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Adaptive Rangeland Decision-Making and Coping with Drought

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Abstract: Grazinglands support the livelihoods of millions of people around the world, as well as supply critical ecosystem services. Communities reliant on rain-fed rangelands are potentially the most vulnerable to increasing climate variability given their dependence on highly climate-sensitive resources. Droughts, which are gradual natural hazards, pose substantial and recurrent economic and ecological stresses to these systems. This study examined management decision-making based on survey responses of 479 California ranchers to: (1) identify the types of drought strategies in-place across California's rangelands and the operation variables driving strategy selection; and (2) examine how individual drought adaptation is enhanced by decision-making factors. Four types of in-place drought strategies were identified and ordered along a gradient of increasing intensity (number) of practices used. Significant background variables driving strategy selection were operation experience with drought, type of livestock operation, grazing system, and land ownership types. Information resource networks, goal setting for sustainable natural resources, and management capacity all acted to enhance individual drought adaptation—defined here by active drought planning and the number of both reactive and proactive drought practices used. Overall, analyses revealed that flexibility in management is a key component of adapting to and coping with drought. Climate policy planning should take into account the diversity of strategies that have been developed by ranchers for multiple generations and within the context of their unique operations, as well as support these working landscapes via a range of adaptation and mitigation options to reduce vulnerability across all types of operations.

Keywords: adaptive capacity; climate variability and change; livestock production; ranching; working landscapes; sustainability science; drought policy

1. Introduction

Around the world, grazinglands support the livelihoods of millions of people and provide millions more with protein, as well as supply critical ecosystem services like water resource protection, biodiversity conservation, and wildlife habitat [1,2]. These working landscapes include grazed rangelands and pasturelands and occupy an estimated one-quarter to two-fifths of the world's land surface—making them the largest and most biologically and physically diverse land resources in the world [2,3]. A rapidly growing world population, increasing demand for "sustainable" food systems, and changing land uses will challenge continued delivery of ecosystem services from these land resources—particularly under the mounting pressures of uncertain climate variability [4,5].

Communities reliant on rangelands are potentially the most vulnerable to climate variability given their dependence on highly climate-sensitive resources [6,7]. Droughts, for example, pose substantial and recurrent economic and ecological stress—placing ranching operations and the ecosystem services they produce at risk. Unlike other natural hazards, drought is a gradual, complex disaster with indistinct start and end points. Severe and widespread droughts can trigger undesirable ecological shifts, which can impact forage and livestock production capacity and directly threaten livelihoods of ranching families and communities. As the impacts of an increasingly variable climate manifest, ranchers and land managers will potentially face more frequent and largely unpredictable climate crises, putting the economic viability and ecological sustainability of working rangelands at increasingly greater risk.

Developing and advancing successful policies and programs will require grassroots participation from stakeholders to first identify and evaluate the agricultural adaptation and mitigation options that have been successful, feasible, and socially acceptable. In the western United States, there is growing evidence that changing climate conditions could bring about more extreme weather events—including greater severity, frequency, duration, and extent of droughts [8]. Ranching families hold multi-generational knowledge of the social, economic, and ecological outcomes of their management strategies, which they have adapted through trial-and-error learning over time [9–11]. Additionally, ranchers have extensive personal experience in coping with drought, which can serve as a "local" example [12,13] of climate impacts in future scenario planning for climate adaptation.

Inherently droughty systems, such as the Mediterranean climate type, provide a unique opportunity to examine agricultural adaptation to climate variability and change. Increased drought frequency and severity markedly compound water issues for Mediterranean climates, where normally hot, dry summers already bring the recurrent challenge of extended drought. In California, drought played a formative role in the state's early history [14], and has continued to impact the state with five multiyear droughts between 1960 and 2010 [15]. Here, I examined results of a 2011 California Rangeland Decision-Making Survey [10], which was completed just prior to the current severe multi-year drought, to better understand the in-place drought strategies that have been adapted over time in response to changing resource conditions.

Building on the adaptive rangeland decision-making framework [16], the goals of this paper were to: (1) identify the types of drought strategies in-place across California's rangelands and the background operation variables driving strategy selection; and (2) examine how individual drought adaptation is enhanced by decision-making factors, including information resource networks, operator values, and management capacity. For the second question, a conceptual model (Figure 1) of hypothesized relationships was constructed based on pathways expected from the adaptive rangeland decision-making framework (see Figure 1 of [16]). In the conceptual model, the information resource network was assumed to influence both goal setting and management capacity [16–18]. Agricultural knowledge networks, social relationships, place-based expertise, and education have been shown to be key pathways for information sharing and goal setting [17,19,20], as well as influence management capacity through increased knowledge and access to management practices, programs, and opportunities [17,20–25]. In turn, goal setting (e.g., valuing future resources), management capacity, and past experience were expected to directly influence individual drought adaptation [12,26–28].

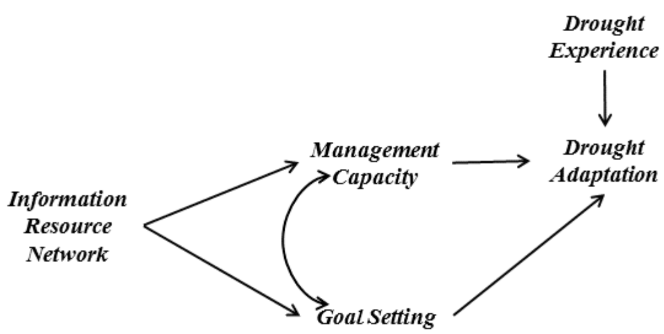

Figure 1. Conceptual model of how individual drought adaptation is potentially linked to key decision-making factors based on pathways expected from the adaptive rangeland decision-making framework from Lubell et al. [16].

Understanding the diversity of in-place drought strategies as well as how decision-making generally influences drought adaptation can help provide management and policy guidance on adaptation and mitigation efforts to enhance resilience, and thus sustainability, of working rangelands to increasing climate variability.

2. Materials and Methods

2.1. Survey Design

As described in Roche et al. [10], a mail survey of ranchers was deployed using the membership list of the California Cattlemen's Association (CCA), a nonprofit trade organization serving cattle ranchers, beef producers, and private rangeland owners across California. Between March and June of 2011, the survey was delivered via a multi contact approach, which included an initial mail survey and return envelope, a reminder letter including option to refuse or note ineligibility, a second mail survey, and a final reminder card [29]. The survey was delivered to 1727 addresses, with 507 surveys returned (33% response rate; American Association of Public Opinion Research, Response Rate 4; respondents' base operations represented 49 of the state's 58 counties [10]). Relative to the Census of Agriculture [30] for California, CCA producer members represent larger operations (median total livestock = 200) [10]).

2.2. Data Collection

The adaptive rangeland decision-making framework, established by Lubell et al. [16], is used here to identify key variables, as well as guide overall analysis. This social-ecological framework (see Figure 1 of [16]) draws on several existing theories of decision-making—including theory of planned behavior [31,32], psychological distance theory [12,13], and diffusion of innovations [20,33]—and is applicable to many agroecological systems [16].

2.2.1. Drought Management Practices and Strategies

The survey collected responses on drought management practices, including practices used to prepare for drought (proactive practices) and practices used in response to drought (reactive practices). Respondents were provided with a list of 17 potential proactive and reactive practices and asked to select all practices they had previously used in managing for drought impacts. Proactive practices included stocking conservatively, resting pastures, incorporating yearling cattle to increase flexibility, grassbanking or stockpiling forage, using weather predictions to adjust stocking, and adding other livestock types to increase flexibility; reactive practices included reducing herd size, purchasing feed, applying for government assistance programs, weaning calves early, renting additional pastures, moving livestock to other locations, earning additional off-ranch income, selling retained yearlings, placing livestock in a feedlot, maintaining herd size; allowing livestock condition declines, and adding alternative on-ranch enterprise. Additionally, respondents were asked if they had previously experienced drought, and if they had a drought management plan in place during the last drought.

2.2.2. Operation Structure

Structural characteristics of the operation have been shown to be key determinants in agricultural decision-making [16,18,26,27,34,35]. These "farm-structure" variables shape the context for decision-making (e.g., ability to access economic resources and inputs) and, therefore, potentially impact individual adoption of innovations and adaptive capacity [16,26,36]. The survey collected responses on several variables related to operation structure, including type and class of livestock, land base, enterprise structure, and grazing management (see Table 1). Respondents were asked about land ownership types (privately owned, privately leased, or publicly leased) that make up their enterprises, and survey mailing ZIP codes were used to determine U.S. Environmental Protection

Agency Level III Ecoregions for base operations. Ecoregions are differentiated based on geographical similarities in resource potential and capacity to respond to disturbances [37].

Table 1. Background operation characteristics hypothesized to influence drought decision-making. Questions were from a rangeland mail survey delivered in March–June 2011 to 1727 producer members of the California Cattlemen's Association.

Question	Value
Livestock	
Total number of cattle	0–22,000 count
Cow-calf operation	Yes/No
Yearling operation	Yes/No
Integrated cow-calf and yearling operation	Yes/No
Land Base	
USEPA Level III Ecoregion	Categorical
Total number of privately owned hectares	0–16,187 count
Total number of hectares	1–2,059,852 count
Enterprise Structure	
Dependence on ranch as a source of income	1–5 scale [1]
Operation includes privately owned land	Yes/No
Operation includes privately leased land	Yes/No
Operation includes publicly leased land	Yes/No
Management	
Grazing system	Categorical

[1] Likert-scale ranging from 1 = "fully disagree" to 5 = "fully agree".

Grazing strategies were previously classified in Roche et al. [9] via analysis of the mail survey's grazing practice questions (i.e., number of pastures, number of herds, livestock density, and timing of grazing and rest). The resulting respondent classifications among the three identified grazing strategies (rotational strategy, season-long continuous strategy, and year-long strategy) for respondents' largest area of private rangeland were used in this paper to indicate grazing system preferences.

2.2.3. Information Sources

Information networks are key in the diffusion and adoption of management practices and successful innovations [16–18]. The survey included numerous questions about respondents' information resources, including the level of education completed (1 to 7 scale ranging from "did not graduate high school" to "advanced degree") and number of family generations in ranching (1 = first-generation rancher; 2 = parents were ranchers; 3 = grandparents were ranchers; 4 = great-grandparents were ranchers; and 5 = great-great-grandparents were ranchers). Respondents were also asked about the number of information sources they used and the perceived quality of each source (1 to 4 scale, ranging from "never use" to "I use this and the quality is excellent"). For analysis, the total number of good or excellent sources were summed for each respondent.

2.2.4. Operator Goals

In individual adaptive decision-making, goal setting and valuation of the natural resources base is key to forward planning [16]. Respondents were provided with a list of nine potential agricultural and natural resource management goals (livestock production, forage production, carbon sequestration, invasive recreation, riparian/meadow health, soil health, water quality, and wildlife) and asked to rank each goal as it related to the operation's priorities (rank of 1 indicated the highest priority). A rank of "10" was assigned to any goals not ranked by individual respondents. For analysis, riparian/meadow health, soil health, water quality, and wildlife rankings were similarly ranked among respondents [10] and therefore averaged into a single variable labeled "supporting goals".

2.2.5. Management Capacity

Operations with more management options (i.e., flexibility) potentially have greater capacity to cope with and adapt to changing conditions [26,38,39]. In addition to questions on diversity of land ownership types, the survey included questions on respondents' experience with common rangeland and ranch practices—following general themes of infrastructure, vegetation management, landscape enhancements, and herd management [20]. Respondents were asked if they had used each of 20 listed practices in the past 5 years and, for the practices used, whether each practice was key, helpful, or not effective in moving toward their goals. Respondents were also asked about their participation in 18 different conservation programs. Conservation programs have been argued to enhance the management portfolio for achieving goals and managing risk [16].

2.3. Data Analysis

The analysis approach was to first identify distinct classes of drought strategies based on survey responses to drought management questions (i.e., reactive and proactive practices) using latent class analysis (LCA). Conditional inference regression models were then used to determine operation structure characteristics driving those class membership probabilities (from LCA). That is, the aim of this second analysis was to identify structural characteristics of operations more likely to have a particular class of drought strategy. Lastly, structural equation modeling (SEM) was used to examine how decision-making factors generally influence individual drought adaptation.

2.3.1. Latent Class Analysis

LCA of drought management responses was implemented using the poLCA package in R [40]. LCA is a statistical method used to classify subjects into unobserved subgroups (i.e., latent classes) based on their response patterns. Latent class models estimate the proportion of subjects in each latent class, the probabilities of observing each response for each latent class, and each subject's predicted latent class membership (i.e., strength of class membership for each respondent). Individuals were assigned to a latent class based on predicted probabilities of membership. LCA fit was determined using Akaike Information and Criteria (AIC) and the likelihood ratio chi-square statistic [40].

2.3.2. Conditional Inference Regression Trees

Conditional inference regression tree analysis was implemented using the party package in R [41] to determine the operation structure variables (Table 1)—as well as operation background experience with drought—associated with respondent preferences for each drought strategy class identified in LCA. This method uses tree structured regression analysis to identify variables likely to predict membership probabilities for each previously identified latent class. This analysis provides a non-parametric class of regression trees that accommodates multiple data types (including categorical and numeric data) and large numbers of candidate predictor variables, as well as allows examination of potential interactions [41–44].

2.3.3. Structural Equation Modelling

SEM was used to examine how adaptive decision-making factors influence individual drought management based on hypothesized pathways (Figure 1). SEM is a multivariate statistical technique that combines path and factor analyses and can therefore be used to examine complex relationships between multiple predictor and response variables (e.g., [45]). Analysis was performed using Stata 13.1 (Stata Corp., College Station, TX, USA) generalized structural equation model estimation command [46]. Poisson regressions were used to model count responses, logistic regressions were used to model binary responses, and linear regressions were used to model normally distributed variables. Model comparisons and goodness of fit were conducted using AIC.

3. Results

3.1. Four Classes of Drought Strategies

LCA of 479 eligible respondents resulted in a final model of 4 classes of drought strategies (Table 2). Loadings (i.e., conditional probabilities of observing each response to each question) for each drought practice question indicate the strategies differentiate on a number of proactive and reactive practices used (see bolded response probabilities in Table 2). The average class assignment probability ranged from 80%–87%, indicating good to high quality classification.

Table 2. Results of latent class analysis of drought management practice questions from a rangeland decision-making mail survey delivered in March–June 2011 to 1727 producer members of the California Cattlemen's Association.

		Class of Drought Strategy [2]			
	Proportion of Respondents [1]	Class 1	Class 2	Class 3	Class 4
Drought response (reactive practices)					
Reduce Herd size	71%	0.08	**0.69** [3]	**0.86**	**0.91**
Purchase feed	70%	0.13	**0.88**	**0.64**	**0.75**
Wean early	40%	0.00	**0.40**	**0.41**	**0.72**
Apply for government assistance	40%	0.01	**0.45**	0.35	**0.67**
Rent additional pasture	27%	0.02	0.35	0.00	**1.00**
Move livestock to another location	24%	0.06	0.20	0.18	**0.75**
Add off-farm income	23%	0.00	0.22	0.30	0.28
Sell retained yearlings	22%	0.00	0.14	0.34	0.35
Place livestock in a feedlot	8%	0.00	0.06	0.07	0.26
Maintain herd size, and allow declines in livestock condition	7%	0.00	0.11	0.04	0.04
Add an alternative on-farm enterprise	4%	0.04	0.03	0.06	0.06
Drought preparation (proactive practices)					
Stock conservatively	35%	0.03	0.22	**0.53**	**0.53**
Rest pastures	24%	0.00	0.11	**0.41**	**0.36**
Incorporate cow-calf and yearling cattle in operation	22%	0.03	0.03	**0.40**	**0.49**
Grass bank	13%	0.00	0.08	0.18	0.23
Use weather predictions to adjust stocking rates	11%	0.00	0.05	0.19	0.18
Add other livestock types	3%	0.00	0.00	0.06	0.05

[1] Proportion of respondents selecting response to each practice question; [2] Conditional probabilities of observing each response under each grazing practice; [3] Response probabilities bolded to highlight primary differences among classes.

Respondents assigned to drought strategy class 1 (10% of respondents) exhibited low adoption of both practices in response to drought (reactive practices) and practices in preparation for drought (proactive practices) (Table 2). Respondents assigned to class 2 (42% of respondents) used a range of practices, with greater emphasis on common reactive practices (reduce herd size, purchase feed, wean early, and apply for government assistance) (Table 2). Class 3 (36% of respondents) emphasized a mixture of reactive and proactive strategies. Specifically, class 3 emphasized reactive practices such as reduce herd size, purchase feed, and wean early; and proactive practices such as stock conservatively, rest pastures, and incorporate cow-calf and yearling cattle in operations. Class 4 (12% of respondents) also used both reactive and proactive strategies, but emphasized a greater number of total practices.

3.2. Background Operation Variables Linked to Drought Strategy Class Selection

Four conditional inference regression trees (Figure 2A–D)—one tree for each drought strategy class identified in LCA—resulted from the analysis of the 479 eligible responses. In general, class 2 and 3 operations were smaller in size (Table 3). The conditional inference tree for class 1 contained only one significant split ($p < 0.05$), resulting in two terminal nodes (Figure 2A). The first split partitioned respondents based on operation experience with drought. Operations that had previously experienced drought were least likely (average membership probability of 0.04) to adopt drought strategy class 1; operations that had not previously experienced drought were most likely (0.87) to adopt drought strategy class 1.

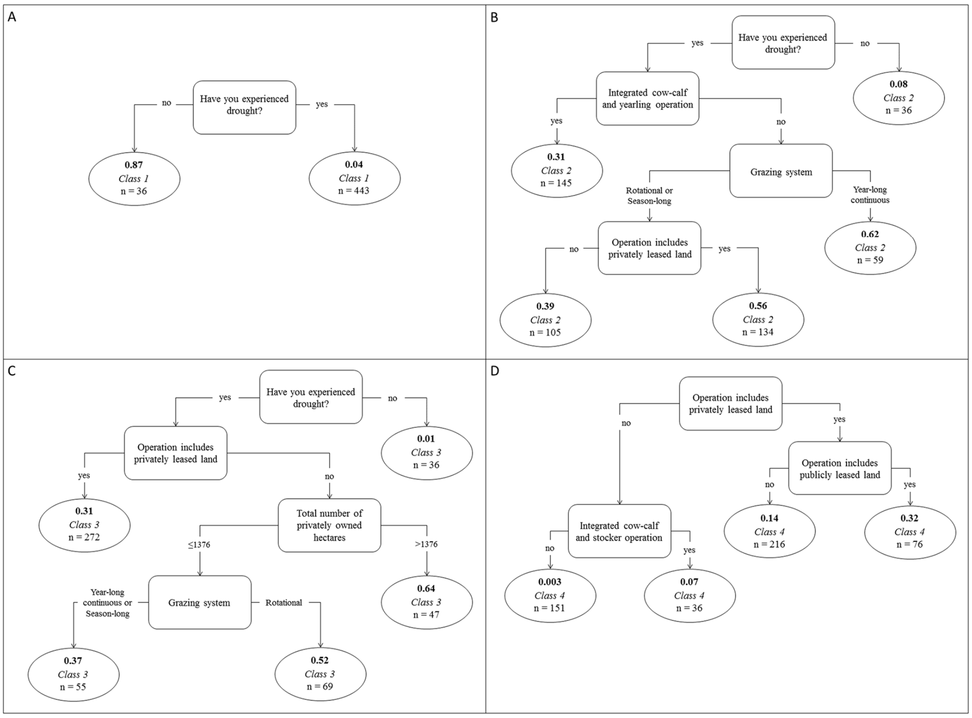

Figure 2. Conditional inference tree models for Classes 1–4 (**A**–**D**) drought management strategies identified in latent class analysis (LCA) of rangeland decision-making mail survey data. The conditional inference regression models explain variation in respondents' (n = 479) membership probabilities acquired from LCA. Bolded values are predicted mean probabilities of respondents with the preceding characteristics adopting each strategy. Respondents were surveyed between March–June 2011, and were producer members of the California Cattlemen's Association. All splits are statistically significant at $p < 0.05$ level.

Table 3. Characteristics of ranching operations assigned to four emergent classes of drought strategies based on latent class analysis of drought management questions in a rangeland decision-making mail survey delivered March–June 2011 to 1727 producer members of the California Cattlemen's Association.

Drought Strategy Class	Respondents Assigned (%)	Mean Total Land Area (ha)	Mean Number of Cow/Calf	Mean Number of Yearlings	Mean Total Number of Cattle
1	10	1332	141	194	343
2	42	2887	220	188	412
3	36	6421	323	321	644
4	12	55,184	645	833	1482

The conditional inference tree for class 2 contained four significant splits ($p < 0.05$), resulting in five terminal nodes (Figure 2B). The first split partitioned respondents based on operation experience with drought. Operations that had not previously experienced drought had a lower probability (0.08) of adopting drought strategy class 2. Among operations that had experienced drought, those that integrated cow-calf and yearling animals only had a 0.31 probability of adopting the drought strategy class 2 (Figure 2B). Operations that had experienced drought, did not integrate cow-calf and yearling animals, and used a year-long continuous grazing system were most likely (0.62) to adopt drought strategy class 2. Operations that had experienced drought, did not integrate cow-calf and yearling animals, used a rotational or season-long grazing system, and had privately leased land were the second most likely (0.56) to adopt drought strategy class 2 (Figure 2B).

The conditional inference tree for class 3 also produced four significant splits ($p < 0.05$), resulting in five terminal nodes (Figure 2C). Similar to classes 1 and 2, the first split partitioned respondents based on operation experience with drought. Operations that had not previously experienced drought had a lower probability (0.01) of adopting drought strategy class 3. Among operations that had experienced drought, those that included privately leased land only had a 0.31 probability of adopting the drought strategy class 3 (Figure 2C). Operations that had experienced drought, did not include privately leased land, and had greater than 1376 ha of privately owned land were most likely (0.64) to adopt drought strategy class 3. Operations that had experienced drought, did not include privately leased land, had less than 1376 ha of privately owned land, and used a rotational grazing system were the second most likely (0.52) to adopt drought strategy class 3 (Figure 2C).

The conditional inference tree for class 4 produced three significant splits ($p < 0.05$), resulting in four terminal nodes (Figure 2D). The first split partitioned respondents based on whether the operation included privately leased land. Operations that included privately leased land and also had access to publicly leased land were the most likely (0.32) to adopt drought strategy class 4. The lowest adoption probabilities for drought strategy class 4 were operations that either (1) did not include privately leased (average membership probabilities <0.1) or (2) included privately leased land but did not have access to public land (0.14) (Figure 2D).

3.3. Decision-Making Factors Driving Individual Drought Adaptation

Structural equation modelling results revealed past experience with drought was positively associated with in-place drought adaptation, which was indicated by the observed variables of active drought plan in place, number of proactive practices used, and number of reactive practices used. Drought adaptation was significantly influenced by goal setting (Figure 3)—lower prioritization (i.e., higher rankings) of future natural resources (e.g., forage production) negatively impacted adaptive capacity. Drought adaptation was positively influenced by management capacity, which was indicated by number of conservation programs used, number of key management practices used, and number of land ownership types. Goal setting and management capacity were not significantly correlated in the final model. Finally, the information resource network—indicated by number of generations ranching, number of good or excellent information sources used, and education level—significantly influenced both goal setting and management capacity.

4. Discussion

I examined drought management decision-making based on survey responses of 479 ranchers from across California. California's rangelands are a notable example of a system vulnerable to increasing climate variability. Because ranchers are largely dependent on rain-fed rangelands, this community is the most sensitive to changing climate patterns and is, therefore, commonly the first to experience the impacts of climate extremes. Climate extremes, like long-term drought, pose cumulative challenges to sustaining rangeland ranching operations and the ecosystem services they provide. With much of the western U.S. predicted to experience increasingly warmer temperatures and greater fluctuations between wet and dry conditions [8], it is imperative we find ways to enhance our capacity to respond to climate stresses and, therefore, reduce system vulnerability.

While individual ranchers develop, implement, and adapt unique strategies for their operations, revealing the identifiable patterns of management types is useful to understanding the range of differences across a community—as well as targeting outreach and policy and planning options [7,27,47–49]. I identified four types (classes 1 through 4; Table 2) of drought strategies in-place across California's diverse rangelands. The resulting classes were ordered along a gradient of increasing intensity (number) of drought practices used. Classes 3 and 4 exhibited high adoption rates across the largest number of practices—as well as greater adoption of proactive practices—suggesting these strategies enabled the greatest flexibility in coping with and adapting to drought [17,26]. In fact, the most used proactive practices (Table 2) emphasized maintaining flexibility and minimizing potential vulnerability to reduced forage availability. As found by others, background operation variables shaped the classes of strategies and practices available, affecting management capacity to adapt to and cope with changing conditions (e.g., [9,16,26,34,35,50,51]). Previous operation experience with drought was a significant primary predictor for most of the classes of drought strategies (Figure 2A–C). In fact, compared to those with previous drought experience, responding operations with no previous drought experience were more likely to adopt the class 1 strategy (Figure 2A)—which had the lowest response probabilities across all practices (Table 2). Many other recent rancher surveys across the western U.S. have also found that drought experience significantly influences drought management planning—as much as doubling self-reported preparedness levels [26–28,52]. In my analysis of the variables driving strategy selection, other significant structuring variables included type of livestock operation (i.e., whether operation integrates cow-calf and yearling animals), grazing system (rotational strategy, season-long continuous strategy, and year-long strategy), and land ownership (private owned, private leased, public leased) (Figure 2B–D).

In terms of individual adaptive decision-making, information resource networks, goal setting for sustainable natural resources, and management capacity all acted to enhance drought adaptation—defined here by active drought planning and the number of both reactive and proactive drought practices used (Figure 3). These results agree with others who have found that information sharing, valuing and sustaining assets, and flexibility are key components in adapting to and coping with change [16,18,25,26,53]. For example, flexibility in management capacity via diverse resource options such as multiple land ownership types (Figures 2D and 3) increases decision-making power in balancing operation-level forage supply and demand. These results also highlight the key roles that trusted, boundary spanning organizations—like Cooperative Extension and USDA Natural Resources Conservation Service (NRCS)—can play in translating science to management and continuing to support and build individual adaptive capacity [10,17,27].

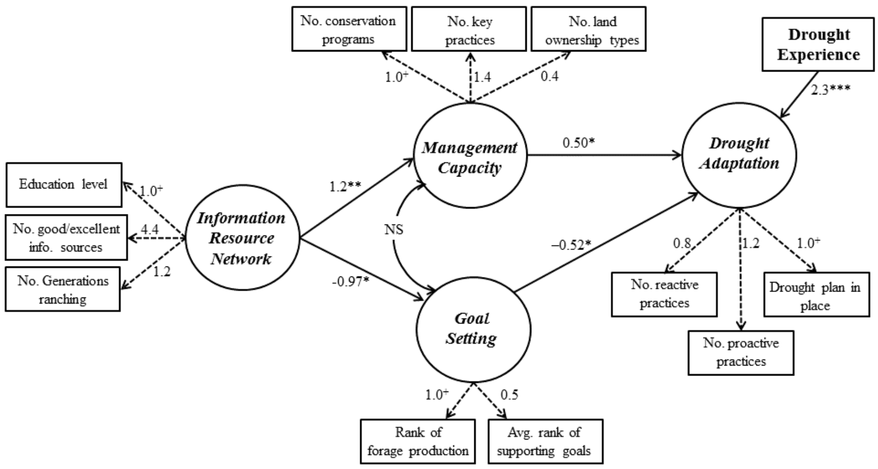

Figure 3. Results of structural equation modelling (SEM) analysis of rancher responses (n = 479) to drought management questions in the rangeland decision-making mail survey, delivered March–June 2011. Latent variables are represented by circles and measured variables are represented by boxes; dashed arrows represent the measurement models (relationships between the measured and latent variables) and the solid arrows represent the process model (i.e., structural relationships between the latent variables). For the education level, scale ranged from 1 = "did not graduate high school" to 1 = "advanced degree"; for goal rankings, scales ranged from 1 = top priority to 10 = lowest priority; drought experience was a binomial yes/no response; and all other indicator variables were counts (no. = number). * = $p < 0.05$, ** = $p \leq 0.01$, *** = $p < 0.001$, NS = Not significant.

5. Conclusions

Analysis of the California Rangeland Decision-Making Survey revealed that flexibility in management is a key component of adaptation (Table 2 and Figure 3). Climate policy planning should take into account the diversity of strategies that have been developed and implemented by ranchers for multiple generations and within the context of their unique operations, as well as support these working landscapes via a range of adaptation and mitigation options to reduce vulnerability across all types of operations. The existing diversity of response types suggests that not all operations will be able to cope with and adapt to climate variability in the same ways, and this would be particularly true for those that would need to completely transform their operations (e.g., via climate-independent income diversification [26,54] to meet one-size-fits-all adaptation and mitigation recommendations. Therefore, policy and planning strategies that support a mix of incremental changes [55] as well as transformational changes [56] will provide a feasible and flexible path to individual long-term adaptation. Ranchers and other agriculturalists in California and elsewhere have identified organizations like Cooperative Extension and USDA NRCS as trusted information sources [10,57,58]; these and other support organizations have both continued and new roles in leading novel research and delivering technical support in building adaptation and mitigation strategies to reduce system vulnerability to future environmental changes. Advancing agricultural adaptation science, management, and policy will require management-scale, participatory research approaches; collaborative and translational science partnerships; and local, state, and national policy and program support for proactive management solutions.

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