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Increasing flexibility in rangeland management during drought

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Abstract. Extreme droughts like the recent 2011–2013 drought impacting the central and western United States present a challenge to sustaining livestock ranching operations and the ecosystem goods and services they produce. Wyoming ranchers manage half of this drought-prone state and are at the forefront of this challenge. We examined Wyoming ranchers' drought management strategies and how ranch characteristics affect drought management flexibility, a key component of resilience, through a mail survey. We find that many survey respondents manage drought in similar ways, by selling livestock and buying feed, highlighting the market risks associated with drought. Ranches that are larger, include yearling livestock, use shorter grazing periods, and/or incorporate alternative on-ranch activities (e.g., hunting) use more drought management practices and thus have greater flexibility. Larger ranches experience fewer drought impacts, highlighting advantages of a larger resource base. Our findings suggest three components of national drought policy that encourages flexibility and thus increases resilience of ranches to drought: (1) encouraging forage-sharing mechanisms; (2) promoting income diversification that is independent of climatic variability; and (3) facilitating a shift to diversified livestock production systems. These measures could increase sustainability of ranching livelihoods and provision of ecosystem services despite predicted increases in intensity and duration of future droughts.

Key words: adaptive capacity; agricultural policy; climate variability; ecosystem services; fragmentation; livestock production; mixed-grass prairie; ranchers; resilience; sagebrush steppe; Wyoming, USA.

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Introduction

Livestock ranching operations manage millions of hectares of US rangeland ecosystems. These operations produce food and are increasingly important for providing ecosystem services as more rangelands are permanently converted to development (Maestas et al. 2003, Brunson and Huntsinger 2008). Droughts like the one that began in 2011 and affected huge areas of the central and western US (Fig. 1A) can trigger undesirable ecological changes in rangelands, reduce livestock production and provision of ecosystem services, and threaten ranching livelihoods. Increasing climate variability (IPCC 2007) heightens the need for the livestock industry and policy makers to move beyond reactive drought management practices and policies (e.g., disaster designations; Fig. 1B) and adapt to drought (Smit and Wandel 2006, Howden et al. 2007, McKeon et

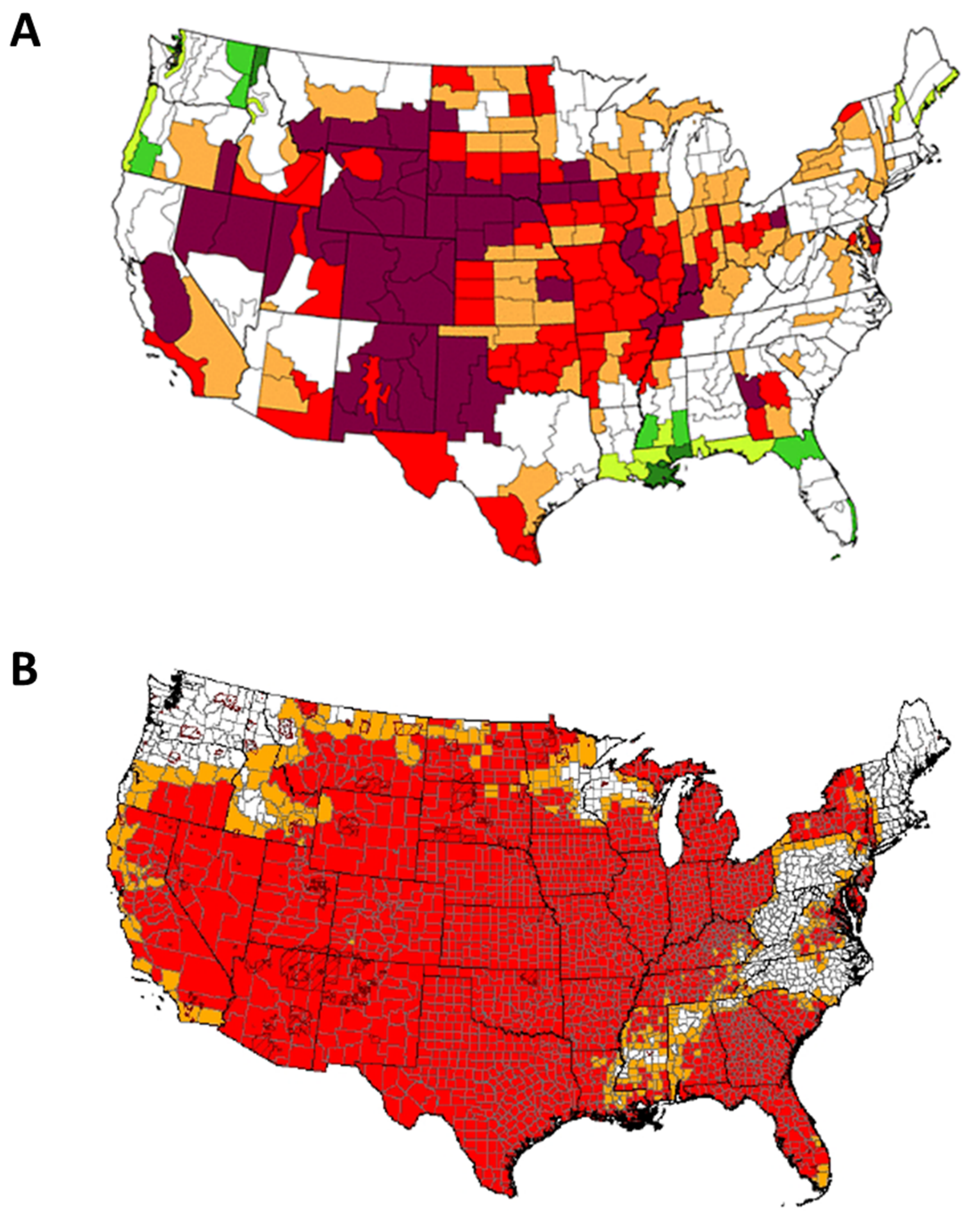

Fig. 1. (A) Much of the United States experienced drought (orange: moderate; red: severe; purple: extreme) in August 2012 according to the Palmer Drought Index, an indicator of long-term drought. (B) Most US counties were eligible to receive drought disaster assistance after the 2012 drought, shown by drought disaster designations (red) and contiguous areas (yellow) in February 2013. Source: NOAA National Climate Data Center; USDA Farm Services Agency.

al. 2009). Given that timing, duration, and severity of future droughts, along with associated risks, are largely unpredictable, flexibility is a key characteristic of management strategies for adapting to drought that may increase resilience of a ranching operation to future droughts (Fazey et al. 2010). We draw on the experiences of Wyoming ranchers, who encounter drought more often than most of the US (Soule 1992), to understand drought management and suggest components of a proactive drought policy for US rangelands.

Drought management involves increasing resilience of the ranching operation to the risks posed by a variable climate (Thurow and Taylor 1999, Howden et al. 2007, McKeon et al. 2009). Livestock ranching operations are vulnerable to production risk because forage production in rangeland ecosystems is linked to growing season precipitation which is highly variable within and between years (Knapp and Smith 2001). Drought reduces the number of livestock rangelands can support, individual animal productivity, and supply of essential commodities like irrigation water for hay production (Box 1). In August 2012, severe or greater drought affected 67% of livestock value in the US (USDA ERS 2012), and cattle and calf numbers were at their lowest level in 60 years as of February 2013 (USDA NASS 2013). Failure to graze rangelands properly during drought can cause ecological degradation, including loss of plant cover and accelerated soil erosion (Thurow and Taylor 1999). Markets are a second, interrelated source of risk to agricultural operations during drought. Many ranchers take similar management actions when drought occurs (Box 1), causing major price fluctuations. For example, when ranchers act in unison to sell livestock during drought, livestock prices often fall. This creates an incentive for ranchers not to reduce the size of their herd, sometimes accelerating ecological degradation (Stafford Smith et al. 2007). Production risks coupled with market risks impact profitability and are the major reason agricultural operations fail during drought (Box 1; Stafford Smith et al. 2007).

Given that timing, duration and severity of future droughts and associated risks are largely unpredictable, flexibility in drought management (e.g., ability to use multiple management options; Box 1) allows ranching operations to adaptively balance forage demand with forage supply, reduce drought impacts, and ultimately increase resilience (Ash and Stafford Smith 2003, Folke 2006, McKeon et al. 2009, Darnhofer et al. 2010, Fazey et al. 2010). The "best" management strategy during one drought may not be the best strategy during the next drought. Thus, operations with more management options during drought may have a greater capacity to endure drought (McAllister et al. 2009). Drought preparation includes efforts to reserve forage in case of drought or vary stocking rate (the number of animals grazing an area over time) with forage supply (Box 1); responses to drought include practices that reduce forage demand, increase forage supply, and increase income from alternative sources (Box 1). Operation characteristics may enhance or constrain ranchers' ability to use drought management practices (Box 1; Fazey et al. 2010). For example, a ranching operation with more land could prepare for drought by grassbanking and respond by moving livestock to another, more productive location (McAllister et al. 2009, Coppock 2011). Smaller operations may lack the land, forage, and economic resources to take these management actions.

Wyoming ranching operations experience drought more often than other parts of the US (Soule 1992) and thus are at the forefront of rangeland drought management. Wyoming features two major US rangeland ecosystems: mixed-grass prairie and sagebrush steppe. Precipitation is low and variable. Wyoming experienced mild drought in 33% and extreme drought in 10% of growing season months from 1895 to 2011 (Palmer Drought Severity Index; data from NOAA National Climatic Data Center). Past and predicted increases in temperature suggest that drought may become more frequent and intense in the future (IPCC 2007, Shuman 2011). Wyoming ranching operations are typical of ranching operations in the western US: their land base includes private and permitted lands (state, federal); cow-calf pairs are the primary grazing enterprise; and they incorporate other activities that affect land management, including hunting and energy development (Coppock 2011, Kachergis et al. 2013).

Our goals are to: (1) describe the drought management practices Wyoming ranchers use and (2) understand how ranching operation characteristics influence flexibility in drought management and drought impacts. We surveyed producer members of the Wyoming Stock Growers Association in January through March 2012, just before the onset of severe drought in Wyoming. We infer flexibility from the number of drought management practices associated with each operation characteristic. Our results represent 307 operations that manage 3.4 million hectares of Wyoming rangelands. We identify actions ranchers can take to increase flexibility in

Box 1

Drought operation characteristics, management, and impacts as conceptualized by the Wyoming Rangeland Decision-Making Survey

We hypothesize that some ranching operation characteristics enable greater flexibility in drought management and reduce impacts from drought. See *Methods* for an overview and explanation of Wyoming ranch characteristics.

Operation characteristics that may increase flexibility in drought management and reduce impacts from drought

Larger operations (total area in ha) may have greater flexibility and fewer impacts during drought for several reasons: (1) access to greater and more heterogeneous forage resources, (2) greater capital reserves, and (3) economies of scale.

Having other activities on the ranch (including extractive recreation [hunting], conventional energy development, other agricultural production, alternative energy development, and non-extractive recreation) increases revenue.

Lower livestock density (greater than 12 ha/AU, vs. 4–12 or less than 4 ha/AU) ensures that forage demand will rarely exceed forage supply.

Shorter grazing period length (moving livestock to another pasture after less than 1 mo or 1–3 mo) allows more control over livestock grazing (e.g. location, distribution) and provides opportunities for grassbanking.

Having yearling livestock may allow a more flexible stocking rate that can be adjusted with available forage and ultimately lead to greater profitability in variable climates.

Drought management strategies: ***How do ranches manage for drought impacts?***

Preparation: (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: (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.

Drought impacts: ***During the last drought, which of the following were impacted more severely than expected?***

(1) grazing capacity; (2) irrigation water availability; (3) winter feed availability; (4) calf weaning weights; (5) livestock reproductive rates; (6) profitability.

(References: Foran and Stafford Smith 1991, Scoones 1995, Hall et al. 2003, Ash and Stafford Smith 2003, Bastian et al. 2006, Stokes et al. 2006, McAllister et al. 2009, Ritten et al. 2010, Torell et al. 2010, Coppock 2011)

drought management and thus enhance the resilience of rangeland ecosystems, livestock production, ecosystem service provision, and ranching operations to changing climate and increasing weather variability. This toolbox of flexible management strategies could inform development of a proactive drought policy for US rangelands as an alternative to reactive drought declarations (Fig. 1B).

Methods

We conducted a mail survey of producer members of the Wyoming Stock Growers Association (WSGA), the largest ranching organization in Wyoming. Producer members are growers of livestock. Survey development is described by Kachergis et al. (2013) and Lubell et al. (2013). The survey was implemented in four stages (Dillman 2007): (1) survey announcements, (2) a questionnaire, (3) a replacement questionnaire, and (4) legitimacy-building efforts via email and print media. We mailed the survey to 749 WSGA producer members. Eighteen percent of survey respondents indicated they did not own or manage livestock and were screened out of the sample. We received 307 partially or fully completed questionnaires for an adjusted response rate of 50%.

Wyoming ranch characteristics revealed by the survey provide context for our analysis of drought management (see complete report in Kachergis et al. 2013). The median ranch size was 4,220 ha, and operations ranged in size from 30 to 185,000 ha. As is traditional in the western US (Coppock and Birkenfeld 1999), most (91%) ranches ran cow-calf pairs, averaging 390 pairs per ranch. Cows are run year-round, with calves generally born in the spring and then weaned in the fall. At this time, some heifer calves are kept as replacements into the breeding cow herd and the remaining heifer calves and steer calves are sold or kept to run as stockers (or yearling cattle). Almost half (44%) of ranches in Wyoming run stockers, with some of these bought in the late winter or spring, grazed on the ranch during the summer, and then sold in the fall. Livestock density varied across Wyoming ranches, with 40% each grazing at a density of less than 4 or 4–12 ha per animal unit (AU, equal to one 453 kg cow with a calf), whereas 20% of the ranches grazed at greater than 12 ha/AU. Most ranches moved livestock to a new pasture after less than three months of grazing the current pasture (less than one month: 42%; one to three months: 41%; year-long or season-long grazing: 13%). Most ranches (74%) had other resource use activities which can provide additional income, with hunting, conventional energy development, and agricultural development most common. We hypothesize that these basic characteristics of ranching operations affect drought management and impacts (Box 1).

Our analysis of survey responses focuses on (1) drought management practices of Wyoming ranchers and (2) relationships between ranch characteristics, drought management practices, and drought impacts (Box 1). We report summary statistics to describe survey respondents' drought management strategies. To understand how ranching operation characteristics influence drought management and impacts, we use multiple logistic regression with model averaging in R (Version 2.15; R Foundation for Statistical Computing; packages arm and MuMIn). Logistic regression predicts the probability of a binomial outcome (e.g., use of a drought management practice), given predictor variables. Model averaging makes inferences based on weighted support from the best logistic regression models. Model averaging accounts for multi-model uncertainty and produces more reliable estimates of effect size than traditional null hypothesis testing (Burnham and Anderson 2002, Grueber et al. 2011). We perform model averaging in several steps: (1) generate a full model set from each response variable and predictor variables; (2) standardize input variables to a mean of 0 and a standard deviation of 0.5 (Gelman 2008); (3) select the best models using a cutoff of $2AIC_c$ (Burnham and Anderson 2002); and (4) compute a weighted average of parameter estimates from the best models using the natural average method (e.g., averaging parameter estimates from models in which each predictor appears). We report the odds ratio, confidence interval, and relative importance (sum of Akaike weights of models in which it appears) for each predictor variable. In this analysis, we only include complete observations, and limit drought management practices to those used by over 15% of ranchers. We infer flexibility in managing drought from the number of drought management practices associated with each operation characteristic.

Results

Drought management and impacts

Nearly all survey respondents reported experiencing drought (95%; N = 291), generally within the last decade (95%; N = 249). During the most recent drought, 60% of survey respondents had a drought management plan in place (N = 274). Most survey respondents use management practices to prepare for drought (81%; N = 279; Fig.

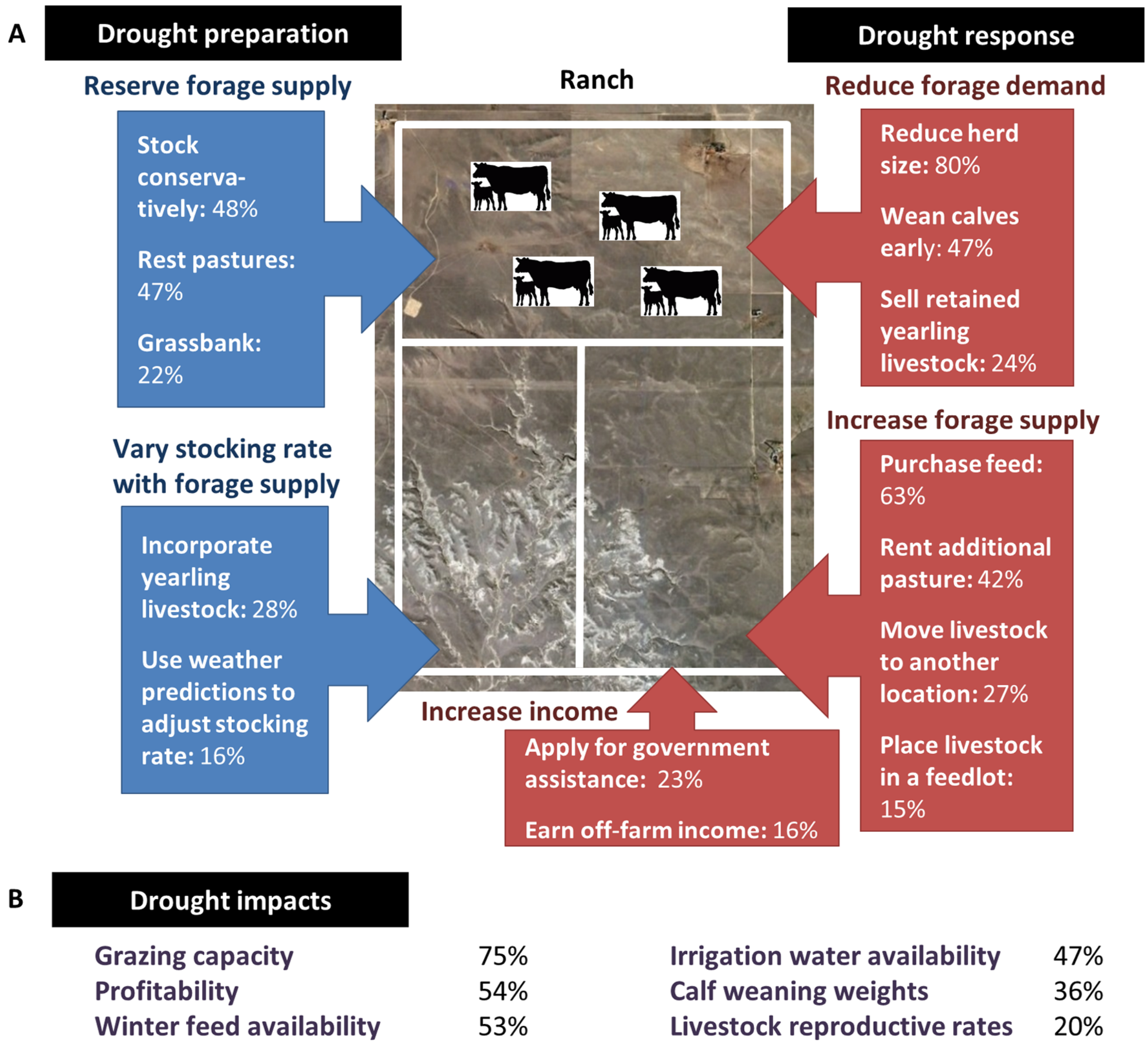

Fig. 2. (A) Drought management strategies Wyoming ranches use to balance forage demand with forage supply, reported as the percentage of respondents who use each practice. (B) Drought impacts on Wyoming ranches that were more severe than expected, with percentages of survey respondents who reported each impact.

2A). Almost all survey respondents use management practices to respond to drought (97%; N = 279; Fig. 2A).

Despite preparation, survey respondents indicated that the previous drought impacted aspects of their ranching operations more severely than expected (Fig. 2B). Over half reported that grazing capacity (75%; N = 281), profitability (54%), and winter feed availability (53%) were affected. Additional impacts were to irrigation water availability (47%), calf weaning weights (36%), and livestock reproductive rates (20%).

Forty percent indicated that drought will be more influential in their management plans and operations in the next 10 years than it has been in the last 10 years (N = 283).

Ranch characteristics influence drought management

Ranching operation characteristics predict which management practices ranchers use to prepare for and respond to drought (Table 1; Appendix: Tables A1 and A2). We infer management flexibility from the number of drought

Table 1. Effects of ranch operation characteristics (top) on drought management practices (left) of Wyoming ranches. A greater number of different drought management practices positively associated with a particular characteristic implies increased flexibility in drought management.

Drought management practice	Ranching operation characteristics						
	Larger size (ha)	Having other activities	Higher livestock density†		Shorter grazing period‡		Having yearling livestock
			4–12 ha/AU	<4 ha/AU	1–3 mo.	<1 mo.	
Drought preparation							
Stock conservatively	+				+	+	+
Rest pastures	+	+			+	+	+
Incorporate yearling cattle	−	+			+	+	+
Grassbank	+	+	−	+	−	+	+
Use weather predictions to adjust stocking rate	+				+	+	+
Drought response							
Reduce herd size	−	+					
Purchase feed	+	+	−	−			
Wean calves early	+	+	−	−			
Rent additional pastures	+	+					−
Move livestock to another location	+	+					+
Sell retained yearling cattle	+	+			+	+	+
Apply for government assistance	+	+	+	−			
Earn additional off-farm income	−	+					−
Place livestock in a feedlot	+	+	−	−	+	+	+

Notes: Effects were identified using multiple logistic regression with model averaging. A plus sign (+) indicates that the ranch operation characteristic is positively associated with use of a practice (odds ratio greater than 1); a minus sign (−) indicates a negative association (odds ratio less than 1). A blank cell indicates no relationship. All ranching operation characteristics are from the "Operation Characteristics" and "Grazing Practices on Private Land that is not Irrigated" sections of the Wyoming Rangeland Decision-Making Survey.

† Density is relative to greater than 12 ha/AU. An animal unit (AU) is a 453-kg cow with a calf.

‡ Grazing period length is relative to continuous grazing through the entire growing season.

management practices associated with each operation characteristic; if a characteristic increases use of many practices, it increases flexibility. Ranches that have a larger land area, use shorter grazing periods, incorporate yearling livestock and/or include other activities (e.g., hunting, conventional energy development) are more likely to use half or more of five management practices to prepare for drought (Table 1). Having yearling livestock and/or shorter grazing periods (moving livestock at least once a month) increase the likelihood of all drought preparation practices; larger size predicts use of all practices except incorporating yearling livestock; other activities increase the likelihood of resting pastures, incorporating yearling livestock, and grassbanking. Stock density has few associations with drought preparation.

Likewise, ranches that are larger and/or incorporate other activities are more likely to use half or more of the nine drought response practices (Table 1). Other activities predict use of all drought response practices; larger size predicts use of all responses except reducing herd size and earning off-farm income. Shorter grazing periods (moving livestock at least once in three months) have few, positive effects on drought response, and including yearlings has mixed effects on drought responses. Higher stock density is negatively associated with many drought responses.

Ranch characteristics influence drought impacts

Ranching operation characteristics predict whether or not a ranch experienced impacts during the last drought that were more severe than expected (Table 2; Appendix: Table A3). Many drought impacts occurred more often on ranches with characteristics that increase drought management flexibility. Ranches that have higher

Table 2. Effects of ranch operation characteristics (top) on drought impacts to Wyoming ranches (left). Negative associations imply that characteristics may reduce impacts during drought.

Drought impact	Ranching operation characteristics						
	Larger size (ha)	Having other activities	Higher livestock density		Shorter grazing period		Having yearling livestock
			4–12 ha/AU	<4 ha/AU	1–3 mo.	<1 mo.	
Grazing capacity		+	+	−			+
Profitability	+	+	+	+	+	+	+
Winter feed availability	−	+	+	+	+	+	+
Irrigation water availability	−	+	+	+			−
Weaning weights		+			+	+	
Reproductive rates	+	+					+

Notes: Effects were identified using multiple logistic regression with model averaging. Symbols and units are as in Table 1. All ranching operation characteristics are from the "Operation Characteristics" and "Grazing Practices on Private Land that is not Irrigated" sections of the Wyoming Rangeland Decision-Making Survey.

livestock density, employ shorter grazing periods, include yearling livestock and incorporate other activities (e.g., hunting, conventional energy development) are more likely to report three of six drought impacts. Ranches with these characteristics report effects on profit and winter feed; all characteristics but shorter grazing periods are associated with impacts to grazing capacity. In contrast, ranches with larger total area are less likely to report two impacts, winter feed and irrigation water. However, larger ranches are more likely to report two other impacts, profit and livestock reproductive rates.

Discussion

We examine rangeland drought impacts and management through the experiences of ranchers, whose decisions affect ecosystem dynamics and sustain ecosystem goods and services across millions of hectares. The Wyoming Rangeland Decision-Making Survey highlights the fundamental challenge of ranching operations to balance forage demand from livestock with highly variable forage supply (Fig. 2). The greatest drought impact to ranching operations is decreased grazing capacity, consistent with our knowledge of rangeland ecosystems and beef cattle ranching operations (Bastian et al. 2006, Coppock 2011; Fig. 2B). Other severe drought impacts identified by ranchers include profitability, winter feed availability, and irrigation water. Survey respondents use a variety of drought management practices to handle impacts (Fig. 2A). The most popular strategies focus on reserving forage supply, reducing herd size, and buying feed, consistent with other studies (Bastian et al. 2006, Coppock 2011; Fig. 2A). The fact that many ranchers use similar drought management practices, potentially triggering major price fluctuations, highlights the market risks associated with drought. This reinforces the importance of flexibility in drought management strategies for drought adaptation, as doing something different may help a producer reduce market risks.

A majority of Wyoming ranching operations take a proactive approach to drought management by planning for drought (60%) and/or by using management practices to prepare before drought occurs (81%). This may represent a change in behavior related to record high temperatures and frequent droughts in Wyoming over the past decade (NOAA National Climatic Data Center). Nearly all ranchers experienced drought between 2002 and 2011. Ranchers may have a heightened awareness of drought due to these recent events, leading to changes in their management. Indeed, 40% of ranchers said that drought would influence their management plans and operations more in the next 10 years than it had in the prior 10 years. Other recent surveys have shown that experiencing drought changes management actions (Dunn et al. 2005, Bastian et al. 2006, Coppock 2011). For example, self-reported drought preparedness doubled 10 years after drought in Utah (Coppock 2011).

Larger ranch size and having other income-generating activities on the ranch (e.g., hunting) consistently increase the number of drought management practices used and thus flexibility in drought management, both before and during drought (Table 1). Additionally, having yearling livestock and using shorter grazing periods are associated with greater flexibility in drought preparation (Table 1). Ranch size affords ecological and economic benefits including heterogeneity of forage, greater capital, and economies of scale (Scoones 1995, Stokes et al. 2006, Hobbs et al. 2008, McAllister et al. 2009). Ranch size may be particularly important in drought-prone Wyoming, which has the largest ranches on average in the US (data from 2007 National Agricultural Census). Other activities on ranches such as recreation, energy development, and additional agricultural production provide income and economic diversification. Nearly half (44%) of survey respondents' operations incorporate yearling livestock in addition to cow-calf pairs, partially because they can be used to adaptively balance forage supply and forage demand. Recent economic modeling efforts suggest that yearlings provide increased flexibility and profitability in variable climates (Ritten et al. 2010, Torell et al. 2010), especially when stocking decisions are adjusted using seasonal weather forecasts. Finally, using shorter grazing periods enable ranchers to reserve forage supply in ungrazed pastures, to be grazed if drought occurs.

Ranch size reduces some drought impacts on Wyoming ranches (Table 2), likely through ecological and economic benefits discussed above (Scoones 1995, Stokes et al. 2006, Hobbs et al. 2008, McAllister et al. 2009). In contrast, other operation characteristics that increase flexibility also increase reported impacts (Table 2). The success of shorter grazing periods, yearling livestock enterprises and other on-ranch activities such as hunting also depend on forage amount, suggesting that income from these activities is also vulnerable to drought. Reducing drought impacts may require (1) large ranch size such that the resource base is sufficient during drought, or (2) income diversification that is independent of drought-related production and market risks. For example, landowner agreements that enable sharing of forage resources (e.g., agistment in Australia; McAllister et al. 2006) may effectively increase ranch size with benefits to ranchers during drought.

We speculate that increased flexibility in drought management may lead to healthier and more productive rangeland ecosystems and more resilient ranching operations by improving the dynamic balance between forage demand and forage supply. The reverse, decline in rangeland ecosystem health and failure of livestock enterprises during drought, is well-documented (e.g., Stafford Smith et al. 2007). Low plant productivity during drought leads to livestock consuming a greater proportion of available rangeland vegetation, potentially damaging grazed plants, reducing total plant cover, and triggering accelerated soil erosion. In Wyoming, risk of ecosystem degradation is greater in sagebrush steppe (western part of the state) than the mixed-grass prairie (eastern part of the state), because a shorter evolutionary history of grazing has led to plants that are less grazing tolerant (Coughenour 1985, Milchunas et al. 1988, Heitschmidt et al. 2005). Ecological degradation in turn heightens production risks to ranching operations whose income depends on forage that ecosystems produce. Flexible drought management strategies mitigate risks by better synchronizing rangeland forage demand with dynamic supply (Fig. 2). Native populations of large herbivores in this region similarly fluctuate with climate-induced changes in plant production (Frank and McNaughton 1992). Ongoing work is exploring the link between ranch drought management practices and ecosystem health through an adaptive grazing management experiment, on-ranch interviews and ecological monitoring (E. Kachergis and J. D. Derner, *unpublished data*).

The Wyoming Rangeland Decision-Making Survey demonstrates that ranch characteristics increase flexibility in drought management and reduce impacts from drought, thus enhancing resilience of ranching operations and the ecosystems they manage. These findings suggest several proactive steps towards development of a national drought policy for rangelands, including: (1) encouraging forage-sharing mechanisms; (2) promoting income diversification that is independent of climatic variability; and (3) facilitating a shift from cow/calf to diversified livestock (i.e., both cow/calf and yearlings) production systems. Given the likelihood of more intense and longer duration future droughts, improving drought management on ranches can sustain provision of ecosystem goods and services not only in Wyoming but on hundreds of millions of acres in the western US.

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Supplemental Material

Appendix

Table A1. Ranching operation characteristics affect drought preparation on Wyoming ranches according to the Wyoming Rangeland Decision-Making Survey.

Drought preparation practice	Ranching operation characteristic	Odds ratio	Odds ratio confidence interval	Relative variable importance
Stock conservatively	Size	1.4	0.8–2.3	0.28
N = 236	Yearlings	1.2	0.7–2.0	0.17
4 models	Grazing period length, 1–3 mo	1.5	0.6–3.6	0.16
	Grazing period length, <1 mo	1.9	0.8–4.5	0.16
Rest pastures	Grazing period length, 1–3 mo	1.3	0.5–3.2	1.00
N = 236	Grazing period length, <1 mo	2.5	1.0–6.1	1.00
4 models	Other activities	1.9	1.0–3.5	1.00
	Size	1.4	0.8–2.5	0.43
	Yearlings	1.4	0.8–2.3	0.40
Incorporate yearling livestock	Yearlings	12.1	5.8–25.1	1.00
N = 236	Grazing period length, 1–3 mo	2.4	0.7–8.3	1.00
3 models	Grazing period length, <1 mo	4.2	1.2–14.4	1.00
	Size	0.7	0.4–1.4	0.27
	Other activities	1.3	0.6–3.0	0.23
Grassbank (stockpile forage)	Other activities	2.6	1.1–6.2	1.00
N = 236	Yearlings	1.7	0.9–3.2	0.53
12 models	Size	1.5	0.8–2.7	0.48
	Density, 4–12 ha/AU	0.7	0.3–1.9	0.40
	Density, <4 ha/AU	1.6	0.7–3.7	0.40
	Grazing period length, 1–3 mo	0.7	0.2–2.3	0.23
	Grazing period length, <1 mo	1.4	0.5–4.1	0.23
Use weather predictions to adjust stocking rate	Size	1.4	0.8–2.3	0.28
N = 236	Yearlings	1.2	0.7–2.0	0.17
4 models	Grazing period length, 1–3 mo	1.5	0.6–3.6	0.16
	Grazing period length, <1 mo	1.9	0.8–4.5	0.16

Notes: Standardized variables were analyzed using multiple logistic regression with model averaging. All ranching operation characteristics are from the "Operation Characteristics" and "Grazing Practices on Private Land that is not Irrigated" sections of the Wyoming Rangeland Decision-Making Survey. Density is relative to greater than 12 ha/AU. An animal unit (AU) is a 453-kg cow with a calf. Grazing period length is relative to continuous grazing through the entire growing season.

Table A2. Ranching operation characteristics affect drought response on Wyoming ranches according to the Wyoming Rangeland Decision-Making Survey.

Drought response practice	Ranching operation characteristic	Odds ratio	Odds ratio confidence interval	Relative variable importance
Reduce herd size	Other activities	1.8	0.9–3.6	0.63
N = 236	Size	0.6	0.4–1.1	0.54
4 models				
Purchase feed	Density, 4–12 ha/AU	0.9	0.4–1.9	1.00
N = 236	Density, <4 ha/AU	0.4	0.2–0.8	1.00
3 models	Other activities	1.5	0.8–2.7	0.38
	Size	1.1	0.7–1.9	0.17
Wean calves early	Density, 4–12 ha/AU	0.6	0.3–1.2	1.00
N = 236	Density, <4 ha/AU	0.4	0.2–0.8	1.00
4 models	Other activities	1.6	0.9–2.8	0.51
	Size	1.3	0.8–2.3	0.39
Rent additional pastures	Size	1.6	0.9–2.9	0.79
N = 236	Other activities	1.6	0.9–3.0	0.72
4 models	Yearlings	0.9	0.5–1.6	0.14
Move livestock to another location	Size	1.5	0.9–2.6	0.52
N = 236	Other activities	1.5	0.8–3.0	0.35
6 models	Yearlings	1.2	0.7–2.2	0.20
Sell retained yearling livestock	Yearlings	3.5	1.8–6.6	1.00
N = 236	Other activities	1.2	0.6–2.5	0.18
4 models	Grazing period length, 1–3 mo	1.9	0.6–6.3	0.18
	Grazing period length, <1 mo	2.3	0.7–7.5	0.18
	Size	1.1	0.6–2.0	0.18
Apply for government assistance	Other activities	3.6	1.5–8.7	1.00
N = 236	Density, 4–12 ha/AU	1.8	0.8–4.2	0.80
3 models	Density, <4 ha/AU	0.8	0.3–1.9	0.80
	Size	1.3	0.7–2.3	0.27
Earn off-farm income	Other activities	3.4	1.3–9.3	1.00
N = 236	Yearlings	0.6	0.3–1.2	0.54
4 models	Size	0.5	0.2–1.4	0.49
Place livestock in a feedlot	Size	2.0	1.1–3.7	1.00
N = 236	Yearlings	2.2	1.0–4.8	0.90
7 models	Grazing period length, 1–3 mo	2.9	0.6–13.9	0.43
	Grazing period length, <1 mo	1.4	0.3–7.1	0.43
	Density, 4–12 ha/AU	0.9	0.3–2.2	0.28
	Density, <4 ha/AU	0.4	0.1–1.2	0.28
	Other activities	1.4	0.5–3.5	0.19

Note: Analyses and units are as in Table A1.

Table A3. Ranching operation characteristics affect drought impacts to Wyoming ranches that were more severe than expected according to the Wyoming Rangeland Decision-Making Survey.

Drought impact	Ranching operation characteristic	Odds ratio	Odds ratio confidence interval	Relative variable importance
Grazing capacity	Density, 4–12 ha/AU	1.7	0.7–3.9	0.28
N = 237	Density, <4 ha/AU	0.9	0.4–2.1	0.28
4 models	Yearlings	1.2	0.6–2.1	0.16
	Other activities	1.2	0.6–2.2	0.16
Profitability	Other activities	2.0	1.1–3.7	1.00
N = 237	Density, 4–12 ha/AU	2.1	1.0–4.3	0.71
10 models	Density, <4 ha/AU	1.1	0.5–2.3	0.71
	Grazing period length, 1–3 mo	2.1	0.9–5.2	0.41
	Grazing period length, <1 mo	2.5	1.0–6.1	0.41
	Yearlings	1.3	0.8–2.3	0.26
	Size	1.3	0.8–2.3	0.26
Winter feed availability	Other activities	2.5	1.4–4.6	1.00
N = 237	Size	0.7	0.4–1.2	0.33
6 models	Grazing period length, 1–3 mo	2.2	0.9–5.4	0.32
	Grazing period length, <1 mo	1.6	0.6–3.9	0.32
	Density, 4–12 ha/AU	1.8	0.8–3.7	0.12
	Density, <4 ha/AU	1.4	0.7–2.9	0.12
	Yearlings	1.1	0.6–1.9	0.10
Irrigation water availability	Density, 4–12 ha/AU	2.1	1.0–4.6	1.00
N = 237	Density, <4 ha/AU	3.8	1.7–8.2	1.00
4 models	Other activities	1.2	0.7–2.2	0.19
	Yearlings	0.9	0.5–1.5	0.18
	Size	0.9	0.5–1.5	0.17
Calf weaning weights	Grazing period length, 1–3 mo	2.2	0.9–5.7	0.28
N = 237	Grazing period length, <1 mo	1.7	0.7–4.4	0.28
3 models	Other activities	1.3	0.7–2.4	0.26
Livestock reproductive rates	Size	1.5	0.9–2.6	0.44
N = 237	Other activities	1.2	0.6–2.5	0.26
5 models	Yearlings	1.2	0.6–2.1	0.12

Note: Analyses and units are as in Table A1.