale and values for each question, and citations for studies from which questions were adapted. The final in-print version of the survey was mailed and then codified and entered by Bureau of Business and Economic Research (BBER) at the University of Montana. See Appendix for a copy of the final survey instrument.

Table 2.0. Montana Drought & Climate Survey questions and measurements used in this study.

Survey Question	Measurement and Values	Citation(s)
Operation & operator characteristics		
Do you consider yourself a____?	O Farmer O Rancher O Both O Neither	Adapted from Yung et al. (2015)
How many generations of farmers/ranchers have there been in your family?	________ years	Lubell et al. (2013); Prokopy et al. (2008); Roche et al. (2015)
What percent of your total household income comes from your farm or ranch operation?	________%	Prokopy et al. (2008); Roche et al. (2015)
Do you have a plan to keep your land in farming or ranching?	O Yes O No O In progress	Lubell et al. 2013
Approximately, what percent of your acres are owned or leased? Please indicate the percent of each, the total should add to 100%.	_____% Owned _____% Private leased _____% Public leased (State or Federal) _____% Other (please specify ____________________)	Prokopy et al. (2008); Roche et al. (2015)
Management goals		
We are interested in the reasons why you are a farmer or rancher. Please indicate how important each of these statements are to you. To increase cattle/crop production To maximize profit through production To earn a living To take care of the land for the future To support habitat health for all species To protect water and soil resources To ensure land does not become fragmented To sequester carbon through farming/ranching practices To provide recreation opportunities For the lifestyle To continue family traditions To help maintain the vitality of rural Montana To provide good jobs To produce food	1-5 Likert scale 1= Very unimportant 2= Unimportant 3= Neither 4= Important 5= Extremely Important	Adapted from Lien et al. (2017), Niska et al. (2012), and Roche et al. (2015)
Use of Information Resources		
We would like to know what information sources you use to make management decisions on your farm or ranch. Please check all the sources that you use.	❑ Conservation District ❑ Montana Dept. of Agriculture ❑ MSU Extension Agents ❑ In-person with other farmers/ranchers	Top 10 of original list of 29 (see Appendix)

	❑ Through social media with other farmers/ranchers ❑ MT DNRC (including MGCC) ❑ Agricultural Research Centers ❑ National Oceanic and Atmospheric Administration (NOAA) ❑ Natural Resources Conservation Service (NRCS) ❑ Montana Stockgrowers Association	Adapted from Lubell et al. (2013)
Management Practices		
Grazing & Livestock Management Intensive rotational grazing Planned grazing for weed and invasive species management Timing grazing for improved pastures Strategic placement of water for livestock and better forage utilization (infrastructure upgrades, piping systems, water tanks) Drought plan (e.g., reduce stocking rates, lease pasture, use additional hay) *Landscape Enhancements* Managing for wildlife habitat Establishing riparian buffers *Monitoring* Established soil and vegetation/range monitoring program to track and respond to change	At what scale do you do this on your farm/ranch? (1-3 scale) 1= Not at all 2= Portion of farm/ranch 3= Entire farm/ranch If used, how long have you been doing this? (1-3 scale) 1= Less than 3 years 2= More than 3 years 3= Experimenting	Practices compiled and adapted from: Panda et al. (2013, 2017); Roche et al. (2015), Sayre et al. (2012), Wezel et al. (2020); USDA (2013); USDA NW Climate Hub (2019); State of Montana - MT Climate Solutions Council (2020)
Government and Conservation-related Program Participation		
We are interested in knowing if you participate in any conservation-related programs. Please take a look at the list below and indicate whether or not you are aware of the program and if you participate in it or not. EQIP Conservation Stewardship Program Conservation Reserve Program MT Agricultural Research Center/Station Programs MT Sage Grouse Habitat Conservation Program Conservation easement Carbon credit program Other landscape or watershed conservation program with private, agency, or non-profit partners	1-4 scale 1= I am not aware of this initiative and have not used it 2= I am aware of this initiative and unable to patriciate 3= I am aware of this initiative and currently participate 4= I am aware of this initiative and have plans to participate in the future	Adapted from Lubell et al. (2013)
Views on Government		

Do you, yourself, agree or disagree with each of the following statements? Government programs have helped farmers and ranchers. I'm not interested in government incentives because they give government power to limit my activities. Government intervention on private land management is necessary. In the future, government incentives will be the best way to improve voluntary conservation on agricultural lands.	1-5 Likert scale: 1= Strongly Disagree 2= Disagree 3= Neither 4= Agree 5= Strongly Agree	Adapted from Lien et al. (2017), Lubell et al. (2013), and Roche et al 2015
Which of the following best represents your political views?	1= Very conservative 2= Somewhat conservative 3= Moderate, middle of the road 4= Somewhat liberal 5= Very liberal 6= Prefer not to say	Lubell et al. (2013)

Survey dissemination

The survey was disseminated in the spring of 2021 using a Dillman Tailored Design Method to encourage maximum participation from survey respondents (Dillman et al. 2014). First, all potential respondents received a pre-survey letter informing them that a questionnaire would arrive soon and asking for participation. Second, all potential respondents received a packet containing a cover letter, a hardcopy questionnaire, and a pre-stamped return envelope. Third, all nonrespondents received a second packet containing a cover letter, a hardcopy questionnaire, and a pre-stamped return envelope. Fourth, all nonrespondents received a third packet containing a cover letter, a hardcopy questionnaire and a pre-stamped return envelope (Dillman et al. 2014)(Table 2.1). The Bureau of Business and Economic Research (BBER) at the University of Montana implemented a receipt control system for all returned mail. Every sampled case was assigned an outcome status. All returned hardcopy questionnaires were coded and data entry for completed questionnaires was visually verified to correct any data entry errors.

Table 2.1. Survey dissemination schedule

Groups	April 10, 2021	May 1, 2021	May 20, 2021	June 17, 2021
Newsletter Postcard Control	Pre-survey notice letter.	Questionnaire packet 1.	Questionnaire packet 2. Mailed to nonrespondents.	Questionnaire packet 3. Mailed to nonrespondents.

The final survey was sent out to 2,999 addresses. However, there were 412 ineligible addresses (i.e. undeliverable, not a farm/ranch, etc.), resulting 2588 eligible addresses (Table 2.2). We received 706 useable surveys (Table 2.4), a response rate of 36.7% when calculated using American Association for Public Opinion Research response rate formula 3 (AAPOR RR3)(American Association for Public Opinion Research, 2016):

$$I/((I+P) + (R+NC+O) + e(UH+UO))$$

Where:

I=Complete Interviews

P=Partial Interviews

R=Refusal and break off

NC=Non-contact

O=Other

UH=Unknown Household

UO=Unknown Other

e=the estimated proportion of cases of unknown eligibility that are eligible. For this survey the value of e=0.641.

The 706 responses obtained in this survey yielded an overall confidence interval of +/- 4.4%. Table 2.3 presents population totals and 95% confidence intervals for the study's three sampling strata.

Table 2.2. Sample strata

Stratum	Name	Sampled N	Sampled and Eligible N
1	Newsletter	1,000	867
2	Postcard	999	874
3	Control	1,000	847

Table 2.3. Study populations and 95% confidence intervals by stratum

	Total	Newsletter	Postcard	Control
Study population	11,155	3,737	3,767	3,651
95% confidence interval	+/- 4.4%	+/- 7.9%	+/- 7.5%	+/- 7.1%

Table 2.4. Summary of survey data collected from the final sample of 2,999 producers

Status of response	#
Completions	706
Refusals	27
Deceased	25
Non-completion due to poor health	1
USPS insufficient address	11
USPS no mail receptacle	7
USPS no such number	6
USPS no such street	1
USPS unable to forward	152
USPS vacant	30
USPS temp away	17
Not a farm or do not farm	162
Not returned	1854

Data from questionnaires were codified and entered using appropriate data labels and flags to facilitate analysis. Spot checks on data entry were performed to ensure accuracy. Data were processed using three statistical software packages: IBM SPSS Statistics Version 28 (2021), SAS Version 9.5 (2021) and Statistics Canada's G-EST Version 2.03 (2019). Basic descriptive statistics, linear regression, and path model analysis were used to analyze the responses.

Weighting

Survey weights were applied in the analysis of these data to improve the accuracy of estimates and help to ensure that the survey is representative of the study population. The consensus in the scientific literature is that correctly constructed and applied weights should be used to produce statistics that describe survey data (Battaglia, et al., 2016; Haziza & Beaumont, 2017; Kish & Frankel, 1974; Rao et al., 2010; Valliant et al., 2013). Weights for the survey were calculated using a three-step process that is also widely accepted in survey research literature (Battaglia, et al., 2016; Haziza & Beaumont, 2017; Haziza & Lesage, 2016; Lavallee & Beaumont, 2016; Valliant et al., 2013). In step one, 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 two, the base weight was modified to adjust for nonresponse (Battaglia et al., 2016; Brick, 2013; Haziza & Lesage, 2016; Kreuter & Olson, 2013; Olson, 2013; Valliant et al., 2013). In step three, the nonresponse-adjusted weight was calibrated to sampling control totals derived from the number of farms or ranches in each sampling strata (Haziza & Beaumont, 2017; Kalton & Flores-Cervantes, 2003; Lavallee & Beaumont, 2016; Sarndal, 2007; Valliant et al., 2013). See Table 2.5 for the nonresponse propensity model variables used for determining survey weighting. Table 2.6 shows a sample list of weighted and unweighted respondent characteristics. Survey weight calibration was conducted using the Gest_Calibration module of Generalized Estimation System version 2.003 (January 2019) developed by Statistics Canada. BBER provided one survey weight in the dataset: a population weight useful for estimating the number of adults in the study population who have a particular characteristic. In addition, BBER provided in the dataset the variables required for a modern statistical package to calculate standard errors and confidence intervals.

Table 2.5. Nonresponse propensity model variables used for determining survey weighting

Variables	Score	df	Sig.
Treatment type	5.22	2	.074
Treatment type (1)	2.10	1	.147
Treatment type (2)	.62	1	.432
Attempts	1933.53	2	.000
Attempts (1)	878.50	1	.000
Attempts (2)	804.59	1	.000
Continuous Crop Acres (Cadastral)	1.56	1	.211
Fallow Acres (Cadastral)	2.67	1	.102
Wild Hay Acres (Cadastral)	2.39	1	.122
Irrigated Acres (Cadastral)	2.08	1	.149
MT Landcover	3.28	1	.070
Overall Statistics	1939.83	9	.000

Table 2.6. Weighted and unweighted respondent characteristics

Characteristic	Unweighted Responses	Weighted Responses	Unweighted Completions
Farmer or rancher			
Farmer	28.4%	29.6%	199
Rancher	30.6%	29.0%	214
Both	33.7%	33.2%	236
Neither	7.3%	7.3%	51
Number of years farming or ranching (mean)	41.6	41.2	680
Number of generations of farmers or ranchers in family (mean)	3	3	695
% of total household income that comes from farming or ranching (mean)	67.3%	67.7%	664
Treatment group			
Letter	31.3%	33.5%	221
Postcard	32.6%	33.8%	230
Control	36.1%	32.7%	255

Nonresponse analysis

Before we conducted statistical analysis for this study, we examined MTDC survey data for nonresponse bias. Nonresponse bias occurs when those who do not respond to a survey are different from those who do respond in a way that influences survey estimates (Dillman et al., 2014). Nonresponse error is only one of four major types of survey error. The other major types of survey error are coverage error, sampling error and measurement error (Groves, 1989). Nonresponse error should be considered in the context of the total survey error framework which views surveys as an information gathering method that maximizes accuracy across all four types of error given constraints such as cost and time (Biemer & Lyberg, 2003). Viewing nonresponse error through the total survey error framework avoids undue concentration on only one type of survey error (nonresponse) and provides a better assessment of overall survey quality.

We present three different examinations of the MTDC survey in the paragraphs that follow. Each examination attempts to evaluate the survey for the presence of potential nonresponse bias. The combined results of these three examinations offer a robust assessment of the MTDC Survey with respect to potential nonresponse bias.

Response rate

Examining the survey's response rate was the first step in evaluating for potential nonresponse bias. One way to assess the quality of the response rate of this survey, and thus indirectly infer whether or not the survey data were negatively impacted by nonresponse bias, was to compare this response rate (36.7%) with response rates obtained by other rigorous mixed-mode, self-administered surveys. A list of such response rates was found in the AAPOR Report of the Task Force on Transitions from Telephone Surveys to Self-Administered and Mixed-Mode Surveys (AAPOR Task Force, 2019). This report listed 21 response rates for mail-web surveys that ranged from 18% to 50%. Accordingly, we assessed that the response rate for this survey was typical for a rigorously conducted survey of this type. This assessment provided some confidence about the quality of the response rate.

However, response rates do not, by themselves, determine nonresponse bias (Curtin et al., 2000; Keeter et al., 2000), pointing to the need to examine more than response rate to determine whether survey data are impacted by nonresponse bias. The next two examinations for potential nonresponse bias occured at the variable of interest level.

Mean differences

The second examination took advantage of information provided by the process used to construct the MTDC survey weights. The survey weights were constructed, in part, to reduce potential nonresponse bias. For this examination, if an analyst compared the mean response to a survey question weighted only to account for the survey design with a mean response weighted to account for the survey design and potential nonresponse bias, then a large difference between the two weighted means may indicate the presence of nonresponse bias (Lohr et al., 2016). The comparison of the two means is described below:

$$\mu_{DWT} - \mu_{FNLWT}$$

Where:

μ_{DWT} = Mean response to a survey question using data weighted to account only for the survey design

μ_{FNLWT} = Mean response to a survey question using data weighted to account for the survey design and potential nonresponse bias

For this comparison we chose 25 survey questions that provided information that was central to the overall purpose of the MTDC survey. A difference between the means that is significant at the 0.05 level offers evidence that weighting for potential nonresponse bias made a large change to the point estimate indicating the presence of possible nonresponse bias. The means and t-tests reported here were calculated using statistical analysis software (SPSS Statistics) that accounted for the effect of the MTDC survey's sample design and weighting on standard errors (IBM Corporation, 2021). Table 2.7 below presents the results of this examination.

Table 2.7. Difference between design weighted and final, nonresponse weighted means

Variable	Mean or Percent Estimate Difference $\mu_{DWT} - \mu_{FNLWT}$	Significance at 95% CI
Q2	--	--
Farmer	-1.2%	No
Rancher	1.6%	No
Both	0.50%	No
Neither	-0.90%	No
Q3	0.42	No
Q4	0.02	No
Q5	-0.35	No
Q6	--	--
Yes	-0.70%	No
No	0.30%	No
In progress	0.40%	No
Q7owned	0.25	No
Q7PrivateL	-0.40	No
Q7publicL	1.74	No
Q11c	0.01	No
Q11f	0.02	No
Q20scaleD	-0.03	No
Q20scaleI	-0.03	No
Q20scaleJ	-0.03	No
Q21scaleA	-0.02	No
Q21scaleB	-0.04	No
Q21scaleC	0.01	No
Q21scaleF	0.02	No
Q21scaleG	0.01	No
Q31a	0.00	No
Q31b	0.02	No
Q31c	0.03	No
Q31d	-0.02	No
Q32	-0.64	No
Q34	0.02	No
Q35	0.01	No

We found no differences that were significant at the 0.05 level between the design weighted and final, nonresponse weighted means. The absence of differences for all 25 questions increased our confidence that nonresponse bias is not present in the data reported by the MTDC survey. However, this examination only looked for effects that might be inferred from nonresponse bias. Accordingly, we conducted a third examination that looked more directly for the presence of nonresponse bias. The third examination again took advantage of information provided by the survey weighting construction process.

Response propensity

The third examination estimated the relationship between responses to the 25 important survey questions and the propensity of the study population to respond to the survey, following the literature demonstrating that nonresponse bias is a function of the covariance between the answers to a question of interest in a survey and the propensity in the study population to respond to the survey (Groves et al., 2009). The propensity to respond to the survey was estimated for each member of the sample using a logistic regression model calculated as a part of the MTDC survey weight construction process (Brick, 2013; Rosenbaum & Rubin, 1984; Valliant & Dever, 2018). According to Groves et al. (2009) nonresponse bias exists in a variable of interest when the likelihood of responding is strongly related to the variable of interest. We used a generalized linear model (GLM) to estimate the relationship between the variables of interest and the propensity to respond to the survey. The model is described below:

$$Y_n = \alpha_0 + \beta_1 X_{1n} + \beta_2 X_{2n} + \varepsilon_n$$

Where:

Y = Response to survey question (dependent variable)

n = Individual respondent

α_0 = Intercept

β_1 = Survey parameter estimate

β_2 = Response propensity parameter estimate

X_1 = Treatment Group

1 = Newsletter

2 = Postcard

3 = Control

X_2 = Response propensity

-1 = Low (respondent is in the lowest 2 quintiles of response propensity for the entire survey sample)

1 = High (respondent is in the highest 2 quintiles of response propensity for the entire survey sample)

ε_n = Error term

This examination controls for treatment group because respondents from each of the three MTDC treatment groups received a somewhat different questionnaire. In addition, we hypothesized prior to the study that the answers to the 25 questions might be related to the treatment group. Using the GLM we also estimated the interaction between survey and response propensity. Since the interactions between survey and response propensity were found not significant in all 25 survey questions, the interaction results are omitted here for the sake of brevity. All of these calculations used statistical analysis software that accounts for the effect of the MTDC Survey's sample design and weighting on standard errors (IBM Corporation, 2021). Table 2.8 presents the results of this examination.

Table 2.8. Relationship between answers to 25 important survey questions and response propensity

Survey Question	Parameter Estimates					Model Effects Significance	
	Treatment Type			Response Propensity		Treatment Type	Response Propensity
	Newsletter	Postcard	Control	Low	High		
Q2	-.075	-.013	.000	.157	.000	.776	.274
Q3	2.871	1.969	.000	-.180	.000	.389	.950
Q4	-.064	.130	.000	.070	.000	.322	.685
Q5	5.290	4.365	.000	.638	.000	.370	.903
Q6	.001	.103	.000	.050	.000	.176	.577
Q7owned	1.329	1.086	.000	-5.556	.000	.889	.144
Q7PrivateL	-7.982	-9.707	.000	6.417	.000	.110	.273
Q7publicL	-2.152	-1.237	.000	5.396	.000	.772	.184
Q11c	.081	.026	.000	.044	.000	.842	.791
Q11f	.110	.075	.000	.032	.000	.705	.843
Q20scaleD	-.055	.068	.000	.233	.000	.400	.061
Q20scaleI	.095	.171	.000	.062	.000	.150	.642
Q20scaleJ	.166	.190	.000	.010	.000	.033	.936
Q21scaleA	.018	-.029	.000	.199	.000	.910	.195
Q21scaleB	.219	.280	.000	.000	.000	.023	.998
Q21scaleC	.157	.200	.000	.083	.000	.090	.459
Q21scaleF	.158	.340	.000	-.158	.000	.002	.247
Q21scaleG	.099	.225	.000	.222	.000	.086	.055
Q31a	-.067	-.153	.000	-.032	.000	.310	.812
Q31b	.004	.088	.000	.057	.000	.687	.694
Q31c	-.309	.016	.000	-.072	.000	.023	.660
Q31d	.172	.012	.000	.082	.000	.349	.635
Q32	-1.476	-.478	.000	1.653	.000	.612	.383
Q34	.050	.134	.000	-.112	.000	.549	.514
Q35	-.064	-.014	.000	.077	.000	.937	.748

Across all 25 questions examined the relationship between response propensity and the variable of interest was not significant at the 0.05 level. Thus, in these 25 questions we found no evidence of nonresponse bias. This finding should increase confidence that a very large portion of the data reported in the MTDC Survey show no evidence of nonresponse bias.

Overall, this analysis found very little evidence of nonresponse bias in the data reported for the MTDC Survey. The response rate for the survey is typical for rigorously conducted surveys of this type. At the variable of interest level, none of the 25 survey response means examined were changed in a statistically significant way by the application of weights that account for potential nonresponse bias. Furthermore, none of the 25 variables of interest demonstrated a statistically significant relationship between the variable and the propensity to respond to the survey. Figure 2.5 shows the geographic distribution of MTDC survey respondents (n= 706) across Montana counties and Figure 2.6 shows the geographic distribution of MTDC survey respondents who are ranchers (n= 450) across Montana counties.

Maps – MTDC Survey Respondents

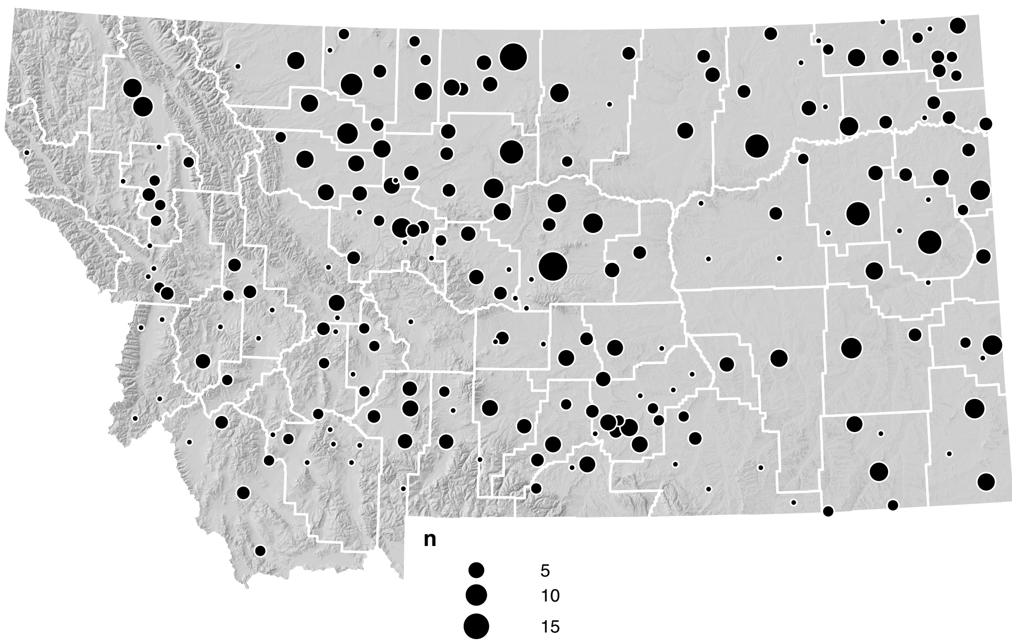


Figure 2.5. Distribution of Montana Drought & Climate survey respondents (n= 706) across Montana counties.

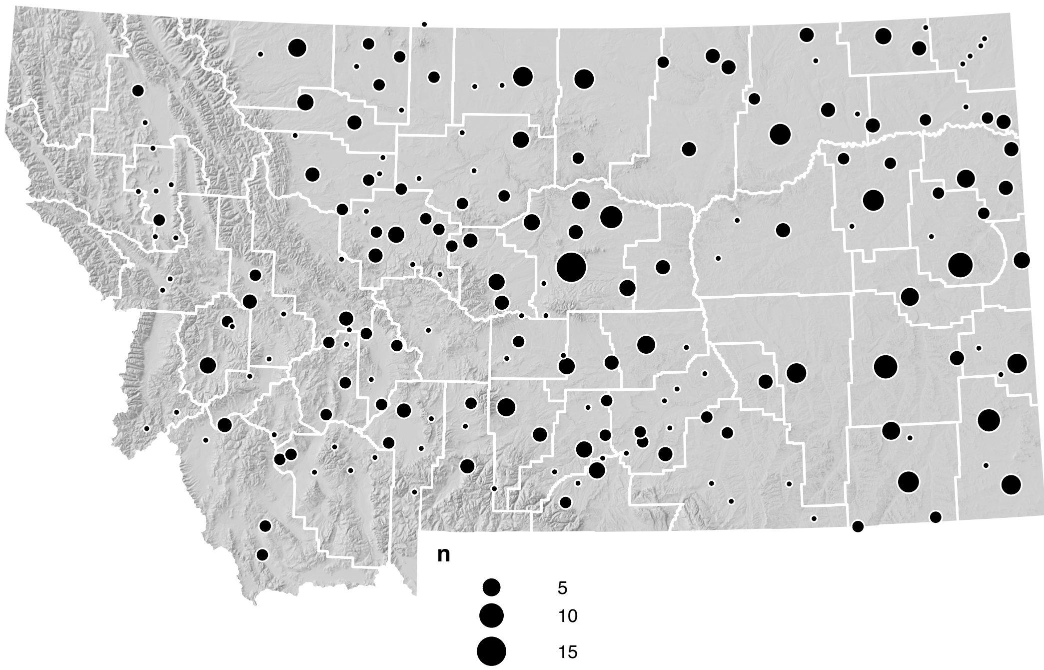


Figure 2.6. Distribution of Montana Drought & Climate survey respondents who are ranchers (n= 450) across Montana counties.

In-depth Interviews with Montana Ranchers

In-depth, semi-structured interviews with ranchers were utilized to gain a more detailed understanding of the factors influencing adaptive capacity and decision-making for responding effectively to drought and other challenges associated with climate variability. Following constructivist grounded theory (Charmaz, 2006), the systematic method for qualitative interview data collection and analysis used in this study was based on the premise that knowledge and meaning are constructed through social processes. In addition to gaining a more nuanced understanding 'what' and 'how' questions related to adaptation processes during in-depth interviews, my conversations with ranchers lead to 'why' questions that helped me situate enabling and constraining factors related to adaptive management within the complex conditions, contexts, and systems in which they operate.

I conducted in-depth, semi-structured interviews in three regions of Montana during fall of 2021. In total, 30 interviews were conducted with 34 ranchers (3 interviews were conducted with couples and one with input from a ranch employee). Geographically, 10 interviews took place on the Rocky Mountain Front, 8 interviews in Southwestern Montana (i.e. Beaverhead-Madison Counties), 10 interviews along the Billings to Miles City corridor, and 2 interviews with bison ranchers in northwestern Montana. These three areas were chosen in order to capture representation from as many climate zones (Figure 2.7) and major land resource areas (Figure 2.8) across the state as possible while also including slightly more representation in areas of the state where livestock production is most important economically (which are often areas where ranching is important socio-culturally as well) (Figures 2.9 and 2.10).

Participants were purposively selected from a long list of potential interviewees generated through expert contacts at Montana State University (MSU) Extension and other social networks that I have been involved with since beginning this research (Brandenburg & Carroll 1995). To access a diversity of views and practices, we selected ranchers who varied in age from early 30s to mid-70s; however most were roughly between ages 50–70 and all interviewees were white. Ranchers had different sizes of ranches and different types of operations, enterprises and classes of livestock (e.g., commercial cow/calf operation, direct-to-market niche operations). Interviewees included predominately cattle ranchers (as cattle are the most common type of livestock raised in Montana and dominate the industry in terms of livestock sales (USDA, 2021)), but I also interviewed three ranchers with predominately sheep operations and three with predominately bison operations to include representation from different types of operations. All ranchers who were contacted agreed to an interview. A small, purposive interview sample for qualitative interviews is justified because my aim was not to identify the statistical distribution or probability of particular adaptation actions or decisions. Rather, the in-depth interviews provided a window into the range of views among Montana ranchers and to gather deep and nuanced qualitative information about ranchers' experience of social and ecological phenomena (i.e. often stories highlighting specific situations/examples), which in turn informs social theory (Burawoy, 1998).

An interview guide was used to ensure comparability between interviews (Creswell, 2013). I began the interviews by asking ranchers to describe their ranching operations, their management goals and practices/strategies to achieve those goals. Then, I asked ranchers questions related to the impacts and perceptions of risk related to drought and other climate-related events, their plans and strategies to mitigate or respond to these risks, and their involvement in and views of government programs and/or public land grazing permits. As part of the MTDC project, during the last part of each interview I presented ranchers with examples of climate information resources developed by the Montana Climate Office. I asked questions related to the relevance and utility of this information for decision-making and solicited feedback on how resources could be improved.

All interviews were audio recorded and professionally transcribed. I used the program NVivo 10 to analyze the data using an iterative process that linked concepts to data through reading and rereading of transcripts and interpretations (Layder 1998; Strauss & Corbin, 1990). From this process 41 codes emerged. I coded for analytic themes related to operation characteristics, management goals, management practices and decisions made in preparation and response to drought and other climate events, impacts and perceptions of drought and climate change, views on government programs, and feedback related to climate information resources presented to them during the interview as part of the MTDC project. After the initial coding of interviews, I used NVivo 10 to filter data by code, or analytic theme, and created 41 separate documents with data from each code. From there, I reviewed each document, identifying sub-themes and patterns of meaning within and across codes, organizing data accordingly. I conducted two additional phases of analysis to synthesize patterns into data tables that were used for this study. Through the iterative process of analysis, my understanding of interview data was also enhanced by reflexivity and reflection on my own motivations and dynamic subject positions (Charmaz, 2006; Creswell, 2013; Smith, 1999).

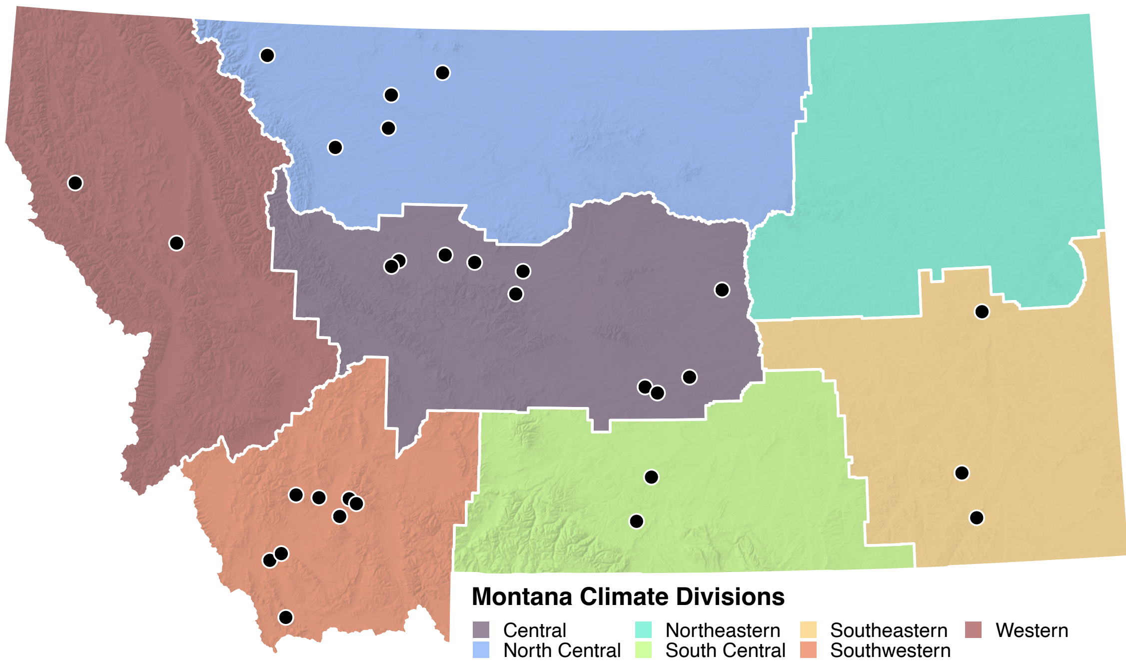


Figure 2.7. Geographic distribution of interview sample across MTDC Climate Zones.

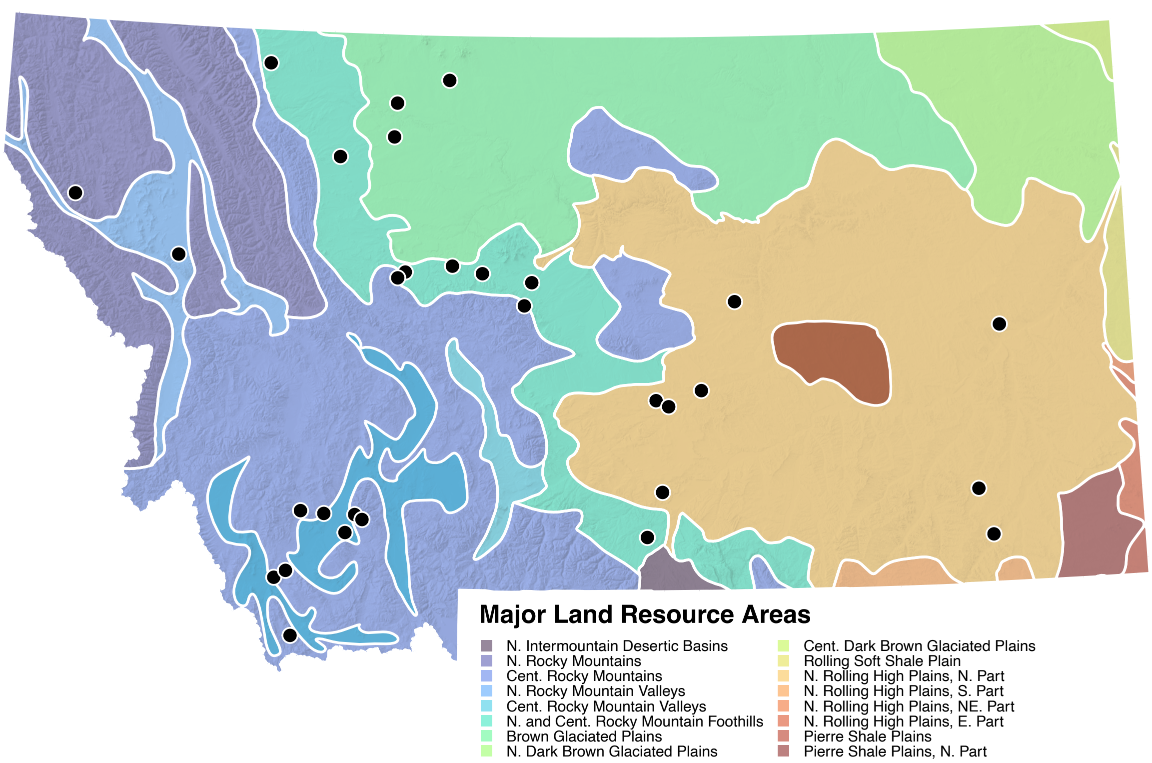


Figure 2.8. Geographic distribution of interview sample across Major Land Resource Areas (MLRAs) in Montana.

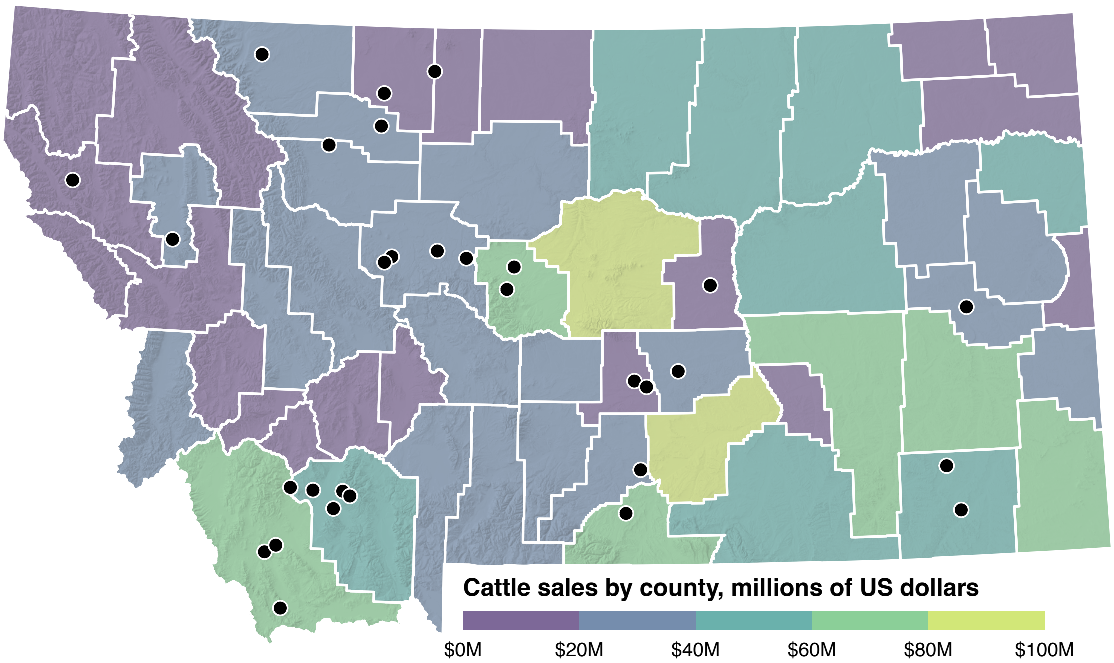


Figure 2.9. Geographic distribution of interview sample overlayed on 2017 USDA-NASS data on cattle sales (USD) by county.

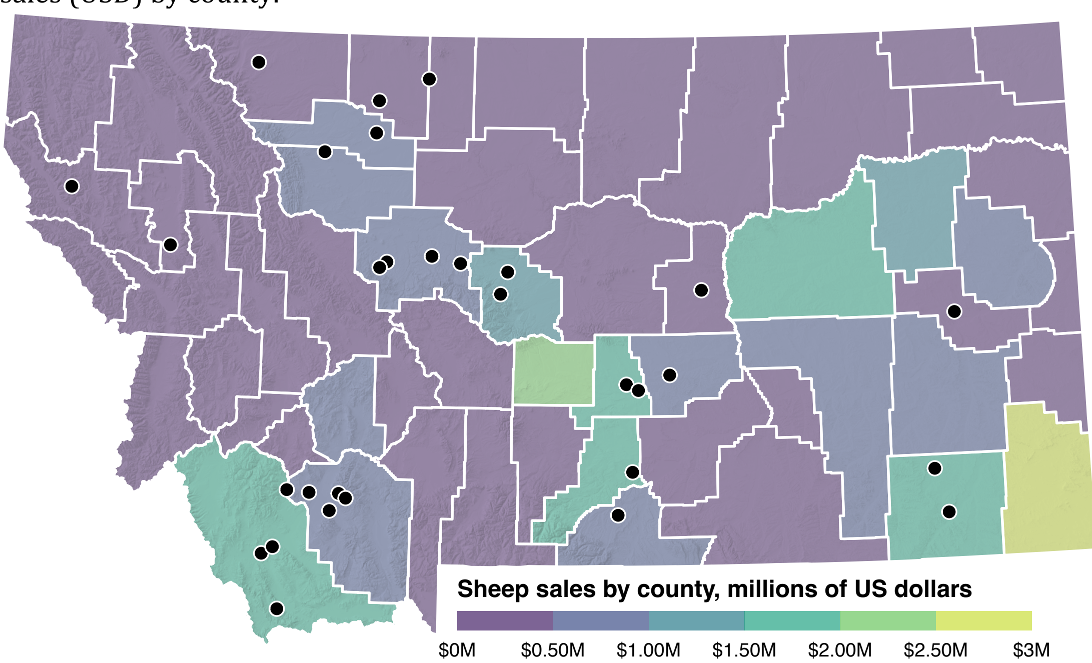


Figure 2.10. Geographic distribution of interview sample overlayed on 2017 USDA-NASS data on sheep sales (USD) by county.

References

AAPOR Task Force. (2019). *Report of the AAPOR Task Force on Transitions from Telephone Surveys to Self-Administered and Mixed-Mode Surveys.* Chicago, Illinois: AAPOR.

American Association for Public Opinion Research. (2016). *Standard Definitions: Final Dispositions of Case Codes and Outcome Rates for Surveys. 9th edition.* Alexandria, VA: AAPOR.

Battaglia, M., Dillman, D., Frankel, M., Harter, R., Buskirk, T., McPhee, C., . . . Yancy, T. (2016). Sampling, data collection, and weighting procedures for address-based sample surveys. *Journal of Survey Statistics and Methodology, 4*, 476-500.

Biemer, P. P., & Lyberg, L. (2003). *Introduction to survey quality.* Hoboken, NJ: John Wiley & Sons, Inc.

Brick, M. (2013). Unit nonresponse and weighting adjustments: A critical review. *Journal of Official Statistics, 29*, 329-353.

Charmaz, K. (2006). *Constructing grounded theory: A practical guide through qualitative research.* London: Sage.

Cornwall, A. (2003). Whose voices? Whose choices? Reflections on gender and participatory development. *World Development*, 31, 1325–1342. URL: http://linkinghub.elsevier. com/retrieve/pii/S0305750X0300086X. doi:10.1016/S0305-750X(03)00086-X.

Cornwall, A., & Jewkes, R. (1995). What is participatory research? *Social Science & Medicine*, 41, 1667–1676.

Creswell J. (2007). *Qualitative inquiry and research design*(2nd ed.). Thousand Oaks, CA: Sage.

Creswell, J. W. (2013). *Qualitative inquiry and research design: Choosing among five approaches.* Sage.

Curtin, R., Presser, S., & Singer, E. (2000). The effects of response rate changes on the index of consumer sentiment. *Public Opinion Quarterly*, 413-428.

Dillman, D.A., Smyth, J.D., and Christian, L.M. (2014). *Internet, phone, mail, and mixed-mode surveys: The tailored design method*. John Wiley & Sons: New York.

Greene J. (2008). Is mixed methods social inquiry a distinctive methodology? *Journal of Mixed Methods Research 2*(1), 7–22.

Groves, R. M. (2006). Nonresponse rates and nonresponse bias in household surveys. *Public Opinion Quarterly*, 646-675.

Groves, R. M., Fowler, F. J., Couper, M. P., Lepkowski, J. M., Singer, E., & Tourangeau, R. (2009). *Survey Methodology: Second Edition.* Hoboken, New Jeresy: John Wiley & Sons, Inc.

Haziza, D., & Beaumont, J.-F. (2017). Construction of weights in surveys: A Review. *Statistical Science, vol. 32*, 206-226.

Haziza, D., & Lesage, E. (2016). A discussion of weighting procedures for unit nonresponse. *Journal of Official Statistics, 32*, 129-145.

IBM Corporation. (2021). *IBM SPSS Statistics for Windows, Version 28.0 including complex samples module.* Armonk, New York.

Kalton, G., & Flores-Cervantes, I. (2003). Weighting methods. *Journal of Official Statistics, vol. 19*, 81-97.

Keeter, S., Miller, C., Kohut, A., Groves, R. M., & Presser, S. (2000). Consequences of reducing nonresponse in a large national telephone survey. *Public Opinion Quarterly*, 125-148.

Kish, L., & Frankel, M. (1974). Inference from complex samples. *Journal of the Royal Statistical Society. Series B (methodological)*, 1-37.

Kreuter, F., & Olson, K. (2013). Paradata for nonresponse error investigation. In F. Kreuter, *Improving Surveys with Paradata: Analytic Uses of Process Information* (pp. 13-42). Hoboken, New Jersey: John Wiley & Sons.

Lavallee, P., & Beaumont, J.-F. (2016). Weighting principals and practicalities. In C. Wolf, D. Joye, T. Smith, & Y.-C. Fu, *The Sage Handbook of Survey Methodology* (pp. 460-476). Sage.

Layder D. (1998). *Sociological Practice: Linking Theory and Social Research*. Sage: London.

Lien, A. M., Svancara, C., Vanasco, W., Ruyle, G. B., & López-Hoffman, L. (2017). The land ethic of ranchers: A core value despite divergent views of government. *Rangeland Ecology and Management*, *70*(6), 787–793. https://doi.org/10.1016/j.rama.2017.06.004

Lohr, S. L., Riddles, M. K., & Monganstein, D. (2016). Tests for evaluating nonresponse bias in surveys. *Survey Methodology*, 195-218.

Lubell, M. N., Cutts, B. B., Roche, L. M., Hamilton, M., Derner, J. D., Kachergis, E., & Tate, K. W. (2013). Conservation program participation and adaptive rangeland decision-making. *Rangeland Ecology & Management*, *66*, 609–620.

Morgan D. (2007). Paradigms lost and pragmatism regained: Methodological implications of combining qualitative and quantitative methods. *Journal of Mixed Methods Research, 1*(1), 48–76.

Niska, M., Vesala, H. T., & Vesala, K. M. (2012). Peasantry and entrepreneurship as frames for farming: Reflections on farmers' values and agricultural policy discourses. *Sociologia Ruralis*, *52*(4), 453–469. https://doi.org/10.1111/j.1467-9523.2012.00572.x

Olson, K. (2013). Paradata for nonresponse adjustment. *The Annals of the American Academy of Political Science and Social Science*, 142-170.

Panda, A., Sharma, U., Ninan, K. N., & Patt, A. (2013). Adaptive capacity contributing to improved agricultural productivity at the household level: Empirical findings highlighting the importance of crop insurance. *Global Environmental Change*, *23*(4), 782–790. https://doi.org/10.1016/j.gloenvcha.2013.03.002

Panda, A. (2017). Vulnerability to climate variability and drought among small and marginal farmers: A case study in Odisha, India. *Climate and Development*, *9*(7), 605–617. https://doi.org/10.1080/17565529.2016.1184606

Prokopy, L. S., Floress, K., Klotthor-Weinkauf, D., & Baumgart-Getz, A. (2008). Determinants of agricultural best management practice adoption: Evidence from the literature. *Journal of Soil and Water Conservation*. https://doi.org/10.2489/jswc.63.5.300

Provenza, F. D. (1991). Viewpoint: range science and range management are complementary but distinct endeavors. Journal of Range Management, 44, 181–183.

Rao, J., Hidiroglou, M., Yung, W., & Kovacevic, M. (2010). The role of weights in descriptive and analytical inferences from survey data: An overview. *Journal of the Indian Society of Agricultural Statistics, 64*, 129-135.

Reid, R. S., Fernandez-Gimenez, M. E., Wilmer, H., Pickering, T., Kassam, K.-A. S., Yasin, A., … Knapp, C. N. (2021). Using research to support transformative impacts on complex, "wicked problems" with pastoral peoples in rangelands. *Frontiers in Sustainable Food Systems, 4*. https://doi.org/10.3389/fsufs.2020.600689

Roche, L. M. (2021). Grand challenges and transformative solutions for rangeland social-ecological systems – emphasizing the human dimensions. *Rangelands*, 1–8. https://doi.org/10.1016/j.rala.2021.03.006

Roche, L. M., Schohr, T. K., Derner, J. D., Lubell, M. N., Cutts, B. B., Kachergis, E., … Tate, K. W. (2015a). Sustaining working rangelands: Insights from rancher decision making. *Rangeland Ecology and Management*, *68*(5), 383–389. https://doi.org/10.1016/j.rama.2015.07.006

Roche, L.M., Cutts, B.B., Derner, J.D., Lubell, M.N., Tate, K.W. (2015b). On-ranch grazing strategies: Context for the rotational grazing dilemma. *Rangeland Ecology & Management 68*, 248–256.

Rosenbaum, P. R., & Rubin, D. B. (1984). Reducing bias in observational studies using subclassification on the propensity score. *Journal of the American Statistical Association*, 516-524.

Sarndal, C.-E. (2007). The calibration approach in survey theory and practice. *Survey Methodology, 33*, 99-119.

Sayre, N. F., Carlisle, L., Huntsinger, L., Fisher, G., & Shattuck, A. (2012). The role of rangelands in diversified farming systems: Innovations, obstacles, and opportunities in the USA. *Ecology and Society*, *17*(4). https://doi.org/10.5751/ES-04790-170443

Smith, L. T. (1999). *Decolonizing methodologies: research and indigenous peoples*. *New York*. https://doi.org/10.1097/NAQ.0b013e318258ba14

State of Montana. (2020). Montana Climate Solutions Plan. Helena, MT. https://deq.mt.gov/files/deqadmin/climate/2020-09-09_montanaclimatesolutions_final.pdf

Teddlie C. & Tashakkori A. (2003). Major issues and controversies in the use of mixed methods in the social and behavioral sciences. In: Tashakkori A, Teddlie C, editors. *Handbook of mixed methods in social and behavioral research.* Thousand Oaks, CA: Sage. 3–50.

Valliant, R., Dever, J. A., & Kreuter, F. (2013). *Practical Tools for Designing and Weighting Surveys.* New York, New, York: Springer.

Valliant, R., & Dever, J. A. (2018). *Survey Weights: A Step-by-Step Guide to Calculation.* College Station, TX: Stata Press.

Wezel, A., Herren, B. G., Kerr, R. B., Barrios, E., Gonçalves, A. L. R., & Sinclair, F. (2020). Agroecological principles and elements and their implications for transitioning to sustainable food systems. A review. *Agronomy for Sustainable Development*, *40*(6). https://doi.org/10.1007/s13593-020-00646-z

Wilmer, H., Augustine, D. J., Derner, J. D., Fernández-Giménez, M. E., Briske, D. D., Roche, L. M., … Miller, K. E. (2018). Diverse management strategies produce similar ecological outcomes on ranches in Western Great Plains: Social-ecological assessment. *Rangeland Ecology and Management*, *71*(5), 626–636. https://doi.org/10.1016/j.rama.2017.08.001

Wilmer, H., Porensky, L., Fernandez-Gimenez, M., Derner, J., Augustine, D., Ritten, J., & Peck, D. (2019). Community-engaged research builds a nature-culture of hope on North American Great Plains Rangelands. *Social Sciences*, *8*(1). https://doi.org/10.3390/socsci8010022

Wilmer, H., Schulz, T., Fernández-Giménez, M. E., Derner, J. D., Porensky, L. M., Augustine, D. J., … Meade, R. (2021). Social learning lessons from collaborative adaptive rangeland management. *Rangelands*, 1–11. https://doi.org/10.1016/j.rala.2021.02.002

Yung, L., Phear, N., Dupont, A., Montag, J., & Murphy, D. (2015). Drought adaptation and climate change beliefs among working ranchers in Montana. *Weather, Climate, and Society*, *7*(4), 281–293. https://doi.org/10.1175/WCAS-D-14-00039.1

USDA-NASS. (2021). 2021 State Agriculture Overview – Montana. https://www.nass.usda.gov/Quick_Stats/Ag_Overview/stateOverview.php?state=MONTANA

USDA. (2013). Climate change and agriculture in the United States: Effects and adaptation. https://www.usda.gov/sites/default/files/documents/CC%20and%20Agriculture%20Report%20(02-04-2013)b.pdf

USDA NW Climate Hub. (2019). Applying soil health management systems to reduce climate and weather risks in the Northwest. https://www.climatehubs.usda.gov/sites/default/files/Mngmt%20Systems%20Reduce%20Risks%20in%20the%20NW.pdf

Chapter 3: Social dimensions of adaptation in rangeland social-ecological systems: A systematic literature review

Abstract:

Rangeland social-ecological systems (SESs), which make up vast tracts of Earth's terrestrial surface, are facing unprecedented change — from climate change and vegetation transitions to large-scale shifts in human land use and changing social and economic conditions. Understanding how people who manage and depend on rangeland resources are adapting to change has been the focus of a rapidly growing body of research, which has the potential to provide important insights for climate change adaptation policy and practice. Here, we use quantitative, qualitative, and bibliometric analyses to systematically review the scope, methods, and findings of 56 studies that examine the social dimensions of adaptation in rangeland SESs. Our review focuses on studies within the climate adaptation, adaptive capacity, and adaptive decision-making sub-fields, finding that, as a whole, this body of research is highly diverse in its disciplinary roots, theoretical origins, and therefore uses a wide range of frameworks and indicators to evaluate adaptation processes. Bibliometric (co-word and co-citation) analyses revealed that the field is fragmented into distinct scholarly communities that use either adaptive capacity or adaptive decision-making frameworks, with a lack of cross-field citation. Given the strengths (and weaknesses) inherent in each sub-field, this review suggests that greater cross-pollination across the scholarship could lead to new insights, particularly for capturing cross-scale interactions related to adaptation on rangelands. Results also showed that a majority of studies are also geographically concentrated in few, high-income countries (i.e. USA, Australia, China), demonstrating a need to extend future research efforts to understudied regions of the globe with rangeland-based livelihoods. Finally, our review highlights the need for more translational rangeland science, where policy- and practice- relevant frameworks evaluating adaptation in rangeland SESs might be developed by co-producing research working with rangeland communities.

Introduction

Globally, rangelands comprise approximately 25–40% of the earth's terrestrial area and are also home to millions of people who derive their livelihoods predominately from livestock grazing (Asner et al., 2004; Reid et al., 2014; Sayre et al., 2013). These diverse working landscapes are critical for safeguarding ecosystem services, producing food and fiber, protecting open space, contributing to local and regional economies, and maintaining cultures and knowledges across the globe (Brunson & Huntsinger, 2008; Sayre et al., 2012).

Rangelands are often described as "social-ecological systems" (SESs) because of the interconnectedness of humans (and their values, organizations, and institutions) with ecological processes (Hruska et al., 2017; Roche, 2021). Rangelands are unique in that they are often tightly coupled and highly diverse SESs, where ranchers and rangeland managers are seasoned to adapting their management goals and practices to reduce their risks in the face of increased complexity and uncertainty (Sayre et al. 2012). At the same time, rapid environmental and socio-economic changes on rangelands today — particularly climate change — present novel challenges for ranchers and rangeland managers (here forward referred to as 'ranchers'). Thus, the ability for ranchers to adapt in new ways is becoming increasingly important (Briske et al., 2015; Joyce et al., 2015; Joyce & Marshall, 2017; Roche 2021).

There is a growing recognition among academic scholars that a focus on the social dimensions of rangeland SESs is important for understanding and supporting desirable adaptation into the future (Reid et al., 2021; Roche, 2021; Wilmer et al., 2018). Yet this scholarship is diverse in its disciplinary roots and dispersed across a wide range of scholarly communities**.** Literature reviews can play an important role in synthesizing past research findings to effectively use the existing knowledge base and to advance current lines of research, especially in the context of rapidly growing bodies of scholarship like climate adaptation (Rosseau, 2012). My objective in this systematic literature review was to use a combination of qualitative, quantitative, and bibliometric analysis techniques to examine how the social dimensions of adaptation processes in rangeland SESs have been studied. Specifically, this review focuses on scholarship that uses climate adaptation, adaptive capacity, and adaptive decision-making frameworks. To that end, I discuss how the strengths of the different research approaches and frameworks examined might be integrated for a more holistic understanding of adaptation and suggest directions for future research that is oriented toward policy and practices that would produce desirable social and ecological outcomes in rangeland systems in light of rapid change.

Approaches to understanding adaptation in rangeland social-ecological systems

Adaptation is recognized as a vital approach for reducing vulnerability and building resilience in rangeland social-ecological systems (Adger, 2006; Adger et al., 2007; Briske et al., 2015; Karimi, 2018). While adaptation has been interpreted and applied in various ways, three common definitions include: 1) the "ability to adjust to a disturbance, moderate potential damage, take advantage of opportunities and cope with the consequences of a transformation" (Gallopin, 2006); 2) the actions of adjusting practices, processes, and capital responses to the threat of climate change (Adger et al. 2007) and 3) structural or behavioral response to climate change that occurs before or after the event and may buffer or sustain activities or transform the state of the social-ecological system (Berrang-Ford et al., 2011; Folke, 2006). Following the literature, adaptation involves both individual choice or 'agency' as well as agency that exists within a context of structures, governance, and institutions.

SES scholars have taken various approaches to examine adaptation to changing social and ecological dynamics on working rangelands. In this review, I focused on studies that used three common concepts — climate adaptation, adaptive capacity, and adaptive decision-making — for examining the social dimensions of adaptation in rangeland SESs. Figure 3.0 depicts the nested relationship between these nested concepts. Across this literature, adaptation takes place predominately in response to climate change or its manifestations (e.g. drought), however some studies examining adaptive rangeland management and decision-making look at adaptation processes in the context of environmental and social change more broadly. Throughout this review, I refer to people who manage livestock on rangelands as "ranchers" and these systems as "working rangelands" with the recognition that pastoralism and herding systems, while included in the studies in this review, are distinct ways of managing rangeland SESs (Galaty & Johnson, 1990; Reid et al., 2014).

Climate adaptation

Climatic conditions are rapidly changing rangeland ecosystem processes and properties (Polley et al., 2013). In recent decades, research that examines climate adaptation among rangeland resource dependent communities has expanded from an initial focus on ecological and economic impacts and adaptation strategies to a broader vision that includes the social dimensions of adaptation (Briske et al, 2015; Joyce and Marshall, 2017). In this review, climate adaptation was used as a keyword to identify studies that explored how ranchers are adapting to climate change and what factors enable and constrain adaptation strategies/behaviors (outside of the adaptive capacity and adaptive decision-making literatures). Climate adaptation studies tend to examine specific practices used by ranchers in order to mitigate the effects of drought and climate-related events and examined factors influenced the adoption of those practices (e.g. Coppock, 2011; Haigh et al., 2019; Karimi et al., 2018).

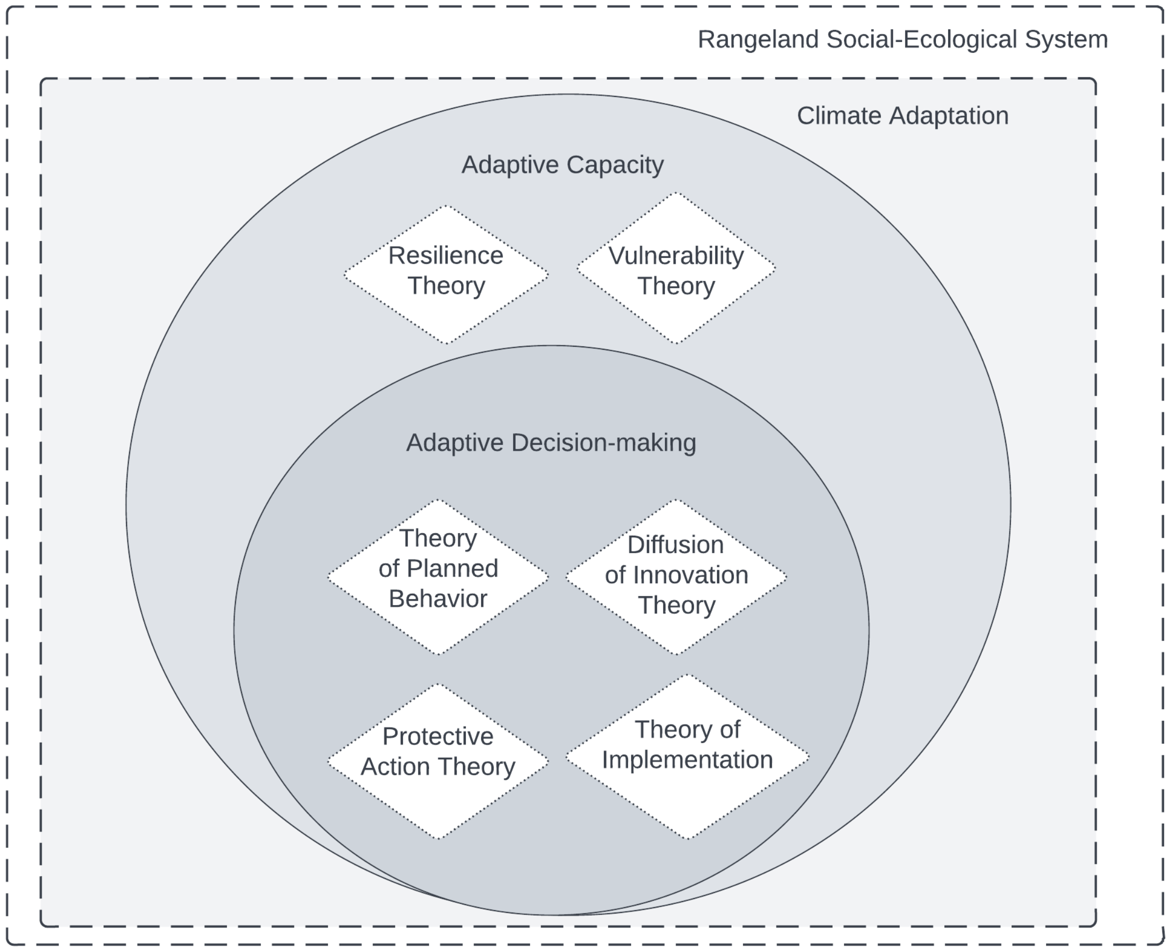


Figure 3.0. This diagram depicts the nested relationship between the concepts of rangeland SESs, climate adaptation, adaptive capacity, and adaptive decision-making. Adaptive capacity scholarship has its theoretical roots in resilience theory and vulnerability theory, which are often applied at a systems-level scale, while adaptive decision-making studies tend to be informed by theories operating at the individual level*.*

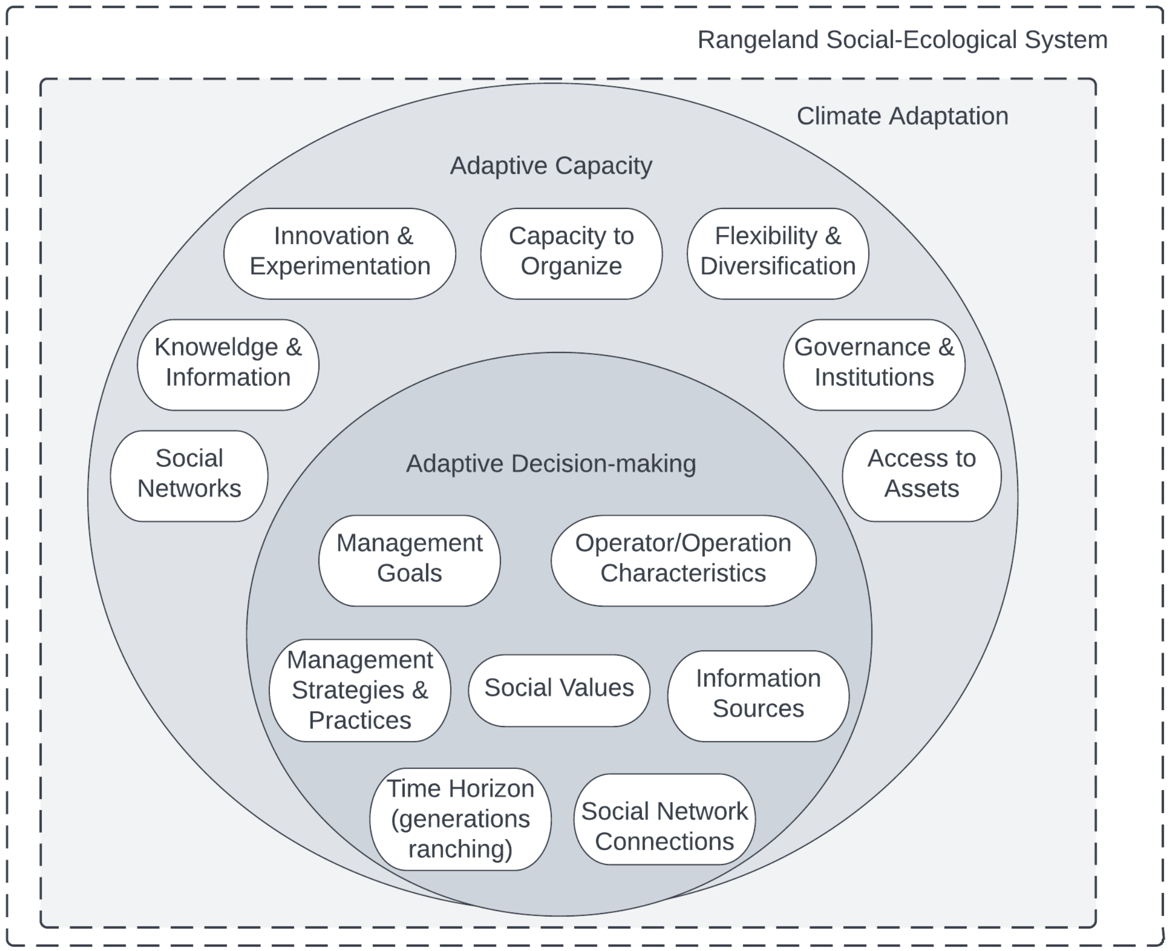


Figure 3.1. We conceptualize rangeland SESs and climate adaptation as the framings within which scholars examine adaptive capacity and adaptive decision-making. Common categories of indicators used to evaluate adaptive capacity (adapted from Engle (2011) Cinner & Barnes, (2019), Gupta 2010) and adaptive decision-making are also shown (adapted from Lubell et al. (2013)).

Adaptive capacity

Adaptive capacity is a concept that has been used widely in the SES, resilience and vulnerability literature as an analytical framework to understand and assess the interplay between structure, agency, and other factors that make up the preconditions for adaptive behavior across diverse contexts and scales (Engle 2011; Siders, 2019; Vallury et al., 2022). While conceptualizations of adaptive capacity have crossed many disciplines, adaptive capacity has been described as the ability of actors to anticipate and respond to perceived or current stresses by mobilizing and managing scarce resources for resilience (Adger, 2007; Engle, 2011). Adaptive capacity is a latent characteristic reflecting the preconditions that influence peoples' ability to anticipate and adapt to change rather than the adaptive behavior itself (Cinner, 2015). Within both the resilience and vulnerability literature, governance and institutions have been cited as critical variables affecting adaptive capacity, recognizing that they can either enable or constrain the agency of actors within the system (Engle 2011). Institutions, or systems of rules, norms, decision-making procedures, and programs that give rise to social practices and guide interactions, can be formal governmental policies or informal social patterns — both of which can promote or constrain adaptive capacity (Berman 2012; Cinner & Barnes, 2019; Gupta 2010). Thus, adaptive capacity has been used to illuminate both individual level factors and institutional level factors that promote or inhibit adaptation within a given system. Figure 3.1 shows common categories of indicators used to evaluate adaptive capacity.

Although adaptive capacity assessments can help clarify the various dimensions that enable or constrain successful adaptations in light of change, considerable gaps in adaptive capacity application exist. Critiques include the diversity (or lack of standardization) of methods and indicators used to evaluate it, a lack of understanding of cross scale (individual to structural) interactions (e.g. between local contexts and global processes), and the challenge of designing research that is practice-oriented and at policy-relevant timescales (Siders., 2019.; Vallury et al., 2022; Whitney et al., 2017).

While adaptive capacity is a rapidly growing concept, a relatively small number of studies have examined adaptive capacity in rangeland SES contexts specifically. At the same time, rangeland SESs across the globe are uniquely vulnerable to the impacts of climate change (Sayre et al., 2013). Rangeland systems face accelerated degradation processes associated with longer and more frequent periods of aridity — which are likely to become a more regular component of these systems — and rangeland managers are faced with the unique challenge of maintaining the productivity and profitability of their enterprises without degrading the grazing resources on which they depend. Thus, understanding the capacity of rangeland systems to adapt to anticipated changes is important for identifying avenues for solutions that will support industries, livelihoods, and communities who depend on them.

Adaptive decision-making

While adaptive capacity provides a theoretical framework for assessing the myriad factors that influence ranchers' ability to respond to climate change, the *capacity* to act is different than adaptive *action*. There is a growing body of research using adaptive decision-making frameworks to understand what ranchers are doing to reduce economic and ecological risk and what factors influence these decisions (Wilmer and Fernández-Giménez, 2015; Wilmer and Sturrock, 2020; Wilmer et al., 2016).

Ranching involves complex decision-making in the face of uncertainty and changing social-ecological systems. Ranchers are continuously adjusting to weather, climate, and range conditions that affect livestock production while also adjusting management for swings in feed prices and cattle, sheep, and other livestock markets (Shrum et al., 2018). For ranchers, adaptive decision-making might entail moving to dynamic grazing practices that are driven by forage availability rather than fixed date or they might improve the genetics of their herd toward more drought and heat-tolerant livestock breeds (Sayre 2012; Wilmer 2018). Or, given that ranchers are highly dependent on sufficient and timely rainfall for rangeland forage production, they may decide to either adopt conservative long-term stocking strategies as a hedge against drought or practice a more dynamic approach in which they vary stocking rates and supplemental feed in response to drought (Shrum et al., 2018; Haigh et al., 2021).

Studies that examine adaptive rangeland decision-making tend to focus on individual-level factors such as operator/operation characteristics, place-based experience, and social values to the process of trial-and-error learning (Lubell et al. 2013) and look at adaptation in the context of smaller scale ecological processes (e.g. regional drought, ranch-level ecological indicators), however, there is also some acknowledgement of the important drivers at socioeconomic scales that exist beyond the individual rancher, including globally integrated commodity markets, agricultural policies and regulations, and broader geographic shifts in agricultural industries (Wilmer et al., 2018). Figure 3.1 shows the conceptual relationship between adaptive capacity and adaptive decision-making in and depicts common categories of indicators used to examine adaptive decision-making for rangeland management (adapted from Lubell et al., 2013).

Research Questions

The objective of this literature review was to examine and synthesize scholarship that uses climate adaptation, adaptive capacity, and adaptive decision-making frameworks to understand the social dimensions of adaptation in rangeland SESs. Broadly, I wanted to understand how each of these three concepts have been employed in the literature with the aim of identifying research gaps and offering insight on ways future research can bridge analyses with actionable recommendations that support desirable adaptation outcomes in rangeland SESs. Specifically, I asked:

1) Which concepts (climate adaptation, adaptive capacity, and adaptive decision-making) and frameworks are most commonly used to evaluate adaptation in rangeland SESs?;
2) What methods and indicators are used to evaluate adaptation processes?;
3) What is the scale of analysis used across this scholarship?;
4) What are the implications for communities (i.e. recommendations for policy or practice) emerging from this scholarship?

Methods

Article selection

The article selection method I used follows the principles for systematic review proposed by Pullin and Stewart (2006) and Berrang-Ford et al (2015). I performed a topic search in the Web of Science database using search terms from the climate adaptation, adaptive capacity, and adaptive decision-making literatures to explore the concept of adaptation in rangeland social-ecological systems (Table 3.0). My search included the terms: 'adaptive capacit*,' 'adaptive management,' 'adaptive decision-making,' 'climate adaptation, 'climate change adaptation,' 'rancher decision making,' 'rangeland decision making.' These terms were combined with 'rangeland' and/or 'ranch' to link these concepts with rangeland systems as the focus of my review. The search was last updated in February, 2022 and returned 671 articles.

Table 3.0. Web of Science Query

Query
TS= (("adaptive capacit*" OR "adaptive management" OR "adaptive decision-making" OR "climate adaptation" OR "climate change adaptation" OR "rancher decision making" OR "rangeland decision making") AND ("rangeland*" OR "ranch*")) 671 results

This suite of search terms resulted in a sufficiently broad scope of research while also generating an optimal number of articles that are relevant to my research question and context (Pullin and Stewart 2006). It is a recommended practice to use a conservative approach in selecting search terms in order to retain all articles that are relevant for answering our research question. Still, there were articles that examine the drivers of adaptation processes in rangelands contexts that were not captured by this search and rangelands literature (see Discussion for more on study limitations). For example, studies on pastoralism were not fully represented. In addition, we did not search terms specific to ecological adaptation, as that would have yielded studies that are not relevant to the scope of our review (focusing on social science studies) and diminished the effectiveness of our analysis (Pullin & Stewart 2006).

Inclusion and exclusion criteria

Articles were included in the final review if they examined social factors, drivers, or predictors that influence adaptive capacity, adaptive decision-making, or climate adaptation strategies among ranchers in livestock-based rangeland SESs. I used four questions to guide the inclusion/exclusion decision-making process, summarized in Table 3.1.

Table 3.1. Inclusion/Exclusion Questions

Question	Description
Question 1: Does the paper have a social science focus?	While there are interdependencies between environmental change processes and human adaptation, I only included studies with a social science focus. In other words, all studies included analyze the factors that shape the human component of rangeland SESs in response to environmental change. Papers were excluded if adaptation examined was predominantly due to social, cultural, or economic dynamics (or a combination), and not directly related to environmental change.
Question 2: Is the paper focused on human adaptation (not ecological) to an environmental stressor?	I included studies focused on human adaptation to an environmental stressor (e.g. climate change, drought, vegetation shifts). I excluded articles that solely examined the ecological outcomes of 'adaptive management' treatments to study sites, but that did not address the social determinants or drivers of those decision-making processes. Similarly, I excluded papers if they simply inventory climate adaptation strategies but did not evaluate drivers or factors influencing the of adoption of those strategies.
Question 3: Does the paper evaluate, assess, measure or characterize adaptive capacity, adaptive decision-making or climate adaptation? In other words, is it empirical (not a review)?	Studies were included if they reported empirical findings based on primary fieldwork or secondary research (i.e. reviews and opinions excluded) examining adaptive capacity, adaptive decision-making or climate adaptation as a system driver or outcome. A study that examined key drivers of different grazing management types but did not seek to understand how grazing management shaped adaptive capacity outcomes would be excluded.
Question 4: Is the paper focused on rangeland managers/ranchers (this includes papers that focus on pastoralists and/or use the term livestock producers)?	Studies included focused on social dimensions of rangeland managers or ranchers. I included studies that used the terms livestock producers or pastoralists. Papers focusing on landowners in general were excluded.

The process for inclusion/exclusion was iterative and included three rounds of reviewing abstracts and then full articles, starting with the initial sample of 671 papers. Figure 3.2 summarizes the decision-making process for inclusion/exclusion and Figure 3.3 shows the resulting number of papers after each round of inclusion/exclusion, which resulted in a final sample of 56 papers.

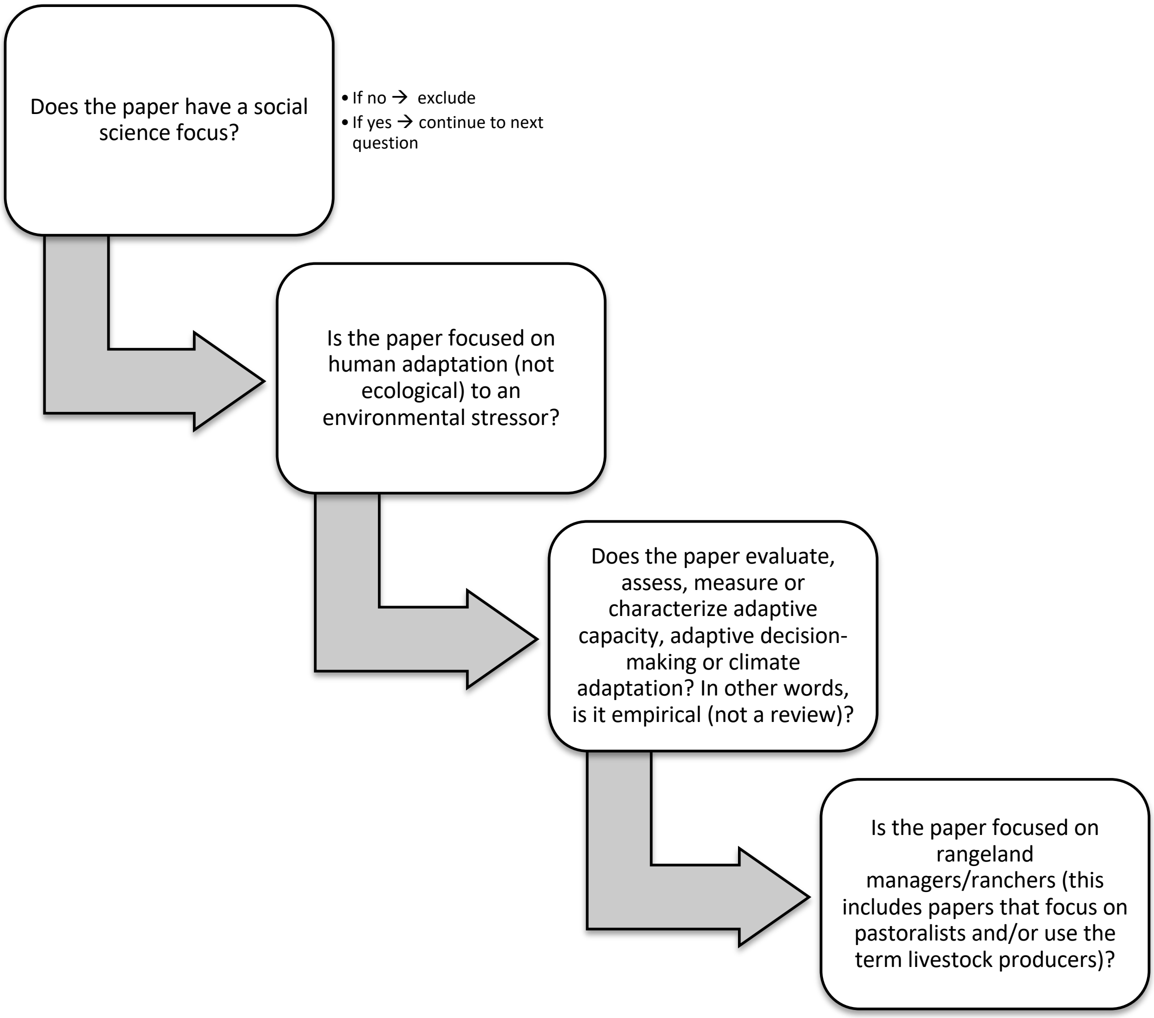


Figure 3.2. Decision flowchart for inclusion/exclusion.

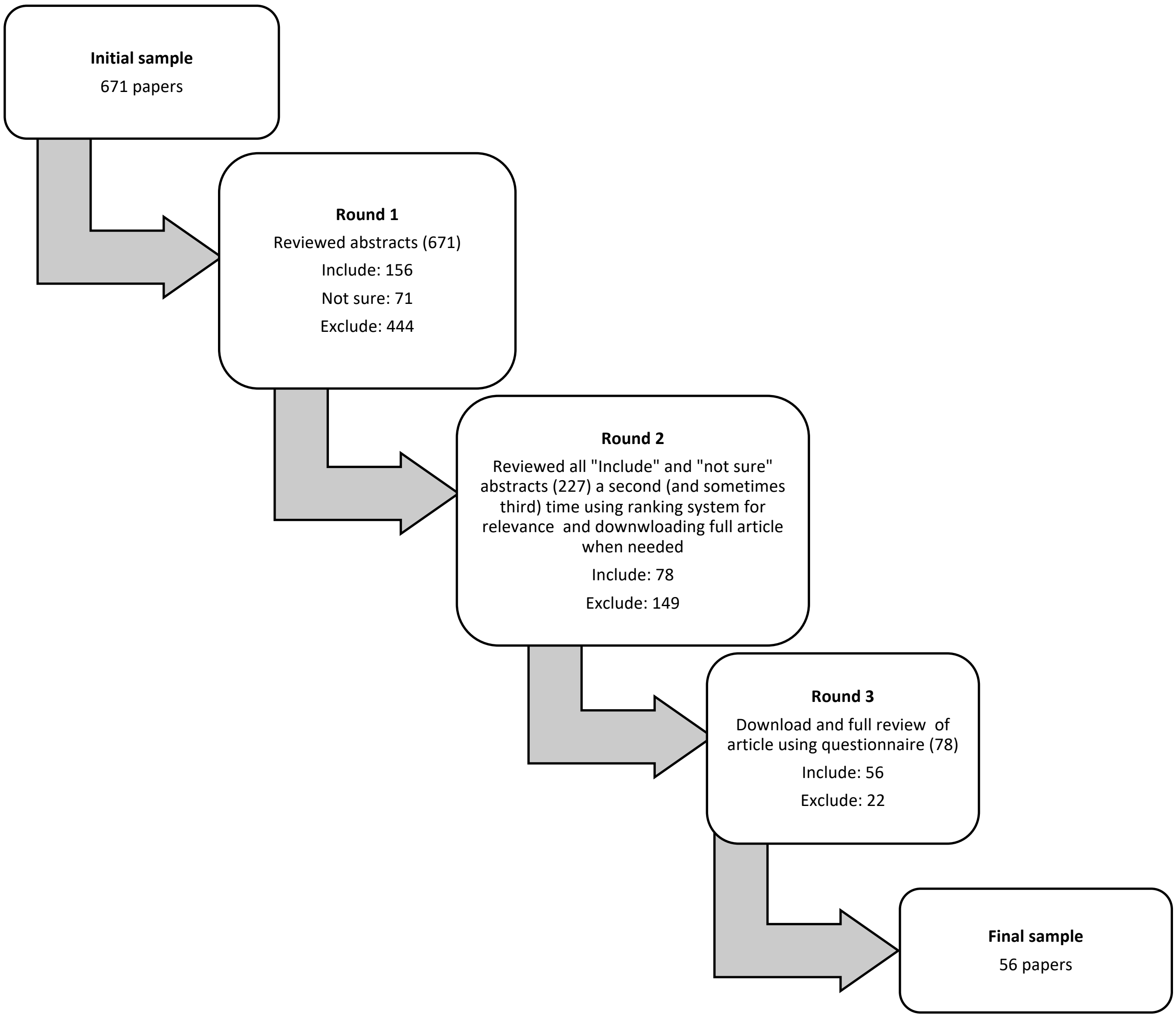


Figure 3.3. Summary of iterative rounds of inclusion/exclusion.

Content analysis

Following the inclusion/exclusion process, I used content analysis to examine the final sample of 56 articles in greater detail. For each article, I filled out a pro-forma questionnaire (Table 3.2) that included basic information about the study (e.g. study location, scale of analysis), questions regarding methods, frameworks, and indicators used in data collection and analysis, and open-ended questions about papers' objectives and implications for policy or practice. Responses to this questionnaire provided critical insight on the theoretical and methodological approaches used to study adaptation on rangelands as well as the research applications of this body of scholarship.

Table 3.2. Questionnaire for content analysis

1. Aim of the study
2. Study location
3. What SES stressor(s) are ranchers adapting to?
4. At what scale is adaptive capacity, adaptive decision-making or climate adaptation being studied in this paper?
5. Methods: What methods were used to collect data? What methods were used to analyze data?
6. Indicators: What framework (if any) and/or indicators were used to evaluate CA/AC/AD?
7. Study findings: In particular, what policy or practice-oriented solutions emerged from the study? How have or how can the results be integrated into decision-making? What are the implications for communities of interest in the study (e.g. of the process, outcomes, or recommendations)?

After filling out the questionnaire for all 56 articles, I examined the responses *across* the literature and took notes on themes and patterns in a separate document. The questions driving this phase of content analysis related primarily to Questions 5–7 and were as follows: 1) What are common methods, frameworks and indicators evaluated for understanding adaptation in rangelands/among rangeland managers?; 2) Do the indicators and methods capture cross-scale interactions and do they align with the scale at which action is needed to environmental stressors?; 3) What insights related to policy and practice emerged from the study? What are key areas of inquiry for more action-oriented future research? I used basic descriptive statistical analysis to understand patterns across Questions 1–4.

Bibliometrics and co-citation analysis

In order to understand and organize this body of research further, I used bibliometric analyses. Bibliometric analyses offer a structured method for analyzing large body of information, to infer trends over time, examine themes researched, and to identify conceptual and theoretical shifts within scholarly fields (Aria & Cuccurullo, 2017; Crane, 1972). For this literature review, I used the open-source *bibliometrix* package, an R-tool for comprehensive bibliometric analyses (Aria

& Cuccurullo, 2017; R Core Team, 2016). Of the final 56 article sample, I was unable to access the necessary data fields (i.e. cited references) through the WoS core collection for two articles (Snaibi et al., 2021 and Wilmer & Sturrock, 2020), resulting in a sample of 54 for the bibliometric analyses. I used the *biblioshiny* app, which provides a web-interface for *bibliometrix* and uses the main functions of the package to carry out the analyses are create plots for basic metrics.

To examine the intellectual, social and conceptual Knowledge structures (K-structures) within this body of literature I use the co-word analysis and co-citation analysis tools in *bibliometrix*. The aim of the co-word analysis was to examine the conceptual structure of this body of literature. The co-word analysis involved using the word co-occurrence network to mapping tool through biblioshiny, which clustered keywords that were extracted from each article. I also used co-citation analysis, the most common analysis in bibliometrics, which uses citation counts to identify and visually depict important or central authors, publications, and journals within a body of literature (Zhao & Strotmann, 2015). Co-citation involves tracking pairs of papers that are cited together in the sample of articles. When the same pairs of papers are co-cited by many authors, clusters of research begin to form. The *bibliometrix* package generates a co-citation network layout using the Fruchterman-Reingold Algorithm (Fruchterman & Reingold, 1991) and clusters nodes based on the density of links (Aria & Cuccurullo 2017, Traag et al., 2019). The co-cited papers, authors, or journals that show up as clusters on co-citation maps tend to share some common theme and can reveal different theoretical and conceptual domains.

Results

Mapping the literature: Concepts, geographic distribution, scale of analysis

Of the 56 articles reviewed, 22 (39%) employed the concept of adaptive capacity, 20 (36%) employed the concept of adaptive decision-making, and 14 (25%) examined climate adaptation more broadly to understand adaptation in rangeland SESs across the globe (Figure 3.4). Over half of the articles reviewed studied adaptation at the regional level (n=29, 51.8%), followed by state (n=9, 16%), county/municipality/district (n=8, 14%), community (n=6, 11%), ranch (n=3, 5%), and national (n=1, 2%) levels (Figure 3.5).

Studies defined 'region' and 'community' in different ways. That is, some studies defined 'community' or 'region' based on geographic or political boundaries, which vary greatly in spatial scale, from smaller natural resource management areas such as the Upper Burdekin 'dry tropics' region studies by Marshall et al. (2011) to the Inner Mongolia Autonomous Region examined in Tan et al.'s (2018) study. Other studies defined regions based on watershed boundaries (e.g. Fang et al., 2011; Habron, 2004) or by a combination of climate vulnerability and agricultural production, such as the Murray-Darling Basin in Australia that is vulnerable to climate change and important for livestock production (Crimp et al., 2010). This lack of consistency in defining larger social groups is a known challenge in the social science literature (McKeown et al 1987, MacQueen et al 2001). Importantly, while the scale of analysis may have been 'region' or 'state,' it was common that the unit of analysis within these studies was the household or individual, which was then aggregated for a final assessment or measure of adaptation.

The majority of the studies (n=31, 55%) examined adaptation of humans (i.e., ranchers, communities) to climate change, followed by broad social-ecological change or a combination of environmental and social stressors (n=12, 21%). A significant portion of studies also explored ranchers' adaptation to drought specifically (n=11, 20%) and two studies examined human adaptation to other specific climate change manifestations (i.e. the *dzud*, winter storms, in Fernandez-Gimenez et al., 2015 and changes in 'frozen soil' change in Fang et al., 2011).

Geographically, studies investigating adaptation in rangeland SESs were conducted predominately in the USA (n = 23, 41%), followed by Australia (n = 11, 20%), China (including the Tibetan Autonomous Region) (n=6, 11%), Mongolia (n=3, 5%) and South Africa (n=3, 5%), Kenya, Iran, and Ethiopia with two studies each (n=2, 4%), and Uganda, Morocco, Tanzania, and Spain with one study each (n=1, 2%). Figure 3.6 shows the geographic distribution of where research took place across the 56 studies.

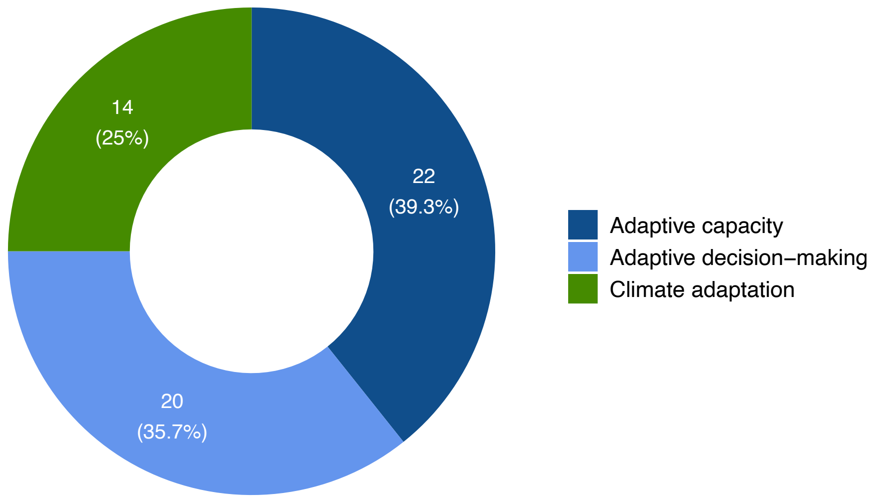


Figure 3.4. Distribution of frameworks/concepts used in studies (n= 56) understand adaptation in rangeland social-ecological systems.

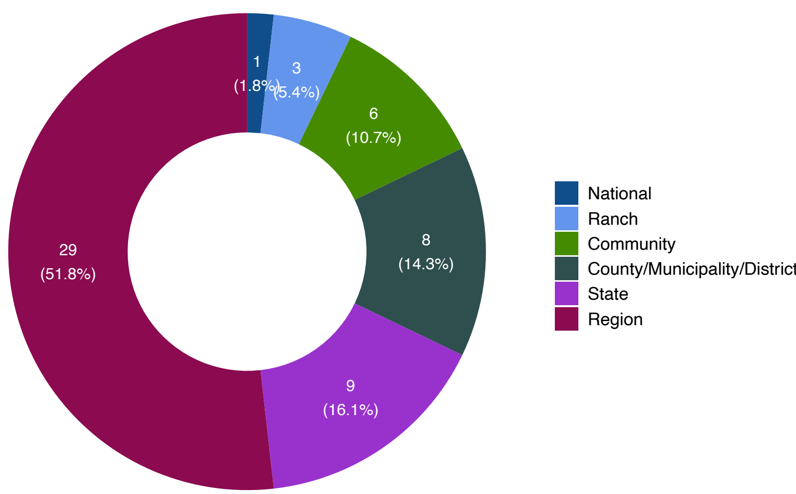


Figure 3.5. Scale of analysis that adaptive capacity, adaptive decision-making or climate adaptation was studied (n= 56).

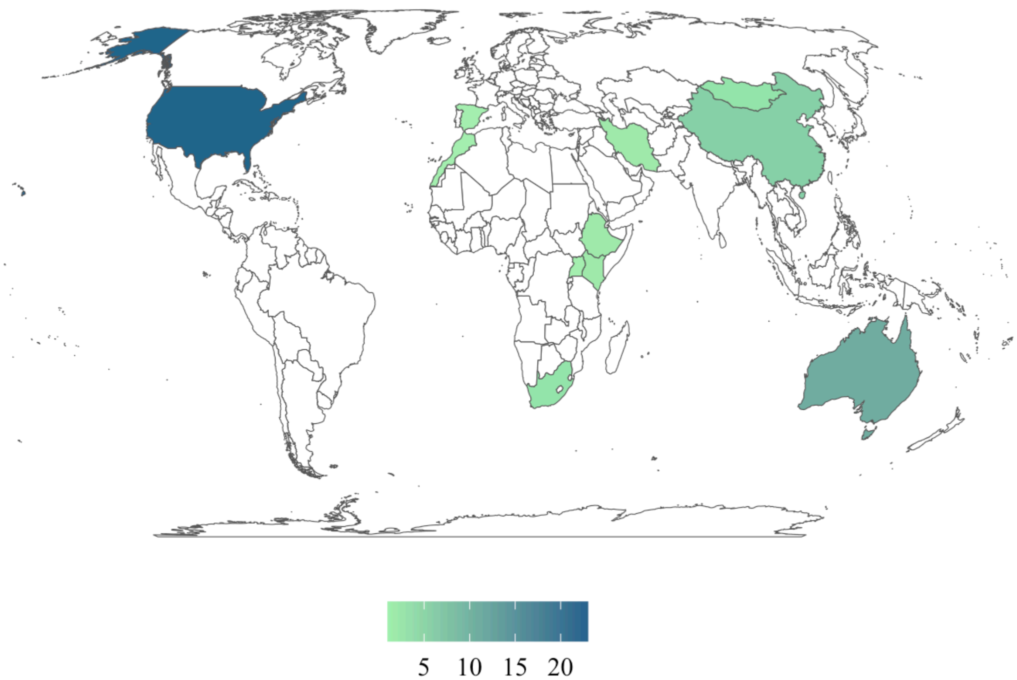


Figure 3.6. Geographic distribution of studies. Colors reflect the number of studies conducted in a country. For example, 23 studies examined adaptation in rangeland social-ecological systems in USA (dark blue). Several countries (light green) had one study (i.e. Uganda, Morocco, Tanzania, Spain). No studies were conducted at a global scale.

Conceptual and intellectual Knowledge-structures (K-structures) using bibliometric analyses

Results from the co-word analysis using *bibliometrix* shows that there are two main conceptual domains in this literature, reflected in the two groupings of keywords (see Figure 5). The first cluster of keywords is centered around “adaptive management” and is most closely associated (i.e. co-occurs) with the keywords “rangeland management,” “decision making,” “ranching,” “policy,” “public lands” and “social learning.” The second large cluster of keywords centered around “adaptive capacity” and is most closely associated with the keywords “climate change adaptation,” “vulnerability,” “resilience” and additional, smaller nodes. As shown in Figure 3.7, there is virtually no overlap between these clusters, meaning that articles using keywords in one cluster do not use the keywords in the other.

The co-citation analysis and resulting co-citation network maps revealed distinct intellectual structures, or groupings, within this literature. The network map of co-cited journals

(Figure 3.8), which reflects journal names that have been cited by articles in our sample, shows two distinct clusters. One cluster (red) is centered around co-cited journals having to do with global environmental change and climate change (e.g. Global Environmental Change, Climatic Change). The other cluster (blue) is centered around co-cited journals that tend to focus on rangeland management or applied rangeland science (e.g., Rangelands, Rangeland Ecology & Management, Journal of Rangeland Management).

From the analysis of co-cited papers (i.e. pairs of papers cited together), three distinct clusters emerged. This co-citation network map (Figure 3.9) shows one cluster (red) that includes papers focusing on adaptive capacity emerging from the resilience and vulnerability literatures (e.g., Adger, 2005; Engle, 2011). Highlighting this theme are prominent nodes in this cluster including the paper by Smit (2006) titled "Adaptation, adaptive capacity and vulnerability" and a paper by Gallopin (2006) titled, "Linkages between vulnerability, resilience and adaptive capacity." The second cluster (green) highlights a distinct grouping of co-cited papers that focus on adaptation and adaptive capacity in rangelands contexts specifically (e.g., Marshall, 2010; Marshall et al., 2011). The third cluster (blue) depicts a grouping of co-cited papers that tend to focus on the concepts of adaptive management and decision-making in rangelands (e.g., Roche et al., 2015, Lubell et al., 2013) with the exception of one paper examining adaptive capacity in rangelands (Marshall & Smaijl, 2013).

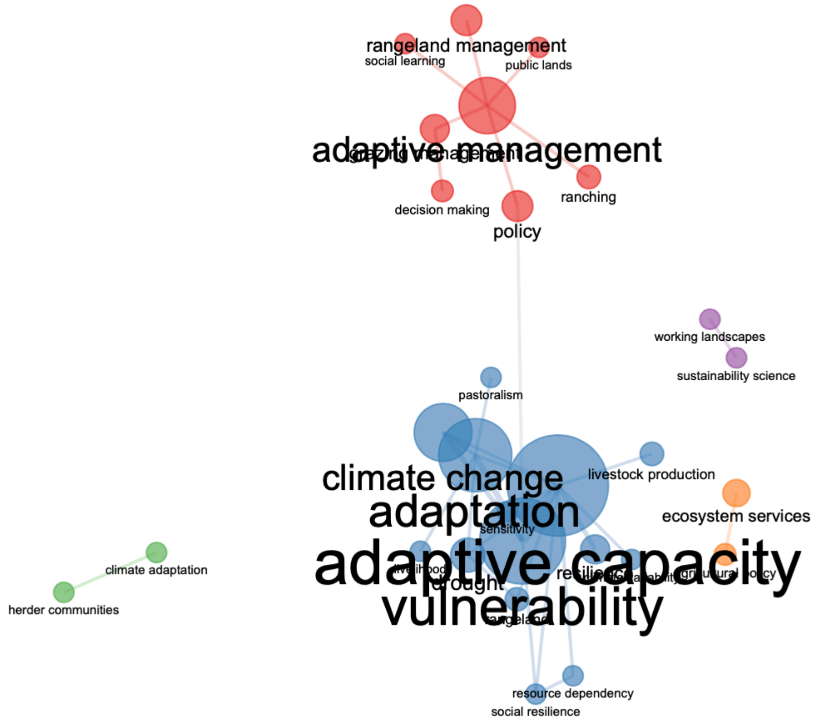


Figure 3.7. Co-occurrence network map based on author's keywords. The size of nodes reflects the number of times keywords occurred in the sample (n= 54). The more closely keywords are related (i.e. more co-occurrences) among articles, the closer they are represented in the map.

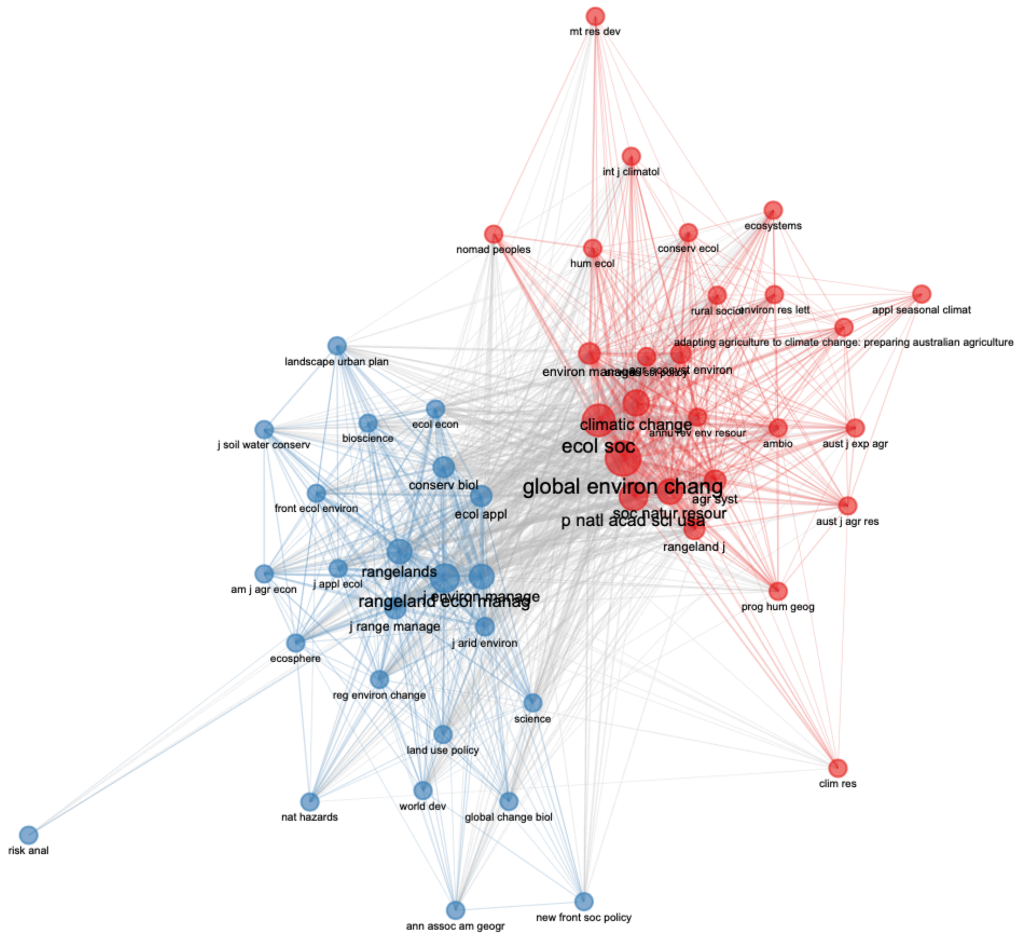


Figure 3.8 . Co-citation network map of co-cited journals. The size of nodes reflects the number of times journals are cited in the reference lists of articles within the sample (n= 54). When journals are cited together in many of the articles in the sample, that is represented by the proximity and linkages of nodes, which make up clusters of associated journals within this scholarship.

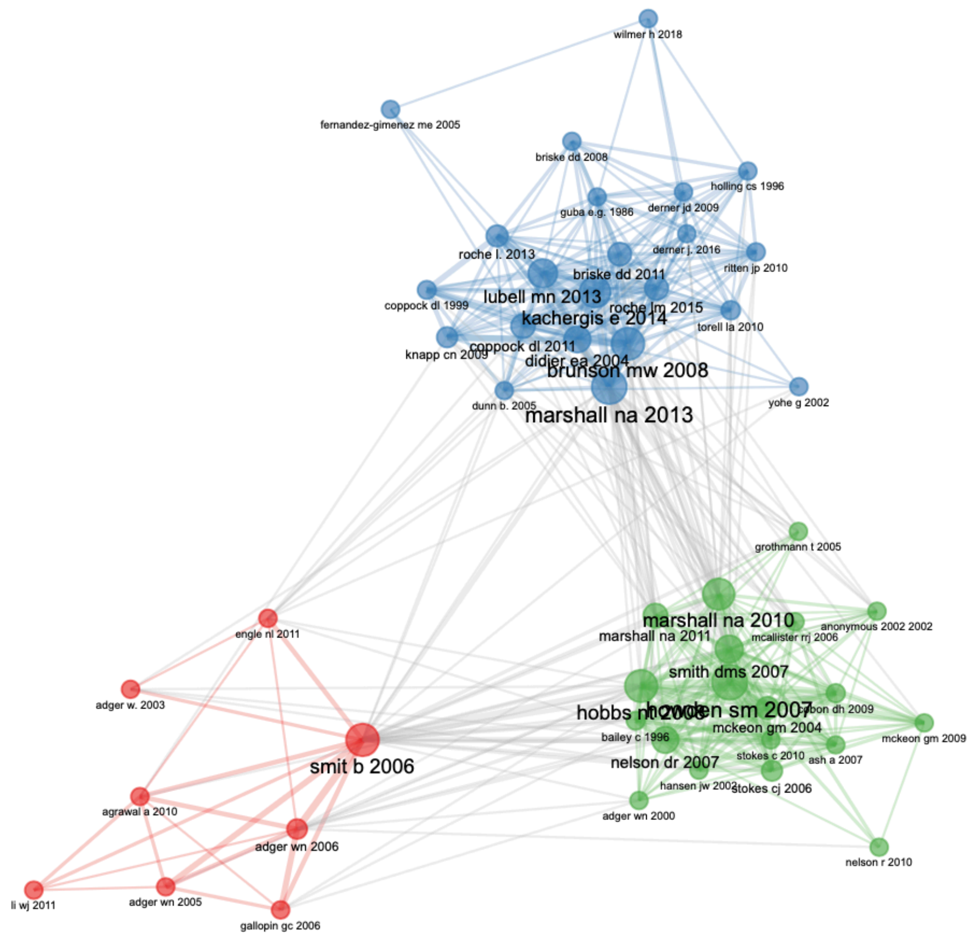


Figure 3.9. Co-citation network map of co-cited papers**.** The size of nodes reflects the number of times papers are cited in the reference lists of articles in our sample (n= 54). When the same pairs of papers are co-cited by many authors, that is represented by the linkages and proximity between nodes, and clusters of research sharing common themes begin to form.

Methods, frameworks, and indicators

Authors used a range of methods for data collection and analysis. Nearly all the research in this review involved primary data collection (e.g., interviews, quantitative surveys) (n=55, 85%) with only one study (Crimp et al., 2010) using exclusively secondary data. Some studies used a combination of primary and secondary data collection methods to leverage multiple data sources (e.g., Fang et al., 2011; Goldman & Riosmena., 2013). Quantitative surveys were the most common method used in this literature (n=25, 45%) to examine adaptation in rangeland SESs, followed by structured or semi-structured interviews (n=21, 37%), which were analyzed using both quantitative (e.g. Ndiritu, 2021) and qualitative approaches (e.g., Lien et al., 2021). Both survey and interview data were collected in three of the studies and seven studies that used other methods other than surveys or interviews to evaluate adaptation in rangeland systems, including policy/document analysis, the use of expert knowledge, stakeholder workshops, participatory and ethnographic approaches, computational modelling, or a combination of multiple methods.

One common approach used to evaluate adaptive capacity in rangeland SESs was frameworks that conceptualize adaptive capacity as an emergent property of the diverse forms of capital (human, social, natural, physical and financial) from which livelihoods are derived. This includes Rural Livelihoods framework developed by Ellis (2000) and built upon Adger (2006) and Cinner et al. (2009), the Sustainable Livelihoods Framework (SLF) (King et al., 2018), the Adaptation, institutions, and livelihood (AIL) framework developed by Agrawal and Perrin (2009), and the Adaptive Capacity Index (ACI) developed by Tan et al., (2018). These approaches typically evaluate indicators representing each 'capital' using qualitative or quantitative analyses (e.g. dimensionality reduction methods such as principal component analysis and/or combined with regressions). For example, the ACI developed by Tan et al. (2018) used survey questions asking about total income and household access to credit to represent "financial capital" and "natural capital" was indicated by pasture productivity per capita and pasture area per sheep unit. Using these frameworks, scholars take the approach that the livelihood and adaptation strategies undertaken are shaped by the changing access to human, social, natural, physical and financial capitals (Ellis, 2000).

Other studies used custom frameworks to examine adaptive capacity in rangeland systems. For example, one framework used widely in the Australian context (i.e. Marshall, 2010; Marshall et al., 2011; Marshall & Smajgl, 2013), conceptualizes adaptive capacity as emerging from cattle graziers' 1) perception of risk; 2) their capacity to plan, learn and reorganise; 3) their proximity to the thresholds of coping, and; 4) their level of interest in adapting to change (Marshall, 2010). Another example is a framework developed by Fernández-Giménez et al (2015) to assess adaptive capacity of Mongolian herders to winter disasters. This framework is comprised of innovation and preparation indices (e.g. a list of preparedness activities such as reserving winter pasture and innovation practices such purchasing breeding stock–goats) as primary indicators of adaptive capacity along with eight intermediary indicators of adaptive capacity identified from the literature (e.g. cognitive social capital in the form of trust and reciprocity and information diversity) (Fernández-Giménez et al., 2015).

Studies using the conceptual framing of adaptive decision-making also used a diverse suite of indicators informed by a range of behavioral and psychological theories. For example, Lubell et al. (2013) used the theory of planned behavior and the diffusion of innovation theory to inform their selection of variables/determinants of adaptive decision-making, while Haigh et al (2021)'s study on ranchers use of drought contingency plans was informed by protective action theory and the theory of implementation. While diverse, these theories, and subsequently the indicators chosen, were often evaluated at the individual-level scale. This contrasts with many of the adaptive capacity studies, which evaluate factors beyond the individual level (i.e. 'structural' factors, such as governance and institutions) that influence adaptation. Methodologically, adaptive decision-making studies often used statistical analysis of survey data where dependent variables were adaptive behaviors (as a proxy for adaptive decision-making) and independent variables were a diverse range of factors hypothesized to influence these behaviors (Haigh et al., 2021; Kachergis et al., 2014; Lubell et al., 2013). Some studies also used qualitative methods such as interviews and participant observation to identify core themes and drivers of the decision-making process for ranchers (e.g. Wilmer et al., 2020; Wilmer & Fernandez-Gimenez, 2015).

Climate adaptation studies also used a wide range of indicators to evaluate adaptation behaviors among ranchers. The theoretical orientation of this scholarship was similarly diverse, from climate vulnerability and resilience (Haigh et al., 2019) to risk management (Coppock, 2011). The most common methodological approach used among the climate adaptation studies was quantitative survey research where researchers employed statistical analyses to understand the relationship between climate adaptation behaviors (dependent variables) and factors thought to influence these behaviors (independent variables). Researchers used a suite of statistical tools, tests, and techniques to understand these relationships, including basic descriptive statistics, directional change tests, principal component analysis (PCA), cluster analysis, and logistic regression. For example, to study drought preparedness among ranchers in Utah, Coppock (2011) used descriptive statistics, directional change tests, and logistic regression to understand what the most influential factors were predicting ranchers' crisis-response tactics during drought and risk-management tactics used for drought preparedness (see Table A2). Similarly, Haigh et al (2019) used statistical analyses to understand what characteristics of Great Plains ranch operations (e.g. number of cattle and calves, percent of income from operation enterprise) predicted drought impacts and drought response actions. (See Table A2 for a list of selected studies and indicators used to evaluate adaptive capacity, adaptive decision-making or climate adaptation in rangeland contexts.)

Implications for policy and practice

An examination of implications for policy and practice across this literature revealed that studies tend to either: 1) provide an assessment that compares regions/communities within a rangeland SES to inform policy focus or resource allocations (e.g. Crimp et al., 2010; Cobon et al., 2009; Wang et al., 2013) or; 2) provide recommendations for policies or programs in response to current adaptation processes (and their determinants) (e.g. King et al., 2018; Lubell et al., 2013; Marshall et al., 2011; Ndiritu, 2021) or as a way to promote future adaptation pathways (e.g. Liao. 2018; Wilmer et al., 2018). For example, falling into the first category was Cobon et al. (2009), a study that employed a "climate change risk management matrix" for the grazing industry of northern Australia to rank and identify the key risk areas, and help prepare risk statements which provide descriptive information that could be useful when advising management and informing policy of risks and vulnerabilities grazing enterprises are faced with. Falling into the second category was Liao (2018), a study highlighting the need for future pastoral policymaking to promoting pathways for large-scale mobility as key to adaptation in the arid and semiarid environment. Or, in Coppock et al. (2011), a U.S. based study, recommendations included the need for policies that would promote higher prices for ranch products, protection of water rights, and encourage more cooperation between ranchers and federal land management agencies during drought. Studies falling into the second category were diverse in terms of their specificity/generalizability of policy recommendations and covered a wide range of policy needs for improved adaptation within rangeland SESs.

Discussion

"Linking the literatures" to capture cross-scale interactions

Adaptation involves both individual agency as well as individual agency that exists within a context of existing structures, governance, and institutions (Cinner et al., 2015; Giddens, 1984; Gupta et al., 2010). To holistically assess adaptation in rangeland SESs, then, there is a need for studies that use methods and indicators that capture cross-scale interactions (Garrick & De Stefano, 2016; Hill & Engle, 2013; Whitney et al., 2017). Yet, the majority of studies reviewed used individual-level indicators (i.e. factors related to 'agency') and lack an examination of the structural factors that enable and constrain adaptation in rangeland SESs. Specifically, adaptive capacity scholarship often recognizes the importance of structural factors for determining the pre-conditions for adaptation, but studies using this concept often favored using index-based approaches where individual and/or household level (i.e. levels of education, access to information, social networks, etc.) indicators were aggregated into an adaptive capacity 'score' or measure (see Table A2). Many of these studies did not use indicators that reflect important — and well-established — factors such as governance, institutions, and collective organization/capitals (Gupta et al., 2010; Vallury et al., 2022). At the same time, the adaptive management and decision-making literatures also tended to lack an examination of the structural factors that influence individual level decisions. In part, this may be a reflection of the predominately social-psychological theories that inform these studies and tend to focus on individual level factors (e.g. Protective Action Theory and Theory of Implementation Intention in Haigh et al., 2021), resulting in variables of interest that are also at the individual level (e.g. aspects of operation/operator characteristics, social values) (see Table A2). Recognizing that there are practical challenges associated with collecting and analyzing data on the wide range of factors influencing adaptation across scales, we argue that there is a need for scholarship that attempts to capture these interactions, particularly regarding factors operating beyond the individual level that influence the options and ability of ranchers and rangeland managers to adapt to change.

The results of our bibliometric analyses suggests that if we want to expand and transform the way we examine and evaluate adaptation in rangeland SESs, greater exchange across scholarly communities (i.e. adaptive capacity and adaptive management scholars) is needed. When we looked at the co-word network (Figure 3.7) and co-citation network (Figure 3.9) for this body of research, we found a lack of connectivity between scholars who employ the concepts of climate adaptation and adaptive capacity with those who use the concept of adaptive decision-making in their work. This shows that while we may *conceptualize* adaptive capacity and adaptive decision-making as related (Figure 3.0 and Figure 3.1), the intellectual communities using these concepts are distinct. The co-word analysis shows two disconnected clusters; 1) studies using the concepts of adaptive management and decision-making and associated keywords (i.e. policy, ranching, public lands, social learning) reflective of applied science and management-oriented disciplines (e.g. range management, rural sociology, public policy) and; 2) scholars using adaptive capacity and climate change adaptation keywords that are more closely associated with strong theoretical disciplines (i.e. resilience, vulnerability, climate change adaptation research). The co-cited journals network also shows that studies tend to either be speaking to fields that publish in more applied, policy and management-oriented journals (e.g. Rangeland Ecology and Management, Regional Environmental Change, Journal of Applied Ecology, Land Use Policy) or to fields that are published in journals that are often broader in scale and scope (e.g. Global Environmental Change, Climatic Change, Society and Natural Resources).

We argue that creating stronger linkages between these scholarly communities might encourage the development of more holistic, cross-scale assessments and lead to new methodological insights related to studying adaptation in rangeland SESs. For example, while Lubell et al. (2013) conceptualize adaptive decision-making as situated within a broader social-ecological context, one could envision more directly measuring the influence of 'external' or 'structural' SES characteristics from adaptive capacity frameworks (e.g. Cinner & Barnes, 2019) such as aspects of governance, regulations or markets that influence individuals decision-making. At the same time, scholars who adopt the 'capitals' approach for understanding adaptive capacity (e.g. Crimp et al (2010), King et al. (2018) Wang et al (2016), see Table A2) might consider looking at the well-established theories of agricultural decision-making (e.g. Theory of Planned behavior or Diffusion of Innovation in Lubell et al. 2013) to develop more nuanced indicators for 'social capital' or 'human capital' that attend to aspects of social values, networks, or operation/operator characteristics known to be influential to adaptation behaviors (Lubell et al., 2013). Integrating the strengths from different approaches to studying adaptation in rangeland SESs at different scales could help move us forward to novel solutions.

A transition toward bridging scholarly communities and moving beyond siloed fields to incorporate knowledge and methods from multiple disciplines will, practically speaking, require substantial support within academic institutions for creating new ways of working. First, there is a need for more effective interdisciplinary training among emerging scholars. Rangeland science needs scholars who are equipped with expertise within their discipline — ecology, animal sciences, economics, sociology, psychology, and so on — and are also provided opportunities to learn about other knowledge systems that will help foster successful and integrative collaborations (Roche, 2021). Second, we suggest that greater intellectual proximity could be facilitated simply through opportunities for closer physical proximity among scholars of different disciplines. Institutions are often designed in ways that quite literally contribute to scholars (and their ideas) remaining in disciplinary "silos" (Goldstein, 2006). Advancing a culture of meaningful collaboration across scholarly communities could be facilitated by innovative changes to campus building design and architecture that facilitates conversations and connections among researchers. Finally, we argue that there is a need for consistent funding that supports collaborative research efforts. Overland and Sovacool (2020) found that, over 30 years of climate change research funding, the natural sciences received ~770% more funding than the social sciences. This highlights a major constraint, given what we know about the critical need to integrate social science in order to understand climate adaptation behavior in rangeland SESs (Briske et al., 2015; Joyce and Marshall, 2017; Roche, 2021).

Addressing 'Gaps on the Map'

Given the critical role that rangelands play in supporting ecosystem services, economic growth and livelihoods for communities across the world (FAO, 2022; Sayre et al., 2012), increasing the geographic reach of research in rangeland SESs is important. Yet, results from this review revealed that there are major "gaps on the map" in terms of where adaptation in rangeland systems is studied. While research is predominately concentrated in just a few parts of the world — namely the US, Australia, and China (Figure 3.6) — there are vast tracts of semi-arid and arid rangeland regions of Africa and South America, among other areas, left understudied. It should be noted that these findings could be partly due to the parameters of our keyword search, in which we used "ranch" and "rangeland" instead of broadening the scope to "pastoralist," "pastoralism," "transhumance," or "livestock producer." Recognizing that potential limitation, our findings point to the importance of broadening the geographic reach of future research efforts, particularly in light of the fact that many of these understudied systems — such as the semi-arid regions on the African continent and in the Middle East — are particularly vulnerable to climate change given their reliance on livestock production for rural livelihoods (Hoffman & Vogel, 2008; Watson et al., 2013). For example, in Iran, rangelands comprise 52% of the countries' total land area and, provide about 67% of the feed requirements for domesticated livestock and are important in sustaining the livelihoods of nearly 16% of rural families (Karimi et al., 2018). Compounded on this reality are other known challenges of coping with the ecological, political, and economic marginality that often exists on rangelands and for those who derive their livelihood from livestock production on them (Cleaver, 2012; Reid et al., 2014; Reynolds et al., 2007; Sayre et al., 2013).

Research in these understudied parts of the world could provide insight on where and how resources might be allocated) to enable place-based and culturally-relevant adaptation that improves social and ecological outcomes. For example, by examining climate adaptation practices among herder families in Iran, Karimi et al. (2018) (a study included in this review) provided recommendations for restructuring traditional livestock production systems and producing information for sustainable management of rangelands. Moreover, just this year, the United Nations (UN) has declared 2026 the International Year of Rangelands and Pastoralists in order to increase investment in and build the adaptive capacity of rangeland and pastoral communities in light of climate change and other pressures (FAO, 2022). Research on adaptation processes in understudied parts of the world could help to identify where investments are made, for whom, and toward what adaptation measures, strategies, and outcomes. For example, another study included in this review by Goldman & Riosmena, (2013) examined adaptive capacity of Massai communities in Northern Tanzania, illuminates how the current institutional landscape has complicated access to resources for the average Maasai herder, how coping techniques (such as mobility and reciprocity) are being modified, and how others, such as purchasing private rights to pasture, are being adopted by some. Goldman & Riosmena, (2013) identify areas for intervention to improve adaptive capacity, such as a focus on strengthening institutional-landscape linkages and address disparities in the distribution of entitlements within communities. While more research in these parts of the world is needed, it is important that researchers reflect on and examine the power mechanisms and structures at play that may shape research and research outcomes. As a recent review on climate change adaptation research by Woroniecki et al., (2019) found, researchers frames of power influence both research outcomes and broader adaptation-power relations, highlighting the need for reflexivity in adaptation research and practice.

From assessment to application: Making research more actionable across scales

While there has been a rapid increase in scientific papers on adaptive capacity and adaptation to climate change in recent years (Berrang-Ford et al., 2011; Vallury et al., 2022), the need for more research on these topics in rangeland SES contexts is as present as ever (Briske et al., 2015; Reid et al., 2021; Roche, 2021). While both science *of* adaptation, and science *for* adaptation are important (Swart et al., 2014), there is a need for scholarship that provides actionable insights that can aid ranchers, policymakers, and other stakeholders in adaptation planning and implementation.

As other scholars have pointed out, conventional disciplinary approaches are insufficiently equipped to deal with the intricately connected and inherently wicked nature of climate change and other SES risks (Roche, 2021; Swart et al., 2014). Transdisciplinary approaches where disciplinary knowledge is exchanged or integrated among scientists (such as adaptive capacity and adaptive decision-making frameworks) is one step in the right direction. However, I suggest that to most effectively address issues related to adaptation in rangeland SESs and connect research to societal needs (i.e. for both policy and practice) today will require more participatory and translational rangeland science approaches, where scientists involve non-scientific stakeholders in the process of co-defining societally relevant questions, co-producing relevant knowledge, and co-learning from the research process (Reid et al, 2021; Roche, 2021).

A few studies in this review provide good examples of research taking a translational approach. First are papers that emerged out of the Collaborative Adaptive Rangeland Management (CARM) project (e.g. Wilmer et al., 2018; Wilmer & Fernandez-Gimenez et al., 2015) which started in 2012 as a large, 10-year, ranch-scale participatory grazing experiment, where the team's goal was to intensively experiment with contrasting grazing practices and then adapt as they learned. From the beginning, the project engaged diverse stakeholders on the research team in co-production of knowledge and evaluation of outcomes that resulted in deep reflection, changing mental models and epistemologies, and learning together (Wilmer et al., 2018, Fernandez-Gimenez et al., 2019). As a result of the project, Wilmer et al. (2018) found that future collaborative adaptive management efforts will benefit from exchange among managers' different experiences and knowledge and from a long-term research in time and funding to social, as well as experimental, processes that promote trust building among stakeholders and researchers over time.

Another example of translational research is a study by Fernández-Giménez et al. (2015), which was part of the MOR2 (Mongolian Rangelands and Resilience) project started in 2008 as a large, 8- year, national-scale project investigating the role of formal community-based natural resource management (CBNRM) in responding and adapting to climate change impacts. The study found that CBNRM herders demonstrated greater adaptive capacity than non-CBNRM herders (due to greater knowledge exchange, information access, linking social capital, and proactive behavior), advancing our understanding of the role of local institutions (specifically donor-initiated CBNRM institutions) in climate adaptation, which has important implications for policy. In this project, the team engaged in yearly meetings with practitioners and government decision-makers at the national level, regional workshops with local and regional decision-makers at the end of the project and evaluation of MOR2 learning opportunities (Reid et al., 2021). The project is exemplary of the inclusion of both Mongolian and American scientists and resulted in deep reflections about the team science conducted by this project (Fernández-Giménez et al., 2019).

These studies show that successful translational research involves designing projects with collaborators and end-users in mind from the very beginning, rather than as an afterthought. In each of these projects, methods emphasized trust-building and an integration of knowledges as scientists worked side-by-side with stakeholders, beginning with ranchers/pastoralists/rangeland managers, to understand their on-the-ground experiences and challenges. Taking this kind of research approach means recognizing that within ranching communities, there is deep, experiential knowledge (and knowledge networks) that are critical to helping inform our understanding of adaptive capacity, decision-making, and climate adaptation on rangelands (Roche 2021). Moreover, these studies demonstrate that, at the heart of translational research approaches is relationship-building in order to identify, define, and solve collective problems.

By embracing translational research approaches, I argue that more meaningful and policy-relevant frameworks and indicators for adaptive capacity, adaptive decision-making will emerge. While this scholarship (particularly adaptive capacity research) has been criticized for lacking consensus on what frameworks and indicators are best for assessment (Siders, 2019), I argue that standardization of evaluation frameworks won't necessarily make research more useful 'on-the-ground.' Rather, there is a need for using translational research approaches to co-produce diverse, place-based, specific indicators or metrics for evaluating adaptation to inform policy and practice. While these approaches may be more "messy," than using an existing frameworks (e.g. Rural Livelihoods Framework, Sustainable Livelihoods Framework), by leaning in to the complexity of decision-making and adaptation contexts of rangeland communities, we will improve the relevance of our science to managers working in real world conditions (Porensky, 2021). In addition, there is a need for more longitudinal and long-term studies that foster science-management partnerships, build trust, and develop our understanding of adaptation over time (Wilmer et al., 2018). As shown in this review, studies that provided policy recommendations were almost entirely single point-in-time assessments, highlighting the there is a need for more research that tracks changes in adaptation capacities, strategies, and processes (capacity, decision-making) based on community experiences, knowledges, and learning over time. While developing more actionable adaptation science will undoubtedly be a challenge, it is a critical time for more “transformative science with society” as Reid et al. (2021) suggest, and it is exciting to think of the new methods, approaches and strategies that might be developed by co-producing research working with rangeland communities.

Conclusion

In this systematic literature review, we used quantitative, qualitative, and bibliometric analyses to document the scope, methods, and findings of studies that examine the social dimensions of adaptation in rangeland SESs. Within the climate adaptation, adaptive capacity, and adaptive decision-making sub-fields, we found that this body of research uses a wide range of frameworks and indicators to evaluate adaptation processes, and that there is a need across these approaches for more policy- and practice- relevant assessments. Bibliometric analyses further revealed that studies employing the concepts of climate adaptation and adaptive capacity tend to emerge out of (and speak to) the resilience and vulnerability scholarship, whereas studies using adaptive decision-making, tend to be embedded within applied science and management-oriented fields. We also found that this body of research is geographically concentrated relative to the vast tracts of globe where rangeland-based livelihoods exist. We argue that there not only a need for more research on adaptation in understudied rangeland SESs, but there is a need for greater integration of knowledge, ideas, and methods across scholarly communities to more effectively evaluate the suite of cross-scale interactions involved in adaptation on rangelands across the globe. Through more collaborative and translational research efforts, new insights on adaptation opportunities and challenges in rangeland SESs might emerge.

References

Adger, W.N. (2006). Vulnerability. *Global Environmental Change, 16*, 268–281.

Adger, W.N., Agrawala, S., Mirza, M.M.Q., Conde, C., O'Brien, K., Pulhin, J., Pulwarty, R., Smit, B., & Takahashi, K. (2007). Assessment of adaptation practices, options, constraints and capacity. In M.L. Parry, O.F. Canziani,J.P. Palutikof,P.J. van der Linden,& C.E. Hanson (Eds*.), Climate change 2007: Impacts, adaptation and vulnerability.* Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, England, pp. 717–743.

Agrawal, A., and N. Perrin. (2009). Climate adaptation, local institutions and rural livelihoods. Pages 350-367 in W. N. Adger, L. Lorenzoni, K. L. O'Brien, editors. Adapting to climate change: thresholds, values, governance. Cambridge University Press, New York, New York, USA. http://dx.doi.org/10.1017/cbo9780511596667.023

Aria, M. and Cuccurullo, C. (2017). bibliometrix: An R-tool for comprehensive science mapping analysis *J. Informetr. 11*, 959–75.

Asner, G. P., Elmore, A. J., Olander, L. P., Martin, R. E., and Harris, A. T. (2004). Grazing systems, ecosystem responses, and global change. *Annu. Rev. Environ. Resour, 29,* 261–299. http://dx.doi.org/10.1146/annurev.energy.29.062403.102142

Berman, R., Quinn, C., & Paavola, J. (2012). The role of institutions in the transformation of coping capacity to sustainable adaptive capacity. *Environmental Development*, *2*, 86–100. https://doi.org/10.1016/j.envdev.2012.03.017

Berrang-Ford, L., Ford, J.D., Paterson, J. (2011). Are we adapting to climate change? *Global Environmental Change 21*, 25–33.

Berrang-Ford L, Pearce T and Ford J D. (2015). Systematic review approaches for climate change adaptation research. *Reg. Environ. Change, 15*, 755–69.

Briske, D. D., Joyce, L. A., Polley, H. W., Brown, J. R., Wolter, K., Morgan, J. A., … Bailey, D. W. (2015). Climate-change adaptation on rangelands: Linking regional exposure with diverse adaptive capacity. *Frontiers in Ecology and the Environment*, *13*(5), 249–256. https://doi.org/10.1890/140266

Carney, D. (2003). Sustainable livelihoods approaches: Progress and possibilities for change. Department for International Development, London.

Cinner, J. E., & Barnes, M. L. (2019). Social dimensions of resilience in social-ecological systems. *One Earth*, *1*, 51–56. https://doi.org/10.1016/j.oneear.2019.08.003

Cinner, J. E., Huchery, C., Hicks, C. C., Daw, T. M., Marshall, N., Wamukota, A., & Allison, E. H. (2015). Changes in adaptive capacity of Kenyan fishing communities. *Nature Climate Change*, *5*(9), 872–876. https://doi.org/10.1038/nclimate2690

Cinner, J. M., Fuentes, B. P., and Randriamahazo, H. (2009). Exploring social resilience in Madagascar's marine protected areas. *Ecology and Society 14*(1), 41–61.

Cleaver, F. (2012). *Development Through Bricolage: Rethinking Institutions for Natural Resource Management.* Abingdon: Routledge.

Cobon, D. H., Stone, G. S., Carter, J. O., Scanlan, J. C., Toombs, N. R., Zhang, X., … McKeon, G. M. (2009). The climate change risk management matrix for the grazing industry of northern Australia. *Rangeland Journal*, *31*(1), 31–49. https://doi.org/10.1071/RJ08069

D. Crane. (1972). *Invisible colleges: Diffusion of knowledge in scientific communities*. University of Chicago Press, Chicago.

Crimp, S. J., Stokes, C. J., Howden, S. M., Moore, A. D., Jacobs, B., Brown, P. R., … Leith, P. (2010). Managing Murray-Darling Basin livestock systems in a variable and changing climate: Challenges and opportunities. *Rangeland Journal*, *32*(3), 293–304. https://doi.org/10.1071/RJ10039

Ellis, F. (2000). *Rural Livelihoods and Diversity in Developing Countries*. Oxford University Press: Oxford.

Engle, N. L. (2011). Adaptive capacity and its assessment. *Global Environmental Change*, *21*(2), 647–656. https://doi.org/10.1016/j.gloenvcha.2011.01.019

FAO. (2022). *UN names 2026 as the International Year of Rangelands and Pastoralists*. Food and Agriculture Organization of the United Nations. https://www.fao.org/newsroom/detail/un-names-2026-as-the-international-year-of-rangelands-and-pastoralists/en

Fang, Y., Qin, D., & Ding, Y. (2011). Frozen soil change and adaptation of animal husbandry: A case of the source regions of Yangtze and Yellow Rivers. *ENVIRONMENTAL SCIENCE & POLICY*, *14*(5), 555–568. https://doi.org/10.1016/j.envsci.2011.03.012

Fernández-Giménez, M. E., Batkhishig, B., Batbuyan, B., & Ulambayar, T. (2015). Lessons from the Dzud: Community-based rangeland management increases the adaptive capacity of Mongolian herders to winter disasters. *World Development*, *68*(1), 48–65. https://doi.org/10.1016/j.worlddev.2014.11.015

Fernández-Giménez, M. E., Augustine, D. J., Porensky, L. M., Wilmer, H., Derner, J. D., Briske, D. D., & Stewart, M. O. (2019). Complexity fosters learning in collaborative adaptive management. *Ecology and Society*, *24*(2). https://doi.org/10.5751/ES-10963-240229

Fernández-Giménez, M. E., A., Allegretti, A., Angerer, J., Baival, B., Batjav, B., et al. (2019a). "Sustaining interdisciplinary collaboration across continents and cultures: lessons from the Mongolian rangelands and resilience project," in Collaboration Across Boundaries for Social-Ecological Systems Science: Experiences Around the World, ed S. Perz (Cham: Palmgrave Macmillan)

Folke, C. (2006). Resilience: The emergence of a perspective for social-ecological systems analyses. *Global Environmental Change, 1*, 253–267.

Fruchterman, T. and Reingold, E. (1991). Graph drawing by force-directed placement Softw. *Pract. Exp., 21*, 1129–64.

Galaty, J.G., Johnson, D.L. (Eds.). (1990). The World of Pastoralism: Herding Systems in Comparative Perspective. The Guilford Press. Retrieved from:< http://www. jstor.org/stable/2563702 >.

Gallopin, G.C. (2006). Linkages between vulnerability, resilience, and adaptive capacity. *Global Environmental Change, 16*(3), 235–316.

Garrick, D. E. and De Stefano, L. (2016). Adaptive capacity in federal rivers: Coordination challenges and institutional responses Curr. *Opin. Environ. Sustain., 21,* 78–85.

Giddens, A. (1984). *The Constitution of Society*. Polity Press, Cambridge

Goldman, M. J., & Riosmena, F. (2013). Adaptive capacity in Tanzanian Maasailand: Changing strategies to cope with drought in fragmented landscapes. *Global Environmental Change – Human and Policy Dimensions, 23*(3), 588–597. https://doi.org/10.1016/j.gloenvcha.2013.02.010

Goldstein, R. N. (2006). Architectural design and the collaborative research environment. *Cell*, *127*(2), 243–246. https://doi.org/10.1016/j.cell.2006.10.007

Gosnell, H., & Travis, W. R. (2005). Ranchland ownership dynamics in the Rocky Mountain West. *Society for Range Management*, *58*(2), 191–198.

Gupta, J., Termeer, C., Klostermann, J., Meijerink, S., van den Brink, M., Jong, P., … Bergsma, E. (2010). The Adaptive Capacity Wheel: A method to assess the inherent characteristics of institutions to enable the adaptive capacity of society. *Environmental Science and Policy*, *13*(6), 459–471. https://doi.org/10.1016/j.envsci.2010.05.006

Habron, G. B. (2004). Adoption of conservation practices by agricultural landowners in three Oregon watersheds. *Journal of Soil and Water Conservation*, *59*(3), 109–115.

Hill M and Engle N L. (2013). Adaptive capacity: Tensions across scales Environ. Policy Gov. 23 177–92

Hoffman, M. T., and C. Vogel. (2008). Climate change impacts on African rangelands. *Rangelands 30*(3), 12–17.

Hruska T, Huntsinger L, Brunson M, et al. (2017). Rangelands as social–ecological systems. In: Briske D, ed. Rangeland Systems . Cham: Springer, 263–302.

Joyce, L. A., & Marshall, N. A. (2017). Managing climate change risks in rangeland systems. In D. D. Briske (Ed.), *Rangeland System: Processes, Management and Challenges,* 491–526. Springer Cham. https://doi.org/10.1007/978-3-319-46709-2_15

Joyce, L. A., Briske, D. D., Brown, J. R., Polley, H. W., McCarl, B. A., & Bailey, D. W. (2013). Climate change and North American rangelands: Assessment of mitigation and adaptation strategies.

Rangeland Ecology and Management, *66*(5), 512–528. https://doi.org/10.2111/REM-D-12-00142.1

Karimi, V., Karami, E., & Keshavarz, M. (2018). Vulnerability and adaptation of livestock producers to climate variability and change. *Rangeland Ecology and Management*, *71*(2), 175–184. https://doi.org/10.1016/j.rama.2017.09.006

Klein, R. (2009). Identifying countries that are particularly vulnerable to the adverse effects of climate change: An academic or a political challenge? *Carbon Clim. Law Rev,. 3,* 284–91.

King, E. G., Unks, R. R., & German, L. (2018). Constraints and capacities for novel livelihood adaptation: Lessons from agricultural adoption in an African dryland pastoralist system. *Regional Environmental Change*, *18*(5), 1403–1410. https://doi.org/10.1007/s10113-017-1270-x

Lien, A. M., Dew, T., Ruyle, G. B., Sherman, N. R., Perozzo, N., Miller, M., & Lopez-Hoffman, L. (2021). Trust is essential to the implementation of adaptive management on public lands. *Rangeland Ecology & Management*, *77*(1), 46–56. https://doi.org/10.1016/j.rama.2021.03.005

Lubell, M. N., Cutts, B. B., Roche, L. M., Hamilton, M., Derner, J. D., Kachergis, E., & Tate, K. W. (2013). Conservation program participation and adaptive rangeland decision-making. *Rangeland Ecology & Management*, *66*, 609–620.

MacQueen, K. M., McLellan, E., Metzger, D. S., Kegeles, S., Strauss, R. P., Scotti, R., Blanchard, L. and Trotter, R. T. (2001). What is community? An evidence-based definition for participatory public health. *Am. J. Public Health, 91,* 1929–38.

Marshall, N. A. (2010). Understanding social resilience to climate variability in primary enterprises and industries. *Global Environmental Change – Human and Policy Dimensions*, *20*(1), 36–43. https://doi.org/10.1016/j.gloenvcha.2009.10.003

Marshall, N. A., Gordon, I. J., & Ash, A. J. (2011). The reluctance of resource-users to adopt seasonal climate forecasts to enhance resilience to climate variability on the rangelands. *Climatic Change*, *107*(3–4), 511–529. https://doi.org/10.1007/s10584-010-9962-y

Marshall, N. A., & Stokes, C. J. (2014a). Influencing adaptation processes on the Australian rangelands for social and ecological resilience. *Ecology and Society*, *19*(2). https://doi.org/10.5751/ES-06440-190214

Marshall, N. A. (2015). Adaptive capacity on the northern Australian rangelands. *Rangeland Journal,*, *37*(18th Biennial Conference of the Australian-Rangeland-Society), 617–622. https://doi.org/10.1071/RJ15054

Marshall, N., & Stokes, C. J. (2014b). Identifying thresholds and barriers to adaptation through measuring climate sensitivity and capacity to change in an Australian primary industry. *Climatic Change*, *126*(3–4), 399–411. https://doi.org/10.1007/s10584-014-1233-x

Marshall, N. A., & Smajgl, A. (2013). Understanding variability in adaptive capacity on rangelands. *Rangeland Ecology and Management*, *66*(1), 88–94. https://doi.org/10.2111/REM-D-11-00176.1

McKeown, C. T., Rubinstein, R. A., and Kelly, J. G. (1987). Chapter 3: Anthropology, the meaning of community and prevention. *Prev. Hum. Serv., 5*, 35–64.

Ndiritu, S. W. (2021). Drought responses and adaptation strategies to climate change by pastoralists in the semi-arid area, Laikipia County, Kenya. *Mitigation and Adaptation Strategies for Global Change*, *26*(3). https://doi.org/10.1007/s11027-021-09949-2

Nelson, R., Kokic, P., Crimp, S., Meinke, H., & Howden, S. M. (2010). The vulnerability of Australian rural communities to climate variability and change: Part I-Conceptualising and measuring vulnerability. *Environmental Science and Policy*, *13*(1), 8–17. https://doi.org/10.1016/j.envsci.2009.09.006

Nelson, R., Kokic, P., Crimp, S., Martin, P., Meinke, H., Howden, S. M., … Nidumolu, U. (2010). The vulnerability of Australian rural communities to climate variability and change: Part II-Integrating impacts with adaptive capacity. *Environmental Science and Policy*, *13*(1), 18–27. https://doi.org/10.1016/j.envsci.2009.09.007

Ng'ang'a, T. W., Coulibaly, J. Y., Crane, T. A., Gachene, C. K., & Kironchi, G. (2020). Propensity to adapt to climate change: Insights from pastoralist and agro-pastoralist households of Laikipia County, Kenya. *Climatic Change*, *161*(3), 393–413. https://doi.org/10.1007/s10584-020-02696-4

Overland, I., Sovacool, B.K. (2020). The misallocation of climate research funding. *Energy Res Soc Sci., 62.* https://doi.org/10.1016/j.erss. 2019.101349

Polley, H. W., D. D. Briske, J. A. Morgan, K. Wolter, D. Bailey, and J. R. Brown. (2013). Climate change and North American rangelands: Trends, projections, and implications. *Rangeland Ecology and Management, 66,* 493–511.

Porensky, L.M. (2021). Embracing complexity & humility in rangeland science. *Rangelands.* In Press. https://doi.org/10.1016/j.rala.2021.03. 007

Pullin, A.S. and Stewart, G.B. (2006). Guidelines for systematic review in conservation and environmental management. *Conserv. Biol., 20*, 1647–56.

R Core Team. (2016). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org

Reid, R. S., Fernández-Giménez, M. E., and Galvin, K. A. (2014). Dynamics and resilience of rangelands and pastoral peoples around the globe. *Annu. Rev. Environ. Resour. 39*, 217–242. https://doi.org/10.1146/annurev-environ-020713-163329

Reid, R. S., Fernandez-Gimenez, M. E., Wilmer, H., Pickering, T., Kassam, K.-A. S., Yasin, A., … Knapp, C. N. (2021). Using research to support transformative impacts on complex, "wicked problems" with pastoral peoples in rangelands. *Frontiers in Sustainable Food Systems, 4*. https://doi.org/10.3389/fsufs.2020.600689

Reynolds, J. F., Smith, D. M., Lambin, E. F., Turner, B. L., 2nd, Mortimore, M., Batterbury, S. P., et al. (2007). Global desertification: Building a science for dryland development. *Science, 316*, 847–851. https://doi.org/10.1126/science.1131634

Roche, L. M. (2016). Adaptive rangeland decision-making and coping with drought. *Sustainability (Switzerland)*, *8*(12). https://doi.org/10.3390/su8121334

Roche, L. M. (2021). Grand challenges and transformative solutions for rangeland social-ecological systems – emphasizing the human dimensions. *Rangelands*, 1–8. https://doi.org/10.1016/j.rala.2021.03.006

Roche, L. M., Schohr, T. K., Derner, J. D., Lubell, M. N., Cutts, B. B., Kachergis, E., … Tate, K. W. (2015). Sustaining working rangelands: insights from rancher decision making. *Rangeland Ecology and Management*, *68*(5), 383–389. https://doi.org/10.1016/j.rama.2015.07.006

Rousseau, D.M. (Ed.) (2012). *The Oxford handbook of evidence-based management.* Oxford University Press.

Sayre, N. F., Carlisle, L., Huntsinger, L., Fisher, G., & Shattuck, A. (2012). The role of rangelands in diversified farming systems: Innovations, obstacles, and opportunities in the USA. *Ecology and Society*, *17*(4). https://doi.org/10.5751/ES-04790-170443

Sayre, N. F., Mcallister, R. R. J., Bestelmeyer, B. T., Moritz, M., and Turner, M. D. (2013). Earth stewardship of rangelands: Coping with ecological, economic, and political marginality. *Front. Ecol. Environ. 11*, 348–354. https://doi.org/10.1890/120333

Shaw, E., & Witt, G. B. (2015). Climate change and adaptive capacity in the Western Australian rangelands: A review of current institutional responses. *Rangeland Journal*, *37*(4), 331–344. https://doi.org/10.1071/RJ15015

Shrum, T. R., Travis, W. R., Williams, T. M., & Lih, E. (2018). Managing climate risks on the ranch with limited drought information. *Climate Risk Management*, *20* (February), 11–26. https://doi.org/10.1016/j.crm.2018.01.002

Siders, A. R. (2019). Adaptive capacity to climate change: A synthesis of concepts, methods, and findings in a fragmented field. *Wiley Interdisciplinary Reviews: Climate Change*, *10*(3), 1–18. https://doi.org/10.1002/wcc.573

Small, H. (1973). Co-citation in the scientific literature: A new measure of the relationship between two documents J. *Am. Soc. Inf. Sci. 24,* 265–9.

Smit, B., and J. Wandel. (2006). Adaptation, adaptive capacity and vulnerability. *Global Environmental Change, 16*(3), 282-292. http:// dx.doi.org/10.1016/j.gloenvcha.2006.03.008

Society for Range Management. (2022). SRM policy statements: Rangeland and range resources. http://rangelands.org/about/policy-statements/

Swart, R., Biesbroek, R., & Lourenço, T. C. (2014). Science of adaptation to climate change and science for adaptation. *Frontiers in Environmental Science*, *2*(Jul), 1–8. https://doi.org/10.3389/fenvs.2014.00029

Tan, S., Li, T., & Huntsinger, L. (2018). Analyzing herder adaptive capacity to climate change: a case study from an ecologically fragile area in Inner Mongolia, People's Republic of China. *Human Ecology*, *46*(3), 399–409. https://doi.org/10.1007/s10745-018-9991-0

Traag, V. A., Waltman, L. and Van Eck, N. J. (2019). From Louvain to Leiden: Guaranteeing well-connected communities. *Sci. Rep. 9,* 1–12.

Vallury, S., Smith, A. P., Chaffin, B. C., Nesbitt, H. K., Lohani, S., Gulab, S., … Allen, C. R. (2022). Adaptive capacity beyond the household: A systematic review of empirical social-ecological research. *Environmental Research Letters*, *17*(6), 063001. https://doi.org/10.1088/1748-9326/ac68fb

Watson, J. E. M., Iwamura, T., & Butt, N. (2013). Mapping vulnerability and conservation adaptation strategies under climate change. *Nature Climate Change*, *3*(11), 989–994. https://doi.org/10.1038/nclimate2007

Wilmer, H., Derner, J. D., Fernández-Giménez, M. E., Briske, D. D., Augustine, D. J., & Porensky, L. M. (2018). Collaborative adaptive rangeland management fosters management-science partnerships. *Rangeland Ecology and Management*, *71*(5), 646–657. https://doi.org/10.1016/j.rama.2017.07.008

Wilmer, H.; York, E.; Kelley, W.K.; Brunson, M.W. (2016). "In every rancher's mind": Effects of drought on ranch planning and practice. *Rangelands, 38*, 216–221.

Wilmer, H., & Fernández-Giménez, M. E. (2015). Rethinking rancher decision-making: A grounded theory of ranching approaches to drought and succession management. *Rangeland Journal*, *37*(5), 517–528. https://doi.org/10.1071/RJ15017

Wilmer, H., & Sturrock, J. (2020). "Humbled by nature": A Rancher's mental model of adaptation in the great plains. *Great Plains Research*, *30*(1), 15–33. https://doi.org/10.1353/gpr.2020.0001

Woroniecki, S., Krüger, R., Rau, A. L., Preuss, M. S., Baumgartner, N., Raggers, S., … Abson, D. (2019). The framing of power in climate change adaptation research. *Wiley Interdisciplinary Reviews: Climate Change*, *10*(6), 1–21. https://doi.org/10.1002/wcc.617

Zhao, D. and Strotmann, A. (2015). Analysis and visualization of citation networks. *Synth. Lect. Inf. Concepts Retr. Serv. 7,* 1–207.

Chapter 4: A revised adaptive decision-making framework for rangeland management

Abstract

Rangelands across the world are facing rapid and unprecedented social and ecological change. In the U.S. 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 partially 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 are hierarchical with monitoring and the use of information being the strongest predictors 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 that 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.

Introduction

Rangelands cover approximately 50% of the world's terrestrial surface (Lund, 2007) and make up the most extensive class of lands in the U.S. West (Sayre et al., 2012; USFS 2012), of which grazing is a primary use (Nickerson et al. 2011; USDA-NRCS 2007). Today, ranchers and rangeland managers in the U.S. 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 (Briske et al., 2015; Cook et al., 2015; Kuwayama et al., 2019; Sayre et al., 2013). In the U.S. 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 & Augustine, 2016; Kuwayama et al., 2019; Roche, 2016). Socially, ranch operations must respond and adapt to changing markets, the pressure of shifting land uses across the West (Gosnell & Travis 2005), and changes in ranch ownership and generational turnover (Hinrichs & Welsh 2003; Hoppe & Banker 2010). Sustaining rangelands, ranch livelihoods, and the suite of suite of ecosystem goods (e.g., livestock production) and services (e.g., wildlife habitat, plant diversity, watershed function) they provide hinges not only on understanding the ecological processes at play, but also a greater understanding of the social processes within these changing systems (Briske et al. 2011; Sayre, 2004).

Adaptive management has been well-established as an effective and necessary means for managing rangeland social-ecological systems in light of change (Derner et al. 2022; McCord & Pilliod, 2022; Stafford Smith, 1996). In the U.S. 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 non-linear 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 & Fernandez-Gimenez, 2009; Roche et al., 2015; Sorice et al., 2012; Wilmer & Fernández-Giménez, 2015; Wilmer & Sturrock, 2020) while, at the same, 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 U.S. 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 adaptive decision-making process, specifically in response to drought and climate related events. Our research objectives were: (1) to test the relationships among factors (e.g. operation/operator characteristics, management goals, information sources, practices) known to drive rancher decision-making at a generalizable scale in the Montana SES context; (2) to identify and quantitatively describe any new or distinct variables contributing to ranchers decision-making process. 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 SESs 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 et al., 2022; Derner & Augustine, 2016; McCord & Pilliod, 2022). Adaptive management of rangelands involves complex and adaptive decision-making across scales; ranchers are tasked with making numerous decisions in order to balance short-term and long-term management priorities as well as local and landscape-level priorities. Adaptive decision-making, then, we define as an individual, social-psychological process which involves iterative learning from experience, observation, and information to effectively respond to and improve outcomes in light of social and ecological change (Derner et al., 2022; McCord & Pilliod, 2022; Lubell et al., 2013; Roche et al., 2015; Wilmer et al., 2015).

As the impacts of climate change manifest in the U.S. West, ranchers make a wide range of adaptive decisions to achieve their management goals while improving rangeland ecosystems and reducing economic risk for their ranching operation. 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 (Haigh et al., 2021; Joyce et al., 2013; Joyce & Marshall, 2017; Sayre et al., 2012; Yung et al., 2015). 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 & Augustine, 2016). While the body of literature on adaptive management has grown rapidly in recent decades, it is also widely recognized that ranchers, especially mutigenerational 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; Wilmer et al. 2016; Yung et al., 2015).

Social scientists have taken various approaches to examining adaptive decision-making in response to social and ecological change. Notably, Lubell et al.'s (2013) adaptive decision-making for rangeland management framework (Figure 4.0), which we build on in this study, 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)'s study tested these proposed variables as they related to rancher decisions to participate in conservation programs. Lubell et al. (2013) estimated the impact of these variables on participation in conservation programs and found that access to conservation information sources were the most significant variable predicting program participation. Their findings also suggest that ranchers with larger amounts of land, an orientation towards the future, and who are opinion leaders are 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) in to their systems-level framework, Lubell et al. (2013) provided a foundational conceptualization of how ranchers individual psychology interacts simultaneously within a social-ecological system. This framework has served as a helpful guide for numerous subsequent studies on adaptive decision-making among ranchers (e.g. Munden-Dixon et al., 2019; Roche, 2016; Roche et al., 2015; Wilmer et al., 2018).

Research on rancher decision-making in the U.S. West has examined a suite of other ranch/rancher characteristics that best predict the use of specific conservation or production-related practices or programs (Didier & Brunson, 2004; Haigh et al., 2021; Haigh et al., 2019; Kennedy & Brunson 2007; Kreuter et al., 2001; Roche et al., 2015). Characteristics predicting adoption of conservation and adaptation-related practices, such as size of ranch, dependence on ranch 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, have been well-described (Didier & Brunson 2004; Greiner et al., 2009; Kelley, 2010; Kennedy & Brunson 2007; Kreuter et al., 2001; Lubell & Fulton, 2007; Marshall & Smajl, 2013). For instance, building on Lubell et al. (2013)'s 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 act to enhance individual drought adaptation (Roche, 2016). In a study on the adoption of drought contingency plans, Haigh et al. (2021) found that larger ranch operations are 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 between 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 data and information about rangeland resource condition and change across scales to support decision-making (Herrick et al., 2006; McCord & 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 (Germino et al., 2022; McCord & Pilliod; Stephenson et al, 2017). 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 as a basis to adapt and improve outcomes (Derner et al., 2022; Derner and Augustine, 2016; McCord & 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 as a way to facilitate faster development of local environmental knowledge when traditional experiential learning modes cannot always keep up (Mccollum et al., 2017; Lynam & Smith, 2004). However, while rangeland monitoring has long been central to the theory and practice of adaptive management, how monitoring influences adaptive management practices and contributes to improved social and ecological outcomes is limited.

As the management objectives across public and private rangelands in the U.S. have become more diverse, the technologies, methods, and indicators used by the rangeland community have also expanded (McCord & 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 U.S. West (Booth and Tueller, 2003; Jones et al., 2018; McCord & Pilliod, 2022; Newingham et al., 2022. There have been efforts to standardize monitoring methods in order to enable opportunities for aggregating data to understand larger scale (i.e. regional) conditions and change across land ownerships (i.e. public and private) while also creating cohesiveness and shared understandings among those doing the monitoring (Kachergis et al., 2021; Toevs et al., 2011). 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 in local research studies (Herrick et al., 2017; Herrick et al., 2018; Toevs et al., 2011). In addition, 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, formal monitoring is it is often weak or missing in practice and designing useful management-relevant monitoring systems has remained a challenge (Newingham et al., 2022; Sayre et al. 2013). 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 & Holling 1990 in 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 is on adaptive decision-making — which, compared to technical issues and advancements, have received relatively little scholarly attention.

Research Questions

While 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 management among ranchers, their combined effects on the adoption of adaptive practices among ranchers using generalizable social science research has 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 Lubell et al. (2013)'s theory 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 between 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? 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.

Based on this hypothesis, we predicted the following (Figure 4.0):

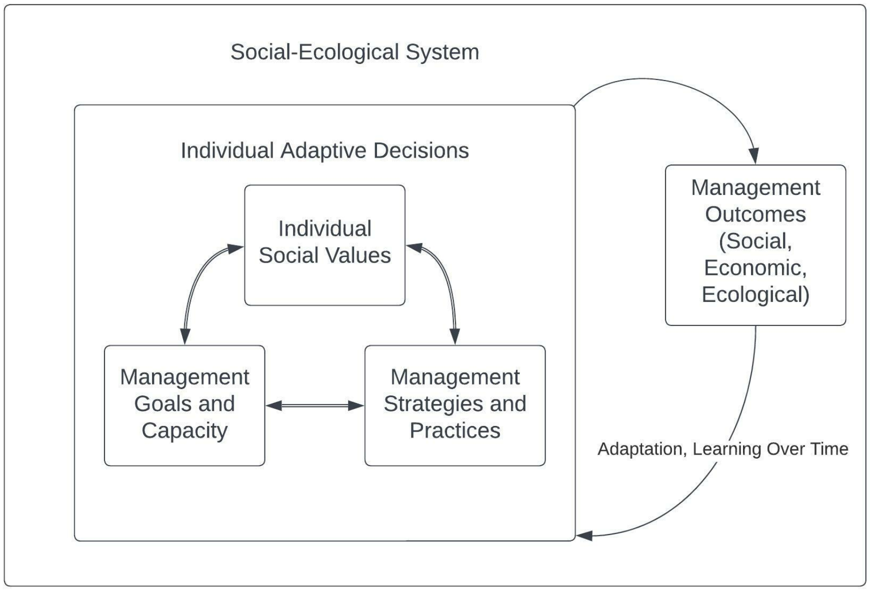
Prediction 1 (P_1): Management goals and information sources will have a significant positive effect on the use of adaptive practices

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 partially 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 predicted 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 predicted that without the use of monitoring to gather data about rangeland resources, ranchers would be less likely to engage in adaptive management practices. We predicted the greatest use of adaptive management practices only 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.



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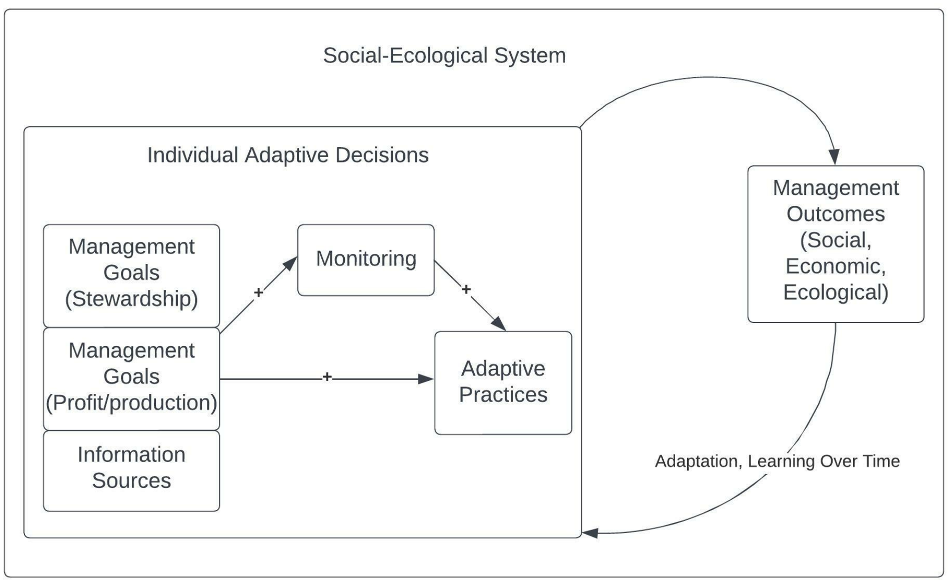


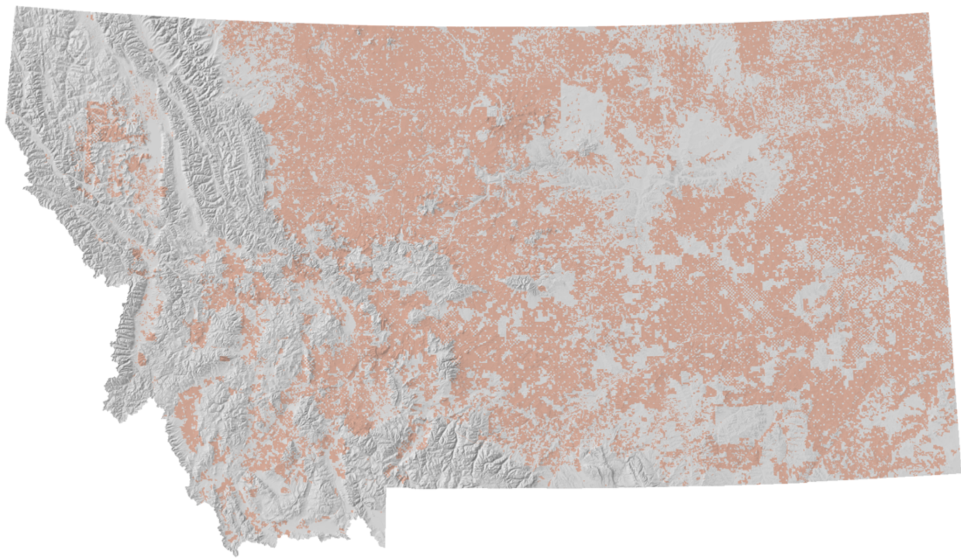
(b)

Figure 4.0. (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 in this study, including the hypothesized relationships between management goals (stewardship and profit/production), 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 (of the State's 94 million acres total) are pasture and rangelands, used primarily for livestock grazing for native rangeland beef cattle cow-calf operations (USDA Census of Ag, 2017). Socio-economically, livestock production is a key agricultural industry in Montana. Regarding the market value of agricultural product sold, cattle and calves alone ($1,715,741,000) exceed 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 (i.e. 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, is public land (MT FWP, 2022). Interestingly, while public rangelands in the U.S. 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 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 U.S. 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 years 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 six months of 2022 (DNRC, 2022). According to the Montana Climate Assessment, 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 mid-century, 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 U.S. for understanding how ranchers, who both use and steward Montana's land and water resources, are making adaptive decisions toward positive social-ecological outcomes.



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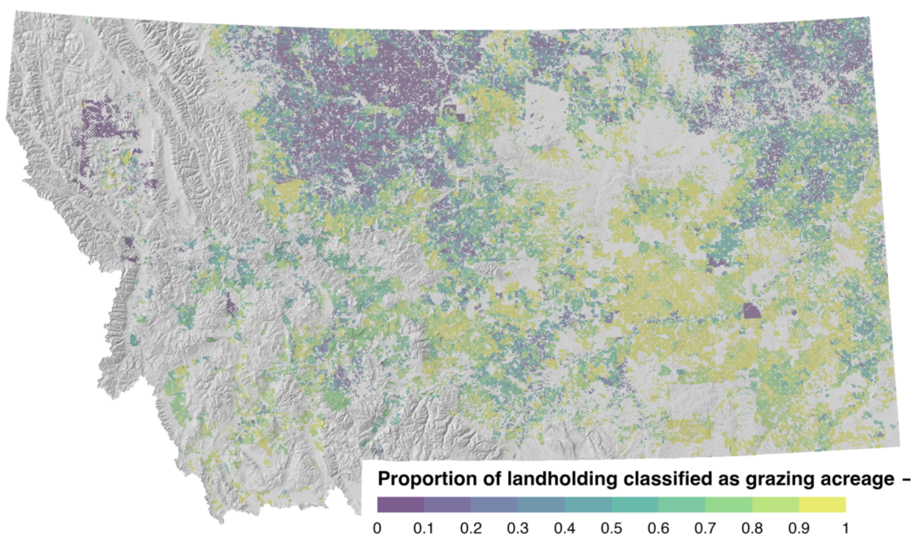


(b)

Figure 4.1. (a) Map showing the distribution of private landholdings of agricultural producers in Montana identified using the FLU, Montana Cadastral, NASS, and MT Landcover datasets. (b) Map showing the proportion of private landholdings in Montana classified as grazing acreage.

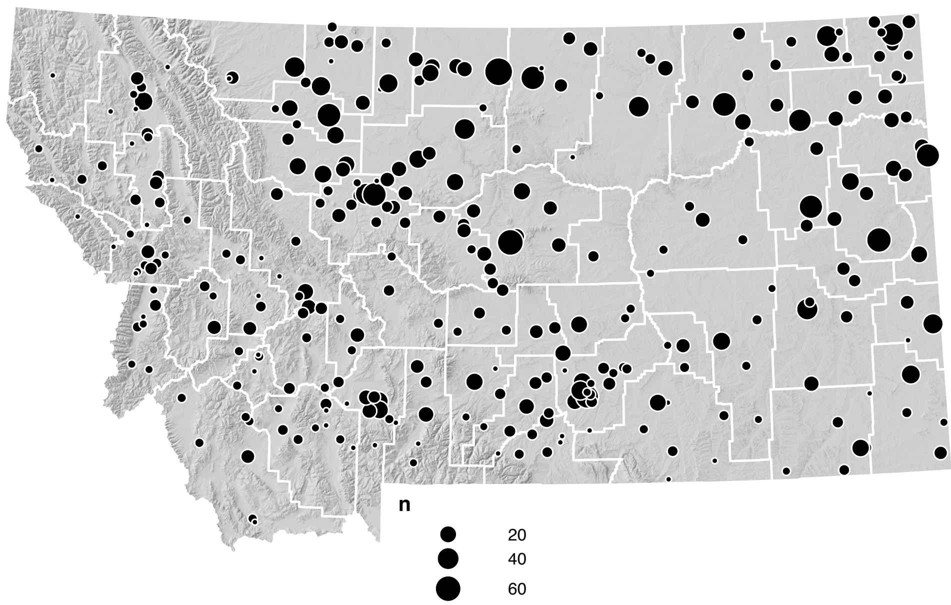


Figure 4.2. Distribution of MTDC survey sample (n=2,999) across Montana counties*.*

Methods

Sampling

Data were obtained for this study using a survey of randomly selected agricultural producers in Montana. This survey was conducted as part of Montana Drought and Climate (MTDC) project, a USDA-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.

For both MTDC and this study, identifying the population of agricultural producers in Montana and drawing our sample for this study followed a five-step process. The analysis to determine a candidate pool of producers used the following three datasets:

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

These datasets are available from the Montana State Library as part of the Montana Spatial Data Infrastructure (http://geoinfo.msl.mt.gov/msdi.aspx).

In Step 1, we standardized owner addresses in the Montana Cadastral (parcel ownership) dataset. By using the Montana Cadastral dataset, we treated landowners who received their tax bills at the same address as the same, recognizing that there are in many cases multiple people living at each address. From this dataset, we retained only the landuse acreage, owner, and address columns. We also standardized owner addresses; for instance, we removed the last four digits of nine-digit zip codes, and we attempted to standardize idiosyncratically-applied street naming conventions, such as abbreviations of 'highway' (hwy') and 'route' (rte). The Montana Cadastral dataset from January, 2018 contains 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 taking the spatial union of owner parcels. In other words, if addresses were the same they collapsed into one landowner with summed landuse acreage. Grouping parcels by owner addresses (street number, street, city, state, and zip) 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. Unfortunately, at the time of this writing, the UPS Address Validation service is no longer available for bulk address validation in the way we used it. Other services, such as those provided by the US Postal Service, may be useful for validating addresses for research purposes in the future.

In Step 3, we identified the agricultural acreage for each landowner. We produced two estimates for the agricultural acreage of each landholding using the 2017 FLU and MT Landcover datasets. For the FLU data, we selected all regions not categorized as "T — forest land", "N — non-commercial forest land", "X — other commercial non-agricultural 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 bein under cultivation (cropland). In Step 4, we applied final inclusion and exclusion criteria to identify working agricultural lands. First, we excluded parcels whose owners listed mailing addresses outside of the state of Montana in the Cadastral database. 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 non-profit landholders such as the Nature Conservancy and the American Prairie Foundation. This further reduced the count of landowners to 292,470. Finally, in order to filter out "amenity" owners (i.e. those who own large parcels taxed as agricultural land but are 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 to be included in the final population. Landowners had to meet at least one of the following criteria:

3) At least 1000 acres identified as FLU agricultural land and at least 50 acres classified as being under cultivation per the Montana Landcover dataset. This proxies ranch operations with a minimal amount of cultivated land for hay/feed.
4) At least 160 acres classified as being under cultivation per the Montana Landcover dataset. This proxies other agricultural producers.

Figure 4.1 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. By examining this map, we were able to visually see where we might expect our sample of agricultural producers to be located in the state. The criteria we applied resulted in the final eligible population of 11,155 agricultural producers from which our sample was drawn.

In Step 5, we used a stratified, random sampling method to draw our final 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 percent (Dillman et al., 2014). Figure 4.2 shows the geographic distribution of MTDC survey sample across Montana counties.

Survey development & dissemination

The survey was disseminated in the spring of 2021 using a Dillman Tailored Design Method to encourage maximum participation from survey respondents. First, all potential respondents received a pre-survey letter informing them that a questionnaire would arrive soon and asking for participation. Second, all potential respondents received a packet containing a cover letter, a hardcopy questionnaire and a pre-stamped return envelope. Third, all nonrespondents received a second packet containing a cover, a hardcopy questionnaire and a pre-stamped return envelope. Fourth, all nonrespondents received a third packet containing a cover letter, a hardcopy questionnaire and a pre-stamped return envelope (Dillman et al. 2014). Research questions and methods were approved by the University of Montana Institutional Review Board prior to survey administration.

In order to understand factors related to adaptive decision-making among ranchers, we asked survey respondents about a number of features related to their own characteristics and features of their operation, replicating previous authors' measures where possible and employing new measures developed from adaptive decision-making literature where existing measures were unavailable or inapplicable (see Table 2.0 in Methods section for all measures).

Management goals were measured with fourteen items reflecting potential management goals (see Table 2.0 in full Methods section) and asked them to rank the importance of each goal on a 1–5 scale from "Very unimportant" to "Extremely important." To identify the "Stewardship" and "Profit/Production" dimensionalities of the fourteen items (Table 4.0) we conducted an exploratory factor analysis on with varimax rotation and then conducted reliability analyses to determine if the scaled items were reliably measuring the same construct (Cronbach alpha >0.7) (Cronbach 1951).

To measure use of various information among ranchers, we provided respondents with a list of 29 information resources adapted to fit our specific study area and context and asked respondents to indicate if they use each source to make management decisions where 0= No and 1= Yes. For this study, composite scores were calculated as the sum of just the top 10 most used information sources (see Table 4.0).

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 in light of drought/climate events (Table 2.0 in Methods section). 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 that they used the practice from the options of "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 ("less than 3 years," "more than 3 years," or "experimenting"). For this study, we re-coded 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.

Monitoring was included in the list of management practices we asked about in the survey and initially conceptualized as a response variable. We asked respondents to indicate whether they "Established soil and vegetation/range monitoring program to track and respond to change." For this variable, we also re-coded responses to yes/no where 0= No, and 1= Yes.

Data from questionnaires were codified and entered using appropriate data labels and flags to facilitate analysis. Spot checks on data entry were performed to ensure accuracy. 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), nonresponse (nonresponse weight), and calibrates the weights to population totals (Battaglia, et al., 2016; Haziza & Beaumont, 2017; Haziza & Lesage, 2016; Lavallee & Beaumont, 2016; Valliant, Dever, & Kreuter, 2013). 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 help to ensure that the survey is representative of the study population. Weights for the survey were calculated using a three-step process that is also widely accepted in survey research literature (Battaglia, et al., 2016; Haziza & Beaumont, 2017; Haziza & Lesage, 2016; Lavallee & Beaumont, 2016; Valliant, Dever, & Kreuter, 2013). In step one, 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 two, the base weight was modified to adjust for nonresponse (Battaglia, et al., 2016; Brick, 2013; Haziza & Lesage, 2016; Kreuter & Olson, 2013; Olson, 2013; Valliant, Dever, & Kreuter, 2013). In step three, the nonresponse-adjusted weight was calibrated to sampling control totals derived from the number of farms or ranches in each sampling strata (Haziza & Beaumont, 2017; Kalton & Flores-Cervantes, 2003; Lavallee & Beaumont, 2016; Valliant, Dever, & Kreuter, 2013; Sarndal, 2007). Survey weight calibration was conducted using the Gest_Calibration module of Generalized Estimation System version 2.003 (January 2019) developed by Statistics Canada.

Data were analyzed using three statistical software packages: IBM SPSS Statistics Version 28 (2021), SAS Version 9.5 (2021) and Statistics Canada's G-EST Version 2.03 (2019). Basic descriptive statistics, linear regression, and path model analysis were used to analyze the responses. Specifically, after conducting exploratory analysis on the relationship between all hypothesized explanatory and response variables and referencing existing scholarship on monitoring for rangeland decision-making, we decided to look further into whether monitoring had a mediating effect. Simply defined, mediation is an extension of simple linear regression in that it adds one or more variables to the regression equation where mediating variables act as "mechanism through which X [explanatory variable] influences Y [response variable]" (Abu-Bader & Jones, 2021; Hayes, 2013).

To determine whether monitoring partially or fully mediated the relationship between 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 (Figure 4.0). We used a p-value of 0.05 to determine significance (Baron & Kenny 1986; Vaske 2008). We used the Sobel (1982) test for indirect mediation effects to confirm the indirect effect of explanatory variables on adaptive practices via the mediator, monitoring (Abu-Bader & 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 2588 eligible addresses. We received 706 useable surveys, an American Association of Public Opinion Research Response Rate 3 (AAPOR RR3) of 36.7%. Among the survey respondents, 450 self-identified as ranchers or both ranchers and farmers and were included in this study. Table 4.0 shows item wording, mean scores with standard deviations, and Cronbach alpha scores for composite variables. Cronbach alpha scores for management goals composite variables were well above the 0.65 cut-off (Vaske 2008) and right at the cut-off for adaptive practices.

Mean age of respondents age was 66 (n = 430), and the majority were male (77.4%; n = 437). Regarding formal education, 10% (n= 47) reported having a professional degree (MS, DDS, DVM, LLB, JD, DD) or beyond (doctorate), 43.7% (n= 191) reported having an Associate or Bachelor's degree, and 46.3% (194) reported having high school/GED equivalent or below. The majority of respondents come from families with three or more generations in ranching (M= 3.57 generations, n = 447). Over 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 in progress. Respondents also relied on ranching as a critical source of income – on average, 73.3% (n= 426) of respondents' total household income comes from their ranching operation.

Respondents tended to operate mostly on land that they own (M= 76.9% of acres owned, n= 434), but private leases (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 made up significant portions of ranchers operations. Consistent with production across Montana, ranchers in our sample indicated they operate on predominately non-irrigated 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 many other types of operations were represented as secondary or primary enterprises. Just under fifteen percent (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 also indicated that they grow crops, with the majority (84.2%, n= 384) reporting that they grow hay, 41.2% (n= 183) grow wheat, 37.3% (n= 162) grow barley, and 16.9% (n= 71) grow pulses (e.g. beans, peas, lentils), 17.3% (n= 71) grow oats. All other types of crops/products we asked about (i.e. buckwheat, corn (for grain or silage), sugar beets, fall potatoes, oil seeds, mixed vegetable/market farm) represented less than 10% of the sample. See Table A1 for all descriptive statistics.

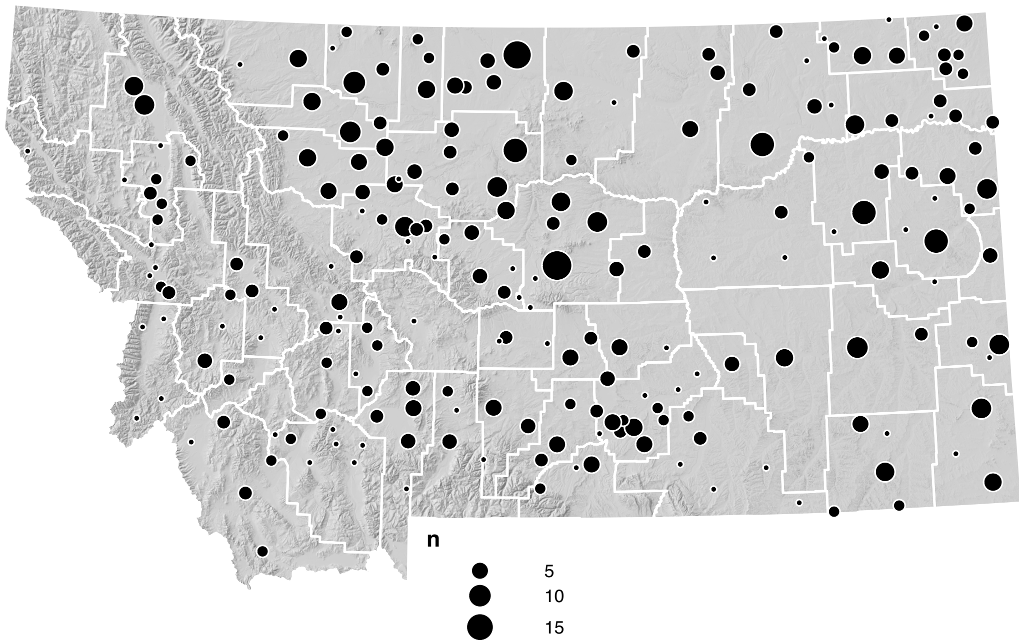


Figure 4.3. Distribution of Montana Drought and Climate survey respondents (n= 706) across Montana counties.

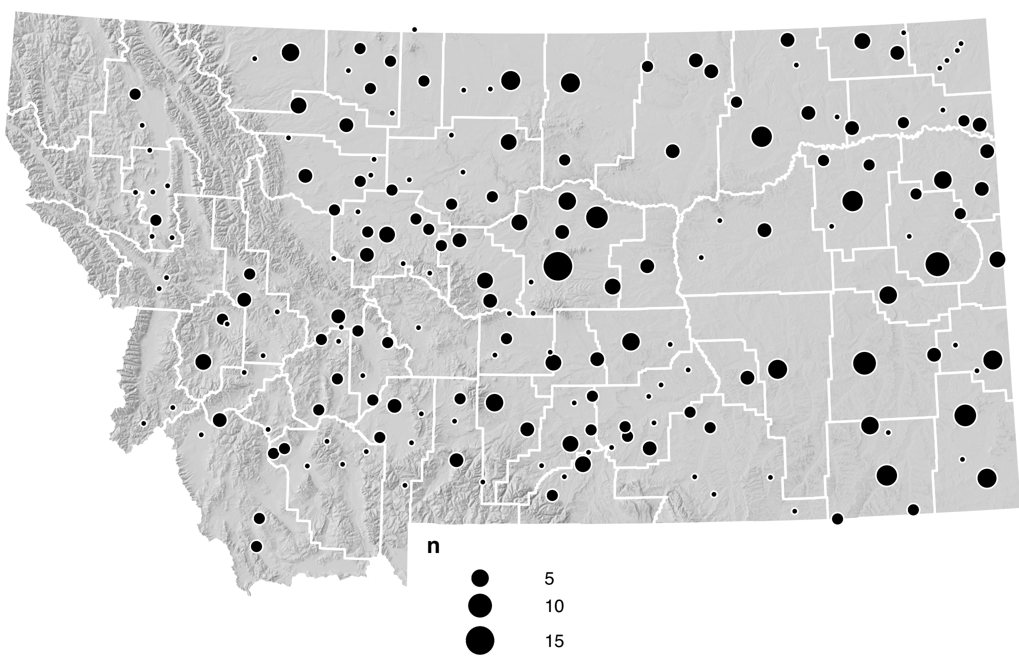


Figure 4.4. Distribution of Montana Drought and Climate survey respondents who are ranchers (n= 450) across Montana counties.

Management goals and information sources

Respondents' management goals fell into two observable categories: 1) agricultural/livestock production goals and; 2) land stewardship and conservation-related goals (see Table 4.0). Management goals related to lifestyle, the continuation of family traditions, and to help maintain the vitality of rural Montana were deemed important to ranchers, but did not emerge as 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 (A1 for complete survey summary statistics).

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 respondents. Following those primary sources of information, ranchers indicated that they use 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 fewer than 25% of respondents.

Monitoring and adaptive management practices

Survey respondents (n=450) used a variety of practices to achieve their goals (see A1 for full list of management practices and summary statistics). Adaptive livestock and grazing management practices used by the majority of ranchers were timing grazing for improved pastures (80.6%, n= 366), using strategic placement of water for livestock and better forage utilization (infrastructure upgrades, piping systems, water tanks) (76.6%, n= 346), and have a drought plan (e.g., reduce stocking rates, lease pasture, use additional hay) (74.3%, n= 337). Following those practices, over half of respondents also 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 just under half of respondents established riparian buffers (41.8%, n= 181). Finally, 42.9% (n=193) of ranchers reported that they have established a soil and vegetation/range monitoring program to track and respond to change.

Table 4.0. Item means, standard deviations, factor loadings, and Cronbach α for all variables.

Variables [a]	**Mean Estimate (SE)**	**Cronbach α**	**n**	**Nested Items**	**Factor loading** [b]	**Mean Estimate (SE)**	**n**
Management Goals (Stewardship)[b]	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
Monitoring [c]	0.47 (.029)		417	Established soil and vegetation/range monitoring program to track and respond to change		
Adaptive Practices [c]	4.53 (.110)	0.648	439	Intensive rotational grazing	.59 (.029)	400
				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

[a] Item wordings are presented here verbatim.

[b] Factor loadings on Management Goals (Stewardship) and Management Goals (Profit/production) components extracted using principal component analysis with Varimax rotation and Kaiser normalization.

[b] 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.

[c] 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.

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 4.1).

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 (β= .360, $p < .001$; β= .372 $p < .001$). When information sources and monitoring were both included in the model, both variables had a significant, positive effect on adaptive practices (β= .215, $p < .001$; β= .319, $p < .001$)(Figure 4.5).

We used the Sobel test to further examine the indirect effect of the explanatory variables on adaptive practices when the mediator variable (M) is included in the model. The Sobel test examines whether the inclusion of a mediator (M) in the regression analysis considerably reduces the effect of the independent variable (X) on the dependent variable (Y). If a significant test statistic results, then there is evidence of total or partial mediation by the mediator variable (Abu-Bader & Jones, 2021). The Sobel test results showed that the indirect effect of the management goals (MGS and MGP) variables on adaptive practices was just barely significant (in other words, statistically different than 0) (z= 2.59492049, p < 01; z= 2.44985556, $p < .05$) while the indirect effect of information sources was significant (z = 4.38316209, $p < .001$) (Table 4.2). 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 (Figure 4.5, Table 4.1, Table 4.2). No covariates were significantly related to use of adaptive practices; we excluded these variables from the final models.

These results provided evidence that there is a hierarchical relationship among the variables driving 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 driving their decision-making.

Table 4.1. Path Analysis Results

Regression Model	n	R^2 (adj)	F	Unstandardized Coefficients - β (SE)	Standardized path coefficients	ρ-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

Table 4.2. Sobel Test Results

Model	A	SE_A	B	SE_B	Sobel test statistic (z)	SE	ρ-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

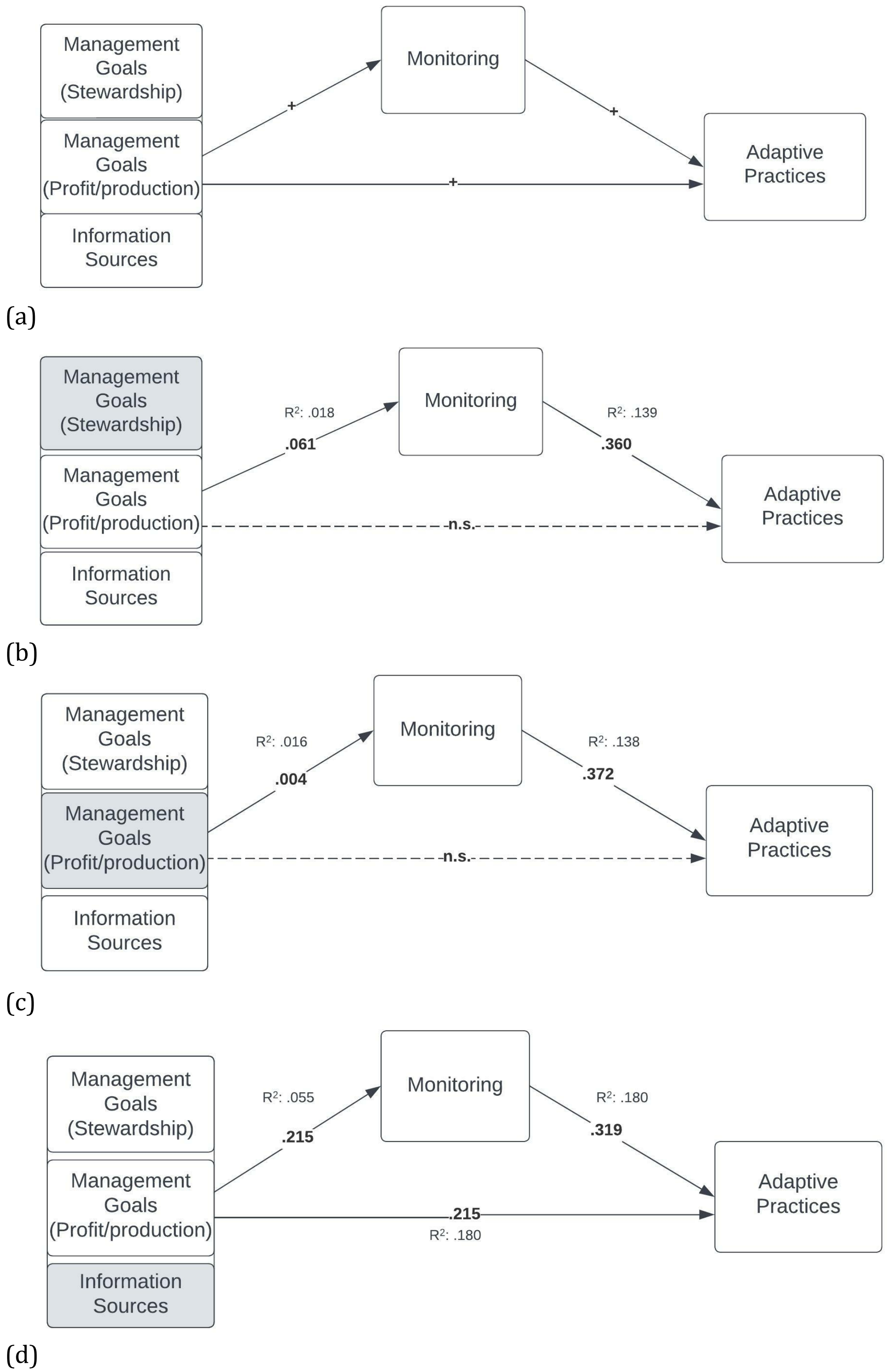


Figure 4.5. Conceptual diagrams showing (a) hypothesized relationships among management goals (stewardship), management goals (profitability), information sources, monitoring, and adaptive practices, and (b)(c)(d) final path models. Solid arrows in (a) represent hypothesized relationships.

Solid arrows in (b)(c)(d) represent significant paths between constructs. Dotted lines in (b)(c)(d) represent nonsignificant (n.s.) paths. Paths in (b)(c)(d) are labeled with standardized path coefficients, R^2 and ρ-value indicators.

Discussion

A revised adaptive decision-making for rangeland management framework

This study contributes to theory of how ranchers manage for and adapt to social and ecological change and uncertainty on rangelands in the U.S. Specifically, we test and build upon existing knowledge of adaptive decision-making within ranching systems. Recognizing that adaptive decision-making among ranchers involves a broader suite of factors and interactions at scales beyond what we examine here, we present a revised adaptive decision-making framework (Figure 4.0) based on the evidence from this study. Our conceptual framework illustrates an empirically grounded extension of earlier conceptualizations (Lubell et al. 2013) (Figure 4.0) summarized in three key points. First, we made the distinction between ranchers' management goals related to stewardship and to 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 loop-learning — or taking in new information and applying it in iterative fashion to adaptive decision-making processes — may be more important than earlier conceptualizations. Third, our path model analysis showed that ranchers use of monitoring mediates (and decreases the influence) of the other factors (use of information and management goals) on their use of adaptive management practices.

In the context of rapid social and environmental change in the West, these revisions to the adaptive decision-making for rangeland management framework highlight two key needs; 1) there is a need to increase the use of monitoring among ranchers and to identify key barriers and needs for adoption; 2) there is a need to facilitate 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, in this study, we did not ask ranchers to specify additional information about their monitoring methods, indicators, how they use monitoring information in management decisions, or why they chose not to use monitoring at all. Thus, the questions arise — monitoring of what, by whom, and how — is most effective for adaptive decision-making? And, what are the constraints to adoption? In this section, we provide a discussion of ongoing challenges related to monitoring for adaptive management and we suggest future research directions based on our findings.

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 U.S. (Fernandez-Gimenez et al., 2005; Peterson, 2010; Sayre et al., 2013). Our results were consistent with these studies, showing that formal monitoring is used by fewer than half of Montana ranchers. Documented barriers 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; Newingham et al., 2022; Stephenson et al., 2017). Not only do these barriers exist for ranchers managing private lands, but empirical evidence suggests the use of long-term monitoring programs among U.S. public lands agencies often fail for similar reasons despite widespread institutional commitments to monitoring as part of an adaptive management strategy (Bricker & Ruggiero, 1998; Sayre et al., 2013; U.S. Forest Service 2006; Williams et al. 2007). For agencies managing grazing on public rangelands, barriers 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 & Bodine, 2008; Sayre et al., 2013).

In contrast to the lack of formal monitoring used by ranchers in the U.S., 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 (Knapp & Fernandez-Gimenez, 2008, 2009; Sayre, 2004; Woods & Ruyle, 2015). Informal monitoring is defined as non-standardized monitoring that relies on personal practice and experience and is typically embedded in local cultural and natural environments (Raymond et al., 2010; Woods & 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 years previously, which they compare with current conditions. For ranchers, Woods & 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 & 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 & Ruyle, 2015).

The disparity in the perceived utility of formal and informal monitoring techniques in conjunction with other social constraints to monitoring speaks to the need for additional social science research that examines these dimensions which have received relatively little scholarly attention in comparison to research addressing technological limitations. 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? How could support from government agencies (e.g. Extension, NRCS) help address these challenges?
- What are the advantages and disadvantages of informal and formal monitoring for adaptive decision-making on U.S. rangelands? And; how could these techniques for acquiring environmental knowledge be integrated to more fully realize the advantages of both?

In Montana, there is an innovative pilot project underway called the Rangeland Monitoring Group (RMG) that provides an example of what a collaborative and participatory research effort attempting to answer some of these questions might look like. RMG engages ranchers, scientists, and non-profit conservation groups, who 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 aforementioned barriers to implementing and using monitoring in management decisions. For instance, regarding the questions "who will do the monitoring and who will pay for it?" 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, for example, 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 exciting opportunity for researchers and ranchers to work together to understand how monitoring can be most effectively integrated into adaptive decision-making toward desired social and ecological outcomes.

Based on the results of this study and what we have learned through RMG discussions, we argue that there is a need for additional research that examines the efficacy of strategies such as those RMG is employing (e.g. increasing local involvement in monitoring, reducing barriers associated with cost, group learning around monitoring and subsequent management decisions) for improving social and ecological outcomes on 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

Consistent with the well-established body of literature looking how the use of information by agricultural producers influences the adoption of agricultural practices (Fernández-Giménez et al., 2019; Kachergis et al., 2013; Lubell et al., 2013; Prokopy et al., 2019; Prokopy et al., 2008; Roche et al., 2015), we found that the use of information sources (including in-person networks) among Montana ranchers is a significant predictor of the use of adaptive practices. Ranchers who use a greater number of information sources are more likely to also use adaptive management practices. We found that Montana ranchers use 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 & Stokes, 2014; Roche et al., 2015; Roche, 2016; Wilmer et al., 2021). Based on these results, we argue that Montana ranchers might benefit from institutionalized and ongoing government funding allocated for supporting peer-to-peer learning opportunities where they can set the agenda 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, one could envision allocating funding to cover the 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 are the most used sources of information may also be well-positioned to link producer knowledge and goals with climate information and adaptive management strategies. Research that has looked at influence of similar types of in-person sources of information — conservation agencies (Gillespie et al., 2007; McBride and Daberkow 2003; Nowak, 1987), attendance at workshops (Claytor, 2015; Nowak, 1987; Singh et al., 2018), and private sector agricultural advisors (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; Cutts et al., 2011; 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 climate-related information itself to be designed to aid decision-making. Numerous studies have shown that climate-related information is especially underutilized in decisions made by agricultural producers (Dilling & Lemos, 2011; Dunne et al., 2015; Lemos et al., 2012; Mase & Prokopy 2014; Preston et al., 2013; Smith et al., 2021). For Montana farmer and ranchers, Smith et al. (2021) found that the underutilization 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. mid-century), in part because shorter timeframes were perceived to be more accurate. These findings are consistent with other studies (Ash et al., 2007; Cash et al., 2006; Dong et al., 2018; McCrea et al., 2005). 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 include both sustaining a profitable operation while also achieving stewardship-related goals, which is consistent with the results of existing studies examining management goals among ranchers in the U.S. West (Kachergis et al., 2013; Roche et al., 2015). This suggests that efforts to support the ranching community in the adoption of or transition to more adaptive practices will be most effective if they highlight how they contribute to ranchers ecological and economic goals in tandem, address potential tradeoffs between these goals, and provide resources specific to ranchers' operations and environmental contexts. Interestingly, in contrast to Roche et al. (2015) and Kachergis et al. (2013), who both found that ranchers' highest priorities were production-related goals followed by environment-related goals, the two goals that ranked highest in importance for Montana ranchers 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, despite rhetoric that has reinforced a public perception that ranchers are antigovernment and anticonservation, research has shown that ranchers in the U.S. 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 mind or "mental models" (Wilmer & 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 U.S. West, significant landownership transitions are underway 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 (Brunson & Huntsinger, 2008; Gosnell & Travis, 2005). 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 U.S. 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 limitations, 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 between 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 upon our results.

References

Abu-Bader, S., & Jones, T. V. (2021). Statistical mediation analysis using the Sobel test and Hayes SPSS Process Macro. *International Journal of Quantitative and Qualitative Research Methods*, *9*(1), 42–61.

Ajzen, I., & Fishbein, M. (1980). *Understanding attitudes and predicting social behaviour.* New Jersey: Prentice-Hall. Englewood Cliffs.

Ash, A., McIntosh, P., Cullen, B., Carberry, P., and Smith, M. S. (2007). Constraints and opportunities in applying seasonal climate forecasts in agriculture. *Austr. J. Agr. Res. 58*, 952–965. doi: 10.1071/AR06188

Battaglia, M., Dillman, D., Frankel, M., Harter, R., Buskirk, T., McPhee, C., . . . Yancy, T. (2016). Sampling, data collection, and weighting procedures for address-based sample surveys. *Journal of Survey Statistics and Methodology, 4*, 476-500.

Booth, D.T., Tueller, P.T. (2003). Rangeland monitoring using remote sensing. *Arid Land Res Manag., 17*(4). 455–467. doi:10. 1080/713936105 .

Brick, M. (2013). Unit nonresponse and weighting adjustments: A critical review. *Journal of Official Statistics, 29*, 329-353.

Bricker, O. P., and M. A. Ruggiero. (1998.) Toward a national program for monitoring environmental resources. *Ecol. Appl. 8*, 326–329.

Briske, D. D., N. F. Sayre, L. Huntsinger, M. Fernandez-Gimenez, B. Budd, And J. D. Derner. (2011). Origin, persistence, and resolution of the rotational grazing debate: integrating human dimensions into rangeland research. *Rangeland Ecology & Management 64*, 325–334.

Briske, D. D., Joyce, L. A., Polley, H. W., Brown, J. R., Wolter, K., Morgan, J. A., … Bailey, D. W. (2015). Climate-change adaptation on rangelands: Linking regional exposure with diverse adaptive capacity. *Frontiers in Ecology and the Environment*, *13*(5), 249–256. https://doi.org/10.1890/140266

Brunson, M. W., & Huntsinger, L. (2008). Ranching as a conservation strategy: Can old ranchers save the new west? *Rangeland Ecology and Management*. https://doi.org/10.2111/07-063.1

Bestelmeyer, B. T., & Briske, D. D. (2012). Grand challenges for resilience-based management of rangelands. *Rangeland Ecology & Management*, *65*(6), 654–663. https://doi.org/10.2111/REM-D-12-00072.1

Cash, D. W., Borck, J. C., and Patt, A. G. (2006). Countering the loading-dock approach to linking science and decision making: comparative analysis of El Niño/Southern Oscillation (ENSO) forecasting systems. *Sci. Technol. Human Values, 31*, 465–494. https://doi.org/10.1177/0162243906287547

Charnley, S., T. E. Sheridan, and N. F. Sayre. (2014). Status and trends of western working landscapes. pp. 13–32 in S. Charnley, T. E. Sheridan, and G. P. Nabhan, editors. *Stitching the* *west back together: conservation of working landscapes.* University of Chicago Press, Chicago, Illinois, USA.

Cook, B. I., Ault, T. R., and Smerdon, J. E. (2015). Unprecedented 21st century drought risk in the American Southwest and Central Plains. *Sci. Adv. 1*:e1400082. doi: 10.1126/sciadv.1400082

Cronbach, L. J. (1951). Coefficient alpha and the internal structure of tests. *Psychometrika, 16*, 97–334. doi:10.1007/bf02310555.

Danielsen, F., N. D. Burgess, A. Balmford, [and 24 others]. (2008). Local participation in natural resource monitoring: A characterization of approaches. *Conservation Biology, 23*, 31–42.

Derner, J. D., Budd, B., Grissom, G., Kachergis, E. J., Augustine, D. J., Wilmer, H., … Ritten, J. P. (2022). Adaptive grazing management in semiarid rangelands: An outcome-driven focus. *Rangelands*, *44*(1), 111–118. https://doi.org/10.1016/j.rala.2021.02.004

Derner, J. D., & Augustine, D. J. (2016). Adaptive management for drought on rangelands. *Rangelands*, *38*(4), 211–215. https://doi.org/10.1016/j.rala.2016.05.002

Dillman, D. A., J. D. Smyth, and L. M. Christian. (2014). *Internet, mail and mixed-mode surveys: The tailored design method.* Hoboken, NJ: John Wiley & Sons Inc.

Didier, E. A., and Brunson, M. W. (2004). Adoption of range management innovations by Utah ranchers. *Rangeland Ecology and Management, 57*, 330–336. doi:10.2111/1551-5028(2004)057[0330:AORMIB]2.0.CO;2

Dong, Y., Hu, S., and Zhu, J. (2018). From source credibility to risk perception: How and when climate information matters to action. *Res. Conserv. Recycl. 136*, 410–417. https://doi.org/10.1016/j.resconrec.2018.05.012

Montana DNRC on behalf of the Governor's Drought & Water Supply Advisory Committee. (2022). Montana Drought Outlook Report – Summer 2022. Web accessed Oct, 2022. http://dnrc.mt.gov/divisions/water/drought-management/drought-documents/drought-outlook-report-summer-2022.pdf

Montana Fish, Wildlife, and Parks (MT FWP). (2022). Public Land Hunting Opportunities. https://fwp.mt.gov/hunt/access/public-lands

Fernandez-Gimenez, M.E., Ruyle, G., McClaran, S.J. (2005). An evaluation of Arizona Cooperative Extension's rangeland monitoring program. *Rangeland Ecology & Management, 58*, 89–98.

Germino, M. J., Torma, P., Fisk, M. R., & Applestein, C. V. (2022). Monitoring for adaptive management of burned sagebrush-steppe rangelands: Addressing variability and uncertainty on the 2015 Soda Megafire. *Rangelands*, *44*(1), 99–110. https://doi.org/10.1016/j.rala.2021.12.002

Gosnell, H., & Travis, W. R. (2005). Ranchland ownership dynamics in the Rocky Mountain West. *Society for Range Management*, *58*(2), 191–198.

Haigh, T. R., Schacht, W., Knutson, C. L., Smart, A. J., Volesky, J., Allen, C., … Burbach, M. (2019). Socioecological determinants of drought impacts and coping strategies for ranching operations in the Great Plains. *Rangeland Ecology and Management*, *72*(3), 561–571. https://doi.org/10.1016/j.rama.2019.01.002

Haigh, T., Hayes, M., Smyth, J., Prokopy, L., Francis, C., & Burbach, M. (2021). Ranchers' use of drought contingency plans in protective action decision making. *Rangeland Ecology and Management*, *74*(1), 50–62. https://doi.org/10.1016/j.rama.2020.09.007

Hayes, Andrew F. (2013). *Introduction to Mediation, Moderation, and Conditional Process Analysis: A Regression-Based Approach.* New York, NY: The Guilford Press.

Haziza, D., & Beaumont, J.-F. (2017). Construction of weights in surveys: A review. *Statistical Science, 32*, 206-226.

Haziza, D., & Lesage, E. (2016). A discussion of weighting procedures for unit nonresponse. *Journal of Official Statistics, 32*, 129-145.

Herrick, J. E., Bestelmeyer, B. T., Archer, S., Tugel, A. J., & Brown, J. R. (2006). An integrated framework for science-based arid land management. *Journal of Arid Environments*, *65* (Conference on Landscape Linkages and Cross Scale Interactions in the Chihuahuan Desert held at the 6th Symposium on Natural Resources of the Chiluahuan), 319–335. https://doi.org/10.1016/j.jaridenv.2005.09.003

Herrick JE ,Van Zee JW, McCord SE, Courtright EM, Karl JW, Burkett LM. (2018). *Monitoring Manual for Grassland, Shrubland, and Savanna Ecosystems*. 1. 2nd ed. USDA- ARS Jornada Experimental Range.

Herrick JE, Karl JW, McCord SE, et al. (2017). Two new mobile apps for rangeland inventory and monitoring by landowners and land managers. *Rangelands 39*(2), 46–55. https://doi.org/10.1016/ j.rala.2016.12.003

Hinrichs, C. C., and Welsh, R. (2003). The effects of the industrialization of US livestock agriculture on promoting sustainable production practices. *Agriculture and Human Values, 20*, 125–141. https://doi.org/10.1023/ A:1024061425531

Hoppe, R. A., and Banker, D. E. (2010). Structure and finances of US farms: Family farm report. Economic Information Bulletin, USDA Economic Research Service. Available at: http://ssrn.com/abstract= 923592 (accessed 23 October 2015).

Jones MO, Allred BW, Naugle DE, et al. (2018). Innovation in rangeland monitoring: Annual, 30 m, plant functional type percent cover maps for U.S. rangelands, 1984–2017. *Ecosphere, 9*(9). https://doi.org/10.1002/ecs2.2430

Joyce, L. A., Briske, D. D., Brown, J. R., Polley, H. W., McCarl, B. A., & Bailey, D. W. (2013). Climate change and North American rangelands: Assessment of mitigation and adaptation strategies. *Rangeland Ecology & Management*, *66*(5), 512–528. https://doi.org/10.2111/REM-D-12-00142.1

Joyce, L. A., & Marshall, N. A. (2017). Managing climate change risks in rangeland systems. In D. D. Briske (Ed.), *Rangeland Systems: Processes, Management and Challenges*. 491–526. Springer Cham. https://doi.org/10.1007/978-3-319-46709-2_15

Kachergis E, Miller SW, McCord, SE, et al. (2021). Adaptive monitoring for multi-scale land management: Lessons learned from the Assessment, Inventory, and Monitoring (AIM) principles. *Rangelands.* https://doi.org/10.1016/j. rala.2021.08.006

Kachergis, E., Derner, J., Roche, L., Tate, K., Lubell, M., Mealor, R., and Magagna, J. (2013). Characterizing Wyoming ranching operations: Natural resource goals, management practices and information sources. *Natural Resources, 4*, 45–54. https://doi.org/10.4236/nr.2013.41005.

Kalton, G., & Flores-Cervantes, I. (2003). Weighting methods. *Journal of Official Statistics, 19*, 81-97.

Kennedy, C., and Brunson, M. W. (2007). Creating a culture of innovation in ranching: A study of outreach and cooperation in West-central Colorado. *Rangelands, 29*,35–40. https://doi.org/10.2111/1551-501X(2007)29[35:CACOII] 2.0.CO;2

Knapp, C. N., and M. E. Fernandez-Gimenez. (2009). Understanding change: Integrating rancher knowledge into state-and-transition models. *Rangeland Ecology & Management, 62*, 510-521.

Knapp, C.N., Fernandez-Gimenez, M. (2008). Knowing the land: A review of local knowledge revealed in ranch memoirs. *Rangeland Ecology & Management, 61*, 148–155.

Knapp, C.N., Fernandez-Gimenez, M.E. (2009). Knowledge in practice: Documenting rancher local knowledge in northwest Colorado. *Rangeland Ecology & Management, 62*, 500–509.

Koontz, T. M., and J. Bodine. (2008). Implementing ecosystem management in public agencies: Lessons from the U.S. Bureau of Land Management and the Forest Service. *Conservation Biology, 22,* 60–69.

Kreuter, U. P., Amestoy, H. E., Ueckert, D. N., and McGinty, W. A. (2001). Adoption of brush busters: Results of Texas county extension survey. *Journal of Range Management, 54,* 630–639. https://doi.org/10.2307/4003663

Kreuter, F., & Olson, K. (2013). Paradata for nonresponse error investigation. In F. Kreuter, *Improving Surveys with Paradata: Analytic Uses of Process Information* (pp. 13-42). Hoboken, New Jersey: John Wiley & Sons.

Kuwayama, Y., Thompson, A., Bernknopf, R., Zaitchik, B., and Vail, P. (2019). Estimating the impact of drought on agriculture using the U.S. Drought monitor. *Am. J. Agric. Econ. 101*, 193–210. https://doi.org/10.1093/ajae/aay037

Lavallee, P., & Beaumont, J.-F. (2016). Weighting principals and practicalities. In C. Wolf, D. Joye, T. Smith, & Y.-C. Fu, *The Sage Handbook of Survey Methodology* (pp. 460-476). Sa

Lien, A. M., Svancara, C., Vanasco, W., Ruyle, G. B., & López-Hoffman, L. (2017). The land ethic of ranchers: A core value despite divergent views of government. *Rangeland Ecology and Management*, *70*(6), 787–793. https://doi.org/10.1016/j.rama.2017.06.004

Lindenmayer, D.B., Likens, G.E., (2010). The science and application of ecological monitoring. *Biol. Conserv. 143*, 1317–1328

Lubell, M. N., Cutts, B. B., Roche, L. M., Hamilton, M., Derner, J. D., Kachergis, E., & Tate, K. W. (2013). Conservation program participation and adaptive rangeland decision-making. *Rangeland Ecology & Management*, *66*, 609–620.

Lubell, M. Fulton, A. (2007). Local diffusion networks act as pathways to sustainable agriculture in the Sacramento River Valley. Calif. *Agric., 61*, 131–137.

Lund, H.G. (2007). Accounting for the world's rangelands. *Rangelands, 29*, 3–10.

Lynam, T. J. P., & Smith, M. S. (2004). Monitoring in a complex world - seeking slow variables, a scaled focus, and speedier learning. *African Journal of Range & Forage Science*, *21*(2), 69–78. https://doi.org/10.2989/10220110409485837

Marshall, N.A.; Smajgl, A. (2013). Understanding variability in adaptive capacity on rangelands. *Rangel. Ecol. Manag., 66*, 88–94.

Marshall, N., & Stokes, C. J. (2014). Identifying thresholds and barriers to adaptation through measuring climate sensitivity and capacity to change in an Australian primary industry. *Climatic Change*, *126*(3–4), 399–411. https://doi.org/10.1007/s10584-014-1233-x

McCord, S. E., & Pilliod, D. S. (2022). Adaptive monitoring in support of adaptive management in rangelands. *Rangelands*, *44*(1), 1–7. https://doi.org/10.1016/j.rala.2021.07.003

Mccollum, D. W., Tanaka, J. A., Morgan, J. A., Mitchell, J. E., Fox, W. E., Maczko, K. A., … Kreuter, U. P. (2017). Climate change effects on rangelands and rangeland management: Affirming the need for monitoring. *Ecosystem Health and Sustainability*, *3*(3), 1–13. https://doi.org/10.1002/ehs2.1264

McCrea, R., Dalgleish, L., and Coventry, W. (2005). Encouraging use of seasonal climate forecasts by farmers. *Int. J. Climatol. 25*, 1127–1137. https://doi.org/10.1002/joc.1164

Montana Fish, Wildlife, and Parks (MT FWP). (2022). Public Land Hunting Opportunities. Accessed Oct 19, 2022. https://fwp.mt.gov/hunt/access/public-lands

Munden-Dixon, K., Tate, K., Cutts, B., & Roche, L. (2019). An uncertain future: Climate resilience of first-generation ranchers. *Rangeland Journal*, *41*(3), 189–196. https://doi.org/10.1071/RJ18023

Newingham, B. A., Kachergis, E., Ganguli, A. C., Foster, B., Price, L., & McCord, S. E. (2022). Lessons given and learned from rangeland monitoring courses. *Rangelands*, *44*(1), 29–38. https://doi.org/10.1016/j.rala.2021.08.003

Nickerson, C., R. Ebel, A. Borchers, and F. Carriazo. (2011). Major uses of land in the United States, 2007. U.S. Department of Agriculture Economic Research Service, Washington, D. C., USA. http://www.ers.usda.gov/Publications/ EIB89/EIB89.pdf

Olson, K. (2013). Paradata for nonresponse adjustment. *The Annals of the American Academy of Political Science and Social Science*, 142-170.

Peterson, D.J. (2010). Rangeland monitoring survey for ranchers: A report of findings. University of Arizona, School of Renewable Natural Resources. Report for University of Arizona Cooperative Extension, Tucson, AZ, USA 32 pp.

Prokopy, L. S., K. Floress, D. Klotthor-Weinkauf, and A. Baumgart-Getz. (2008). Determinants of agricultural best management practice adoption: Evidence from the literature. *Journal of Soil & Water Conservation, 63*(5), 200.

Rangeland Monitoring Group (RMG). (2022). Web accessed October 2022. https://highplainsstewardship.org/collaborative-rangeland-monitoring-and-management-in-montana/

Robinson, N. P., Allred, B. W., Naugle, D. E., & Jones, M. O. (2019). Patterns of rangeland productivity and land ownership: Implications for conservation and management. *Ecological Applications*, *29*(3), 1–8. https://doi.org/10.1002/eap.1862

Roche, L. M. (2016). Adaptive rangeland decision-making and coping with drought. *Sustainability*, *8*(12), 1–13. https://doi.org/10.3390/su8121334

Roche, L. M., Schohr, T. K., Derner, J. D., Lubell, M. N., Cutts, B. B., Kachergis, E., … Tate, K. W. (2015). Sustaining working rangelands: Insights from rancher decision making. *Rangeland Ecology and Management*, *68*(5), 383–389. https://doi.org/10.1016/j.rama.2015.07.006

Sarndal, C.-E. (2007). The calibration approach in survey theory and practice. *Survey Methodology, 33*, 99-119.

Sayre, N. F., Biber, E., & Marchesi, G. (2013). Social and legal effects on monitoring and adaptive management: A case study of National Forest grazing allotments, 1927-2007. *Society & Natural Resources*, *26*(1), 86–94. https://doi.org/10.1080/08941920.2012.694579

Sayre, N. F., Carlisle, L., Huntsinger, L., Fisher, G., & Shattuck, A. (2012). The role of rangelands in diversified farming systems: Innovations, obstacles, and opportunities in the USA. *Ecology and Society*, *17*(4). https://doi.org/10.5751/ES-04790-170443

Sayre, N.F., McAllister, R.R.J., Bestelmeyer, B.T., Moritz, M., Turner, M.D., (2013b). Earth stewardship of rangelands: Coping with ecological, economic, and political marginality. *Front. Ecol. Environ., 11*, 348–354

Sayre, N.F. (2004). Viewpoint: The need for qualitative research to understand ranch management. *Rangeland Ecology & Management, 57*, 668–674.

Stafford Smith, M. (1996). Management of rangelands: Paradigms at their limits. In: J Hodgson and A Illius (eds) The Ecology and Management of Grazing Systems. CAB International, Wallingford, UK. 325–357.

Sorice, M. G., J. R. Conner, LI. P. Kreuter, and R. M. Wilkins. (2012). Centrality of the ranching lifestyle and attitudes toward a voluntary incentive program to protect endangered species. *Rangeland Ecology & Management, 65*,144-152.

Stephenson, M. B., Wilmer, H., Bolze, R., & Schiltz, B. (2017). Evaluating an on-ranch rangeland monitoring program in Nebraska. *Rangelands*, *39*(5), 143–151. https://doi.org/10.1016/j.rala.2017.08.001

Walters, C. J., and C. S. Holling. (1990). Large-scale management experiments and learning by doing. *Ecology, 71,* 2060–2068.

Toevs, GR, Karl JW, Taylor JJ, et al. (2011). Consistent indicators and methods and a scalable sample design to meet assessment, inventory, and monitoring information needs across scales. *Rangelands, 33*(4):14–20. https://doi.org/10.2111/1551- 501X- 33.4. 14

USDA NASS. (2017). Census of Agriculture – State Profile (Montana). www.nass.usda.gov/AgCensus

United States Department of Agriculture Natural Resources Conservation Service (USDA-NRCS). (2007). Summary report: 2007 natural resources inventory. U.S. Department of Agriculture Natural Resources Conservation Service, Washington, D.C., USA. http://www.nrcs. usda.gov/Internet/FSE_DOCUMENTS//stelprdb1041379.pdf. http://dx.doi.org/10.2172/910936

U. S. Forest Service. (2006). *Forest Service manual.* Washington, DC: U.S. Department of Agriculture.

United States Forest Service (USFS). (2012). *About rangelands*. U.S. Forest Service, Washington, D.C., USA. http://www.fs.fed.us/rangelands/whoweare/index.shtml

Valliant, R., Dever, J. A., & Kreuter, F. (2013). *Practical Tools for Designing and Weighting Surveys.* New York, New, York: Springer.

Vaske, J. (2008). *Survey research and analysis: Applications in parks, recreation and human dimensions*. State College, PA: Venture Publishing.

USDA-NRCS. (2003). *National range and pasture handbook*. US Department of Agriculture, Natural Resources Conservation Service, Washington D.C., USA 84 pp.

Whitlock C, Cross W, Maxwell B, Silverman N, Wade AA. (2017). 2017 Montana climate assessment. Bozeman and Missoula MT: Montana State University and University of Montana, Montana Institute on Ecosystems. https://doi.org/10.15788/m2ww8w.

Wollstein, K., Wardropper, C. B., & Becker, D. R. (2021). Outcome-based approaches for managing wildfire risk: Institutional interactions and implementation within the "gray zone." *Rangeland Ecology & Management*, *77*(1), 101–111. https://doi.org/10.1016/j.rama.2021.04.007

Williams, B. K., R. C. Szaro, and C. D. Shapiro. (2007). *Adaptive management: The U.S. Department of Interior technical guide.* Washington, DC: Adaptive Management Working Group, U.S. Department of the Interior.

Wilmer, H., Augustine, D. J., Derner, J. D., Fernández-Giménez, M. E., Briske, D. D., Roche, L. M., … Miller, K. E. (2018). Diverse management strategies produce similar ecological outcomes on ranches in Western Great Plains: Social-ecological assessment. *Rangeland Ecology and Management*, *71*(5), 626–636. https://doi.org/10.1016/j.rama.2017.08.001

Wilmer, H., & Fernández-Giménez, M. E. (2015). Rethinking rancher decision-making: A grounded theory of ranching approaches to drought and succession management. *Rangeland Journal*, *37*(5), 517–528. https://doi.org/10.1071/RJ15017

Wilmer, H., & Sturrock, J. (2020). "Humbled by nature": A rancher's mental model of adaptation in the great plains. *Great Plains Research*, *30*(1), 15–33. https://doi.org/10.1353/gpr.2020.0001

Wilmer, H., Schulz, T., Fernández-Giménez, M. E., Derner, J. D., Porensky, L. M., Augustine, D. J., … Meade, R. (2021). Social learning lessons from collaborative adaptive rangeland management. *Rangelands*, 1–11. https://doi.org/10.1016/j.rala.2021.02.002

Woods, S. R., & Ruyle, G. B. (2015). Informal rangeland monitoring and its importance to conservation in a U.S. ranching community. *Rangeland Ecology and Management*, *68*(5), 390–401. https://doi.org/10.1016/j.rama.2015.07.005

Yung, L., Phear, N., Dupont, A., Montag, J., & Murphy, D. (2015). Drought adaptation and climate change beliefs among working ranchers in Montana. *Weather, Climate, and Society*, *7*(4), 281–293. https://doi.org/10.1175/WCAS-D-14-00039.1

Chapter 5: Situating 'structures': How government programs and public lands grazing permits shape adaptation on U.S. working rangelands

Abbreviations

NRCS United States Department of Agriculture-Natural Resources Conservation Service
Introduction
BLM Bureau of Land Management
EQIP Environmental Quality Incentives Program
CSP Conservation Stewardship Program
CRP Conservation Reserve Program
USDA United States Department of Agriculture

Abstract

Ranchers are — and have always been — highly adaptive to social and environmental change. In the U.S., ranchers make adaptive decisions shaped not only by their own goals, but also within a nested institutional context that includes both formal and informal institutions. Understanding these cross-scale interactions is becoming increasingly important given the role ranchers play in stewarding both private and public rangelands in the U.S., particularly in light of drought and other climate-related concerns. This study examines how government programs and grazing permits administered by public lands agencies (i.e. Forest Service, Bureau of Land Management) influence Montana ranchers' ability to adapt to drought and other climate-related events. Our results from a quantitative survey (n= 450) and in-depth interviews with 34 ranchers in Montana were used to understand ranchers' participation in a suite of government-administered programs and their perceptions of how these institutional arrangements enable or constrain their adaptive capacity and adaptive decision-making processes. Our findings suggest that government programs can both enable and constrain adaptation. Four key themes emerged: 1) inflexibilities in programs and permits limit adaptive management strategies that are tailored to local conditions; 2) slowness and inefficiency of government programs limits timely management responses (to drought in particular); 3) relationships with local agency representatives influence the efficacy of program implementation on-the-ground, and; 4) ranchers' political ideologies and views related to

government involvement in land management influence participation in programs. Our results reflect the complex suite of cross-scale factors influencing ranchers' use of institutional arrangements to adapt to changing rangeland systems. We discuss the need for research and practice-oriented efforts that use participatory approaches for identifying ways in which government programs and permits can more effectively enable ranchers' ability to manage for and adapt to complex and changing conditions.

Introduction

Rangeland management has often been called both an "art and a science" because of the multitude and complexity of factors influencing ranchers' adaptive capacity and adaptive decision-making processes in light of change (Meuret & Provenza, 2015; Roche, 2021; Reid et al., 2021; Sayre, 2017). Ranchers are constantly making decisions about how to manage their operations depending on their own social, economic, and ecological objectives while also managing in accordance with government programs and policies (e.g. public lands grazing permits, water rights, and government administered cost share and incentive programs). In recent decades, climate change has introduced new dynamics and uncertainties. On U.S. rangelands, increased fluctuations of temperature and precipitation are likely to result in significant changes in land and water regimes that influencing rangeland ecology and productivity and affecting millions of people whose livelihoods are linked to livestock grazing (here forward referred to as 'ranchers') (Briske et al., 2015; Polley et al, 2013). At the same time, ranchers have had to respond to other beyond-ranch social and ecological changes including market integration in the livestock industry (MacDonald & McBride 2009) and shifting land uses toward amenity ranching, non-production uses, and urbanization (Gosnell & Abrams, 2011; Gosnell & Travis, 200; Sorice et al., 2014). In this way, the decision-making context for adaptive management involves both individual choice or 'agency' as well as agency that exists within a context of 'structural' factors. Understanding how these factors interact is becoming increasingly important given the role that ranchers play in stewarding both private and public lands in the U.S. West (Brunson & Huntsinger, 2008; Sayre et al., 2012), particularly in light of drought and other climate-related concerns (Briske et al., 2015; Coppock, 2011; Joyce et al., 2013; Joyce & Marshall, 2017; Mccollum et al., 2017).

In the U.S., rangeland management takes place within a nested institutional context shaped by formal institutions as well as informal institutions (Belsky & Barton, 2018; Reiners, 2012; Wollstein et al., 2021; Schlager & Cox, 2018). Formal institutions are codified in policies and regulations that are legally enforceable, such as government programs (e.g. Conservation Stewardship Program, Conservation Reserve Program, EQIP) and permits administered by public lands agencies (i.e. Forest Service, Bureau of Land Management) for grazing on public rangelands, which include terms and conditions on when and how intensively ranchers may graze livestock. In contrast, informal institutions are socially shared rules and expectations that are created, communicated, and enforced by cultural norms and social interactions (Christiansen & Neuhold 2012; Schlager & Cox 2018). Informal institutions often play a critical role in how formal institutions are interpreted and implemented. For example, a recent study on outcome-based rangeland management found that BLM staff beliefs about the efficacy of grazing to manage fire risk, their tenure, and their relationships with permittees (among other factors) influenced whether a field office was willing to explore various formal administrative tools (e.g. terms and conditions for grazing permits, NEPA documents authorizing tools such as targeted grazing) that would offer permitees greater latitude in grazing following fire and responding to other environmental changes (Wollstein et al., 2021). Thus, in contexts where formal and informal institutions interact, sometimes referred to as “gray zones” (Christiansen and Neuhold, 2012; Landsbergen & Orosz 1996), formal institutions that are guided by laws and regulations can be implemented differently from place to place (Hruska et al., 2017). In order for ranchers and rangeland managers to respond to drought and other climate related concerns, there is a need for institutions — both formal and informal — that support both adaptive capacity, or “the adaptation space within which adaptation actions or decisions are feasible" (Adger & Vincent, 2005), and adaptive decision-making within dynamic rangeland systems (Boyd & Svejcar 2009).

In Montana, considerable gaps remain in our understanding of how institutions both enable and constrain the ability of ranchers to adapt to climate change in desirable ways. Using structuration theory to frame this study, I examine the role of government programs and permits in ranchers' adaptive capacity and decision-making. The study objectives were to: 1) understand ranchers participation in government programs and permits — the extent to which they participate, their motivations, and experiences; 2) to understand their perceptions of how these institutional arrangements enable or constrain their ability to manage for and adapt to drought and other climate events and; 3) to synthesize policy and practice-oriented recommendations based on ranchers needs and interests.

Theoretical Framework: 'Structures' and 'agency' in adaptive capacity and decision-making

Adaptation to climate change is often studied using a social-ecological systems (SES) perspective, which considers both ecological change and the way humans plan for and respond to resource availability and risk at multiple scales (Adger et al., 2005; Joyce et al., 2013; Joyce and Marshall, 2017). In social-ecological systems (SESs), it is widely recognized that human adaptation is not autonomous: it involves individual choice or 'agency' that exists within a context of 'structural' factors, including formal and informal institutions such as policies, regulations, property rights and social norms (Adger et al, 2005; Gupta et al., 2010; Vincent, 2007; Whitney et al., 2017). Structuration theory has been used in climate adaptation research to illuminate the influence of structures, both formal and informal, on individual and household level actions (e.g. Gupta et al., 2010; Wyss, 2013; Wyborn et al., 2015). Structuration theory helps bring to light the fact that humans do not pursue activities in a fully rational way. Rather, our actions and decisions are directed by social norms and expectations as well as formal laws, rights, and regulations that bound the conditions in which interactions take place (Giddens, 1984). Thus, there is a reciprocal dependency between structures, defined as "the rules and resources recursively implicated in social reproduction" and agency of individuals within this system (Giddens, 1984). Agency, then, refers not only to the intentions people have in doing things but to their capability of doing those things in the first place. Agency also implies power (or lack thereof) (Garud et al., 2007; Giddens, 1984; Wyborn et al., 2015).

From a structuration theory perspective, institutions and the mechanisms of deliberation and decision-making (i.e. policy processes) are the structures in which humans pursue shared goals, reconcile differences, and respond to threats and opportunities (Dovers & Hezri, 2010; Giddens, 1984; Gupta et al., 2010; IDGESC, 1999; Zijderveld, 2000). In the context of climate change, institutional change is often discussed in reference to formal policy processes or interventions that would allow decisions to be informed and made differently (Dovers & Hezri, 2010; Gupta et al., 2010; Wyborn et al., 2015).

Within the growing body of adaptive capacity scholarship, there is an emphasis on the role that institutions have in determining a system's ability to adapt to climate change (Agrawal, 2008; Brown et al., 2010; Engle, 2011; Engle & Lemos, 2010; Gupta et al., 2010). However, in practice, adaptive capacity research has been critiqued for not adequately measuring these dimensions and for a lack of studies that provide actionable, policy and practice-oriented recommendations (Siders, 2019; Vallury et al., 2022). In rangeland SES contexts, adaptive capacity assessments have tended to emphasize individual-level determinants (e.g. level of education, income, access to credit) (e.g. Marshall, 2015; Marshall & Smaijgl, 2013) and informal institutions (such as social networks) while downplaying or excluding the role of formal institutions on adaptive capacity of ranchers or rangeland managers (Crimp et al., 2010; King et al., 2018).

Similarly, the adaptive management and adaptive decision-making literatures tend to focus on ranchers' individual management goals and decisions in light of change (Lubell et al., 2013; Roche et al., 2015). Much like the adaptive capacity literature, assessments of adaptive decision-making often examine a suite of individual and ranch characteristics — such as education level, operation size, capital, income, and access to information — and how they provide explanatory power for adaptation-related decisions (e.g. Haigh et al., 2021, Lubell et al. 2013). Methodologically, these studies have tended to employ survey data collection and subsequent statistical analysis favoring individual-level analyses over qualitative or mixed-methods approaches. Rangeland social scientists have recognized the need to engage with a wider range of theoretical and methodological approaches, such as the broad body of literature using a political ecology lens, for understanding the cross-scale factors that influence how ranching decisions are made (Reid et al., 2021; Roche, 2021; Sayre, 2004). However, there remains a considerable gap in research that employs these approaches in rangeland SES contexts and provides actionable recommendations for institutional changes needed to support adaptation.

Institutions and adaptation in U.S. rangeland SESs

Institutions can both enable and constrain adaptation responses. In the U.S., formal institutions can limit the flexibility and support needed for adaptive approaches to land management (Benson and Stone 2013). Specifically, research has demonstrated that adaptive approaches have been hindered by "law values" — such as stationarity, certainty and finality -- within U.S. legal institutions, which often fail to account for the changing nature of social-ecological systems, assume predictability of environmental and social outcomes, and default to linear rather than iterative decision-making processes (Benson & Stone 2013; Frohlich et al., 2018; Schultz, 2008). For example, in the U.S. rangelands context, a number of studies have documented how inflexibilities (or 'stationarity') in public lands policy and grazing permitting have limited the use of grazing and other tools for managing wildfire risk, which is expected to increase as a result of climate change (Moseley & Charnley 2014 ; Schultz et al., 2019; Wollstein et al., 2021).

Evidence from studies across disciplines have also demonstrated that there are a variety of other institutional barriers limiting rangeland managers' ability to adapt at temporal and spatial scales necessary in light of drought and climate change (Belsky & Barton, 2018; Brown et al., 2017; Kachergis et al., 2014; Lien et al, 2021; Wyborn et al, 2015). For example, Brown et al. (2017) and others (Smith et al., 2021; Mase & Prokopy, 2014) have highlighted the lack of climate data at fine enough spatial resolution, which hinders the ability of state and regional level agencies (i.e. NRCS and Extension) to provide technical and financial support to rangeland managers in the face of drought. In addition, there is a need for more timely access to information regarding the likelihood of reaching predefined critical seasonal rainfall milestones, within-season rainfall deficits, or multiyear forecasts to support ranchers' decision-making regarding stocking rates, destocking contingencies, expectations of herd and individual-level animal performance, and feed purchases (Lemos et al., 2012; Mase & Prokopy, 2014; Smith et al., 2021). Other institutional barriers include a lack of accessible USDA certified processing facilities and a highly consolidated beef supply chain that is oriented toward the sale of calves destined for feedlots and cattle of uniform size, color and shape (Barnes, 2011; Hendrickson & Heffernan, 2007; Sayre et al., 2012). Many commercial slaughtering facilities will not, for example, process small batches of locally finished cattle or smaller than standard cattle, diminishing opportunities for ranchers to pursue greater genetic variability, such as smaller breeds that thrive during drought or other strategies for diversifying their operations in light of change (Hendrickson et al., 2020; IPES-Food, 2021; Sayre et al., 2012; Woodall & Shannon, 2018).

Contrastingly, there are institutional programs, such as drought assistance and conservation incentive programs, that can enable adaptive management in light of climate change (Belsky & Barton, 2018; Gutwein & Goldstein 2013). Every year, the federal USDA drought assistance program allocates millions of dollars to producers to offset impacts of drought. In 2021, for example, $21 million was allocated to the Natural Resources Conservation Service's (NRCS) collaboration with the Department of Interior's (DOI) WaterSMART Initiative to help farmers and ranchers conserve water and build drought resilience in their communities (USDA-NRCS, 2021).

Other federal disaster relief programs can include emergency loans, grace periods for unpaid insurance premiums, support for moving water to livestock, and access to grazing and haying lands (disasterassistance.gov).

Conservation-related government programs provide additional avenues for ranchers in the U.S. to access financial support for practices that help mitigate risk and/or help support ecosystem function (e.g. watershed health, biodiversity, wildlife habitat) in light of drought and other climate events. For ranchers who derive their income primarily (or exclusively) from livestock-based operations, conservation practices can be an added financial burden. Thus, there have been a range of incentive-based programs developed by the federal and state governments to increase revenue and/or reduce costs. In Montana, these include (but are not limited to) the Montana Sage Grouse Habitat Improvement Program, conservation easements, EQIP, the Conservation Stewardship Program, and the Conservation Reserve Program.

Importantly, the efficacy of institutions in enabling drought and climate related adaptation can depend on *how* institutional programs and policies are implemented on the ground. This area of interpretation within formal rules has been referred to as the “gray-zone” (Christiansen & Neuhold 2012; Landsbergen & Orosz 1996; Wollstein et al., 2021). Wollstein et al. (2021) use this framing in their examination of administrative policies and barriers to using outcome-based approaches to manage wildfire risk on public rangelands in Idaho, and found that differences in the informal institutions (e.g. beliefs about the efficacy of grazing to manage fire risk, and leadership and staff experience) led to different interpretations of latitude found within formal institutions such as NEPA requirements and influenced whether or not BLM field offices explored ‘gray zones’ for OBM implementation. Another study by Brown et al. (2017) found that there is inconsistent adoption and application of ecological site (ES) information across agencies (i.e. Bureau of Land Management, Forest Service, NRCS), thus limiting its utility in providing recommendations and technical assistance to ranchers and rangeland managers in drought response decision-making.

Other studies have highlighted how the relational aspects within the "gray zone" influence the implementation of policies and other formal institutional processes on-the-ground. For example, Lien et al. (2021) interviewed ranchers and Forest Service employees in Arizona and New Mexico and found that implementing adaptive management with the goal of reducing conflict (by allowing experimentation and increasing management flexibility where there are competing viewpoints), hinges on the level of trust between permittees and the US Forest Service. Where trust is lacking, adaptive management may amplify existing conflict (Lien et al., 2021). Similarly, research results from the Collaborative Adaptive Rangeland Management (CARM) experiment, a 10-yr, interdisciplinary project conducted at the USDA Agriculture Research Service (ARS) Central Plains Experimental Range, showed that future collaborative adaptive management efforts will involve investments toward research that promotes trust-building among stakeholders over time and involves commitment to sharing and acknowledge managers' different rangeland management experiences and knowledges (Wilmer et al., 2018).

While ranchers are constantly adapting to a variety of changes in their operating environment, their individual agency is shaped by the institutional context in which ranchers make decisions. Yet, there are very few studies looking at how formal and informal institutions influence ranchers' adaptive capacity and decision-making. To help fill this gap, I examined the ways in which working ranchers in Montana perceive the role of government programs and permits in enabling or constraining their ability to manage for drought and other climate events. Similar to other studies (Head et al., 2011; Yung et al., 2015), the environmental stressor of focus in this study was drought given that it was the most imminent and local climate-related concern for ranchers during this research.

Research Questions and Methods

I used a mixed-methods research approach, employing both quantitative and qualitative methods, to understand the role of institutions in Montana ranchers' adaptive capacity and decision-making strategies as they plan for and respond to drought and other climate events. Specifically, I asked:

1) What government-related programs and public lands grazing permits do ranchers participate in?
2) How are these institutional arrangements enabling or constraining their ability to manage adaptively in light of drought and climate-related events?
3) What changes to these programs and permits could be made to meet ranchers' needs? and;
4) What are ranchers' views related to government involvement in rangeland management more broadly?

Data Collection and Analysis

Montana Drought & Climate Survey

In order to understand ranchers' participation in government programs and their views of government at a state-wide level, we developed survey questions that were included as part of the Montana Drought and Climate (MTDC) project survey (see full Methods section for more details on MTDC sampling and survey development). Figure 5.0 shows the total landholdings of agricultural producers in Montana identified using the FLU, Montana Cadastral, NASS, and MT Landcover datasets from which we drew our sample. Figure 5.1 depicts the MTDC survey sample distribution across Montana counties. The survey was developed using Qualtrics software and disseminated using a Dillman Tailored Design Method (Dillman et al., 2014). First, a pre-survey letter was sent, informing potential respondents that a questionnaire would arrive soon. Second, all potential respondents received a packet containing a cover letter, a hardcopy questionnaire and a pre-stamped return envelope. Third, all nonrespondents received a second packet containing a cover, a hardcopy questionnaire and a pre-stamped return envelope. Fourth, all nonrespondents received a third packet containing a cover letter, a hardcopy questionnaire and a pre-stamped return envelope (Dillman et al., 2014).

To understand ranchers' participation in government programs, we followed the survey question design by Lubell et al. (2013). For six different government programs (EQIP, Conservation Stewardship Program, Conservation Reserve Program, MT Agricultural Research Center/Station Programs, Conservation easements, Carbon credit program), we asked ranchers to select whether they were not aware of the program, aware but choose not to participate, aware and currently participate, or aware with plans to participate in the future (Table 5.0). We also included space a line in the survey for respondents to write or type in the name of "other landscape or watershed conservation program with private, agency, or non-profit partners)" they participate in. Following Lubell et al (2013)'s adaptive decision-making framework with an emphasis on decision-making over time, this question format allows respondents to indicate a range of different behavioral responses rather than just a yes/no question. In order to get a sense for the extent of our sample also involved in negotiating grazing permits with government agencies (i.e. Bureau of Land Management, U.S. Forest Service, State of Montana), we asked ranchers to indicate the percentage (%) of land that is publicly leased (in addition to listing percentage of land that is owned, privately leased, or 'other').

To understand ranchers' attitudes about government support in land management, we asked four Likert-scale questions (1= Strongly Disagree, 2= Disagree, 3= Neither, 4= Agree, 5= Strongly Agree) about their personal experiences with government programs and incentives and about their attitudes on government intervention as a way to support land management more broadly (Table 5.1). We asked ranchers to indicate their political views by selecting one of five options, including "Very conservative," "Somewhat conservative," "Moderate, middle of the road," "Somewhat liberal," "Very liberal," and "Prefer not to say."

Data from questionnaires were codified and entered using appropriate data labels and flags to facilitate analysis. Spot checks on data entry were performed to ensure accuracy. Data were analyzed using three statistical software packages: IBM SPSS Statistics Version 28 (2021), SAS

Version 9.5 (2021) and Statistics Canada's G-EST Version 2.03 (2019). Basic descriptive statistics were used to analyze the responses. 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), nonresponse (nonresponse weight), and calibrates the weights to population totals (Battaglia, et al., 2016; Haziza & Beaumont, 2017; Haziza & Lesage, 2016; Lavallee & Beaumont, 2016; Valliant, Dever, & Kreuter, 2013). Survey weights were applied in the analysis of these data to improve the accuracy of estimates and help to ensure that the survey is representative of the study population.

In-depth interviews

While survey data provided basic descriptive information related to ranchers participation in and social/political values related to government programs, in-depth interviews were the primary data used to understand how ranchers perceived the role of government administered programs and permits in supporting (or not) their ability to manage adaptively for drought and other climate events and what ranchers felt would improve these programs to meet their needs. I conducted in-depth, semi-structured interviews in three regions of Montana, all of which were experiencing drought during the time of the interviews. In total, 30 interviews were conducted with 34 ranchers (3 interviews were conducted with couples and one with input from a ranch employee), including 10 interviews in the Rocky Mountain Front, 8 interviews in Southwestern Montana (i.e. Beaverhead-Madison Counties), 10 interviews along the Billings to Miles City corridor, and 2 interviews with bison ranchers in northwestern Montana. These three areas were chosen in order to capture representation from as many climate zones and major land resource areas across the state as possible while also including slightly more representation in areas of the state where livestock production is most important economically (which are often areas where ranching is an important livelihood socio-culturally as well). Figure 5.2 depicts the geographic distribution of interview sample across Montana Climate Divisions (a) and the geographic distribution of interview sample overlayed on 2017 USDA-NASS data on cattle sales (USD) by county (b).

Participants were purposively selected from a long list of potential interviewees generated through expert contacts at Montana State University (MSU) Extension and other social networks that I have been involved with since beginning this research (Brandenburg & Carroll, 1995). To access a diversity of views and practices, we selected ranchers who varied in age from early 30s to mid-70s, however most were roughly between ages 50–70 and all interviewees were white. Ranchers had different sizes of ranches and different types of operations, enterprises and classes of livestock (e.g., commercial cow/calf operation, direct-to-market niche operations). Interviewees included predominately cattle ranchers (as cattle are the most common type of livestock raised in Montana and dominate the industry in terms of livestock sales (USDA-NASS, 2021), but we also interviewed three ranchers with predominately sheep operations and three with predominately bison operations. All ranchers who were contacted agreed to an interview. Given the small, purposive interview sample, results are not statistically generalizable (i.e., conclusions cannot be drawn regarding the proportion of ranchers who hold the different views described below). Rather, the in-depth interviews provide a window into the range of views among Montana ranchers and builds detailed knowledge of particular case studies (i.e. often stories highlighting specific situations/examples), which in turn informs social theory (Burawoy, 1998).

An interview guide was used to ensure comparability and consistency between interviews (Patterson & Williams, 2002). I began interviews by asking ranchers to describe their ranching operations, their management goals, and the practices/strategies they use to achieve those goals. Then, I asked ranchers questions related to the impacts and perceptions of risk related to drought and/climate events, their plans/strategies to mitigate or respond to risk in the future, what government programs/permits they are involved with, and how those institutional arrangements have helped or hindered their ability to manage adaptively.

Interviews were audio recorded, professionally transcribed, coded in NVivo 10, and analyzed using an iterative process that linked concepts to data through reading and rereading of transcripts, interpretations, and social theory (Layder 1998; Strauss and Corbin 1990). From this process 41 codes emerged, of which the initial codes "social values," "EQIP, CSP, CRP, cost shares," "NRCS, DNRC, MSU Extension" and "Public lands grazing" included data most relevant to this analysis. After the initial coding of interviews, I identified sub-themes and patterns of meaning within and across codes, and organized data accordingly through two additional phases of analysis. The interview excerpts below provide illustrative examples of both the patterns found across ranchers' responses as well as the diversity ranchers experiences participating in government programs and empirical evidence to support the interpretations articulated in this article.

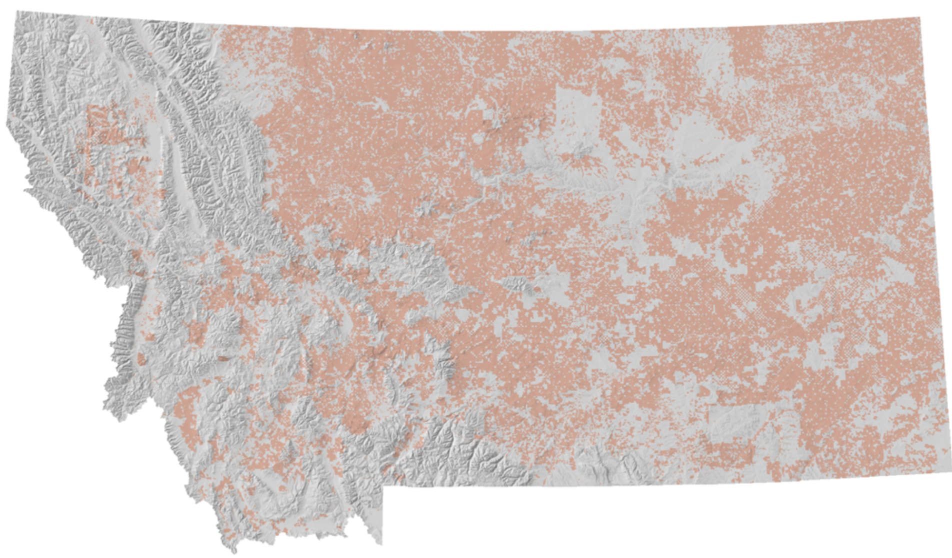


Figure 5.0. Total landholdings of agricultural producers in Montana identified using the FLU, Montana Cadastral and MT Landcover datasets.

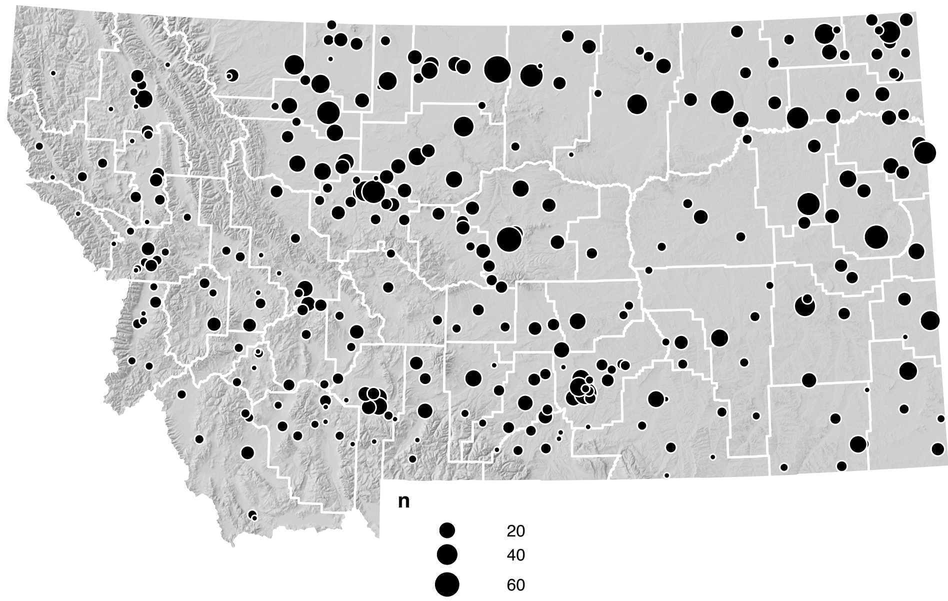
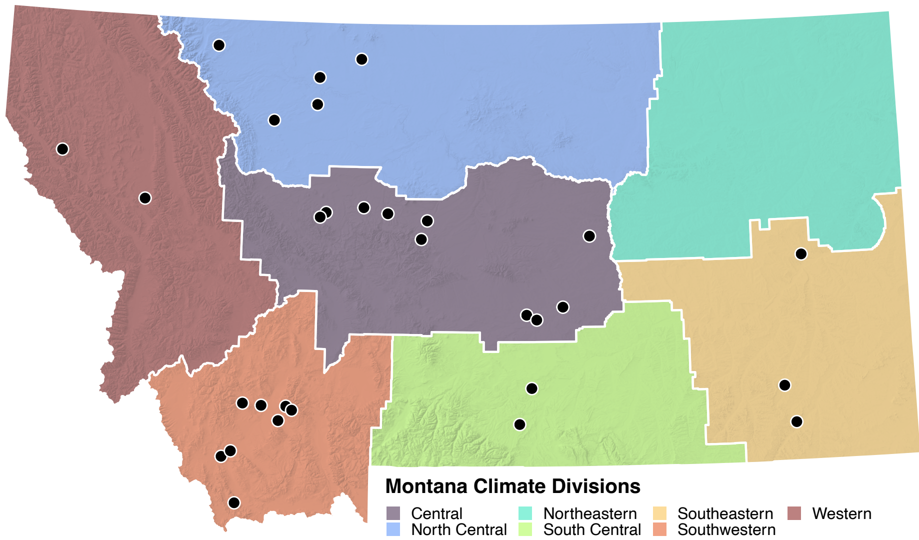
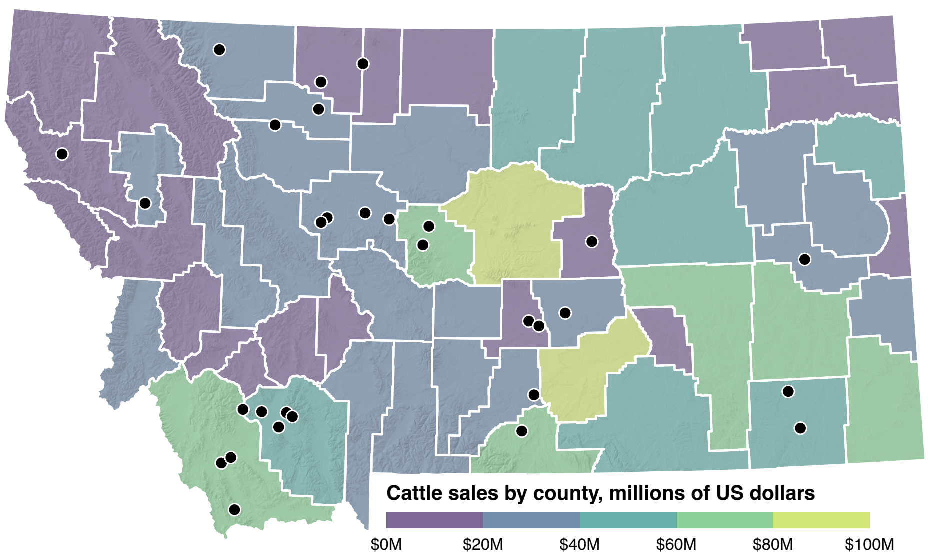


Figure 5.1. MTDC survey sample distribution across Montana counties. Locations of points are roughly centers of ZIP codes associated with each mailing address in the sample.



(a)



(b)

Figure 5.2. (a) Geographic distribution of interview sample across Montana Climate Divisions and (b) Geographic distribution of interview sample overlayed on 2017 USDA-NASS data on cattle sales (USD) by county.

Results

Respondent characteristics

The final survey was delivered to 2,999 addresses, however there were 412 ineligible addresses (i.e. undeliverable, not a farm/ranch, etc.), resulting 2,588 eligible addresses. We received 706 useable surveys, an American Association of Public Opinion Research Response Rate 3 (AAPOR RR3) of 36.7%. Among the survey respondents, 450 self-identified as ranchers or both ranchers and farmers and therefore were included in our sample. At the time of the survey, the average age of respondents 66 (n = 430), slightly older than the national average of 58.6 yr (USDA NASS, 2017) and most respondents were male (77.4%; n = 437). Respondents were generally very experienced with, on average, 42.7 years of experience ranching) (n= 443). Respondents also tended to come from generational ranching families with, on average, three or more generations in ranching (M= 3.57 generations, n = 447). Over 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 in progress. Respondents also relied on ranching as a critical source of income – on average, 73.3% (n= 426) of respondents' total household income comes from their ranching operation.

Respondents tended to operate mostly on land that they own (M= 76.9% of acres owned, n= 434), but private leases (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 made up significant portions of ranchers operations. As one might expect in Montana, ranchers indicated they operate on predominately non-irrigated land, with, on average 14.2% irrigated acres across all land tenure types**.** The majority of respondents included cow-calf enterprises (89.9%, n= 398), but many other types of operations were represented as secondary or primary enterprises. Just under fifteen percent (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 also indicated that they grow crops, with the majority (84.2%, n= 384) reporting that they grow hay, 41.2% (n= 183) grow wheat, 37.3% (n= 162) grow barley, and 16.9% (n= 71) grow pulses (e.g. beans, peas, lentils), 17.3% (n= 71) grow oats. All other types of crops/products we asked about (i.e. buckwheat, corn (for grain or silage), sugar beets, fall potatoes, oil seeds, mixed vegetable/market farm) represented less than 10% of the sample. See Table A1 for all descriptive statistics.

Participation in conservation programs & views on government

For the seven conservation programs we asked about in our survey, we found that there is a low level of awareness for the majority of these programs; between 26% and 53% of respondents were unaware of (and have not used) these programs. Among the ranchers who are aware of a particular program, more do not participate than currently participate. And, for all programs, among those who are aware of the initiative, few (less than 10% in most cases, except EQIP with 13.2%) have plans to participate in the future (Table 5.0).

Among ranchers who responded to the survey, 63.3% (n= 269) consider their political views to be either somewhat conservative or very conservative, 22.4% (n= 99) have moderate or 'middle of the road' views, 5.0% (n= 25) have somewhat liberal or very liberal views, and 9.3% (n= 38) preferred not to say. The majority of respondents (68.6%, n= 305) agreed or strongly agreed that government programs have helped farmers and ranchers, yet over half of respondents agreed or strongly agreed (62.0%, n= 273) that government intervention on private land management is unnecessary. Respondents were split almost equally on whether they agreed/strongly agreed (27.5%, n= 127) or disagreed/strongly disagreed (30.6%, n= 131) (41.8%, n= 172, responded neither agree/disagree) with the statement "I'm not interested in government incentives because they give government power to limit my activities." There were also almost equal numbers of respondents who agreed/strongly agreed, disagreed/strongly disagreed, and were neutral to the statement "In the future, government incentives will be the best way to improve voluntary conservation on agricultural lands" (32.5%, n=144, disagreed/strongly disagreed, 32.9%, n= 140, were neutral, 34.6%, n= 149, agreed/strongly agreed) (Table 5.1).

Table 5.0. Conservation program participation among ranchers

Item	I am not aware of this initiative and have not used it	I am aware of this initiative and unable to participate	I am aware of this initiative and currently participate	I am aware of this initiative and have plans to participate in the future	Mean Estimate (SE)	Unweighted Count (n)
EQIP	30.7%	31.7%	24.4%	13.2%	2.20 (0.062)	389
Conservation Stewardship Program	40.1%	37.2%	15.8%	6.9%	1.90 (0.057)	375
Conservation Reserve Program	26.5%	54.6%	16.2%	2.7%	1.95 (0.045)	379
MT Agricultural Research Center/Station Programs	45.8%	34.4%	11.1%	8.7%	1.83 (0.059)	390
MT Sage Grouse Habitat Conservation Program	49.39%	41.8%	5.8%	3.1%	1.63 (0.042)	399
Conservation easement	35.6%	51.5%	7.6%	5.2%	1.82 (0.050)	386
Carbon credit program	53.0%	35.3%	1.7%	9.9%	1.69 (0.057)	389

Table 5.1. Ranchers' views of government involvement in rangeland management

Item	Strongly Disagree	Disagree	Neither	Agree	Strongly Agree	Mean Estimate (SE)	Unweighted Count
Government programs have helped farmers and ranchers	3.0%	4.7%	23.7%	55.8%	12.8%	3.71 (.048)	437
I'm not interested in government incentives because they give government power to limit my activities	5.9%	24.7%	41.8%	22.1%	5.4%	2.96 (.053)	430
Government intervention on private land management is unnecessary	1.2%	12.9%	23.9%	41.0%	21.0%	3.68 (.056)	432
In the future, government incentives will be the best way to improve voluntary conservation on agricultural lands	10.2%	22.3%	32.9%	28.9%	5.7%	2.98 (.061)	433

During in-depth interviews, ranchers readily offered examples of how both flexibility and inflexibilities in programs and permits influenced their ability to manage adaptively for drought and other climate-related events. The following section is organized in to four themes that emerged:

Theme 1: Inflexibilities in formal government programs and permits limit adaptative management tailored to local conditions

Many ranchers provided examples of how rigidities in the criteria or "terms" for participating in government programs posed barriers for adaptive management tailored to their local conditions. Three stories (Data Box 1) told by ranchers during interviews illustrate how the specifications of government administered cost-share programs for fencing and water development projects "don't fit the environment and the landscape" or don't work "on the ground," limiting their utility. For instance, one rancher (A) described a cost-share program in which the criteria for building fence were such that it wouldn't "hold up" or "have a long life" given the wildlife movement or the heavy snowfall on their ranch. Another rancher (B) described that in order to be better prepared for drought, they wanted to participate in a cost-share program to develop a new water holding system to promote better grazing, but that their proposal "didn't qualify" and the specifications of the water tanks that fit under the program would not "do any good" because they were too small and not made out of long-lasting materials. In addition to rigid specifications for equipment and materials, one rancher (C) described how, from their perspective, government programs aren't channeling resources toward supporting practices or systems ranchers already have in place to be adaptive. Instead, the programs are "valuing change," creating more work, and sometimes, from this ranchers' view, encouraging poor management. This rancher provided an example of a government program their predecessor participated in to fence off a riparian area, which forced them into overutilizing another pasture, which they described as a "bad practice." The rancher expressed that, while this program may have made sense "in somebody's office someplace, […] when you get out here on the ground and go to plug that equation in, it doesn't make any sense."

Other ranchers described how they have stopped participating or "shied away" from government programs because they don't create grazing plans that work for their specific operation. For instance, one rancher expressed how, when working with the NRCS, the agency wanted "to move cattle on their schedule and according to their timeframe and not necessarily what worked for our cattle." Another rancher described how when working through the EQIP program to build cross fences or water lines, the "rules and regulations or how they want things done are just not right most of the time" and that it is often "cheaper to do it yourself without their input" or that when you do participate "you've got to go back and redo it because the way they do things just doesn't work." This rancher has decided that they will continue managing in their way "and if it fits [their] program and you want to pay me for it, that's fine. If not, that's fine also."

While many ranchers described the barriers posed by inflexible or one-size-fits-all program specifications, a few ranchers suggested ways to reduce these constraints. One rancher (A) expressed the need for having "some sort of feedback loop […] for those program agents and those people who administer those programs" so that they could describe to agency representatives "here's why I put this fence how I do, or here's why we make the tanks the way we do. Here's the pros, and here's the cons." Another rancher felt as though programs would be better if they were developed from "a producer's standpoint" from the very beginning, suggesting that the government could have "an old, retired rancher that had been successful for a number of years to weigh in before they sign, or help write the dang things."

Data Box 1. Formal institutional factors shaping adaptive management — spatial considerations.

(A) Okay, so like, they tell you how you can build your fence…[…] Spacing. and how many wires, and how high, and all of these things, right? That doesn't account for terrain. It doesn't account for wildlife patterns. Doesn't account for heavy, heavy snowfall. It's not adaptive. It's like, if you want us to pay for it, it has to be to these specs. It's like, well, but those specs in this environment, in this landscape aren't necessarily the best suited. Well, these are our specs. It's like, okay, so do you do it, and waste the money and the project, knowing that that fence, for example, isn't going to hold up or have a long life because it's built to specs that don't fit the environment and the landscape? […]

(B) Well, for drought. I know one thing I want to do. I got a leased place over here and the government offered to help 75% to repair a failed system. But what I want to do is... technically in my mind it was failed. It's just water running down, but you needed a collection box and build a spring box and everything. That is repairing that, but that didn't qualify... I'd like to put in some spring boxes and water troughs in a pasture and they would do better grazing on that side hill... it's a big long side hill. They'd graze it better. And it would be better for everything. They'd have a good water supply. Otherwise, it wasn't... and it didn't qualify […] when they first started doing tanks, redoing tanks, they had a little concrete tank and put that in, but that's not good because it'll only water maybe 50, 60 cows where you put in a big water tank, a big tire, you can water 100 cows out of that. Well, they would cost share on the whole thing, but concrete tanks was about the only thing you could get at that time. Or you could get a little metal tank that would rust out in two or three years. And so you went to the concrete tanks and they're just not enough water volume in there to do any good

(C) Those programs aren't set up so that they value what people already have going, instead they're valuing change, but if you don't need to change- […] It's entirely infuriating for most of us. Basically, if I were to get myself involved with those, I would have to hire an employee. Not because I can improve the production on my ranch, just to deal with the government.

Case in point, my predecessor, he put a fence along the rim up here to fence the riparian off, but that was the source of water for my cows to drink out of. And they spent a whole bunch of money developing a couple springs that don't run enough water to water cows, no matter how much money you pour at it. And so essentially, it just fenced off a whole bunch of acreage that is not very

> usable. And now, it forced me to use that one pasture the same time of year, every year, which is a bad practice. Because that's the only time there's enough water in those springs to keep the tanks full enough that I can water cows. […] So yeah. They paid my predecessor a bunch of money to do that, to build this fence, but it actually created a problem for me and forced me into being a bad manager. Where, if we didn't have to follow the guidelines, and we could have fence in a water gap at the creek, then yeah. That would've been more practical but that didn't fit the piece of paper in the form.[…] It makes sense in somebody's office someplace, but when you get out here on the ground and go to plug that equation in, it doesn't make any sense.

Theme 2: Slowness and inefficiency of formal government program implementation limits timely management responses (to drought in particular)

Many ranchers expressed that government programs were too slow, inefficient, or cumbersome to assist them with the short-term impacts of drought or to help them make changes to their operations to adapt to longer term drought and climate events. Ranchers consistently said that the "strings" attached, the "hoops you got to jump through," or the number of regulations made it so that they questioned whether programs would support them in making timely changes or if it would be worth it or not to, as one rancher put it, "waste my time for a few bucks here and there."

One rancher (A) shared that, on their ranch, in order to manage in a way that is "beneficial to the land" in light of drought they need to graze different pastures every year — and to be able to get water to those pastures — across public and private land boundaries. However, they expressed that if they tried to use NRCS cost-share funding to get a water pipeline for water that goes across BLM leases, it would "take too long to get them on the ground" limiting their ability to manage well. In addition to the barriers for getting water to necessary pastures, the rancher described that the authorization process for them to be able to graze for different periods from year to year on their lease is inefficient, taking many months to get approval because the permit they have is not set up for that kind of flexibility.

Another rancher (B) described how all of the "technical aspects" that accompany programs, such as NRCS will cost-share projects, make it so that the cost of the project is cheaper if they do it all themselves. Other ranchers echoed this sentiment:

> So the regulations don't make it illegal to do this...[…] They make it impractical. And a lot of the same thing has happened on our Forest Service leases. In the BLM lease and things like that, they don't make it illegal, they just make it so it's just not worth it. And everybody's just like, "Ah, nah. Just bag it." You know?

A few ranchers lamented about how the government processes have gotten slower since the 1980s and 1990s. One rancher commented on how, in the 80s and 90s, "things happened quickly and there weren't many strings. And we got an awful lot done pretty efficiently." Another rancher recalled how, in the 90s, "it would take a year for us to plan a project and implement it. And now it could be 10 years." A third rancher expressed how they felt that the slowness of government processes is the result of increasing litigation against government agencies:

> It's political. Most of the beginnings of the rotational grazing that we put in were when I came home from college in 1982. And at that time, the Bureau of Land Management and the NRCS were incredibly helpful at putting in cross-fencing and water development and all kinds of things. And now the Bureau of Land Management is... It's really hard to get anything positive done. And a lot of that has to do with the lawsuits that get filed against them, that limit just about everything you can do, positive or not.

Some ranchers saw the amount of paperwork involved in government programs as problematic, commenting that it makes participating "a challenge" and that the application processes could be "more streamlined." One rancher expressed that they don't participate in the Conservation Stewardship Program because there is "a little a little too much bookwork involved" for them to be interested. They went on to say, "We do EQIP things now, but we don't want to fill out the paperwork. And then comes to things just not being so tight anymore." Another rancher suggested simple changes such as providing more online applications "would be huge" in terms of lowering the barriers to participation, providing the example of an FSA program that they wanted to be involved in "but you can't click here to apply."

Data Box 2. Formal institutional factors shaping adaptive management — temporal considerations.

(A) And then the same, we've gotten NRCS funds […] to do water development. And the same thing for their funds have to be used in a certain amount of time. So if we're going to go across BLM with a pipeline, we can't use those funds because it'll take too long to get them on the ground. […] So our place is about half public land and half private land. And so when you're trying to manage across both and you can't put a pipeline to get a water trough, that limits how well you can manage those pastures because you can't get them water on one whole end…[…] So both for drought reasons, but also just for general management reasons. And then we do the same thing for them. We built a cross fence that had already gotten approval from the previous landowner, but now every year we have to ask for a different period of grazing in what had been one whole pasture. So every year we have to get that authorized. Would be nice to not have to do that. And it's not a big deal. They sign off on it. But it's because it's beneficial to the land to do it with a different period of use than what permit is actually for. We have to do it every year and sometimes it takes many months to do that.

(B) There was a really good program that got put together by a little focus group in [name of County] County about changing out windmills for solar. But the strings that accompany this change, we can afford to install the solar ourself cheaper than we can participate in a program. […] A lot of times, the NRCS will cost-share projects. And one project will turn out to be the project from hell where things go wrong. And so they put in all kinds of new rules. There's a thing called a state technical committee. And I don't get in on these very much. It's really hard to listen to, but it's important because they put down all the hoops you have to jump through, and technical aspects that accompany each type of project. Well, there's no incentive for them for things to be less technical.[…] So they just add things. And pretty quick, the list of hoops you have to jump through to do a project is so big that you just say, "Shit, I don't need to do that."[…] Since these hoops have accrued slowly over such a long period of time, I don't know how the hell you would dismantle it. There's no incentive to scale things back. Because each one of those little rules that got put in place, there was a reason. It wasn't stupidity.

Theme 3: Relationships with local government agency representatives influence formal government program implementation (Factors in the "Gray Zone")

Ranchers consistently described how the efficacy of government programs hinges on having working relationships with local agency representatives (i.e. Range Conservationist with the Forest Service, Range Management Specialist with NRCS, etc). During one interview, before I could finish asking the question, "What changes to government programs, policies, regulations, would enable better adaptive management or response to things like drought and other..." one rancher responded without hesitation, "Partnerships. Get those folks back out on the ground, working with us. Let's work as a team." Another rancher readily shared their feelings that:

> A lot of it boils down to the person on the ground, and the office, the area office. And what comes down from up on top too. […] Because we've had, oh, four or five, six different range cons. And the last to have been not very good. And then the one we have now is fantastic. He came in years ago and he says, "Let's go up and look at this." First time that somebody's said that. And so, we went up and I showed him some of the problems, and some of the things that we'd like to work on, and what we have done, and so forth.

One rancher (A) shared a similar story about how they have had flexibility to experiment with higher stock density on their public land grazing permit as a result of the collaborative relationship they had with the "field guy" who was willing to work with them to implement a monitoring program to see how the change was effecting the range over time (instead of simply saying 'no'). By providing third-party monitoring data, this rancher was able demonstrate that they are holding themselves accountable for not only doing what works best for them, but also for the interests they share (with BLM) around improving metrics for the health of land and wildlife. Other ranchers responded with very similar answers, noting that, for government programs to be a win-win for ranchers (and agencies) both, "It really depends on the people on the ground that make it work. If you don't have the right person on the ground, it doesn't work.[...]." Some ranchers expressed that working relationships involve effective communication that involves active listening and feedback. One rancher commented that it is "really good to be able to talk to somebody, and have them come out and say, "No, you need to do this," or, "Let me find out about that." Another rancher shared that working with Extension services and people is positive in their small community because "they'll come right to your place and talk to you, you know?"

Ranchers expressed how the implementation of programs and permits, specifically whether they are adapted to fit local rangeland conditions and whether they are implemented in a timely manner, depends on their local agency representatives. One rancher (C) described how having right "person on the ground" involved having a BLM or Forest Service representative who would work with them to adjust “standards that work across the board” to fit “local conditions.” They acknowledged that while it “is happening,” it “depends on the person on the ground, and it doesn’t happen everywhere.” Another rancher (D) described how, despite having “fair flexibility” with their grazing, they struggled to work with their BLM field office to get approval for a temporary water trough in order to respond to drought conditions in the short term and to develop water for optimal management in the long term. Given their anticipated timeline of nine months for approval on the temporary water trough, they were resigned to hoping “in nine months we’re not in a drought anymore.”

In contrast, other ranchers have had negative experiences working with government agency representatives, and expressed that they feel misunderstood and due to a lack of on-the-ground, collaborative decision-making. One rancher commented that there was a disconnect regarding basic management goals and values between them and agency representatives, saying that they “just don’t seem to understand what I’m trying to do and they can understand they’re worried about... To me, they’re not worrying about the same things that I worry about.” Similarly, another rancher expressed that one of their biggest problems with regard to managing adaptively for drought was a lack of cooperation from their Forest Service ranger, who “can’t get his mind around all this management” because, the rancher felt, they lack knowledge about grazing given that they don’t have formal training in the field. This disconnect put the rancher in a “tough spot” for making what they felt were the best management decisions. Ranchers also expressed that agency representatives did not make time for engaging in collaborative work on-the-ground:

> If the agency people could come out and actually look at the land and come up with the grazing plan with the permitee, rather than just saying, "You come into the office, and you sign these papers, and this is just the way it’s always been.”

Data Box 3. Factors in the Gray Zone shaping adaptive management

(A) Oh, we just have huge flexibility. But we've had to earn it because we have to have third party monitoring. We have to give them a grazing plan every year. We have to give more actuals every year. And we're a little bit of a pain in the butt because the billing and stuff is a lot more complicated. But we've been doing this with them for over 30 years and early on, I think they were very doubtful with this high stock density. They didn't really believe in it. But there was a really good field guy at the time that was willing to work with us. And we made a lot of mistakes, but the data shows that […] The riparian areas are much more healthy, there's less bare ground. It's more diversity. We monitor for wildlife. […] So you have to get the flexibility and you have to be accountable. And I think this is a big question with people doing new stuff is that you just can't tell them you're going to be cool and you're going to do it right. You have to measure what you're doing.

(B) Right now we've got a forest ranger that's a [type of specialization] biologist. I don't think a [type of specialization] biologist is ever qualified to be a forest ranger on a district that is one of the biggest grazing districts on the [name of national forest]. He can't get his mind around all this management. He thinks it's devastating. That's our biggest problem. We can't get any cooperation from this guy. He doesn't understand management, so he's afraid he's going to get sued all the time. We're in a tough spot here.

(C) And unfortunately, some of the standards that the BLM have, and I don't know if it's Forest Service too, but on our particular allotment, on the property up there, be it private or BLM, there is ground that takes three acres per cow per month, and then there's ground that takes 10 acres, or 15 per cow per month. They don't see that. They see it is an average of five acres per cow per month, instead of taking the individual pastors into account, that are like this, and all rock. […] So I mean, some of that... And when you're working with a big entity like the BLM, they have to have certain standards that work across the board. But then they also need to adjust for local conditions. […] Some of that is happening, but that depends on the person on the ground, and it doesn't happen everywhere.

(D) I think a lot of the policy things with the BLM come back to just your relationship with the field office. Yeah. And I feel like we have fair flexibility in our grazing, but specifically we asked about putting a temporary water. There is a water trough in the pasture, but there's only one, the rest of it is usually reservoir water. And so we wanted to add another trough next to the road, next to the county road, right here. And it takes nine months to get approval for a temporary water trough. So hopefully in nine months we're not in a drought anymore. And that's an annual thing. So every year in October, should we ask for approval for temporary water that we may or may not need? […] Which is not as big of a deal on our end as it would be for the BLM to go through all of the clearances needed every year for something that we hopefully only need one in 15 […] we have a really extensive water network, but the place that we bought does not and we would like to add water. But one pasture, same thing as almost all BLM, and so if we want to get water to one side of it, it's a five year approval process….to get a water line approved. So we're like, "We'll probably just figure it out where it's not optimum, but we'll put it on private land somewhere else." Which I think defeats the purpose too. It takes so long because they're being so careful for all of the different wildlife species for the most part is why it takes so long. So then if we're all just doing it on private land to avoid that, we're maybe not thinking about the wildlife species as a conservation across the landscape.

Theme 4: Ranchers' views on government intervention in rangeland management influences program participation

Ranchers described how their views on independence, autonomy, and self-reliance influenced their perceptions and use of government programs. Many ranchers expressed anti-government sentiments, describing how they feel that "government's never the answer," that they are not "looking for more government" (B) or that the government needs to get "the hell out of the way." One rancher said, "the worst news I can get is, 'Hi, I'm here from the government. I'm here to help you.' I'm like, 'Oh no.'" Some ranchers also commented on how they are "all pretty proud and don't usually like taking the money," don't like "taking advantage" of government programs, and feel that they should "stand on our own feet and be responsible for ourselves." One rancher (C) expressed how, given the slowness and inefficiencies within the government "to really do any good," taking away government programs so that ranchers needed to do things on their own "wouldn't be bad." Another rancher shared their views regarding government programs, saying, "I kind of come from a conservative old school. So when they're throwing money at you, I think, whoa, it's got to... they throw money everywhere. Someone's got to pay it back sometime."

At the same time, many ranchers expressed the tension between wanting to be self-reliant and feeling as though they needed to participate because of the competitive system they are part of. One rancher expressed how, while his wife doesn't want them to participate in programs because "she doesn't think that we need it and there's others that do," he feels that "if we don't do it, then ExxonMobil will do it. And Delta airlines does it, and JBS the packing plant does it, there's a finite amount of money that's being thrown out there and if we don't scoop up ours some corporate monopolies is going to scoop it up." Another rancher felt that, despite not usually participating in programs, that this year with drought and COVID assistance available, "that thought changed a lot and people are like, "Well, it's out there. If we don't take it, it's going to go to something else." A third rancher expressed their hesitation with taking government money, saying how they don't often spend time “worrying about government programs” but that “every once in a while it’s nice to check it….like COVID….Okay, I’ll take it.” One rancher (A) described the tension as “a dichotomy” between feeling, on the one hand, as though ranchers should “be responsible for ourselves” and not wanting to take “so-called free money.” On the other hand, given that the farming/ranching community is “in competition with each other,” they will put their “conservative ideals aside” and “apply for everything there is.”

Data Box 4. Ranchers views on government influence their decisions to participate in programs

(A) So, that’s a dichotomy. I think we should all stand on our own feet and be responsible for ourselves, but I’m the first one at that FSA office to get any payment that comes down the pike.[…] I don’t feel particularly good about taking that so-called free money. That’s your tax money. But whether I like it or we as a farming/ranching community likes it, we are all in competition with each other. If my neighbor gets a $40,000 payment for whatever and I get all high-minded and say, "No, I’m not doing it," then I’m an idiot. So, I put my conservative ideals aside and go over there and apply for everything there is.

(B) Well, in my mind, government’s never the answer. So I’m not really looking for more government. I like when people have incentives to solve problems, or to produce, or to become more efficient. I think it’s amazing what they achieve. But I’m not looking for more government.

(C) I have a philosophical problem taking advantage of some of these programs. But it also, if you don’t, you’re at a disadvantage. […] And a lot of times, the government works too slowly too late to really do any good. But I’m also of a mind that if you took away all the programs, it wouldn’t be bad. And make it more of a you need to do it on your own.

Discussion

Following the call from a number of scholars for additional research examining how individual adaptation interacts with social, economic, and environmental forces at multiple scales (e.g., Briske et al., 2015; Vincent, 2007; Whitney, 2017; Yung et al., 2015), our study shows how ranchers’ adaptive capacity and adaptive decision-making contexts — or their ‘‘adaptation envelope’’ (Wyborn et al., 2015) — is shaped by both individual and institutional level factors. By examining if and how ranchers engage in conservation-related government programs, we demonstrate how institutions, both formal and informal, influence ranchers’ ability to manage for and adapt to drought and climate change. In the following section, we discuss aspects of formal institutions, elements within the gray zone, and their interaction of with individual-level factors that influence ranchers' adaptive management strategies. We provide recommendations for future research and policy efforts based on our findings.

Addressing the 'means' of institutional change to support the 'ends' of adaptive management

Our results demonstrate the need for institutional programs and processes that more effectively support ranchers' adaptive management. Ranchers described how inflexibilities in government programs and permits do not encourage adaptive management strategies that are tailored to specific places, contexts and conditions and how slowness and inefficiencies in government programs limit timely adaptive management responses. Our findings, which highlight that structures influence individual-level adaptation responses, align with a growing awareness among adaptation scholars that institutions are important factors shaping the adaptive capacity and behaviors of individuals, households, and communities (Agrawal, 2008, 2010). Agrawal (2010) argues that institutions have always acted as ''the fundamental mechanism through which communities adapted in the past to climatic variability and they will be the primary mechanism mediating adaptation to climate change in the future.'' Yet, while studies may acknowledge the importance of institutions in adaptation processes (e.g. Adaptation, institutions, and livelihood (AIL) framework developed by Agrawal & Perrin, 2009), they tend to lack the specificity needed to address the mechanisms of institutional change that would encourage desirable adaptation outcomes. In other words, as Dovers & Hezri (2010) argue, the main purposes (the 'ends') of policy and institutional change to enable adaptation are often mentioned, but there is a need for the identification of actual and/or possible reform options (the 'means').

Following this call, in the context of U.S. rangeland SESs, we ask; what 'means' or mechanisms within government programs and permits are needed to facilitate the 'ends' of adaptive management? What possible reforms to programs would encourage desirable social-ecological outcomes while maintaining enough flexibility to account for differences in climates and contexts? What institutional changes are needed so that government programs and permits can address the temporal scale (or timeframe) at which management decisions need to be made in the face of rapidly changing and, at times, unpredictable climatic conditions? And, what changes could be made to programs (e.g. cost-share programs for water development) so that they are *designed* from the very beginning with place-based adaptation in mind?

Based on our findings, three key themes emerged as necessary 'means' to enhance government programs for enabling adaptive management: 1) increasing flexibility within government programs to allow ranchers to achieve desired outcomes in ways that fit their operations and local conditions and; 2) the need for participatory design approaches when developing programs intended to assist ranchers and; 3) the need for collaborative, working relationships between ranchers and government representatives in order to navigate the gray zones of program and policy implementation on-the-ground.

1) Increasing the flexibility of government programs and permits to support timely and locally adaptive management responses

Ranchers consistently described the need for government programs and permits that have eligibility requirements and criteria for participation that are flexible enough so that they can implement changes to meet their needs while also addressing concerns that are priorities for government agencies. Many ranchers described how one-size-fits-all program specifications and rigidities in the terms of participation weren't conducive to desirable outcomes for anyone — rather, inflexible criteria for planning, design, materials, equipment, installation, and so on, often presented barriers to adaptively managing land and water resources in light of drought and climate change. Scholars agree that core tenants of adaptive management include management flexibility and feedback mechanisms that promote iterative learning and adjustments from previous management actions to improve future decisions and outcomes (Derner & Augustine, 2016; McCord

& Pilliod, 2022). Thus, for government programs to support adaptive management, it is critical that they incorporate avenues for flexible management and feedback mechanisms for tracking outcomes over time. Recognizing this need, the BLM recently developed the Outcome-Based Grazing demonstration initiative to increase the flexibility of public land grazing permits to account for changes in weather, forage production, effects of fire or drought, and other aspects of ecological variability. This project offers options to livestock operators seeking greater flexibility to respond to the changes in forage condition and productivity from season-to-season instead of following a fixed, prescriptive plan. In order to ensure that habitat and vegetation goals on BLM land are met, permitees who participate in the program develop cooperative monitoring plans to track these outcomes. This program, while in its infancy, could provide an important example for other government programs to move toward being more 'outcome oriented' — where robust monitoring is used to track progress toward ecological goals on private lands, while allowing greater flexibility on the means to achieve them. For example, EQIP, a cost-share program of USDA's NRCS, supports producers interested in improving natural resources with practices that promote soil health, water quality, wildlife habitat development, invasive species management, and so on. Ranchers described EQIP as having rigid guidelines regarding *how* projects are designed and implemented — guidelines that could be loosened, but with monitoring protocols added, giving ranchers more discretion (and creativity) to implement solutions that work for their ranch while also meeting shared goals.

Developing government programs and permits that provide ranchers with increased flexibility and authority to drive management decisions rather than follow prescriptive instructions also aligns with ranchers' views regarding government involvement in land management. Many ranchers in this study characterized ranch management as an individual endeavor, describing that they didn't want "government interference" and that they would prefer to be self-reliant. This antigovernment rhetoric is consistent with other studies examining factors related to conservation- and adaptation-related practices among ranchers in the U.S. West (Lubell et al., 2013; Yung et al., 2015). At the same time, some ranchers explained that they enroll in programs even despite negative views of government or a lack of trust in the government because it is a strategy to augment their income, offset costs, and risk buffer (providing counter examples to Lubell et al. 2013's findings). The tension that ranchers described between feeling that government programs have helped in supporting desirable adaptation while also feeling as though they want autonomy when it comes to land management could be eased by programs that turn more of the decision-making authority around *how* objectives are met into the hands of ranchers while ensuring that they are indeed met through monitoring methods that track agreed upon ecological metrics and indicators.

2) Increasing opportunities for ranchers to participate in the design and development of government programs

In this study, we found there are low rates of participation in government programs among Montana ranchers and that, for many ranchers, their lack of interest and involvement was because programs often aren't designed to accommodate their individual goals, operations, and/or local conditions and contexts. Moreover, ranchers expressed that the efficacy of government programs intended to support adaptive management can hinge on whether or not local government agency representatives were willing (and able) to work with them to identify ways in which program resources could be tailored to fit their needs. In order to address some of these constraints, we argue that there is a need for more opportunities for ranchers to participate in the design and development of current and future government programs. The need for collaborative, deliberative, and participatory approaches for developing and implementing effective adaptation strategies that involve multiple stakeholders is well-documented in the adaptation literature (Brown et al., 2015; Wilmer et al., 2018; Wyborn et al., 2015). The focus of this literature is most often at local scales of engagement, however we posit that there is a need for participatory approaches in the development of institutional responses at scales from the local up to state, regional, and national levels. According to Dovers & Hezri (2010), participatory policy design involves three dimensions: (1) strategies for direct community participation in local management and implementation; (2) public participation in broader policy and institutional changes that will shape those activities; and (3) participation in the production and interpretation of scientific and other knowledge. In the context of U.S. rangeland management, we argue that all three of these dimensions are needed to develop programs that support adaptation strategies and work for ranchers and rangeland managers.

In Montana, there is a need for research that documents existing mechanisms for ranchers to participate in policy and program development, examines if and how they are effective, and suggests improvements for more meaningful engagement. For example, one avenue for ranchers' perspectives to be integrated into broader policy and institutional change is through the Rangeland Resource Committee. The Committee is composed of six ranchers located across the state and appointed by the governor and provides guidance and feedback to the Rangeland Resources Program of the Montana Department of Natural Resources and Conservation (DNRC). In addition, the USDA's FSA has Local County Committees that were formed to provide producers with opportunities to shape decisions about how federal programs are administered locally. However, based on our findings, there seems to be an ongoing need for more (or more meaningful) opportunities for participation and feedback on program development and implementation, particularly with regard to programs administered at the federal level by USDA's NRCS (e.g. EQIP, CSP) or the Farm Service Agency (e.g. CRP). An important avenue for future research might be to investigate how existing mechanisms for engaging ranchers in policy and program development function in order to inform the development of future participatory approaches for developing climate adaptation programs for ranchers.

3) A focus on effective communication and collaboration to improve factors in the 'gray zone' of government program and permit implementation

In our study, gray zones — where formal administrative tools (e.g. terms and conditions for grazing permits or cost-share programs) meet informal institutions (e.g. relationships, social norms) — influenced if and how ranchers were able to use programs and permits to leverage or augment their ability to manage effectively for drought and other climate related events. Specifically, informal institutions — including relationships between Forest Service or BLM agents and grazing permittees, their experience and expertise in rangeland management, and knowledge of local conditions ranchers histories of land management stewardship — influenced whether a field office worked with ranchers to explore and navigate through gray zones collaboratively or not. While agency personnel may work within the same regulatory framework for determining the stipulations of programs and public land grazing permits, ranchers expressed that there were differences among agency representatives in their willingness to integrate ranchers knowledge of local conditions and ideas for grazing management. In other words, while some agency representatives were willing to expand gray zones, others restricted them, thereby influencing adaptive approaches to management. Our findings are consistent with other studies that have highlighted the influence of government agency culture, including the interactions of beliefs about resource use and willingness to experiment, for enabling or constraining adaptive management (Frohlich et al. 2018; Koontz & Bodine 2008; Wollstein et al., 2021).

While our results confirm the well-documented tension between adaptive management of dynamic natural systems and rigid regulatory structures and administrative law (Fischman & Ruhl, 2016), they also highlight areas within the gray zone where this tension may be eased. Consistent with Wollstein et al. (2021), our study shows that when positive relationships exist between ranchers and local government agency personnel, gray zones can be used to develop desirable, and "win-win," social-ecological outcomes. When these relationships aren't present, the body of scholarship on collaborative adaptive management highlights the importance of participatory processes in increasing coordination between ranchers and agencies for reducing the impacts of drought and increasing resilience (e.g., Fernández-Giménez et al., 2019; Wilmer et al., 2018). Specifically, relationship-building might involve increasing transparency around the terms, criteria, or prescriptions related to government programs and grazing permits as well as trainings for agency personnel on effective communication, including active and humble listening. This might address the need that ranchers expressed in our study regarding the desire feel heard and for their local expertise and place-based knowledge to be recognized, valued, and integrated into grazing permit or cost-share project development. An emphasis on fostering active and humble listening among agency representatives would also align with findings from other studies (e.g. Wilmer et al., 2018) suggesting that successful collaborative rangeland management will involve the recognition and integration of multiple knowledges among stakeholders as well as the development of trust among partners.

Conclusion

This study builds upon existing research on adaptive capacity and adaptive decision-making in rangeland SES contexts. By examining how government programs and permits influence adaptive management strategies for Montana ranchers, we demonstrate the important role of institutions in both enabling and constraining ranchers' adaptive capacity and decision-making across both public and private U.S. rangelands. We found that the inflexibilities and inefficiencies of government programs and permits constrained ranchers ability to adaptively manage for climate events such as drought. In addition, we found that there are important interactions between formal and informal institutions, such as the relationships ranchers have with local agency representatives, that influence government program implementation on-the-ground. Highlighting the institutional factors shaping ranchers adaptation processes we hope will prompt future research and policy efforts aimed at developing government programs and permits that enhance ranchers' ability to adapt to complex and changing conditions.

References

Adger, W.N. (2006). Vulnerability. *Global Environmental Change, 15*. 268–281.

Adger, W. N., Arnell, N. W., & Tompkins, E. L. (2005). Successful adaptation to climate change across scales. *Global Environmental Change*, *15*(2), 77–86. https://doi.org/10.1016/j.gloenvcha.2004.12.005

Adger, W.N., Agrawala, S., Mirza, M.M.Q., Conde, C., O'Brien, K., Pulhin, J., Pulwarty, R., Smit, B., & Takahashi, K. (2007). Assessment of adaptation practices, options, constraints and capacity. In M.L. Parry, O.F. Canziani,J.P. Palutikof,P.J. van der Linden,& C.E. Hanson (Eds*.), Climate change 2007: Impacts, adaptation and vulnerability.* Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, England, pp. 717–743.

Agrawal, A. (2008). The role of local institutions in adaptation to climate change. In: International Forestry Resources and Institutions Program, Working Paper, # W081-3. MI: University of Michigan, Ann Arbor.

Allen, C.R., Gunderson, L.H. (2011). Pathology and failure in the design and implementation of adaptive management*. Journal of Environmental Management, 92*, 1379–1384 .

Ajzen, L, and M. Fishbein. (1980). *Understanding attitudes and predicting behavior*. Englewood Cliffs, NJ, USA: Prentice-Hall. 296

Barnes, M. (2011). Low-input grassfed livestock production in the American West: Case studies of ecological, economic, and social resilience. *Rangelands 33*(2), 31-40. http://dx.doi. org/10.2111/1551-501X-33.2.31

Battaglia, M., Dillman, D., Frankel, M., Harter, R., Buskirk, T., McPhee, C., . . . Yancy, T. (2016). Sampling, data collection, and weighting procedures for address-based sample surveys. *Journal of Survey Statistics and Methodology, 4*, 476-500.

Benson, M.H. , Stone, A.B. (2013). Practitioner perceptions of adaptive management implementation in the United States. *Ecology and Society, 18*, 32.

Belsky, J. M., & Barton, A. (2018). Constitutionality in Montana: A decade of institution building in the Blackfoot Community Conservation Area. *Human Ecology*, *46*(1), 79–89. https://doi.org/10.1007/s10745-018-9967-0

Boyd, C.S. , Svejcar, T.J. (2009). Managing complex problems in rangeland ecosystems. *Rangeland Ecology & Management, 62*, 4 91–4 99 .

Brandenburg, A. M., and M. S. Carroll. (1995). Your place or mine? The effect of place creation on environmental values and landscape meanings. *Soc. Nat. Resour., 8*, 381–398. https://doi.org/10.1080/ 08941929509380931

Briske, D. D., Joyce, L. A., Polley, H. W., Brown, J. R., Wolter, K., Morgan, J. A., … Bailey, D. W. (2015). Climate-change adaptation on rangelands: Linking regional exposure with diverse adaptive capacity. *Frontiers in Ecology and the Environment*, *13*(5), 249–256. https://doi.org/10.1890/140266

Brown, P. R., Hochman, Z., Bridle, K. L., & Huth, N. I. (2015). Participatory approaches to address climate change: perceived issues affecting the ability of South East Queensland graziers to adapt to future climates. *Agriculture and Human Values*, *32*(4), 689–703. https://doi.org/10.1007/s10460-015-9584-0

Brown, H., Nkem, J., Sonwa, D., Bele, Y. (2010). Institutional adaptive capacity and climate change response in the Congo Basin forests of Cameroon. *Mitigation and Adaptation Strategies for Global Change, 15* (3), 263–282.

Brown, J., Alvarez, P., Byrd, K., Deswood, H., Elias, E., & Spiegal, S. (2017). Coping with historic drought in California rangelands: Developing a more effective institutional response. *Rangelands*, *39*(2), 73–78. https://doi.org/10.1016/j.rala.2017.01.002

Burawoy, M. (1998). The extended case method. *Social Theory, 16*, 4–33. https://doi.org/10.1111/0735-2751.00040.

Christiansen, T. , Neuhold, C. (2012). *International handbook on informal governance*. Edward Elgar, Northampton, MA, USA 574 pages .

Coppock, D. L. (2011). Ranching and multiyear droughts in Utah: Production impacts, risk perceptions, and changes in preparedness. *Rangeland Ecology & Management,*, *64*(6), 607–618. https://doi.org/10.2111/REM-D-10-00113.1

Crimp, S. J., Stokes, C. J., Howden, S. M., Moore, A. D., Jacobs, B., Brown, P. R., … Leith, P. (2010). Managing Murray-Darling Basin livestock systems in a variable and changing climate: Challenges and opportunities. *Rangeland Journal*, *32*(3), 293–304. https://doi.org/10.1071/RJ10039

Derner, J.D. , Augustine, D.J. (2016). Adaptive management for drought on rangelands. *Rangelands, 38*, 211–215.

Dovers, S. R., & Hezri, A. A. (2010). Institutions and policy processes: The means to the ends of adaptation. *Wiley Interdisciplinary Reviews: Climate Change*, *1*(2), 212–231. https://doi.org/10.1002/wcc.29

Engle, N.L., Lemos, M.C. (2010). Unpacking governance: Building adaptive capacity to climate change of river basins in Brazil. *Global Environmental Change, Special issue on Adaptive Capacity to Global Change in Latin America, 20*, 4–13.

Fischer, F. (2003). *Reframing Public Policy: Discursive Politics and Deliberative Practices.* Oxford: Oxford University Press.

Frohlich, M.F. , Jacobson, C. , Fidelman, P. , Smith, T.F. (2018). The relationship between adaptive management of social-ecological systems and law: A systematic review. *Ecology and Society, 23,* 23.

Fuglie, K. O., and C. A. Kascak. (2001). Adoption and diffusion of natural-resource-conserving agricultural technology*. Review of Agricultural Economics, 23,* 386-403.

Garud, R., Hardy, C., Maguire, S. (2007). Institutional entrepreneurship as embedded agency: An introduction to the special issue. *Organization Studies, 28*(7), 957–969.

Giddens A. (1984). *The Constitution of Society - Outline of the Theory of Structuration*. Cambridge, Polity Press.

Gosnell, H., and J. Abrams. (2011). Amenity migration: Diverse conceptualizations of drivers, socioeconomic dimensions, and emerging challenges. *GeoJournal, 76*(4): 303–322.

Gosnell, H., & Travis, W. R. (2005). Ranchland ownership dynamics in the Rocky Mountain West. *Society for Range Management*, *58*(2), 191–198.

Gupta, J., Termeer, C., Klostermann, J., Meijerink, S., van den Brink, M., Jong, P., Nooteboom, S., Bergsma, E. (2010). The adaptive capacity wheel: A method to assess the inherent characteristics of institutions to enable the adaptive capacity of society. *Environmental Science & Policy, 13*(6), 459–471.

Haigh, T., Hayes, M., Smyth, J., Prokopy, L., Francis, C., & Burbach, M. (2021). Ranchers' use of drought contingency plans in protective action decision making. *Rangeland Ecology and Management*, *74*(1), 50–62. https://doi.org/10.1016/j.rama.2020.09.007

Haigh, T. , Koundinya, V. , Hart, C. , Klink, J. , Lemos, M. , Mase, A.S. , Prokopy, L. , Singh, A. , Todey, D. , Widhalm, M. (2018). Provision of climate services for agriculture: Public and private pathways to farm-decision making. *Bulletin of the American Meteorology Society, 99*(9), 1781–1790.

Haziza, D., & Beaumont, J.-F. (2017). Construction of weights in surveys: A review. *Statistical Science, 32*, 206-226.

Haziza, D., & Lesage, E. (2016). A discussion of weighting procedures for unit nonresponse. *Journal of Official Statistics, 32*, 129-145.

Head, L., J. Atchison, A. Gates, and P. Muir. (2011). A fine-grained study of the experience of drought, risk and climate change among Australian wheat farming households. *Ann. Assoc. Amer. Geogr., 101*, 1089–1108. https://doi.org/10.1080/ 00045608.2011.579533.

Hendrickson, M., Howard, P., Miller, E., Constance, D. (2020). The Food System: Concentration and Its Impacts. https://farmaction.us//wp-content/uploads/2020/11/Hendrickson-et-al.-2020.-Concentration-and-Its-Impacts-FINAL.pdf

Hendrickson, M., and W. Heffernan. (2007). *Concentration of agricultural markets*. Department of Rural Sociology, University of Missouri, Columbia, Missouri, USA. http://www.foodcircles.missouri.edu/07contable.pdf

Hruska, T. , Huntsinger, L. , Brunson, M. , Li, W. , Marshall, N. , Oviedo, J.L. , Whit- comb, H. (2017). Rangelands as social-ecological systems. In: Briske, D.D. (Ed.), *Rangeland systems: processes, management and challenges.* Springer Nature, Cham, Switzerland, pp. 263–302 .

IPES-Food. (2022). *The politics of protein: examining claims about livestock, fish, 'alternative proteins' and sustainability*. www.ipes-food.org

IDGEC Scientific Planning Committee. (1999). *Institutional Dimensions of Global Environmental Change.* IHDP Report No. 9, Bonn.

Joyce, L. A., & Marshall, N. A. (2017). Managing climate change risks in rangeland systems. In D. D. Briske (Ed.), *Rangeland Systems: Processes, Management and Challenges.* 491–526. Springer Cham. https://doi.org/10.1007/978-3-319-46709-2_15

Joyce, L. A., Briske, D. D., Brown, J. R., Polley, H. W., McCarl, B. A., & Bailey, D. W. (2013). Climate change and North American rangelands: Assessment of mitigation and adaptation strategies. *Rangeland Ecology and Management*, *66*(5), 512–528. https://doi.org/10.2111/REM-D-12-00142.1

Kachergis, E., Derner, J. D., Cutts, B. B., Roche, L. M., Eviner, V. T., Lubell, M. N., & Tate, K. W. (2014). Increasing flexibility in rangeland management during drought. *Ecosphere*, *5*(6), 1–15. https://doi.org/10.1890/ES13-00402.1

King, E. G., Unks, R. R., & German, L. (2018). Constraints and capacities for novel livelihood adaptation: lessons from agricultural adoption in an African dryland pastoralist system. *Regional Environmental Change*, *18*(5), 1403–1410. https://doi.org/10.1007/s10113-017-1270-x

Landsbergen, D. , Orosz, J.F. (1996). Why public managers should not be afraid to enter the "gray zone." *Adminitration & Society, 28*, 238–265.

Lavallee, P., & Beaumont, J.-F. (2016). Weighting principals and practicalities. In C. Wolf, D. Joye, T. Smith, & Y.-C. Fu, *The Sage Handbook of Survey Methodology,* 460-476. Sage.

Lemos, M.C. , Kirchhoff, C.J. , Ramprasad, V. (2012). Narrowing the climate information usability gap. *Nature and Climate Change, 2*, 789–794 .

Lien, A. M., Dew, T., Ruyle, G. B., Sherman, N. R., Perozzo, N., Miller, M., & López-Hoffman, L. (2021). Trust is essential to the implementation of adaptive management on public lands. *Rangeland Ecology and Management*, *77*, 46–56. https://doi.org/10.1016/j.rama.2021.03.005

Lubell, M. N., Cutts, B. B., Roche, L. M., Hamilton, M., Derner, J. D., Kachergis, E., & Tate, K. W. (2013). Conservation program participation and adaptive rangeland decision-making. *Rangeland Ecology & Management*, *66*, 609–620.

MacDonald, J.M., and W.D. McBride. (2009). The transformation of US livestock agriculture scale, efficiency, and risks. *Economic Information Bulletin*. https ://doi.org/10.2139/ssrn.13540 28

Marshall, N. A. (2015). Adaptive capacity on the northern Australian rangelands. *Rangeland Journal*, *37*(18th Biennial Conference of the Australian-Rangeland-Society), 617–622. https://doi.org/10.1071/RJ15054

Marshall, N.A. , Gordon, I.J. , Ash, A.J. (2011). The reluctance of resource-users to adopt seasonal climate forecasts to enhance resilience to climate variability on the rangelands. *Climate Change, 107*, 511–529 .

Marshall, N. A., & Smajgl, A. (2013). Understanding variability in adaptive capacity on rangelands. *Rangeland Ecology & Management*, *66*(1), 88–94. https://doi.org/10.2111/REM-D-11-00176.1

Mase, A. S., and Prokopy, L. S. (2014). Unrealized potential: A review of perceptions and use of weather and climate information in agricultural decision making. *Weather, Climate, and Society, 6,* 47–61. https://doi.org/10.1175/WCAS-D-12-00062.1

Mccollum, D. W., Tanaka, J. A., Morgan, J. A., Mitchell, J. E., Fox, W. E., Maczko, K. A., … Kreuter, U. P. (2017). Climate change effects on rangelands and rangeland management: Affirming the need for monitoring. *Ecosystem Health and Sustainability*, *3*(3), 1–13. https://doi.org/10.1002/ehs2.1264

Meuret, M., & Provenza, F. D. (2015). When art and science meet: Integrating knowledge of French herders with science of foraging behavior. *Rangeland Ecology & Management*, *68*(1), 1–17. https://doi.org/10.1016/j.rama.2014.12.007

Woodall, P, Shannon, TL. (2018). Monopoly power corrodes choice and resiliency in the food system. *The Antitrust Bulletin*, *63*(2), 198-221. https://doi.org/10.1177/0003603X18770063

Moseley, C. , Charnley, S. (2014). Understanding micro-processes of institutionalization: Stewardship contracting and national forest management. *Policy Science, 47*, 69–98 .

Morgan, J. A., J. D. Derner, D. G. Milchunas, and E. Pendall. (2008): Management implications of global change for Great Plains rangelands. *Rangelands, 30*, 18–22. https://doi.org/10.2111/1551-501X(2008)30[18:MIOGCF]2.0.CO;2.

Moser, S. C., and J. A. Ekstrom. (2010). A framework to diagnose barriers to climate change adaptation. *Proc. Natl. Acad. Sci. USA, 107,* 22026–22031. https://doi.org/10.1073/pnas.1007887107.

Nelson R, Kokic P, Crimp S, Howden SM. (2010). The vulnerability of Australian rural communities to climate variability and change: part 1—conceptualising and measuring vulnerability. *Environ Sci Pol, 13*, 8–17.

Reid, R. S., Fernandez-Gimenez, M. E., Wilmer, H., Pickering, T., Kassam, K.-A. S., Yasin, A., … Knapp, C. N. (2021). Using research to support transformative impacts on complex, “wicked problems” with pastoral peoples in rangelands. *Frontiers in Sustainable Food Systems*, *4*. https://doi.org/10.3389/fsufs.2020.600689

Reiners, D. (2012). Institutional effects on decision making on public lands: An interagency examination of wildfire management. *Public Administration Review, 77*, 177–186 .

Roche, L. M. (2021). Grand challenges and transformative solutions for rangeland social-ecological systems – emphasizing the human dimensions. *Rangelands*, 1–8. https://doi.org/10.1016/j.rala.2021.03.006

Sayre, N. F. (2017). *The Politics of Scale: A History of Rangeland Science*. Chicago and London: The University of Chicago Press.

Sayre, N.F. (2004). Viewpoint: The need for qualitative research to understand ranch management. *Rangeland Ecology & Management, 57*(6). 668–674.

Schlager, E. , Cox, M. (2018). The IAD framework and the SES framework: An introduction and assessment of the Ostrom Workshop frameworks. In: Weible, C.M., Sabatier, P.A. (Eds.), *Theories of the policy process*. Westview Press, Boulder, CO, USA, 215–252.

Schultz, C.A. , McCaffrey, S.M. , Huber-Stearns, H.R. (2019). Policy barriers and opportunities for prescribed fire application in the western United States. *International Journal of Wildland Fire, 28*, 874–884.

Schultz, C. (2008). Responding to scientific uncertainty in U.S. forest policy. *Environmental Science Policy, 11*, 253–271

Smith, A. P., Yung, L., Snitker, A. J., Bocinsky, R. K., Metcalf, E. C., Jencso, K., & Smith, A. P. (2021). Scalar mismatches and underlying factors for underutilization of climate information: Perspectives from farmers and ranchers. *Frontiers in Climate*, *3*(April). https://doi.org/10.3389/fclim.2021.663071

Sorice, M.G., U.P. Kreuter, B.P. Wilcox, and W.E. Fox. (2014). Changing landowners, changing ecosystem? Land-ownership motivations as drivers of land management practices. *Journal of Environmental Management, 133,* 144–152.

Strauss, A., and J. Corbin. (1990). *Basics of Qualitative Research: Grounded Theory Procedures and Techniques.* 2nd ed. Sage Publications, 272 pp.

USDA-NRCS. (2021, October). News Release: USDA Invests $21 Million in Effort to Help Producers Build Drought Resilience. https://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/newsroom/releases/?cid=NRCSEPRD1841021

USDA-NASS. (2021). 2021 State Agriculture Overview (Montana). https://www.nass.usda.gov/Quick_Stats/Ag_Overview/stateOverview.php?state=MONTANA

United States Department of Agriculture - National Agricultural Statistics Service. (2017). Table 52: Selected Producer Characteristics 2017 and 2012. https://www.nass.usda.gov/Publications/AgCensus/2017/Full_Report/Volume_1,_Chapter_1_US/st99_1_0052_0052.pdf

Valliant, R., Dever, J. A., & Kreuter, F. (2013). *Practical Tools for Designing and Weighting Surveys.* New York, New, York: Springer.

Vincent, K. (2007). Uncertainty in adaptive capacity and the importance of scale. *Global Environmental Change, 17*, 12–24.

Whitney, C. K., Bennett, N. J., Ban, N. C., Allison, E. H., Armitage, D., Blythe, J. L., … Yumagulova, L. (2017). Adaptive capacity: From assessment to action in coastal social-ecological systems. *Ecology and Society*, *22*(2). https://doi.org/10.5751/ES-09325-220222

Wilmer, H., Derner, J. D., Fernández-Giménez, M. E., Briske, D. D., Augustine, D. J., & Porensky, L. M. (2018). Collaborative adaptive rangeland management fosters management-science partnerships. *Rangeland Ecology and Management*, *71*(5), 646–657. https://doi.org/10.1016/j.rama.2017.07.008

Wollstein, K., Wardropper, C. B., & Becker, D. R. (2021). Outcome-based approaches for managing wildfire risk: Institutional interactions and implementation within the “gray zone.” *Rangeland Ecology & Management*, *77*(1), 101–111. https://doi.org/10.1016/j.rama.2021.04.007

Wyborn, C., Yung, L., Murphy, D., & Williams, D. R. (2015). Situating adaptation: How governance challenges and perceptions of uncertainty influence adaptation in the Rocky Mountains. *Regional Environmental Change*, *15*(4), 669–682. https://doi.org/10.1007/s10113-014-0663-3

Wyss, R. (2013). Cooperation for climate adaptation in tourism: An agenda for the Alps based on structuration theory. *Revue de Géographie Alpine*, *101*(4), 0–8. https://doi.org/10.4000/rga.1880

Yung, L., Phear, N., Dupont, A., Montag, J., & Murphy, D. (2015). Drought adaptation and climate change beliefs among working ranchers in Montana. *Weather, Climate, and Society*, *7*(4), 281–293. https://doi.org/10.1175/WCAS-D-14-00039.1

Zijderveld, A.C. (2000). *The Institutional Imperative – The Interface of Institutions and Networks*. University Press, Amsterdam.

Chapter 6: Conclusion

The rapid social and ecological change taking place in rangeland systems has prompted a growing interest in contributions from the social sciences to improve our understanding about how ranchers and rangeland managers are adapting to these challenges. In particular, recent climatic trends and climate model projections indicate that climate change will modify rangeland ecosystems in ways that will necessitate deliberate adaptation strategies among ranchers and rangeland managers. This dissertation responds to the need for SES approaches and the use of social science methods to examine how ranchers, whose livelihoods depend on rangeland resources, are adapting to climate change.

In Chapter 3, I systematically reviewed the growing body of scholarship (n= 56 studies) examining the social dimensions of adaptation in rangeland social-ecological systems, finding that these studies are geographically concentrated in few high income countries, and theoretically and conceptually fragmented into distinct scholarly communities. In Chapter 4, I built upon previous conceptualizations of adaptive decision-making for rangeland management. Using a path model analysis, I examined factors that influence Montana ranchers' (n= 450) adaptive decision-making in light of drought and climate change, including ranchers' management goals, use of information sources (including social networks), and monitoring. In Chapter 5, I used a mixed methods approach to examine how 'structures' — specifically government programs and grazing permits administered by public lands agencies — influence Montana ranchers' ability to adapt to drought and other climate-related events. Based on my analysis of survey data (n= 450) and in-depth interviews (n= 34), I found that government programs both enable and constrain ranchers ability to manage adaptively. Following my results, I discuss ways in which government programs and permits might more effectively enable ranchers' ability to manage for and adapt to complex and changing conditions. As a whole, this dissertation reflects a commitment to research that uses and develops methodological approaches for conducting meaningful social science research with ranchers in the U.S., expands upon theory and concepts related to climate change adaptation, informs policy and practices for management, and illuminates future research directions. Below I describe the contributions of this work.

Methodological contributions

Methodologically, the contributions of this dissertation are twofold; 1) I respond to recent calls for utilizing quantitative, qualitative and participatory social science methods to expand our understanding of rangeland SESs and; 2) my approach to survey research provides a potentially very useful, method for future researchers aiming to understand characteristics of agricultural producers at the state-level. In recent years, scholars in the field of rangeland science and management have articulated the need for greater integration of the natural and social sciences in order to address critical challenges on working rangelands (Roche, 2021; Reid et al., 2021). Given rangeland science and management has its roots in rangeland ecology, animal sciences, and other "natural" science disciplines, the emphasis recently has been toward expanding the "human dimensions" — or our understanding of the social elements — of rangeland systems in order to foster transformative rangeland science, learning, and management (Roche, 2021; Sayre et al., 2012; Sayre, 2017). Specifically, mixed methods research as well as participatory, community-based research approaches have been gaining traction. Following this call, in this study I took a mixed methods social science approach, using a combination of in-depth interviews, survey data collection, and participatory research methods, which, together, lead to a thorough understanding of Montana ranchers' adaptation context and strategies. Using a combination of methods also created multiple avenues for me to engage in meaningful ways with the Montana ranching community. While the state-wide scale of this project presented some limitations for iterative conversations and relationship-building with ranchers, the methods I used promoted valuable mutual learning that I anticipate will help inform and catalyze solutions that meet multiple social, economic and ecological objectives in light of change (Reid et al., 2021; Wilmer et al., 2019; Wilmer et al., 2021).

This study was also methodologically unique in that our Montana Drought & Climate team developed an approach for identifying the population of agricultural producers from a suite of geospatial datasets which could be useful for future researchers in Montana or elsewhere. Currently, there is no standard way to identify the population agricultural producers at the state level (in the U.S.) from which to draw a sample for survey research. As described in the Methods section, I used four geospatial datasets to differentiate active or "working" lands from non-agricultural or "amenity" lands and to identify a candidate pool of producers whose names and addresses were associated with those parcels. This method allowed me to avoid some of the nonresponse bias pitfalls associated with relying on various producer organizations or networks (e.g. Stockgrowers Associations, Cattlemen's Associations) commonly used for sampling and survey dissemination. This is evidenced by the rigorous survey weighting process and nonresponse bias testing where I found very little evidence of nonresponse bias in the data reported for the MTDC Survey. In addition, by using geospatial data I was also able to examine and visually depict the geographic location of survey respondents in relation to climatological zones and ecological regions in the state. In this way, this method for conducting survey research is conducive to understanding both ecological and social aspects of working rangeland SESs in tandem.

Theoretical contributions

This dissertation advances both SES research and adaptive decision-making theory through an examination of how ranchers manage for and adapt to social and ecological change and uncertainty on rangelands in the U.S. I expand SES research by conceptually and empirically linking adaptive capacity and adaptive decision-making in the context of rangeland SESs as well as extending adaptive decision-making theory for rangeland management developed by Lubell et al. (2013). Based on my systematic literature review in Chapter 3, I visually depict how adaptive capacity and adaptive decision-making are conceptually related, despite these concepts being used by distinct scholarly communities (Figure 3.0). While it is widely recognized across the literatures that adaptation involves both individual agency as well as agency that exists within a context of 'structures' (Cinner et al., 2015; Giddens, 1984; Gupta et al., 2010), I found that studies tended to use individual-level indicators (i.e. factors related to 'agency') and lack an examination of the structural factors that enable and constrain adaptation in rangeland SESs. I argue that there is a need for scholarship that merges the concepts of adaptive capacity and adaptive decision — and the theories that inform them — in order to develop methods and indicators for assessing factors that influence the adaptation among ranchers that capture cross-scale interactions. In Chapter 5, I respond to my Chapter 3 and the call from other scholars for additional research examining how individual adaptation interacts with social, economic, and environmental forces at multiple scales (e.g. Yung et al., 2015; Vincent, 2007). I show, empirically, how ranchers' adaptive capacity and adaptive decision-making contexts are both shaped by both individual and institutional level factors. By examining if and how ranchers engage in conservation-related government programs, I demonstrate how institutions, both formal and informal, interact with individual level factors and influence ranchers' ability to adapt to drought and climate change.

Recognizing that adaptation involves a complex suite of factors across scales, approaching rangelands as social-ecological systems requires understanding individual's mental models, what drives their decisions, and how their decision-making processes change through learning (Lynam & Stafford Smith, 2004; Sayre et al., 2012). In this dissertation, I test and build upon existing theory of adaptive decision-making within ranching systems. In Chapter 4, I proposed a revised adaptive decision-making framework that is an empirically grounded extension of earlier conceptualizations (Lubell et al. 2013) (Figure 4.0). Consistent with Lubell et al.'s (2013) framework, I demonstrated the significant role of management goals and the use of information in ranchers' adaptive decision-making process. Unlike previous conceptualizations, however, I found that ranchers use of monitoring is also a significant, positive predictor of adaptive decision-making. Specifically, I found that ranchers use of monitoring mediates (and decreases) the influence of the other factors (use of information and management goals) on their use of adaptive management practices – an assertion that has been made in the rangeland management literature but has lacked empirical evidence. These findings demonstrate that the role loop-learning — or taking in new information and applying it in iterative fashion to adaptive decision-making processes — may be more important to adaptive decision-making than earlier conceptualizations suggest.

Management implications

In the field of rangeland science and management, there have been recent calls for scholarship that provides actionable insights that can aid ranchers, policymakers, and other stakeholders in adaptation planning and implementation. There is a widely recognized need for not only science *of* adaptation, but science *for* adaptation that involves science-management partnerships (Reid et al., 2021; Swart et al., 2014; Wilmer et al., 2021). The results of the analyses in this dissertation have a few key management implications that I outline here.

First, results from the path model analysis in Chapter 4 highlight the need to facilitate access to and use of rangeland monitoring and other sources of information for adaptive decision-making. Based on our results, I suggest that there is a need to reduce some of the documented barriers to the adoption of formal monitoring among ranchers including 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; Newingham et al., 2022; Stephenson et al., 2017). As outlined in Chapter 4, innovations such as forming community-based monitoring groups that train local technicians might save on expenses given that a majority of monitoring costs are for travel and logistics for third-party consultants (RMG, 2022). Establishing place-based monitoring groups might also promote the identification of key indicators for local ecosystems based on both existing literature and ranchers' on-the-ground experiences, group learning, and discussions around management decisions and outcomes. In addition, there is a need to reduce barriers to monitoring among agencies managing grazing on public rangelands, including the constraints of adequate funding, lack of human capacity, inadequate collaboration between ranchers and agency personnel, and limited innovations toward creating flexibility in the approaches to monitoring itself (Danielsen et al. 2008; Koontz & Bodine, 2008; Sayre et al., 2013).

In addition, based on the results of Chapter 5, I argue that Montana ranchers might benefit from institutionalized and ongoing government funding allocated for supporting peer-to-peer learning opportunities where they can set the agenda and discuss their own experiences, knowledge, and experimentation with adaptive management practices in response to drought and climate events. For instance, in Montana, there could be support for establishing networks in each of Montana's seven climate zones or within watersheds for ranchers who want to share and learn from one another in the midst of current drought conditions and funding that covers their travel expenses. Based on the findings of this research, I also argue that it is important that there is available, timely and relevant information on current and projected impacts of drought and climate events, along with information on adaptive management strategies in response to these changes. In Montana, entities such as MSU Extension, Conservation Districts, NRCS, Montana Dept of Agriculture, and Montana Stockgrowers Association, were found to be the most used sources of information by ranchers and are well-positioned to provide information on climate information and adaptive management strategies. Moreover, cooperation among these diverse entities for communicating information to ranchers could potentially bring new ideas and opportunities to the table for adaptive rangeland management.

The results from Chapter 5, examining the role of conservation-related government programs and permits on ranchers' ability to manage for and adapt to drought and climate change also highlight policy and management-relevant needs. Findings from this Chapter illuminate the need for institutional programs and processes that more effectively support ranchers' adaptive management. Specifically, three key themes emerged as necessary means to enhance government programs for enabling adaptive management: 1) increasing flexibility within government programs to allow ranchers to achieve desired outcomes in ways that fit their operations and local conditions and; 2) the need for participatory design approaches when developing programs intended to assist ranchers; and 3) the need for collaborative, working relationships between ranchers and government representatives in order to navigate the gray zones of program and policy implementation on-the-ground. While, on the one hand, my research highlights the well-documented tension between adaptive management of dynamic natural systems and the rigid structures in which management occurs, it also highlights ways in which these constraints may be lessened.

Beyond the management implications of this dissertation research, the Montana Drought & Climate project as a whole was designed and developed with management objectives in mind. For example, findings from the MTDC project will inform the development of improved climate information resources with our partners at the Montana Climate Office that meets the needs of producers for timely and effective decision-making to respond to drought and climate change. In addition, the MTDC survey provides robust and generalizable data on operation/operator characteristics, demographic information, and other data on the agricultural community in Montana that we anticipate being useful to our partners at MSU Extension and other management-oriented entities. Thus, this dissertation reflects just one piece of a larger project that, together, have and will continue to span the boundaries between science and management and engage different voices in the conversation around sustaining working agricultural lands in Montana.

Future research directions

Over the course of this dissertation research, it became clear there is a need for future research that utilizes SES perspectives and social science methods to understand and inform adaptive management in rangeland systems in light of rapid change and increasing uncertainty. Here I outline a number of challenges in our understanding of social processes at both the individual and institutional levels with regard to how to monitor and manage rangeland systems which offer avenues for future research opportunities.

First, the exclusion of adaptive decision-making processes from conventional rangeland management research has left gaps in our understanding of how the social components of these systems function and interact with ecological components (Briske et al., 2008; Lubell et al., 2013). Just as this study follows a body of work examining drivers of rangeland managers' decision-making, there is a need for additional research that continues to enhance our understanding of ranch adaptive decision-making. Specifically, future research could endeavor to understand processes that lead to specific strategies (such as high intensity-short duration grazing management, herd genetics, or ranch diversification strategies). Additionally, our understanding of adaptive decision-making would benefit from research that looks at ranch-scale learning and transformation over longer time frames.

In addition, results from Chapter 4 suggest that there is a need to further understand the disparity in the perceived utility of monitoring within the science community with the lack of adoption among ranchers and managers. This speaks to the need for research that examines the social dimensions of rangeland monitoring, which have received relatively little scholarly attention in comparison to research addressing technological limitations. Researchers might consider 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? How could support from government agencies (e.g. Extension and NRCS) help address these challenges?
- What are the advantages and disadvantages of informal and formal monitoring for adaptive decision-making on U.S. rangelands? And, how could these techniques for acquiring environmental knowledge be integrated to more fully realize the advantages of both?

There is also a need to advance our understanding of rangeland management in the U.S. West through more in-depth research examining institutions — how government and non-government sponsored programs and policies function to either enable or constrain desirable adaptation. While Chapter 5 took a "broad strokes" look at institutional factors influencing ranchers adaptive management strategies, the study highlights that, in Montana and in the U.S. West more broadly, there is a need for research that documents specific policies and programs that ranchers utilize for adaptive management, examines if and how they are effective, and suggests improvements for more meaningful engagement. Future research might respond to the following questions:

- How do rangeland and natural resource management institutions that operate at different scales (e.g. local, regional, and federal) influence the adaptive capacity of rangeland social-ecological systems and the adaptive decision-making processes of ranchers? And;
- What are the most effective ways to integrate local and scientific knowledge to create institutions that support adaptive management?

In order to carry out this research effectively, I suggest, as others have, that research methods should incorporate opportunities for regular engagement between scientists, ranchers, and other stakeholders as well as the ability for feedback to be integrated into institutional programs.

Lastly, I echo the sentiment of other rangeland SES scholars that conventional disciplinary approaches are insufficiently equipped to deal with the complex and cross-scale issues such as climate change adaptation on rangelands (Roche, 2021; Swart et al., 2014). Rather, as I suggest in Chapter 3, there is a need to advance rangeland SES scholarship through cross-pollination of theory and concepts across scholarly disciplines. There is also a need to broaden the reach of rangeland SES research to understudied regions of the globe. While this dissertation research explored ranchers' adaptations to drought and climate related change in Montana, additional research in diverse rangeland SESs will aid in assessing and expanding upon our results.

Additionally, effectively connecting rangeland SES research to societal needs will require more participatory and translational rangeland science approaches, where scientists involve non-scientific stakeholders in the process of co-defining relevant questions, co-producing knowledge, and co-learning from the research process (Reid et al, 2021; Roche, 2021; Wilmer et al., 2021). In my review of existing literature — and in my own research experience — it is clear that successful translational research involves designing projects with collaborators and end-users in mind from the very beginning, rather than as an afterthought. I envision future research that emphasizes integrating knowledges, where scientists work alongside ranchers to understand their on-the-ground experiences and challenges. Taking this kind of research approach will involve both a recognition (and humility among scientists) that within ranching communities, there is deep, experiential knowledge that is critical to helping inform our understanding of adaptive capacity, decision-making, and climate adaptation on rangelands (Roche, 2021). While developing more translational science will undoubtedly be a challenge, I am hopeful emphasizing relationship-building and mutual learning will lead to research that contributes to more meaningfully and effectively identifying and solving the collective challenges facing rangeland SESs today.

References

Briske, D. D., Bestelmeyer, B. T., Stringham, T. K., & Shaver, P. L. (2008). Recommendations for development of resilience-based state-and-transition models. *Rangeland Ecology & Management*, *61*(4), 359–367. https://doi.org/10.2111/07-051.1

Cinner, J. E., Huchery, C., Hicks, C. C., Daw, T. M., Marshall, N., Wamukota, A., & Allison, E. H. (2015). Changes in adaptive capacity of Kenyan fishing communities. *Nature Climate Change*, *5*(9), 872–876. https://doi.org/10.1038/nclimate2690

Danielsen, F., N. D. Burgess, A. Balmford, [and 24 others]. (2008). Local participation in natural resource monitoring: A characterization of approaches. *Conservation Biology, 23*, 31–42.

Fernandez-Gimenez, M. E., Ruyle, G., & McClaran, S. J. (2005). An evaluation of Arizona Cooperative Extension's rangeland monitoring program. *Rangeland Ecology & Management, 58*, 89–98.

Giddens A. (1984). *The constitution of society - Outline of the theory of structuration*. Cambridge, Polity Press.

Gupta, J., Termeer, C., Klostermann, J., Meijerink, S., van den Brink, M., Jong, P., Nooteboom, S., & Bergsma, E. (2010). The adaptive capacity wheel: A method to assess the inherent characteristics of institutions to enable the adaptive capacity of society. *Environmental Science & Policy, 13*(6), 459–471.

Koontz, T. M., & J. Bodine. (2008). Implementing ecosystem management in public agencies: Lessons from the U.S. Bureau of Land Management and the Forest Service. *Conservation Biology, 22,* 60–69.

Lubell, M. N., Cutts, B. B., Roche, L. M., Hamilton, M., Derner, J. D., Kachergis, E., & Tate, K. W. (2013). Conservation program participation and adaptive rangeland decision-making. *Rangeland Ecology & Management*, *66*, 609–620.

Newingham, B. A., Kachergis, E., Ganguli, A. C., Foster, B., Price, L., & McCord, S. E. (2022). Lessons given and learned from rangeland monitoring courses. *Rangelands*, *44*(1), 29–38. https://doi.org/10.1016/j.rala.2021.08.003

Rangeland Monitoring Group (RMG). (2022). Collaborative Rangeland Monitoring and Management in Montana. https://highplainsstewardship.org/collaborative-rangeland-monitoring-and-management-in-montana/

Reid, R. S., Fernandez-Gimenez, M. E., Wilmer, H., Pickering, T., Kassam, K.-A. S., Yasin, A., … Knapp, C. N. (2021). Using research to support transformative impacts on complex, "wicked problems" with pastoral peoples in rangelands. *Frontiers in Sustainable Food Systems*, *4*. https://doi.org/10.3389/fsufs.2020.600689

Roche, L. M. (2021). Grand challenges and transformative solutions for rangeland social-ecological systems – emphasizing the human dimensions. *Rangelands*, 1–8. https://doi.org/10.1016/j.rala.2021.03.006

Sayre, N. F. (2017). *The politics of scale: A history of rangeland science*. The University of Chicago Press.

Sayre, N. F., Biber, E., & Marchesi, G. (2013). Social and legal effects on monitoring and adaptive management: A case study of national forest grazing allotments, 1927-2007. *Society & Natural Resources*, *26*(1), 86–94. https://doi.org/10.1080/08941920.2012.694579

Sayre, N. F., Debuys, W., Bestelmeyer, B. T., & Havstad, K. M. (2012). “The range problem” after a century of rangeland science: New research themes for altered landscapes. *Rangeland Ecology & Management*, *65*(6), 545–552. https://doi.org/10.2111/REM-D-11-00113.1

Swart, R., Biesbroek, R., & Lourenço, T. C. (2014). Science of adaptation to climate change and science for adaptation. *Frontiers in Environmental Science*, *2*, 1–8. https://doi.org/10.3389/fenvs.2014.00029

Stephenson, M. B., Wilmer, H., Bolze, R., & Schiltz, B. (2017). Evaluating an on-ranch rangeland monitoring program in Nebraska. *Rangelands*, *39*(5), 143–151. https://doi.org/10.1016/j.rala.2017.08.001

Vincent, K. (2007). Uncertainty in adaptive capacity and the importance of scale. *Global Environmental Change*, *17*(1), 12–24. https://doi.org/10.1016/j.gloenvcha.2006.11.009

Wilmer, H., Schulz, T., Fernández-Giménez, M. E., Derner, J. D., Porensky, L. M., Augustine, D. J., … Meade, R. (2021). Social learning lessons from collaborative adaptive rangeland management. *Rangelands*, 1–11. https://doi.org/10.1016/j.rala.2021.02.002

Yung, L., Phear, N., Dupont, A., Montag, J., & Murphy, D. (2015). Drought adaptation and climate change beliefs among working ranchers in Montana. *Weather, Climate, and Society*, *7*(4), 281–293. https://doi.org/10.1175/WCAS-D-14-00039.1

Appendix A: Montana Drought and Climate Survey

Photo: Ada Smith, UM graduate student and 9-mile resident

MONTANA DROUGHT AND CLIMATE PROJECT SURVEY

Montana Drought & Climate

UNIVERSITY OF MONTANA

Sponsored by:

U.S. Department of Agriculture

University of Montana W.A. Franke College of Forestry and Conservation

Administered by:

University of Montana Bureau of Business and Economic Research

PLEASE START HERE!

DETAILS OF YOUR OPERATION

1. Are you involved in agriculture in some way (owning, leasing, or managing farmland or ranchland)? Please mark one button (X).

O Yes
O No

2. Do you consider yourself a____? Please mark one button (X).

O Farmer
O Rancher
O Both
O Neither

3. How many years have you been farming/ranching?

_________ years

4. How many generations of farmers/ranchers have there been in your family?

_________ # of generations

5. What percent of your total household income comes from your farm or ranch operation?

_________%

6. Do you have a plan to keep your land in farming or ranching? Please mark one button (X).

O Yes
O No
O In progress

7. Approximately, what percent of your acres are owned or leased? Please indicate the percent of each, the total should add to 100%.

______% Owned
______% Private leased
______% Public leased (State or Federal)
______% Other (please specify ____________________)

8. Approximately, what percentage of your acres are irrigated (including owned and leased acres)?

_________%

9. We are interested in knowing what you grow and/or raise on your farm or ranch. Please check (X) all that apply.

☐ Wheat (e.g. winter, durum, spring)
☐ Buckwheat
☐ Barley
☐ Pulses (e.g. beans, peas, lentils)
☐ Oats
☐ Corn (for grain or silage)
☐ Sugar Beets
☐ Hay
☐ Fall Potatoes
☐ Oil Seeds (e.g. canola, mustard, safflower, flaxseed)
☐ Mixed Vegetable/Market Farm
☐ Cow-Calf Operation
☐ Yearling/Stocker Operation
☐ Sheep
☐ Other livestock (bison, goats, horses, swine, poultry)
☐ Dairy

10. Is any part of your operation certified organic? Please mark one button (X).

O Yes
O No

GOALS AND BARRIERS

11. We are interested in the reasons why you are a farmer or rancher. Please indicate how important each of these statements are to you. Please circle one number for each item.

	Very unimportant	Unimportant	Neither Important nor Unimportant	Important	Extremely important
a. To increase livestock/crop production	1	2	3	4	5
b. To maximize profit through production	1	2	3	4	5
c. To earn a living	1	2	3	4	5
d. To take care of the land for the future	1	2	3	4	5
e. To support habitat health for all species	1	2	3	4	5
f. To protect water and soil resources	1	2	3	4	5
g. To ensure land does not become fragmented	1	2	3	4	5
h. To sequester carbon through farming/ranching practices	1	2	3	4	5
i. To provide recreation opportunities	1	2	3	4	5
j. For the lifestyle	1	2	3	4	5
k. To continue family traditions	1	2	3	4	5
l. To help maintain the vitality of rural Montana	1	2	3	4	5
m. To provide good jobs	1	2	3	4	5
n. To produce food	1	2	3	4	5

12. To what extent are the following barriers to achieving your goals as a farmer or rancher? Please circle one number for each item.

	Not a barrier	A barrier I can overcome	A barrier that is difficult for me to overcome
a. Markets/commodity prices	1	2	3
b. Cost of inputs	1	2	3
c. Lack of and/or cost of labor	1	2	3
d. Availability and/or cost of insurance	1	2	3
e. Uncertainty about production and revenue	1	2	3
f. Terms of loan(s)/debt	1	2	3
g. Lack of local/in-state meat processing	1	2	3
h. Government regulations	1	2	3
i. Terms of government programs	1	2	3
j. Access to land	1	2	3

VIEWS ON THREE-MONTH FORECASTS

13. We are interested in what you think about three-month forecasts. Three-month forecasts are seasonal forecasts predicting <u>temperature</u> and <u>precipitation</u> for the next three months. Please indicate how much you agree or disagree with the following statements about three-month forecasts. Please circle one number for each item.

	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
a. Even though three-month forecasts are not always accurate, they are still useful	1	2	3	4	5
b. I need to see how three-month forecasts are benefitting other producers before I will use them in my operation	1	2	3	4	5
c. I have found three-month forecasts to be useful in making decisions about my farm/ranch operation	1	2	3	4	5
d. I need three-month forecasts to be more accurate for them to be useful to me	1	2	3	4	5
e. I rely on my own past experience rather than three-month forecasts	1	2	3	4	5
f. I would use three-month forecasts if an organization I trusted endorsed this information	1	2	3	4	5
g. I need to experiment with three-month forecasts to determine if they are useful	1	2	3	4	5

14. Please tell us how much you agree or disagree with the follow statements:
Three-month forecasts about temperature and precipitation… Please circle one number for each item.

	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
a. ...are provided in time for me to make a decision	1	2	3	4	5
b. ...are specific to my farm/ranch	1	2	3	4	5
c. ...are relevant to the decisions I make	1	2	3	4	5
d. ...are accurate	1	2	3	4	5
e. ...help me reduce financial risks	1	2	3	4	5
f. ...help me maintain or increase crop yields	1	2	3	4	5
g. ...help me maintain or increase forage productivity	1	2	3	4	5
h. …help me improve environmental outcomes on my farm/ranch	1	2	3	4	5
i. …are at a spatial scale that is local enough to be useful	1	2	3	4	5

15. Please tell us how much you agree or disagree with the following statements: I don't trust three-month forecasts about temperature and precipitation because… Please circle one number for each item.

	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
a. ...I don't know where they came from	1	2	3	4	5
b. ...I don't trust the organizations who produce them	1	2	3	4	5
c. ...they are always changing	1	2	3	4	5
d. ...they contradict one another	1	2	3	4	5

VIEWS ON PROJECTIONS FOR 2050

16. We are interested in your views on the usefulness of projections for how <u>temperature</u> and <u>precipitation</u> will change by 2050. Please indicate how much you agree or disagree with the following statements about these projections. Please circle one number for each item.

	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
a. I would use projections for 2050 more if I knew other farmers/ranchers used this information	1	2	3	4	5
b. I don't trust the projections for 2050 because I don't know where they came from	1	2	3	4	5
c. I would use projections for 2050 more if I better understood the people and process that created this information	1	2	3	4	5
d. I don't trust the organizations who produce projections for 2050	1	2	3	4	5
e. I would use projections for 2050 more if an organization I trusted endorsed this information	1	2	3	4	5
f. Projections for 2050 are useful to me in making short-term decisions	1	2	3	4	5
g. Projections for 2050 are useful to me in making long-term decisions	1	2	3	4	5
h. Projections for 2050 are not useful because the timeframe is too far away	1	2	3	4	5

17. What kind of climate information do you need that you <u>do not</u> currently have? (Please describe below.)

____

____

USE OF INFORMATION FOR MANAGEMENT DECISIONS

18. We would like to know what information sources you use to make management decisions on your farm or ranch. Please check all the sources that you use.

- ☐ Conservation District
- ☐ Montana Dept. of Agriculture
- ☐ MSU Extension Agents
- ☐ USDA Northern Plains Climate Hub
- ☐ Montana Drought and Climate
- ☐ Montana Mesonet
- ☐ AERO
- ☐ US Forest Service
- ☐ US Fish and Wildlife Service
- ☐ Independent consultants
- ☐ Holistic Resource Management
- ☐ Montana Grain Growers Association
- ☐ Cattlefax
- ☐ In-person with other farmers/ranchers
- ☐ Through social media with other farmers/ranchers
- ☐ MT DNRC (including MGCC)
- ☐ Montana Natural Resources Council (NRC)
- ☐ Agricultural Research Centers
- ☐ Northern Plains Resource Council
- ☐ Montana Climate Office
- ☐ National Oceanic and Atmospheric Administration (NOAA)
- ☐ Natural Resources Conservation Service (NRCS)
- ☐ Bureau of Land Management
- ☐ Private Industry input advisors
- ☐ DTN (Data Transmission Network)
- ☐ Montana Stockgrowers Association
- ☐ National Cattleman's Beef Association
- ☐ Montana Organic Association
- ☐ AgriMET (BOR)

MANAGEMENT PRACTICES

19. We are interested in knowing more about your management practices. Please review the list below, indicating which practices you use and don't use. For those that you use, please let us know at <u>what scale</u> and <u>for how long</u> you have been using them. Please mark one button (X) for each item, in each set of answers.

	At <u>what scale</u> do you do this on your farm/ranch?			**If used, <u>how long</u> have you been doing this?**		
	Not at all	Portion of farm/ ranch	Entire farm/ ranch	Less than 3 years	More than 3 years	Experimenting
Vegetation						
a. Practice crop rotation (diversified rotations)	O	O	O	O	O	O
b. Use cover crops in place of crop fallow	O	O	O	O	O	O
c. Select crops and forage species to increase carbon sequestration	O	O	O	O	O	O
d. Use drought tolerant crop varieties	O	O	O	O	O	O
e. Manage for sudden onset of drought through earlier spring and fall planting	O	O	O	O	O	O
f. Use prescribed burning for pest and weed management	O	O	O	O	O	O
Soil & Water Management						
g. Use no till or reduced till farming	O	O	O	O	O	O
h. Integrate pulses into cropping mix	O	O	O	O	O	O
i. Integrate crops/livestock to improve soil	O	O	O	O	O	O
j. Use organic fertilizers	O	O	O	O	O	O
k. Upgrade to more efficient irrigation systems	O	O	O	O	O	O

20. Please tell us about your management practices around diversification, monitoring, managing risk, and landscape enhancements. Please mark one button (X) for each item, in each set of answers.

	At what scale do you do this on your farm/ranch?			**If used, how long have you been doing this?**		
	Not at all	Portion of farm/ ranch	Entire farm/ ranch	Less than 3 years	More than 3 years	Experimenting
Diversification						
a. Sell products from different farm/ranch enterprises (e.g., timber, honey, hand crafted goods)	O	O	O	O	O	O
b. Income from services beyond what we grow/raise (e.g., tourism, outfitting/guiding)	O	O	O	O	O	O
c. Use certifications to get a higher premium on products (e.g., organic, humane handling)	O	O	O	O	O	O
Monitoring						
d. Established soil and vegetation/range monitoring program to track and respond to change	O	O	O	O	O	O
e. Use precision agriculture (intensive use of data and monitoring) to increase efficiency and optimize inputs	O	O	O	O	O	O
Insurance & Contracts						
f. Purchase crop insurance	O	O	O	O	O	O
g. Purchase pasture, range, and forage insurance	O	O	O	O	O	O
h. Use contracts to deal with crop price volatility	O	O	O	O	O	O
Landscape Enhancements						
i. Managing for wildlife habitat	O	O	O	O	O	O
J. Establishing riparian buffers	O	O	O	O	O	O

21. If you raise livestock, please continue telling us about your livestock and grazing management practices. If you do not raise livestock, please skip to Question 25. Please mark one button (X) for each item, in each set of answers.

	At what scale do you do this on your farm/ranch?			**If used, how long have you been doing this?**		
	Not at all	Portion of farm/ ranch	Entire farm/ ranch	Less than 3 years	More than 3 years	Experimenting
Grazing & Livestock Management						
a. Intensive rotational grazing	O	O	O	O	O	O
b. Planned grazing for weed and invasive species management	O	O	O	O	O	O
c. Timing grazing for improved pastures	O	O	O	O	O	O
d. Breeding or improving herd genetics for drought and heat	O	O	O	O	O	O
e. Late spring/early summer calving	O	O	O	O	O	O
f. Strategic placement of water for livestock and better forage utilization (infrastructure upgrades, piping systems, water tanks)	O	O	O	O	O	O
g. Drought plan (e.g., reduce stocking rates, lease pasture, use additional hay)	O	O	O	O	O	O

22. Which best describes your grazing management? Please mark one button (X).

- O Extensive - few pastures, long grazing duration—weeks to months
- O Moderate - many pastures, moderate grazing duration— many weeks
- O Intensive - many pastures, shorter grazing duration—days to weeks

23. I keep written or electronic documentation of grazing plans and goals. Please mark one button (X).

- O Never
- O Rarely
- O Sometimes
- O Often

24. I rely on my own experience and the experience of past generations for grazing planning. Please mark one button (X).

- O Never
- O Rarely
- O Sometimes
- O Often

CONSERVATION PROGRAM PARTICIPATION

25. We are interested in knowing if you participate in any conservation-related programs. Please take a look at the list below and indicate whether or not you are aware of the program and if you participate in it or not. Please mark one button (X) for each item.

	I am not aware of this initiative and have not used it	I am aware of this initiative and unable to participate	I am aware of this initiative and currently participate	I am aware of this initiative and have plans to participate in the future
a. EQIP	O	O	O	O
b. Conservation Stewardship Program	O	O	O	O
c. Conservation Reserve Program	O	O	O	O
d. MT Agricultural Research Center/Station Programs	O	O	O	O
e. MT Sage Grouse Habitat Conservation Program	O	O	O	O
f. Conservation easement	O	O	O	O
g. Carbon credit program	O	O	O	O
h. Other landscape or watershed conservation program with private, agency, or non-profit partners	Please list here: ________			
	O	O	O	O

EXPERIENCE WITH DROUGHT, FLOODING, AND EXTREME WEATHER

26. We are interested in your experiences with drought, flooding, and extreme weather. Please indicate how much you agree or disagree with the following statements. Please circle one number for each item.

<u>I have experienced….</u>

	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
a. ...losses due to drought in the last ten years	1	2	3	4	5
b. ...losses due to saturated soils and/or flooding in the last ten years	1	2	3	4	5
c. ...losses due to extreme heat in the last ten years	1	2	3	4	5
d. ...losses due to extreme cold in the last ten years	1	2	3	4	5

I am worried…

	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
e. ...that drought will harm my farm or ranch operation in the future	1	2	3	4	5
f. ...that extreme heat will harm my farm or ranch operation in the future	1	2	3	4	5
g. ...that flooding will harm my farm or ranch operation	1	2	3	4	5
h. …that extreme cold will harm my farm or ranch operation	1	2	3	4	5

27. We want to know what you think about the following statements. Please indicate how much you agree or disagree with the following statements. Please circle one number for each item.

	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
a. Even if there is a drought, there is not much I can do about it	1	2	3	4	5
b. Recent drought conditions are temporary and Montana's climate will return to normal in the near future	1	2	3	4	5
c. On my farm/ranch, we are experiencing bigger swings year-to-year (e.g., one year wet, another year dry)	1	2	3	4	5
d. I have the capacity to overcome the barriers I face in order to achieve my goals as a farmer/rancher	1	2	3	4	5
e. I believe that drought conditions will get worse over the next 10 years	1	2	3	4	5
f. I experiment with new practices that change the way I run my operation	1	2	3	4	5
g. There's too much uncertainty about future changes to the climate to justify changing my agricultural practices and strategies	1	2	3	4	5
h. Changing my practices to cope with future changes to the climate is important for the long-term success of my farm/ranch	1	2	3	4	5

VIEWS ON CLIMATE

28. Which of these three statements about the Earth's temperature comes closest to your view? Please mark one button (X).

- O The Earth is getting warmer mostly because of human activity such as burning fossil fuels
- O The Earth is getting warmer mostly because of natural patterns in the Earth's environment
- O There is no solid evidence that the Earth is getting warmer
- O Not sure

29. How much, if at all, do you think that global climate change is affecting… Please circle one number for each item.

	Not at all	Not too much	Some	A great deal
a. The United States	1	2	3	4
b. Your local economy	1	2	3	4
c. Your farm/ranch operation	1	2	3	4

30. When do you think global climate change will begin harming people in your community? Please mark one button (X).

- O Never
- O They are being harmed now
- O In 10 years
- O In 25 years
- O In 50 years
- O In 100 years
- O Not sure

31. Do you, yourself, agree or disagree with each of the following statements? Please circle one number for each item.

	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
a. Government programs have helped farmers and ranchers	1	2	3	4	5
b. I'm not interested in government incentives because they give government power to limit my activities	1	2	3	4	5
c. Government intervention on private land management is unnecessary	1	2	3	4	5
d. In the future, government incentives will be the best way to improve voluntary conservation on agricultural lands	1	2	3	4	5

DEMOGRAPHIC INFORMATION

32. What year were you born?

_________ (year)

33. What is your gender? Please mark one button (X)

O Male
O Female
O Non-binary

34. What is the degree you have received? Please mark one button (X)

O none
O High school diploma or equivalent GED
O Associate degree
O Bachelor's degree
O Professional degree (MS, DDS, DVM, LLB, JD, DD)
O Doctorate degree (Ph.D. or Ed.D.)

35. Which of the following best represents your political views? Please mark one button (X)

O Very conservative
O Somewhat conservative
O Moderate, middle of the road
O Somewhat liberal
O Very liberal
O Prefer not to say

36. Are you willing to answer follow up questions about this type of information in the future? Please mark one button (X)

O Yes If yes, please provide us with your name and email and/or telephone number below:
Your name and contact information will not be connected to your survey responses.

____

O No

Please think back to the Montana Drought & Climate newsletters and postcards we sent you over the past 2 years. Here are some definitions of terms that may be helpful as you answer the below questions.

Seasonal forecast*:* Three-month predictions of temperature and precipitation from NOAA's Climate Prediction Center
Mid-century outlook*:* Projections for how temperature and precipitation will change by 2050
Climate analog*:* A way to represent projections by comparing the current climate of one location with the future climate of another (e.g., in 2050 the climate of Fort Benton will be similar to the current climate of Utah Valley).

37. We want to know how useful the Montana Drought & Climate newsletter was for you. Please indicate how useful each of the sections were. Please circle one number for each item.

	Not at all useful	Somewhat useful	Useful	Very useful
a. Review of recent temperature and precipitation	1	2	3	4
b. Review of recent drought conditions	1	2	3	4
c. Review of recent snowpack conditions	1	2	3	4
d. Review of recent soil moisture conditions from satellite data	1	2	3	4
e. El Niño and La Niña information	1	2	3	4
f. Seasonal three-month forecasts	1	2	3	4
g. Mid-century outlook	1	2	3	4
h. Climate analogs	1	2	3	4

38. To what extent did the following information from Montana Drought & Climate influence your decisions about __what to plant and/or when to plant__? Please circle one number for each item.

This question is not applicable to me **O** Not applicable

	No influence	Some influence	Strong influence
a. Review of recent temperature and precipitation	1	2	3
b. Review of recent soil moisture conditions from satellite data	1	2	3
c. El Niño and La Niña information	1	2	3
d. Seasonal three-month forecasts	1	2	3
e. Mid-century outlook	1	2	3

39. To what extent did the following information from Montana Drought & Climate influence your decisions about __when and how much to irrigate__? Please circle one number for each item.

This question is not applicable to me **O** Not applicable

	No influence	Some influence	Strong influence
a. Review of recent temperature and precipitation	1	2	3
b. Review of recent soil moisture conditions from satellite data	1	2	3
c. El Niño and La Niña information	1	2	3
e. Seasonal three-month forecasts	1	2	3
f. Mid-century outlook	1	2	3

40. To what extent did the following information from Montana Drought & Climate influence your decisions about <u>stocking rates and grazing practices</u>? Please circle one number for each item.

This question is not applicable to me — O Not applicable

	No influence	Some influence	Strong influence
a. Review of recent temperature and precipitation	1	2	3
b. Review of recent soil moisture conditions from satellite data	1	2	3
c. El Niño and La Niña information	1	2	3
d. Seasonal three-month forecasts	1	2	3
e. Mid-century outlook	1	2	3

41. To what extent did the following information from Montana Drought & Climate influence your decisions about <u>which and/or how much inputs (seeds, herbicides, pesticides, fertilizer) to purchase</u>? Please circle one number for each item.

This question is not applicable to me — O Not applicable

	No influence	Some influence	Strong influence
a. Review of recent temperature and precipitation	1	2	3
b. Review of recent soil moisture conditions from satellite data	1	2	3
c. El Niño and La Niña information	1	2	3
d. Seasonal three-month forecasts	1	2	3
e. Mid-century outlook	1	2	3

42. To what extent did the following information from Montana Drought & Climate influence your decisions about <u>which and/or how much insurance to purchase?</u> Please circle one number for each item.

This question is not applicable to me — O Not applicable

	No influence	Some influence	Strong influence
a. Review of recent temperature and precipitation	1	2	3
b. Review of recent soil moisture conditions from satellite data	1	2	3
c. El Niño and La Niña information	1	2	3
d. Seasonal three-month forecasts	1	2	3
e. Mid-century outlook	1	2	3

43. We want to know what you think of the Montana Drought & Climate newsletter and/or website. Please indicate how much you agree or disagree with the following statements. Please circle one number for each item.

	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
a. I read these newsletters and/or visited the website	1	2	3	4	5
b. I looked forward to receiving these newsletters/postcards	1	2	3	4	5
c. This information was relevant to my farm or ranch	1	2	3	4	5
d. This information influenced my farming or ranching decisions	1	2	3	4	5
e. I trusted this information	1	2	3	4	5
f. This information made me feel more prepared for the future	1	2	3	4	5
g. This information helped me understand the uncertainty around the three-month forecast about temperature and precipitation	1	2	3	4	5
h. This information helped me understand the uncertainty around projections about how temperature and precipitation will change by 2050	1	2	3	4	5
i. Based on this information, I now view climate information as more useful for my operation	1	2	3	4	5
j. I think that using this information can increase my profitability	1	2	3	4	5
k. I did not find this information to be accurate	1	2	3	4	5
l. I did not find this information very easy to understand	1	2	3	4	5
m. I used other climate information instead of this information	1	2	3	4	5

44. Do you want to receive Montana Drought & Climate newsletter in the future? Please mark one button (X).

O Yes
O No

45. How do you prefer to get this information? Please mark one button (X).

O Newsletter
O Postcard reminding me to go to the website
O I plan on visiting the website, but no not want to receive reminder postcards
O I do not want this information

THANK YOU VERY MUCH FOR YOUR HELP WITH THIS IMPORTANT SURVEY!

Appendix B: Montana Drought and Climate Survey Summary (Table A1)

Table A1. Montana Drought and Climate Survey summary statistics

Section 1: Details of Operation	**Percent or Mean Estimate (SE)**	**Unweighted Count**
Do you consider yourself a_____?		700
Farmer	29.6% (2.1%)	199
Rancher	29.0% (2.0%)	214
Both	33.2% (2.1%)	236
Neither	8.2% (1.3%)	51
How many years have you been farming/ranching?	42.71 (.948)	443
How many generations of farmers/ranchers have there been in your family? (years)	3.57 (.066)	447
What percent of your total household income comes from your farm or ranch operation? (%)	73.33 (1.800)	426
Do you have a plan to keep your land in farming or ranching?		447
Yes	86.6% (1.9%)	384
No	3.5% (.8%)	23
In progress	9.8% (1.7%)	40
Approximately, what percent of your acres are owned or leased? Please indicate the percent of each, the total should add to 100%.		
______% Owned	76.91 (1.421)	434
______% Private leased	31.20 (2.029)	188
______% Public leased (State or Federal)	20.73 (1.436)	193
______% Other (please specify	26.39 10.457)	6
Approximately, what percentage of your acres are irrigated (including owned and leased acres)?	14.24 (1.591)	432
We are interested in knowing what you grow and/or raise on your farm or ranch. Please check all that apply.		
Wheat		183
Buckwheat		1
Barley		162
Pulses		73
Oats		71
Corn		26
Sugar Beets		7
Hay		384
Fall Potatoes		5
Oil Seeds		34
Mixed Vegetable/Market Farm		2
Cow-Calf Operation		398
Yearling/Stocker Operation		69
Sheep		26
Other livestock		77
Dairy		3
Is any part of your operation certified organic?		444
No	98.0% (.8%)	434
Yes	2.0% (.8%)	10

Section 2: Management Goals and Barriers	Mean Estimate (SE)	Unweighted Count
We are interested in the reasons why you are a farmer or rancher. Please indicate how important each of these statements are to you. 1= Very unimportant 2= Unimportant 3= Neither 4= Important 5= Extremely Important		
To increase livestock/crop production	3.80 (.058)	429
To maximize profit through production	4.11 (.062)	418
To earn a living	4.19 (.067)	429
To take care of the land for the future	4.29 (.061)	429
To support habitat health for all species	3.83 (.060)	425
To protect water and soil resources	4.18 (.062)	429
To ensure land does not become fragmented	4.02 (.064)	420
To sequester carbon through farming/ranching practices	3.14 (.064)	417
To provide recreation opportunities	2.76 (.062)	425
For the lifestyle	4.01 (.067)	429
To continue family traditions	4.02 (.066)	430
To help maintain the vitality of rural Montana	3.98 (.069)	433
To provide good jobs	3.43 (.060)	427
To produce food	4.14 (.059)	433
To what extent are the following barriers to achieving your goals as a farmer or rancher? 1= Not a barrier 2= A barrier I can overcome 3= A barrier that is difficult for me to overcome		
Markets/commodity prices	2.61 (.030)	441
Cost of inputs	2.60 (.031)	429
Lack of and/or cost of labor	2.19 (.045)	426
Availability and/or cost of insurance	2.23 (.038)	429
Uncertainty about production and revenue	2.44 (.033)	434
Terms of loan/debt	1.86 (.043)	428
Lack of local/in-state processing	2.25 (.042)	433
Government regulations	2.41 (.038)	432
Terms of government programs	2.13 (.039)	430
Access to land	1.96 (.047)	427

Section 3: Views on Three-Month Forecasts	Mean Estimate (SE)	Unweighted Count
We want to know what you think about three-month forecasts. Three-month forecasts are seasonal forecasts predicting *temperature* and *precipitation* for the next three months. Please indicate how much you agree or disagree with the following statements about three-month forecasts. 1= Strongly disagree 2= Disagree 3= Neither 4= Agree 5= Strongly Agree		

Even though three-month forecasts are not always accurate, I still find them useful	3.59 (.047)	443
I need to see how three-month forecasts are benefitting other producers before I will use them in my operation	2.77 (.048)	439
I have found three-month forecasts to be useful in making decisions about my farm/ranch operation	3.16 (.045)	441
I need three-month forecasts to be more accurate for them to be useful to me	3.49 (.045)	438
I rely on my own past experience rather than three-month forecasts	3.60 (.048)	432
I would use three-month forecasts if an organization I trusted endorsed this information	3.07 (.049)	439
I need to experiment with three-month forecasts to determine if they are useful	3.16 (.051)	442
Three-month forecasts about temperature and precipitation…		
...are provided in time for me to make a decision	3.07 (.041)	435
...are specific to my farm/ranch	2.77 (.045)	430
...are relevant to the decisions I make	3.00 (.050)	429
...are accurate	2.75 (.045)	431
...help me reduce financial risks	2.84 (.049)	427
...help me maintain or increase crop yields	2.87 (.046)	428
...help me maintain or increase forage productivity	2.93 (.048)	429
…help me improve environmental outcomes on my farm/ranch	2.91 (.049)	433
…are at a spatial scale that is local enough to be useful	2.84 (.045)	433
I don't trust three-month forecasts about temperature and precipitation because…		
...I don't know where they came from	3.09 (.047)	434
...I don't trust the organizations who produce them	2.94 (.048)	431
...they are always changing	3.41 (.047)	434
...they contradict one another	3.27 (.047)	432

Section 4: Views on Projections for 2050	**Mean Estimate (SE)**	**Unweighted Count**
We want to know your views on the usefulness of projections for how *temperature* and *precipitation* will change by 2050. Please indicate how much you agree or disagree with the following statements about these projections. 1= Strongly disagree 2= Disagree 3= Neither 4= Agree 5= Strongly Agree		
I would use projections for 2050 more if I knew other farmers/ranchers used this information	2.52 (.050)	431
I don't trust the projections for 2050 because I don't know where they came from	3.22 (.054)	426
I would use projections for 2050 more if I better understood the people and process behind this information	3.13 (.055)	430
I don't trust the organizations who produce projections for 2050	3.17 (.052)	426
I would use projections for 2050 more if an association/organization I trusted endorsed this information	3.01 (.050)	429
Projections for 2050 are useful to me in making short-term decisions	2.45 (.046)	431

Projections for 2050 are useful to me in making long-term decisions	2.65 (.053)	430
Projections for 2050 are not useful because the timeframe is too far away	3.68 (.060)	432

Section 5: Use of Information for Management Decisions	**Unweighted Count**
We would like to know what information sources you use to make management decisions on your farm or ranch. Please check all the sources that you use.	
Conservation District	206
Montana Dept. of Agriculture	186
MSU Extension Agents	224
USDA Northern Plains Climate Hub	22
Montana Drought and Climate	102
Montana Mesonet	8
AERO	5
US Forest Service	24
US Fish and Wildlife Service	30
Independent consultants	50
Holistic Resource Management	5
Montana Grain Growers Association	61
Cattlefax	60
In-person with other farmers/ranchers	324
Through social media with other farmers/ranchers	117
1MT DNRC (including MGCC)	127
Montana Natural Resources Council (NRC)	78
Agricultural Research Centers	128
Northern Plains Resource Council	27
Montana Climate Office	30
National Oceanic and Atmospheric Administration (NOAA)	120
Natural Resources Conservation Service (NRCS)	144
Bureau of Land Management	67
Private Industry input advisors	48
DTN (Data Transmission Network)	20
Montana Stockgrowers Association	141
National Cattleman's Beef Association	77
Montana Organic Association	9
AgriMET (BOR)	7

Section 6: Management Practices	**Mean Estimate (SE)**	**Unweighted Count**	**Mean Estimate (SE)**	**Unweighted Count**
We are interested in knowing more about your management practices. 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've been using it.	1= Not at all 2= Portion of farm or ranch 3= Entire farm or ranch		1= Less than 3 years 2= More than 3 years 3= Experimenting	
Vegetation				
Practice crop rotation (diversified rotations)	2.08 (.047)	420	2.03 (.017)	276
Use cover crops in place of crop fallow	1.53 (.039)	394	2.08 (.054)	152

Select crops and forage species to increase carbon sequestration	1.30 (.035)	406	2.00 (.087)	85
Use drought tolerant crop varieties	1.97 (.046)	406	2.01 (.026)	247
Manage for sudden onset of drought through earlier spring and fall planting	1.75 (.048)	403	1.99 (.036)	189
Use prescribed burning for pest and weed management	1.22 (.028)	412	2.03 (.052)	72
Soil & Water Management				
Use no till or reduced till farming	2.08 (.048)	415	1.92 (.033)	243
Integrate pulses into cropping mix	1.42 (.043)	405	1.95 (.039)	106
Integrate crops/livestock to improve soil	2.08 (.044)	407	1.99 (.020)	270
Use organic fertilizers	1.46 (.039)	409	1.98 (.048)	135
Upgrade to more efficient irrigation systems	1.42 (.039)	413	2.00 (.028)	114
Diversification				
Sell products from different farm/ranch enterprises (e.g., timber, honey, hand crafted goods)	1.27 (.033)	424	2.00 (.048)	82
Income from services beyond what we grow/raise (e.g., tourism, outfitting/guiding)	1.30 (.034)	423	2.03 (.046)	86
Use certifications to get a higher premium on products (e.g., organic, humane handling)	1.34 (.038)	416	1.99 (.033)	86
Monitoring				
Established soil and vegetation/range monitoring program to track and respond to change	1.65 (.044)	417	2.00 (.040)	168
Use precision agriculture (intensive use of data and monitoring) to increase efficiency and optimize inputs	1.48 (.042)	414	2.05 (.061)	117
Insurance & Contracts				
Purchase crop insurance	1.86 (.050)	413	2.01 (.021)	206
Purchase pasture, range, and forage insurance	1.61 (.046)	412	2.00 (.035)	157
Use contracts to deal with crop price volatility	1.52 (.044)	403	2.03 (.033)	128
Landscape Enhancements				
Managing for wildlife habitat	1.86 (.046)	421	2.00 (.024)	213
Establishing riparian buffers	1.59 (.043)	413	2.00 (.032)	150
If you raise livestock please continue telling us about your livestock and grazing management practices.				
Grazing & Livestock Management				
Intensive rotational grazing	1.82 (.046)	400	1.98 (.031)	212
Planned grazing for weed and invasive species management	1.89 (.047)	398	1.99 (.023)	229
Timing grazing for improved pastures	2.38 (.039)	401	1.99 (.017)	336
Breeding or improving herd genetics for drought and heat	1.93 (.055)	399	2.01 (.021)	188
Late spring/early summer calving	1.82 (.055)	385	1.90 (.035)	174
Strategic placement of water for livestock and better forage utilization (infrastructure upgrades, piping systems, water tanks)	2.33 (.043)	408	2.01 (.012)	315
Drought plan (e.g., reduce stocking rates, lease pasture, use additional hay)	2.33 (.044)	403	2.01 (.026)	316

Which best describes your grazing management? 1= Extensive - few pastures, long grazing duration—weeks to months 2= Moderate - many pastures, moderate grazing duration— many weeks 3= Intensive - many pastures, shorter grazing duration—days to weeks	1.90 (.032)	417
I keep written or electronic documentation or grazing plans and goals. 1=Never 2= Rarely 3= Sometimes 4= Often	2.35 (.070)	413
I rely on my own experience and the experience of past generations. 1=Never 2= Rarely 3= Sometimes 4= Often	3.71 (.032)	414

Section 7: Conservation Program Participation	**Mean Estimate (SE)**	**Unweighted Count**
We are interested in knowing if you participate in any conservation-related programs. Please take a look at the list below and indicate whether or not you are aware of the program and if you participate in it or not. 1= I am not aware of this initiative and have not used it 2= I am aware of this initiative and unable to patriciate 3= I am aware of this initiative and currently participate 4= I am aware of this initiative and have plans to participate in the future		
EQIP	2.20 (.062)	389
Conservation Stewardship Program	1.90 (.057)	375
Conservation Reserve Program	1.95 (.045)	379
MT Agricultural Research Center/Station Programs	1.83 (.059)	390
MT Sage Grouse Habitat Conservation Program	1.63 (.042)	399
Conservation easement	1.82 (.050)	386
Carbon credit program	1.69 (.057)	389

Section 8: Experience with Drought, Flooding, and Extreme Weather	**Mean Estimate (SE)**	**Unweighted Count**
We are interested in your experiences with drought, flooding, and extreme weather. Please indicate how much you agree or disagree with the following statements. 1= Strongly disagree 2= Disagree 3= Neither 4= Agree 5= Strongly Agree		

I have experienced….		
...losses due to drought in the last ten years	4.02 (.054)	440
...losses due to saturated soils and/or flooding in the last ten years	2.95 (.074)	428
...losses due to extreme heat in the last ten years	3.63 (.059)	432
…losses due to extreme cold in the last ten years	3.72 (.052)	438
I am worried…		
...that drought will harm my farm or ranch operation in the future	3.97 (.052)	437
...that extreme heat will harm my farm or ranch operation in the future	3.72 (.058)	431
...that flooding will harm my farm or ranch operation	2.90 (.066)	428
...that extreme cold will harm my farm or ranch operation	3.50 (.059)	432
We want to know what you think about the following statements. Please indicate how much you agree or disagree with the following statements.		
Even if there is a drought, there is not much I can do about it	3.24 (.062)	430
Recent drought conditions are temporary and Montana's climate will return to normal in the near future	3.32 (.052)	430
On my farm/ranch, we are experiencing bigger swings year-to-year (e.g. one year wet, another year dry)	3.16 (.055)	430
I have the capacity to overcome the barriers I face in order to achieve my goals as a farmer/rancher	3.34 (.049)	431
I believe that drought conditions will get worse over the next 10 years	2.90 (.053)	432
I experiment with new practices that change the way I run my operation	3.47 (.049)	426
There's too much uncertainty about future changes to the climate to justify changing my agricultural practices and strategies	2.98 (.055)	431
Changing my practices to cope with future changes to the climate is important for the long-term success of my farm/ranch	3.38 (.054)	427

Section 9: Views on Climate	Percent or Mean Estimate (SE)	Unweighted Count
Which of these three statements about the Earth's temperature comes closest to your view? (Please check one)		422
The Earth is getting warmer mostly because of human activity such as burning fossil fuels	14.0% (2.0%)	61
The Earth is getting warmer mostly because of natural patterns in the Earth's environment	45.5% (2.9%)	194
There is no solid evidence that the Earth is getting warmer	26.9% (2.6%)	113
Not sure	13.6% (2.0%)	54
How much, if at all, do you think that global climate change is affecting… 1= Not at all 2= Not too much 3= Some 4= A great deal		432
The United States	2.52 (.053)	434
Your local economy	2.33 (.054)	433
Your farm/ranch operation	2.31 (.055)	436
When do you think global climate change will begin harming people in your community?		
Never	27.3% (2.5%)	120
They are being harmed now	14.7% (2.1%)	61
In 10 years	5.9% (1.4%)	24
In 25 years	3.4% (1.1%)	14
In 50 years	1.3% (.6%)	7
In 100 years	1.5% (.7%)	6
Not sure	45.8% (2.8%	198

Section 10: Views on Government	Mean Estimate (SE)	Unweighted Count
Do you, yourself, agree or disagree with each of the following statements? 1= Strongly Disagree 2= Disagree 3= Neither 4= Agree 5= Strongly Agree		
Government programs have helped farmers and ranchers.	3.71 (.048)	437
I'm not interested in government incentives because they give government power to limit my activities.	2.96 (.053)	430
Government intervention on private land management is necessary.	3.68 (.056)	432
In the future, government incentives will be the best way to improve voluntary conservation on agricultural lands.	2.98 (.061)	433

Section 11: Demographic Information	Percent or Mean Estimate (SE)	Unweighted Count
What year were you born?	1955.74 (.755)	430
What is your gender?		437
Male	77.4% (2.5%)	350
Female	22.5% (2.5%)	86
Non-binary	.01% (.01%)	1
What is the degree you have received? (please check one)		432
None	2.7% (1.0%)	9
High school diploma or equivalent GED	43.6% (2.8%)	185
Associate degree	16.7% (2.1%)	72
Bachelor's degree	27.0% (2.5%)	119
Professional degree (MS, DDS, DVM, LLB, JD, DD)	9.2% (1.6%)	44
Doctorate degree (Ph.D, or Ed.D)	.8% (.5%)	3
Which of the following best represents your political views? (please check one)		431
Very conservative	34.7% (2.8%	137
Somewhat conservative	28.6% (2.5%)	132
Moderate, middle of the road	22.4% (2.4%)	99
Somewhat liberal	3..8% (1.0%)	19
Very liberal	1.2% (.6%)	6
Prefer not to say	9.3% (1.7%)	38

Appendix C: Selected indicators used to examine adaptation in rangelands (Table A2)

Table A2. Selected indicators used to examine or evaluate adaptive capacity, adaptive decision-making or climate adaptation in rangeland contexts. These indices illustrate the breadth of variables being used in the field and the complexity of factors that determine “adaptivity” for ranchers.

Study	Framework/Theory	Indicator Categories or Dimensions	Indicators/Variables		Other papers using same or similar framework
Adaptive Capacity					
Crimp, S. J. et al. (2010). Managing Murray-Darling Basin livestock systems in a variable and changing climate: challenges and opportunities.	Rural Livelihoods framework developed by Ellis (2000)	Capitals	Secondary data from the Australian Agricultural and Grazing Industries Survey (ABARE 2003)	Indicators derived from self-assessment workshops	King, E. G., Unks, R. R., & German, L. (2018). (Uses Sustainable Livelihoods Framework (SLF)) Wang et al. (2016). (Uses Adaptation, institutions, and livelihood (AIL) framework developed by Agrawal and Perrin (2009))
		Human capital	Education of operator Education of spouse Health	Age of farmers Attitude/enthusiasm/participation in natural resource management Experience Skilled/unskilled labour availability	
		Social capital	Landcare membership Partners Internet	Access to information/extension Local networks/communication Regulations	
		Natural capital	Mean PGIA Dams Vegetation potential	Water availability/security Aspects of management (fire, pests, planning) Biodiversity and native vegetation Changing farm size Groundcover Soil health/land capability Weeds	
		Physical capital	Plant and machinery index Structures index Livestock index	Fencing New breeds of stock Water infrastructure	

		Financial capital	Capital Mean total cash income Access to finance	Access to government NRM funding/drought relief Diversification of income streams/off-farm income Farm management deposits Farm profitability	
Tan, S., Li, T., & Huntsinger, L. (2018). Analyzing Herder Adaptive Capacity to Climate Change: A Case Study from an Ecologically Fragile Area in Inner Mongolia, People's Republic of China.	Adaptive Capacity Index (ACI)	Adaptive Willingness	Awareness of climate change Measures to cope with disasters	Pastoralists perceive climate change (Yes/No) Pastoralists take measures to cope with disasters (Yes/No)	
		Adaptive Capital	Human Capital	Number of working family members Education level of the household head	
			Natural Capital	Pasture productivity per capita (Million kg/person) Pasture area per sheep unit	
			Physical Capital	Has a covered pen (Yes/No) Has a motor-pumped well (Yes/No) The value of fixed assets (Thousand yuan) Number of livestock	
			Financial Capital	Total income (Million yuan) Household access to credit (Yes/No)	
			Social Capital	Access to technical information (Yes/No) Access to price information (Yes/No) Takes part in some form of cooperation (Yes/No) Participates in social insurance (Yes/No)	
Marshall, N.A. (2010) Understanding social resilience to climate variability in primary enterprises and industries	Nadine Marshall's Framework	Four dimensions	Survey questions on a scale of 1–4, where any value greater than 2 is considered to be a positive response.		Marshall, N. A., Gordon, I. J., & Ash, A. J. (2011). Marshall, N. A., & Smajgl, A. (2013)..
		(i) their perception of risk	E.g. 90.1% of graziers believed that they were more ''likely to survive drought compared to other cattle producers''.		
		(ii) their capacity to plan, learn and reorganise,	E.g. Most graziers (83.5%) said that, ''at the onset of drought [they] plan a way to survive it''.		

		iii) their proximity to the thresholds of coping, and	E.g. Over 55% of graziers thought that,"the uncertainty surrounding drought is worse than the drought event itself", where 75.5% said that their family was, "used to bad times and [they know they] will survive future drought."	Marshall et al. (2014). Marshall, N. A., & Stokes, C. J. (2014).
		(iv) their level of interest in adapting to change.	E.g. 83.5% of graziers were, "interested in learning how [they] could better prepare for drought." Some graziers (60.4%), "attend workshops to get new ideas to better manage drought" and 71.5%, "talk about strategies to survive drought with others".	Marshall, N., & Stokes, C. J. (2014).
Fernández-Giménez et al (2015). Lessons from the Dzud: Community-Based Rangeland Management Increases the Adaptive Capacity of Mongolian Herders to Winter Disasters	Innovation and preparation indices were used as primary indicators of adaptive capacity	Preparedness activities (13 total)	Reserve winter pasture, Reserve spring pasture, Reserve dzud pasture, Fall or summer otor, Cull unproductive animals in fall, cut hay, Prepare hand fodder, Purchase and store grain, Purchase and store concentrate, Purchase and store other feed, Vaccinate livestock, Deworm livestock, Treat livestock for external parasites	
	8 intermediary indicators of adaptive capacity identified from the literature	Innovation practices (21 total)	Purchase breeding stock–camels, Purchase breeding stock–horses, Purchase breeding stock–cattle, Purchase breeding stock–sheep, Purchase breeding stock–goats, Intentionally change species composition of herd, Sell animals to reduce herd size, Fence pasture, Fence hay field, Fence or improve natural water source, Dig a new well, Repair existing well Plant fodder or grass, Use fertilizer, Use irrigation, Plant garden for food, Take action to reduce soil erosion, Take action to restore damaged lands or natural resource, Take part in formal monitoring of environmental conditions, Take other action to protect key resource, Intentionally not breed animals because of dzud	
		structural social capital (bonding and linking networks)	Question asking respondents who had helped them during a time of need within the past 5 years.	
		cognitive social capital (trust and reciprocity)	Cognitive social capital was assessed using 6 items on a 3-point Likert-type scale (disagree, neutral, agree)	
		community leadership	Responses to 4 survey items. E.g. "My community has good informal leaders whom we trust"	
		pro-activeness	A summative index of 6 items E.g. Talked with experts about rangeland issues	
		information diversity	an index of access to 15 different information sources	

		knowledge exchange	an index of access to 4 different types of information E.g. "I know people I can talk with about.. Livestock health, reproduction, and nutrition"	
		income diversity	income diversity using a simple summative index of the number of different income sources reported by each household (out of a possible 16).	
Adaptive Decision-making / Adaptive Management				
Lubell et al (2013). Conservation program participation and adaptive rangeland decision-making.	Theory of planned behavior Diffusion of innovation theory	Dependent Variables: Rates of Participation in Conservation Management Programs Independent variables:	For 18 different conservation programs, ranchers selected whether they were 1) not aware of the program 2) aware but choose not to participate 3) aware and currently participate, or 4) aware with plans to participate in the future.	Wilmer et al.. (2018). Roche et al. (2015).
		Operator/operation characteristics	Private acres Public acres Education Income	
		Off-ranch income sources	"Yes" answers to seven types of possible sources: other agricultural production, nonextractive recreation, conventional energy-development, extractive recreation, alternative energy development, and any other unspecified a	
		Time horizon	Succession plan Generations	
		Social network connections	Opinion leader Conservation information sources	
		Social values	Views on the role of government Views on private property rights Government trust	
Haigh et al. (2021). Ranchers' Use of Drought Contingency Plans in Protective	Two bodies of social-psychological decision-making theory:	Drought management actions that producers took	Purchase more hay or feed than usual to supplement existing feed stocks Graze fall or winter pastures earlier than planned Destock pastures more than usual (through any culling, early weaning, ending grazing contracts, sending to feedlot, etc.) Cull and sell more breeding animals than usual	

Action Decision Making.	Protective action theory	Whether or not they had a plan for drought	Yes No I don’t know
	Theory of Implementation Intention	Use and influence of a range of drought monitoring information sources,	On-farm rain gauge or soil moisture sensors Own assessment of crop range or livestock conditions National Weather Service U.S. Drought Monitor
		Operational characteristics	Land base Experience Financial resources Education Range condition Irrigation Summer drylot/feedlot
Kachergis et al. (2014). Increasing flexibility in rangeland management during drought.		Drought plan and other drought management practices (Dependent variables)	Preparation practices: (1) incorporate yearling livestock; (2) grassbank (stockpile forage); (3) stock conservatively; (4) rest pastures; (5) use 1-3 mo weather predictions to adjust stocking rate. Response practices: (1) purchase feed; (2) reduce herd size; (3) earn off-farm income; (4) rent additional pasture; (5) apply for government assistance; (6) sell retained yearling livestock; (7) move livestock to another location; (8) wean calves early; (9) place livestock in a feedlot. Flexibility in managing drought is inferred from the number of drought management practices associated with each operation characteristic.
		Drought impacts	(1) grazing capacity; (2) irrigation water availability; (3) winter feed availability; (4) calf weaning weights; (5) livestock reproductive rates; (6) profitability.

		Ranch operation characteristics (Explanatory variables)	Operation size Diversification Livestock density Grazing period length Having yearling livestock or not
Climate Adaptation			
Coppock, D. L. (2011). Ranching and Multiyear Droughts in Utah: Production Impacts, Risk Perceptions, and Changes in Preparedness.	Risk management theory	Factors thought to influence drought preparedness (Independent variables)	1) income/brood herd size 2) ranch location 3) whether or not respondents were public grazing permittees 4) degree of ranch management experience 5) previous use of drought crisis-response tactics, 6) level of formal education 7) operator age 8) degree that previous drought had negatively affected their operations, and 9) whether an operator expected another multiyear drought to occur soon.
		Crisis-response tactics used by Utah ranchers during the 1999-2004 drought	Enrolled in government relief programs Relied on emergency purchases of hay Relied on emergency sales of livestock Obtained emergency water Relied on emergency trucking to move livestock Claimed tax write-offs Renegotiated bank loans Other Obtained relief from private sources
		Risk-management tactics used by Utah ranchers in 2009 for drought preparedness.	Improving water for livestock Diversifying family income Improving irrigation for hay production Improving land management Reducing stocking rates Enrolling in government disaster compensation programs Increasing capacity for hay production Purchasing feed insurance Seeking extension information Using internet drought forecasts 493 Using forward contracting for livestock sales Increasing capacity for hay storage Planning to use grass banks Renegotiating bank loans

			Other Using forward contracting for hay purchases
Ndiritu, S. W. (2021). Drought responses and adaptation strategies to climate change by pastoralists in the semi-arid area, Laikipia County, Kenya.	Climate change adaptation literature	Variables hypothesized to influence the adoption of adaptation strategies (independent variables)	Average annual rainfall Average annual temperature Number of times delay in rainy season affected livestock since 2000 Number of times drought affected livestock since 2000 Access to early warning information after devolution Access to grazing provided by private ranches Wealth index Livestock size in a standardized unit (TLU) Age of the household head (years) Gender Highest level of education in the household (years of schooling Household size Distance to the main market (km) Credit - Access to credit after devolution Pastoralism the main activity of this household
		Climate adaptation measures (dependent variables)	1) Mobility - increased mobility in terms of distance and frequency 2) Fodder purchase and storage 3) Change in water management 4) Shift Livelihoods - Partial shift to other livelihoods, 5) Herd management - overall management of the herd (reducing herd size, selling and banking livestock assets)
Haigh et al. (2019). Socioecological Determinants of Drought Impacts and Coping Strategies for Ranching	Climate vulnerability theory Resilience theory	Characteristics of the ranch organization used in analysis to predict drought impacts and response (independent variables)	pasture hectares number of cattle and calves percent of income from operation enterprise ecological description of pastures/range access to irrigation feed resources reserve forage capacity grazing system use of Pasture, Rangeland, Forage Insurance (PRF)

Operations in the Great Plains	A drought mgmt. framework informed by a conceptual framework by Chapin et al. (2009) linking resilience and vulnerability as complementary theoretical approaches to understanding change	Drought response actions (dependent variables)	supplemental feeding grazing pastures earlier than usual grazing cover crops or residues moving animals to feedlot send-ing custom grazed animals home early, leasing or purchasing additional grazing land, early weaning selling culls earlier than usual reducing stockers and/or breeding animals.
		Drought severity and impacts	Drought severity measured using the median Standardized Precipitation Evapotranspiration Index (SPEI) value calculated monthly for each county represented in the survey sample Five survey based measures of drought impacts: impact to forage feed capacity rangeland health animal production cash flow value of the ranch operation