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Original Research

Building Ranch Resilience to Drought: Management Capacity, Planning, and Adaptive Learning During California's 2012–2016 Drought ☆

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ABSTRACT

Drought is one of the most complex and destructive natural hazards for rangeland managers to cope with given its inherently variable spatial and temporal impacts. California's devastating 2012–2016 drought highlights a critical need to develop adaptive strategies for coping with an increasingly variable climate. During the 2012–2016 drought, we interviewed 48 California ranchers to assess both on-ranch drought impacts and the effectiveness of implemented drought management practices. Three themes were identified based on the Adaptive Decision-Making Framework: 1) management capacity (i.e., operator demographics and operation structure), 2) drought planning and flexibility, and 3) adaptive learning (i.e., impacts experienced and effectiveness of drought management practices). Ranchers underscored the significance of drought planning, flexible management strategies, and prior experience as key factors that enabled them to navigate the 2012–2016 drought. In addition, ranchers described how explicit, proactive planning informed drought management decisions that prioritized long-term economic and ecological resilience. Although multispecies grazing was the least used proactive practice, it was identified as the most effective proactive practice by interviewed ranchers who had adopted it as a drought management tool (4.38 out of five effectiveness ranking; eight operators). Multispecies grazers (MSGs) significantly differed from single-species grazers (SSGs) in adoption of several reactive drought management practices, suggesting MSGs potentially have greater flexibility in coping with and adapting to drought. Resurgent strategies that prioritize management flexibility to mitigate drought impacts, such as multispecies grazing, may offer promise in helping ranchers adapt to future droughts. Interviewed ranchers emphasized that forward planning, including a range of proactive and reactive management strategies, were key in building flexibility and, ultimately, their resilience to drought.

Introduction

Drought is a fundamental driver on nearly all global landscapes and plays an important role in shaping how rangeland social-ecological systems function (Havstad et al., 2018; Slette et al., 2019; Thurow and Taylor, 1999). Broadly, drought is defined as a climate water deficit resulting in negative ecological, economic, and social impacts (Kelley et al., 2016; Kiem et al., 2016; Snyder et al., 2019; US Drought Monitor, 2020). This natural hazard can produce acute shocks as well as induce long-term system stress, making drought one of the most complex and destructive climate hazards for land managers (Kiem et al., 2016; Roche, 2016). Widespread, severe droughts restrict the capacity of affected landscapes to provide critical ecosystems services, such as food, fiber, water, and biodiversity (Sayre et al., 2013). Globally, rangelands support almost one-third of the human population, including approximately one billion ranchers and pastoralists who directly rely on rangelands for their livelihoods (Roche et al., 2021; Sayre et al., 2013). In-turn, these land managers make decisions that influence rangeland health and resilience to disturbances, such as drought. Given the social, ecological, and economic uncertainty and complexity surrounding drought, effective adaptation and mitigation strategies must account for both the land and the land manager (Joyce and Marshall, 2017; Marshall and Smajgl, 2013; Roche, 2016).

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Rangelands will continue to be challenged by the interacting effects of drought and climate change, as rising temperatures and greater precipitation variability compound natural drought patterns (Kiem et al., 2016; Pathak et al., 2018; Williams et al., 2020). In the Western United States, ranches and rangelands increasingly face multi-year, severe droughts that challenge adaptation strategies. Research suggests the region recently emerged from a relatively wet century and is currently in the worst "megadrought" in 1200 yr (Griffin and Anchukaitis, 2014). These interacting environmental pressures are amplified as resource demands increase to support a growing population and, in turn, rangeland is targeted for conversion to higher value land uses. The southwestern United States highlights this issue, as characteristically low and variable precipitation is coupled with rapid population growth and development across the region (Brunson, 2012; Mackun, 2019). While both urban and rural communities are affected by drought, ranchers and pastoralists are particularly vulnerable, largely relying directly on rain-fed rather than irrigated lands for their livelihoods (Kachergis et al., 2014; Marshall and Stokes, 2014; Brown et al., 2016; Macon et al., 2016; Roche, 2016).

Resilience-based management, with its focus on flexibility and adaptive learning, offers a useful strategy for addressing the multifaceted challenges land managers face in adapting to novel conditions, especially within the context of "wicked" problems like drought (Marshall and Stokes, 2014). Drought exemplifies a wicked problem, lacking a singular best solution for mitigating its impacts, with success defined in various ways by stakeholders with different values and perspectives (Brunson, 2012). This creates layers of ecological and social complexity for land managers as they simultaneously adapt to novel climate impacts while sustaining their operations. A critical component of building drought resilience is individual adaptive capacity—the ability of individuals to adjust to disruptive events through experience, learning, and problem solving (Marshall, 2015; Joyce and Marshall, 2017). Drivers of individual capacity and decision-making can be better understood within an *adaptive rangeland decision-making framework*. This approach emphasizes that long-term ranch sustainability relies on flexibility and capacity to adapt to changing social and ecological conditions (Lubell et al., 2013). Building flexibility into management planning is a cornerstone of adaptation in general, and drought resilience in particular (Fazey et al., 2010; Joyce et al., 2013; Kachergis et al., 2014; Derner and Augustine, 2016; Macon et al., 2016; Roche, 2016).

California exemplifies how compounding climate-related impacts, such as drought, and increasing land use pressure threaten rangelands and the ranchers who manage them. There are approximately 16,745 rangeland livestock operations in California and one-half of the state's 23 million rangeland hectares are grazed by commercial livestock (CALFIRE-FRAP, 2017; Roche et al., 2015; USDA NASS, 2020). California's historic 2012–2016 drought offered an opportunity to glean insights from on-the-ground managers and apply the lessons learned to better understand drivers of adaptive capacity in preparing for and responding to climate change impacts. During the 2012–2016 drought, we interviewed 48 California ranchers to assess both on-ranch drought impacts and the effectiveness of implemented drought management practices. These insights can inform future adaptation and mitigation strategies for rangeland management and policy decision-making.

Methods

Interview design and data collection

Rancher interview participants were identified through network sampling (Noy, 2008) in collaboration with University of California Cooperative Extension (UCCE), California Cattlemen's Association (CCA), and the California Wool Growers Association (CWGA). This approach does not result in a random sample and, therefore, is not intended to draw broad inferences; rather, this sampling approach provides an opportunity to explore participant experiences in-depth, which is important for understanding climate change adaptation (Yin, 2013). Interview participants were enrolled in the study from spring through fall of 2016 until no new information emerged from continued data collection (Gentles et al., 2015). Interviews were semi-structured, including both closed-ended questions with pre-determined categories and probing open-ended questions. Interviews varied from one to three hours in length, and discussions covered ranch characteristics, impacts, and drought adaptation methods. Questions were informed from the literature and pilot tested with collaborating ranchers and UCCE professionals. This study was approved by the University of California, Davis Institutional Review Board (IRB) protocol 786,140–3.

We collected contextual data on operator demographics and operation characteristics. Questions about operation characteristics were structured by livestock enterprise(s) and land resource base. We defined each livestock species managed as a separate enterprise within each ranching operation and categorized operators as either single-species grazers (SSGs) or multispecies grazers (MSGs) based on their reported livestock enterprises (cattle, sheep, and goats). Sheep and goats were combined for analysis since only four operations managed goats and each of these operations also managed sheep. We considered the land resource base within ownership type (private owned, private leased, public leased, contract grazed), as well as within forage resource type (rangeland, including mountain meadow, irrigated pasture, crop aftermath, and supplemental feed) and season of grazing (fall, winter, spring, summer).

Experience has been shown to be a key predictor of drought-decision making (Macon et al., 2016; Roche, 2016). Therefore, we collected quantitative and qualitative data on impacts experienced from both past droughts and the current drought (2012–2016). We developed a list of potential impacts based on discussions with collaborating partners, review of existing literature, and our previous surveys and interviews with California ranchers (Roche et al., 2021; Roche et al., 2015). We specifically queried 15 drought impacts (see Table 1), as well as asked interviewees to rank severity of currently experienced impacts on a 1–5 scale (1= slight impact to 5 = severe impact). Impact data were only collected if applicable; for example, impacts related to reproduction and weaning were reported as "not applicable" for stocker (yearling) operators. We also asked about management actions specifically taken to prepare for future droughts (proactive practices) and to respond to current droughts (reactive practices) (see Table 2), which were adapted from previous rancher surveys (Kachergis et al., 2014; Roche, 2016).

Data analysis

Interviews were audio recorded and transcribed. Interview text was organized through an iterative process, summarizing responses into *a priori* and emergent codes to capture the intent of the information provided under our primary themes. The primary themes were originally guided by the *adaptive rangeland decision-making framework* factors (i.e., management capacity, practices and strategies, and adaptive learning; see below) that have been hypothesized to enhance adaptation (Lubell et al., 2013). Codes were adjusted and refined over multiple readings, with the initial coding completed by the last author and then reviewed and re-coded as necessary by the first and third authors (Wilmer et al., 2018). To ensure validity of the qualitative data analysis, the first, third, and last authors reviewed and cross-checked code interpretations.

Summary statistics were used to report operator demographics, on-ranch drought impacts (proportion of interviewees experiencing

Table 1
2012–2016 drought impacts and severity of impact as reported by interviewed ranchers. Interviewees ranked the severity of drought impacts on a 1–5 scale (1= slight impact to 5= severe impact).

Impact	No. of interviewees experiencing	N	%	Impact severity
Reduced forage production	47	48	97.9	3.94
Increased expenses	43	48	89.6	3.65
Tree/brush mortality	33	48	68.8	3.15
Increase in invasive weeds	30	48	62.5	3.37
Reduced stock water availability or quantity	29	47	61.7	4.03
Reduction in surface water	15	26	57.7	3.60
Reduced revenues	24	48	50.0	3.50
Decrease in weaning weights	21	44	47.7	3.14
Reduction in reproductive rates	21	45	46.7	3.19
Increased herd health problems	18	48	37.5	3.56
Increase in wildfire severity	16	48	33.3	4.13
Reduction in groundwater	6	20	30.0	3.17
Increase in losses from poisonous plants	12	47	25.5	2.25
Loss of leased land	10	43	23.3	3.30
Reduced number of employees	3	38	7.9	3.33

Table 2
Use and effectiveness of proactive and reactive drought management practices as reported by interviewed ranchers. Interviewees ranked the effectiveness of practices they used to prepare for (proactive practices) and respond to (reactive practices) drought on a 1–5 scale (1= not effective to 5= highly effective). Mean effectiveness was calculated as the mean of individual rankings by ranchers who reported using the practice.

Practice		n	No. of interviewees adopting	%	Mean effectiveness ranking
Proactive	Incorporate pasture rest	48	43	90	4.21
	Grass bank (stockpile forage)	48	36	75	3.89
	Identify animals that would be sold	46	32	70	4.00
	Conservative stocking	48	32	67	4.31
	Purchase forage insurance	48	18	38	3.78
	Use 1–3 month weather predictions	48	17	35	3.06
	Added another livestock class	48	11	23	3.73
	Added other livestock species	48	8	17	4.38
Reactive	Purchased feed	48	38	79	4.39
	Applied for government assistance	48	34	71	3.50
	Reduced herd/flock size	48	31	65	4.03
	Weaned early	47	29	62	4.07
	Sold retained females	45	27	60	3.96
	Changed irrigation practices	32	19	59	3.47
	Developed stockwater	48	27	56	4.44
	Kept more feed grown on ranch	29	12	41	4.25
	Allowed livestock condition to decline	48	14	29	3.36
	Rented additional pasture	48	11	23	4.55
	Moved livestock to new location	46	7	15	4.14
	Added on-ranch enterprise	47	7	15	4.00
	Placed livestock in a feedlot	46	6	13	4.17
	Earned off-ranch income	47	6	13	4.33

impacts, mean responses), and use and perceived effectiveness of drought practices (proportion of interviewees adopting practices, mean responses). Operator demographics were also summarized by enterprise using descriptive statistics. The number of respondents is reported throughout; for cases where $n < 48$, the associated question did not apply to the operational structure of one or more respondents.

The *adaptive rangeland decision-making framework* grounds our examination of individual drought adaptation (Lubell et al., 2013; Roche, 2016). Broadly, adaptive decision-making recognizes the uncertainty, ambiguity, and unpredictability inherent in real-world systems. Previous applications of the framework have highlighted how the interplay of individual-level factors and the unique social-ecological system within which each rancher operates contributes to social, ecological, and economic outcomes and adaptive learning over time (Lubell et al., 2013; Roche, 2016; Wilmer et al., 2018; Munden-Dixon et al., 2019; Smith et al., 2023).

To assess drought management decision-making outcomes, we examined relationships between adoption of protective practices (i.e., proactive and reactive drought practices) and impacts resulting from the 2012–2016 drought for the interviewed ranchers. The goal of this analysis is to further understand the outcomes for this group of interviewed ranchers; outcomes are not to be inferred to a broader population. Not all practices and impacts applied to every operation; for example, ranchers managing only stocker cattle (i.e., not cow-calf herds) would not adopt early weaning as a drought management strategy or experience reduced weaning weights as a drought impact. Therefore, we constructed drought protection and drought impact indices as weighted means. We first constructed a drought practice adoption index by weighting practice effectiveness ratings (x) by the number of practices (w) used, which was then divided by total number of potential drought practices identified by each interviewee:

$$\text{drought protection index} = \frac{\sum_{i=1}^{n} w_i \cdot x_1}{\sum_{i=1}^{n} w_i}$$

We constructed a drought impact index by weighting drought impact severity ratings by the number of impacts (m) experienced, which was then divided by total number of potential drought impacts for each interviewee:

$$\text{drought impact index} = \frac{\sum_{i=1}^{n} m_i \cdot s_1}{\sum_{i=1}^{n} m_i}$$

We used simple linear regression models to analyze relationships between adoption of protective practices and drought impact, examining reactive and proactive drought practices in individual

and combined models. Regression analyses were conducted using Stata 15 (StataCorp, 2017) and standard diagnostics were used to confirm assumptions were met.

For MSG and SSG comparisons, we used summary statistics to describe on-ranch drought impacts (proportion of interviewees experiencing impacts, mean responses) and use and perceived effectiveness of reactive and proactive drought practices (proportion of interviewees adopting practices, mean responses). We used logistic regression (StataCorp, 2017) to test mean group differences (MSGs vs SSGs) in past drought impacts experienced (yes/no), current drought impacts (yes/no), and drought practices used (yes/no).

Results

We identified and contacted 52 rangeland-based livestock operators eligible for enrollment in the study. In total, 48 operators were interviewed; interviewees represented 33 beef cattle enterprises and 28 small ruminant enterprises. Below, we describe our results via three themes based on the Adaptive Decision-Making Framework: 1) management capacity (i.e., operator demographics and operation structure), 2) drought planning and flexibility, and 3) adaptive learning (i.e., impacts experienced and effectiveness of drought management practices). Unless otherwise noted, the presented results are based on data from 48 ranch operators.

Management capacity: Operator demographics and operation structure

Mean age of interviewees was 59; the youngest interviewed manager was 31 and the oldest was 86. The majority of interviewees were male (37 operators). Most interviewees (40 operators) were from multigenerational ranching families, and the mean number of years as a ranch manager was 31 (cattle-only operations = 36 yr; multispecies operations = 30 yr; small ruminant-only operations = 25 yr). Eight identified themselves as first-generation ranchers (two cattle-only operators; four small ruminant-only operators; four multispecies operators).

Ranching and livestock production was reported as a critical source of household income, spanning a broad range of operation sizes and types. Cattle-only interviewees (20 operators) reported livestock production contributed a mean of 62% to their household income, while multispecies (13 operators) and small ruminant-only (15 operators) interviewees reported livestock production contributed a mean of 49% and 29% to their household income, respectively. Median herd size was 374 head for cattle enterprises (range of 33–7540; 33 operators), and median sheep flock size was 610 head (range 3–20,415; 28 operators).

Mean total land resource base of interviewed operations was 7,327 ha, with a median ranch size of 1293 ha Many interviewed ranchers operated in more than one California county (Figure 1). Proportion of land ownership types comprising operations differed across operation types; for example, the majority of the land resource base for operations that included small ruminants (i.e., small ruminant-only or multispecies operations) were composed of public lands whereas cattle-only operations were composed of similar proportions of private owned, private leased, and public leased lands. To meet annual forage needs, the small ruminant operators interviewed were able to make use of an additional forage type, crop aftermath, not used by interviewed cattle operators.

Operation structure influenced drought management strategies implemented by interviewed ranchers. Large ranches in particular have more opportunities to access resources that greatly increase their flexibility and, therefore, their ability to make proactive management decisions (Roche, 2016). When asked about multispecies grazing as a drought strategy, one rancher highlighted their current operation structure as a constraint to adopting the strategy:

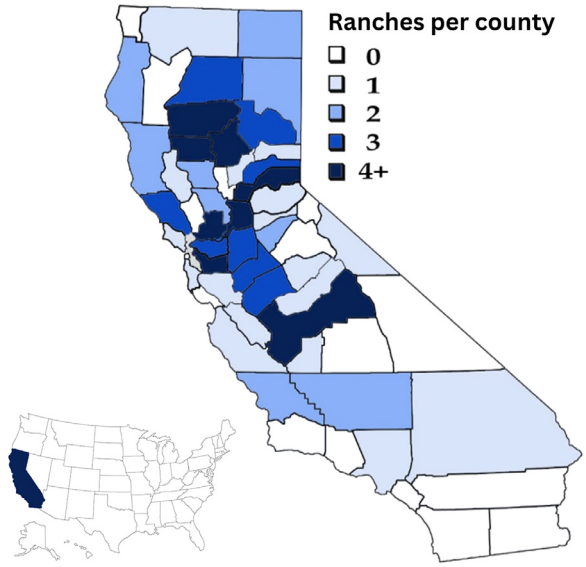

Figure 1. Map of operation locations of interviewed ranchers throughout California. As several interviewed ranchers operate in multiple counties, operation location is defined by the primary ranch location (i.e., home ranch).

> *"Us cow guys pay to graze the ground and the goat guys are the smart ones—they get paid to do it. [laugh] The goat thing is kinda interesting but it would require you to get geared up in a totally different way. Until my kids are older, I'm not there yet.*
>
> Rancher R (Single Species Grazer, cattle)

Drought planning and flexibility

Ranchers underscored the significance of planning and prior experience as key factors that enabled them to navigate the 2012–2016 drought. Many interviewees emphasized the basic value of planning to build in adaptation and management flexibility into their operations, for example:

> *"I think the management part is just the flexibility. We try to always have a backup plan. The hardest part to manage in a drought is the cow-calf. The yearlings, you can always pick them up and go someplace. It might not be the most profitable but you can always take them to feed somewhere, whether you go to the feedyard or do something. But the cow-calf part is the hardest to manage."*
>
> Rancher C (SSG, cattle)

> *"I'm a pretty strong believer that if you manage for a drought all the time then you're gonna be all right in our area [Humboldt County]."*
>
> Rancher G (SSG, cattle)

Flexibility was often linked to proactive planning practices. Interviewed ranchers employing grass banking (saving residual forage from rested or lightly used pastures) and conservative stocking generally indicated these were the most effective proactive drought management practices.

> *"I'd rather stock more conservatively. You can always add to or bring somebody else's cattle in. The problem is, whenever you want to bring somebody else's cattle in they usually have feed too. But the relationships I'm trying to develop now are guys that have grass when I don't and I have grass when they don't. It's not real easy to do."*
>
> Rancher B (Multi-Species Grazer)

"Too many ranchers look out instead of look down. They look at the cow instead of the feed source that's there to feed them."

Rancher H (SSG, cattle)

Furthermore, linking proactive practices with reactive ones may have aided ranchers in formulating their drought plans. Below, one northern California cattle rancher underscores the value of combining grass banking, a proactive practice, with reducing herd numbers, a reactive practice, to enhance flexibility:

"I always leave an adequate amount of forage behind when coming off the winter feed. When you come back in the fall, if you don't have green grass production, you've got old feed for them. And if you supplement they'll manage until you do get into the winter feed. Like this year, I had old feed, and still had old feed. I sold some cows in November and sold some more in January. Every 2 weeks it didn't rain the window starts closing in terms of our rainfall season, so you've got to make a decision. You wait another 2 weeks or 30 days and take the risk that the rain doesn't come. Now all your cows are suffering as opposed to reducing the numbers and let the other cattle have more room. It worked out OK. I had many friends that had to liquidate more cattle than I did but they were in areas that have less rainfall than what we had here."

Rancher A (SSG, cattle)

Twenty-six of the ranchers interviewed had a drought management plan in place when the 2012–2016 drought began; 19 of these interviewees had previous drought experience (32 multi-drought managers out of 48 total operators) and seven had no drought experience (16 first-drought managers out of 48 total operators). Both explicit (e.g., record keeping, decisions based on documented information, development and reevaluation of goals) and tacit (e.g., unwritten traditions, lack of documentation) planners (Wilmer et al., 2018) emphasized how previous experience had informed their drought management decision-making:

"We developed one [drought plan] as we went I guess, it was a seat of the pants kind of thing. But again we worked off of our experience from Australia and tried to get ahead of the curve rather than behind."

Rancher E (MSG)

"So, I don't have one written down, but we used our best practices from the previous experience."

Rancher F (MSG)

For some, the experience of managing through the 2012–2016 drought was a catalyst for more explicit planning:

"[I did] not [have] as much [of a strategy] as I should have. I wasn't prepared for it to continue. So that's why I'm jumping on board now with the water plans [working with US Department of Agriculture, Natural Resources Conservation Service (NRCS) to develop water systems]. I'm going to try to be much more prepared for next year."

Rancher D (SSG, cattle)

Ranchers also indicated managing drought recovery as an important piece of overall drought planning. For example, one rancher described the importance of adjusting stocking rates to enhance grass productivity post-drought:

"Slowly stock back to normal stock capacities versus *ramping up right away to get back to where you were. That way the land can heal, the grasses can regenerate seed to populate. Because we saw a lot of germination start and stall and actually die. So, we lost those seed crops that replenish seed that's in the ground. We lost this. We need to let that occur. So, we'll get the more healthy, stronger, productive grasses coming forward instead of the least productive grasses, which is what's happening to a lot of ranchers who don't read the cards well."*

Rancher F (MSG)

Adaptive learning: Drought impacts and effectiveness of management practices

The drought impacts experienced most by interviewed ranchers included reduced forage production (47 operators) and increased expenses (43 operators) (Table 1). According to interviewed ranchers, the most effective drought management practices were those that helped them balance forage supply and demand (Table 2). The most effective proactive practices included pasture rest (4.21 out of five effectiveness ranking; 43 operators), grass banking (3.89 out of five effectiveness ranking; 37 operators), identifying animals to sell (4.00 out of five effectiveness ranking; 36 operators out of 46), and conservative stocking (4.31 out of five effectiveness ranking; 32 operators).

In open ended questions, interviewed ranchers described the importance of proactive drought management and the benefits of explicit planning. For example, one rancher described how identifying animals to sell (4.00 out of five effectiveness ranking; 36 operators) informed culling decisions that prioritized improving herd genetics:

"Genetically, I think it [identifying animals that could be sold in case of drought] is very important because you can identify those of quality from your records to keep the better animals to genetically improve your herd."

Rancher N (SSG, cattle)

Another rancher described how the use of 1–3 month weather predictions (3.06 out of 5 effectiveness ranking; 17 operators) was a catalyst for decision-making that prioritized the conservation of forage resources and rangeland health.

"That [using 1–3 month weather predictions to adjust stocking rate] helped, if nothing else, light a fire under you when they kept saying that we don't see a bunch of rain coming, so it made us just make sure we got off our rangeland earlier when all of the prognosis were it's not gonna get much better."

Rancher L (SSG, cattle)

One rancher, who adopted critical dates as a new strategy during the 2012–2016 drought, emphasized its importance and rated it five out of five in terms of effectiveness:

"We started thinking about 'what are our critical dates'. You have to consider scenarios and think through them."

Rancher M (MSG)

One large-scale operator highlighted pasture rest and having access to forage in different regions as key proactive strategies that sustained their operation during the 2012–2016 drought:

"For the 2012–2015 drought, I would say we were at 26–27% total loss on the deal but we managed around it because we didn't put the cattle in [Ranch A], we put them in here [Ranch B] because we had the fall feed. Now this year we didn't get the fall feed but I've increased the cattle back down there because I rested it, or half rested it, for last year."

Rancher H (SSG, cattle)

The ecological impacts experienced most by interviewed ranchers included tree and brush mortality (33 operators), increases in invasive weeds (30 operators), reductions in stock water (29 operators), and reductions in surface water (15 operators). In open ended questions, many interviewees mentioned the ecological impacts they observed. For example, one northern California rancher observed unprecedented changes in water availability:

"It [the current drought] has dropped the water table, some of the springs have run dry that have been there for generations. And the other big thing is that when we do get a rain and it fills the reservoir up, within a week's time you'll see it down 3–4 feet where the ground's taken the water. So, the water table is down lower than what it's been before."

Rancher H (SSG, cattle)

Compounding the ecological and economic impacts of drought, multi-year droughts can have severe consequences for mental health (Macon et al., 2016; Wilmer et al., 2016). We found California's historic drought was no exception; during open-ended interview questions, ranchers noted that managing through the drought brought overwhelming stress—the effects of which may have stretched the limits of individual adaptive capacity. Eight interviewees mentioned that California's 2012–2016 drought had caused considerable emotional distress and negative impacts to their mental health. For example:

"*Ranching is about making the land better. It's not satisfying to go to work every day when you see things go backward. You don't feel good about it*."

Rancher I (MSG)

"*The stress period probably comes in the month of November, in between seasons waiting for rains. That's the most difficult time.*"

Rancher G (SSG, cattle)

"We've occasionally done that [purchasing feed]. We did that last year when we came off a month early. We were able to acquire some inside feed from the neighbor… The drought years cause you to spend more man hours out there, keeping cattle scattered, trying to find ways to get utilization out of that ground. We try to find a way to stay out there as long as you can. That's the biggest thing. It seems like it adds a level of stress because you're always concerned, like, oh man, we better drive up there and check… Water hauling, that's the one thing we have had to do. That's probably one of the key things in drought conditions, hauling water. We hired a guy to haul to 2, 3, 4 different ponds."

Rancher J (SSG, cattle)

When we examined drought decision-making outcomes across interviewed ranchers, we found drought impact (i.e., weighted mean of number and severity of drought impacts) was positively related to overall drought protection (i.e., weighted mean of adoption and effectiveness ratings of all drought practices) ($p = 0.002$) for interviewed ranchers. In individual models, we found drought impact was significantly and positively related to drought response specifically (i.e., weighted mean of adoption and effectiveness ratings of reactive drought practices) ($p < 0.001$), but was not significantly ($p > 0.1$) related to drought preparation.

Effectiveness of multispecies grazing as a proactive drought management strategy

While examining the adaptive learning processes of interviewed ranchers, we found that those who had adopted multispecies grazing as a drought strategy identified it as the most effective proactive practice (4.38 out of five effectiveness ranking; eight operators) (Table 2). Surprisingly, multispecies grazing was ranked higher than more commonly used drought management practices, such as conservative stocking and pasture rest (Coppock, 2011; Kachergis et al., 2014; L.M. Roche, 2016). Of the 48 ranchers we interviewed, 13 were MSGs and 35 were single species grazers. The majority of MSGs (8 out of 13) added a second species to their operation as an intentional drought management strategy; the remaining five MSGs grazed Multiple species for reasons other than drought management. The majority (10 of 13) of multispecies grazers were originally small ruminant operators who added cattle as a second species. MSGs typically managed larger herds than single-species grazers (MSG, cattle enterprises: mean = 1048 head, range = 33 – 7540 head; MSG, sheep/goat enterprises: mean = 3753, range = 26 – 20,415; SSG, cattle enterprises: mean = 912, range = 50 – 2850; SSG, sheep/goat enterprises: mean = 2260, range = 32 – 8280).

Generally, interviewed ranchers did not consider adding a livestock class as effective as adding a new livestock species (Table 2). Managing multiple classes can increase marketing flexibility, as stockers and feeders do not require a long-term management investment; for example, selling yearlings typically involves fewer trade-offs than selling mature or replacement females, particularly in terms of preserving valuable herd genetics (Kachergis et al., 2014). Adding another livestock species, particularly those with differing forage preferences, potentially also adds flexibility by diversifying access to both forage sources and markets. In response to questions about whether multispecies grazing specifically increased flexibility during drought, some interviewed ranchers specifically highlighted the benefits of market flexibility for MSGs:

"I think it definitely makes you more flexible because you can decide to sell off different asset classes and you can ramp up or ramp down. I'm at the stage now that the thing I'm going to destock is cows, not yearlings. The cow revenue will make up for loss of weaned calf revenue. So my revenue will be the same and I'll be able to reinvest in other stuff. More ewes. If I find the right deal with the right sheep I would buy $100,000 worth of sheep. But I'm not going to do that until I have the fences tight, the guard dogs that come with them, all that."

Rancher B (MSG)

"[Having ewes does] not [increase flexibility] with regard to a drought. I think it increases your flexibility with regard to income because it doesn't always go along with the cattle prices. A few years ago the sheep prices were very high. I kind of backed down a little bit, but it's nice to kind of diversify your income."

Rancher P (MSG)

"*That [adding an additional species of livestock] hasn't been in response to drought. The diversification— that's been in response to the market. The sheep is something we really enjoy. Also, because we have such a coyote brush infestation on these ranches the sheep definitely go after it more than the cattle. Even though they'll never get rid of it, maybe they'll slow down the succession a little bit more than just the cattle would.*

Rancher Q (MSG)

Other interviewed ranchers specifically highlighted the benefits of forage resource flexibility for MSGs:

"Yeah, [adding other livestock types helps increase flexibility in drought]. I think if it gets to the point where we have a really extreme drought, the sheep start looking a lot better. Because I think sheep are more resilient. They have less demand for water. They're most likely able to utilize this fog drift that we get on the coast better than the cattle. That's why we want to grow our sheep because we'd like that to be more of an income generator for the ranch."

Rancher Q (MSG)

We expanded our operation during drought, but not directly because of drought. We were working hard to find more places, and obtained more access. Mobility is key for sheep, especially when you have a grass-fed product. Sheep are a powerful tool and increased our flexibility.

Rancher O (MSG)

Table 3
Proactive and reactive drought management strategies used as reported by multispecies grazers (MSGs) and single-species grazers (SSGs). Total number of interviewees (n) varies as not all practices applied to every operation.

	Management Practice	Multispecies grazers			Single-species Grazers		
		No. of interviewees adopting	n	%	No. of interviewees adopting	n	%
Proactive	Added another livestock class	4	13	31%	7	35	20%
	Grass bank (stockpile forage)	11	13	85%	25	35	71%
	Conservative stocking	9	13	69%	23	35	66%
	Incorporate pasture rest	12	13	92%	31	35	89%
	Use 1–3 month weather predictions	5	13	38%	12	35	34%
	Identify animals that would be sold	11	12	92%	21	34	62%
	Purchase forage insurance	6	13	46%	12	35	34%
Reactive	Added on-ranch enterprise	**3**	**13**	**23%***	4	34	12%
	Purchased feed	10	13	77%	28	35	80%
	Kept more feed grown on ranch	5	8	63%	7	21	33%
	Allowed livestock condition to decline	1	13	8%	**13**	**35**	**37%***
	Reduced herd/flock size	**11**	**13**	**85%***	20	35	57%
	Earned off-ranch income	1	13	8%	5	34	15%
	Rented additional pasture	3	13	23%	8	35	23%
	Applied for government assistance	**12**	**13**	**92%***	22	35	63%
	Sold retained females	8	12	67%	19	33	58%
	Moved livestock to a new location	**4**	**12**	**33%***	3	34	9%
	Weaned early	**11**	**12**	**92%***	18	35	51%
	Place livestock in a feedlot	2	12	17%	4	34	12%
	Changed irrigation practices	3	7	43%	16	25	64%
	Developed stockwater	8	13	62%	19	35	54%

* Indicates values within the respective category that are statistically different ($P \leq 0.1$) between MSGs and SSGs.

Although there were several apparent differences in drought impacts experienced by MSGs compared to SSGs, only invasive weed impacts for past droughts was significantly ($p = 0.062$) different between the groups. In terms of drought management practices, MSGs were significantly more likely than SSGs to apply for government assistance ($p = 0.074$), wean early ($p = 0.033$), add an alternative on-ranch enterprise ($p = 0.048$), and move livestock to a new location ($p = 0.056$) (Table 3). MSGS were also more likely than SSGs to reduce herd size ($p = 0.092$), while SSGs were more likely to allow livestock condition to decline ($p = 0.074$) (Table 3).

Discussion

California's 2012–2016 drought, recognized as the worst drought in the previous 1200 years (Griffin and Anchukaitis, 2014), was widely regarded by interviewees as the most severe event they had experienced as ranch managers. Regardless of operation structure or management planning, all interviewees reported they were at least somewhat unprepared to cope with the unprecedented conditions of the current drought. In addition, ranchers reported experiencing more drought impacts compared to previous droughts. This was likely related to the duration of exceptional drought conditions; for example, California received no measurable precipitation between December 2013 and January 2014 (Macon et al., 2016). As droughts are expected to increase in intensity, frequency, and severity, the 2012–2016 drought offers a unique opportunity to prepare for future droughts with strategies that proved most successful for on-the-ground managers.

Drought planning and flexibility

Developing a portfolio of both proactive and reactive practices can add flexibility at multiple time scales, buffering impacts, enhancing an operation's abilities to cope with drought threats, and, ultimately, building critical resilience to climate hazards (Grothmann and Patt, 2005; Fazey et al., 2013; Joyce et al., 2013; Kachergis et al., 2014; McClaran et al., 2015; Derner and Augustine, 2016; Macon et al., 2016; Roche, 2016; Haigh et al., 2021). Forward planning and proactive practices not only enhanced flexibility but also enabled ranchers to mitigate drought impacts while simultaneously prioritizing long-term operational goals. For instance, proactively identifying animals for sale allowed ranchers to balance necessary reductions in forage demand while maintaining herd genetics. We found that purchasing feed, receiving government assistance, and selling stock were the most common reactive practices used by interviewed ranchers during the 2012–2016 drought. Previous work across the western United States has found similar results—reactive practices are centered around balancing forage supply and demand during drought (Coppock, 2011; Kachergis et al., 2014; Macon et al., 2016). However, the effectiveness of this strategy can be dampened if over-reliance compounds market risks; for example, once the market is saturated with reactively culled stock, then prices are reduced (Kachergis et al., 2014). Interviewed cattle ranchers recognized market strength as a key component of their ability to manage through the historic drought—in 2014, arguably one of the worst drought years for California, national cattle prices remained at a record high which allowed ranchers to sell stock without jeopardizing profit (Macon et al., 2016; Woodmansee et al., 2021). Reactive practices are an important component of drought management planning. However, as drought intensity, frequency, and severity are predicted to increase, the effectiveness of reactive practices may be dulled by over-use—for example, frequently purchasing feed can threaten the economic sustainability of operations.

Adaptive learning

Range livestock production (i.e., matching forage to demand) and drought management are both spatially and temporally complex, often requiring that managers apply innovation and local knowledge in order to persist (Sayre et al., 2013; Wilmer and Fernández-Giménez, 2015). We found that drought impact was positively related to overall drought protection, which was driven by adoption of drought response strategies. In other words, interviewed ranchers who reported greater impact also reported greater protection through reactive management strategies as they learned to adapt over time. However, we posit that this does not mean that proactive practices were ineffective. Rather, proactive practices likely mitigated some impacts—particularly earlier in the 2012–2016 drought—but effectiveness potentially waned as drought conditions persisted and intensified. This result likely speaks more to the severity of the historic drought than the effectiveness of

proactive management— the severity and duration of the 2012–2016 drought were too great to be mitigated by proactive strategies alone. In addition, ranchers were interviewed approximately three years into the drought; the timing of interviews likely influenced their ranking of practice effectiveness, as perception has been shown to be shaped by recent, rather than collective, coping experiences (Grothmann and Patt, 2005; McClaran et al., 2015). Moreover, management practices were presented to interviewees as a dichotomy, using a proactive versus reactive classification. On the ground, however, these practices likely span a gradient and involve more nuanced approaches. For example, some interviewees described how they plan in advance to manage drought reactively, such as by proactively identifying animals for potential herd reductions during drought. Overall, our findings highlight how overwhelming drought impacts were; the interviewed ranchers who adopted many proactive practices experienced just as many impacts as those with less proactive practices at the beginning of the 2012–2016 historic drought. Essentially, these ranchers were forced to cope reactively in order to sustain their operations.

Multispecies grazing: Proactive drought management strategy

Multispecies grazing (e.g., grazing both large and small ruminants) has had resurging interest as a protective action to diversify ranching portfolios and increase flexibility, particularly during drought years, as it can potentially maximize available forage resources by capitalizing on differing foraging habits of cattle versus small ruminants (Walker, 1994; Joyce et al., 2013; Polley et al., 2013; Briske et al., 2015; Balachowski et al., 2018; Sowers et al., 2019). Large and small ruminant animals have developed different dietary preferences and, subsequently, complementary foraging habits. Generally, large ruminants like cattle prefer to graze herbaceous plants (grasses and forbs) and their large size allows them to be more generalist grazers and consume high volumes of forage; small ruminants like sheep are more easily moved (e.g., less permanent infrastructure needs) and noted for their abilities to access forage typically unavailable to larger animals (Walker et al., 2006). In addition, integrating complementary grazers within an operation can optimize forage use while potentially mitigating climate change risks (e.g., reduce wildfire fuel loads) and environmental threats (e.g., noxious weed invasion) (DiTomaso, 2000; Davies et al., 2010).

In the case of California's 2012–2016 drought, multispecies grazing may have provided a complement of both forage resource and market flexibility that was particularly helpful in sustaining the interviewed MSG operations. MSGs reported experiencing less impacts than SSGs during previous droughts. However, the unprecedented conditions of the current drought appear to have diminished any potential insulative effects of MSG on drought impacts. Our results suggest that multispecies grazing has the potential to buffer multiple undesirable drought impacts at once, such as optimizing available forage while controlling less desirable invasive grasses, forbs, and shrubs. In addition, small ruminants may also offer increased flexibility to accessing forage that would be inaccessible to cattle due to lack of infrastructure, drinking water requirements, forage quality, and size of property.

MSGs used more reactive drought management strategies compared to SSGs, indicating they have more flexibility to cope with drought. Notably, allowing livestock conditions to decline was the only reactive practice that significantly more SSGs relied upon compared to MSGs. In addition, more SSG operators reported reduced reproductive rates as a drought impact while MSGs reported no change. Differences in gestation period between cattle and small ruminants may have contributed to the observed differences between SSGs and MSGs, as small ruminants have more time to recover from a decline in body condition before breeding than cattle. This example highlights how some reactive practices can have far-reaching consequences-drought-related feed shortages can result in declining livestock conditions, which in-turn negatively impacts conception rates, calf crop, and calving interval for at least one season (Balachowski et al., 2018). In addition, allowing livestock conditions to decline often results in increased grazing pressure on the land resource base, leading livestock to consume toxic plants that are typically avoided when adequate forage is available (Schohr et al., 2020). Allowing livestock condition to decline to the point that long-term production objectives are negatively impacted (e.g., reduced reproductive rates) provides limited flexibility and signals users are reaching the limits of their adaptive capacity.

Operation structure influences the severity of drought impacts experienced—ranches with a robust portfolio of proactive and reactive management practices are more able to adapt to drought (i.e., size, managing multiple classes, conservative stocking rates, and additional on-ranch income) (Kachergis et al., 2014; Roche, 2016). In contrast, ranches with fewer resources, and therefore less management flexibility, often have less adaptive capacity (Kachergis et al., 2014; Roche, 2016). Given MSGs, on average, manage larger operations than SSGs, it is likely that these operators also have access to a greater number of resources in general. For example, several MSGs discussed that drought-related market conditions and forage availability actually presented opportunities to expand their operations.

Overall, interviewed ranchers highlighted how explicit planning, that includes both reactive and proactive management strategies, were key in building flexibility and, ultimately, their resilience to the 2012–2016 drought. In addition, we found that previous drought management experience enhanced planning and aided interviewed ranchers in managing through multiple years of historic drought conditions. Although the severity and duration of the 2012–2016 drought eventually forced all ranchers to cope reactively, the buffering effect of proactive management strategies appeared to be a key component of ranch resilience to drought.

Implications

Our results underscored the significance of management capacity, drought planning, and adaptive learning as key factors that enabled interviewed ranchers to navigate the 2012–2016 drought. In particular, management flexibility—including forward planning and previous experience—is critical to managing through uncertainty. As ranching operation structure is diverse, no single drought management strategy can offer one-size-fits all success in mitigating impacts. We found that proactive strategies may not have the ability to mitigate drought impacts alone—however, when combined with reactive practices, they are an important part of drought management. In particular, novel proactive strategies may hold the key to adapting to future drought conditions; the utility of these strategies, and why ranchers choose to adopt them, should be explored in future research. For example, strategies that prioritize flexibility, such as the resurgent practice of multispecies grazing, may offer promise in helping ranchers adapt to future droughts. Supporting operators in developing explicit drought plans, that include a range of proactive and reactive strategies, will be critical for enhancing both ranch and grazing land resilience to drought.

CRediT authorship contribution statement

Grace Woodmansee: Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Supervision, Visualization, Writing – original draft, Writing—review & editing. **Dan Macon:** Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Supervision, Visualization, Writing—original

draft, Writing—review & editing. **Tracy Schohr:** Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Supervision, Visualization, Writing—original draft, Writing—review & editing. **Leslie Roche:** Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing—original draft, Writing—review & editing.

Declaration of competing interest

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

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