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On-Ranch Grazing Strategies: Context for the Rotational Grazing Dilemma☆

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ABSTRACT

Considerable debate remains over the efficacy of rotational grazing systems to enhance conservation and agricultural production goals on rangelands. We analyzed responses to grazing management questions in the Rangeland Decision Making Surveys of 765 California and Wyoming ranchers in order to characterize on-ranch grazing strategies and identify variables influencing strategy adoption. Two-thirds of respondents practice on-ranch rotational grazing strategies, indicating ranchers do experience benefits from rotation which have not been documented in experimental comparisons of rotational and continuous grazing systems. Limited on-ranch adoption of intensive rotational strategies (5% of respondents) indicates potential agreement between research and management perceptions about the success of this particular strategy for achieving primary livestock production goals. Over 93% of all rotational grazer respondents were characterized as using *extensive* intragrowing season rotation with moderate (few wk to mo) grazing period durations, moderate (2.4–8 ha·animal unit) livestock densities, and growing season rest periods. Variables associated with ranchers' grazing preferences included a mixture of human dimensions (goal setting, views on experiment and risk tolerance, information networks), ranch characteristics (total number of livestock, land types comprising ranch), and ecoregions. We also found that the majority of grazing systems research has largely been conducted at spatial and temporal scales that are orders of magnitude finer than conditions under which on-ranch adaptive grazing management strategies have been developed. Resolving the discrepancies between the grazing systems research and management knowledge base will require substantive communication and novel approaches to participatory research between scientists and managers.

Introduction

Across the globe, there is lively debate on the efficacy of rotational grazing strategies to conserve and improve natural and agricultural resources on rangelands (Briske et al., 2011a, 2013; Monbiot, 2014; Savory, 2013). The basic idea of the rotational grazing system is to set periods of grazing and nongrazing (rest), with the goal of enhancing production through increased growth of vegetation and increased forage–harvest efficiency of grazing livestock (Briske et al., 2008). Various classes of grazing strategies (e.g., continuous, rest rotation, and short duration) have been institutionalized and promoted via the academic community, conservation incentive funding programs, federal public grazing lands policies, and others (Briske et al., 2011b). Recent scientific syntheses have concluded that rotational grazing strategies of the manner and scale researched thus far provide no unique ecological or agricultural benefits in comparison with continuous grazing strategies (Briske et al., 2008, 2011a) These syntheses appear to conflict with *experiential* knowledge and perceptions of the successes of place-based, adaptively managed, rotational grazing strategies on working landscapes (Briske et al., 2011a,2011b; Grissom and Steffens, 2013; Norton et al., 2013; Teague et al., 2011, 2013).

Research on grazing strategy has predominantly focused on comparisons of biophysical outcomes (e.g., livestock weight gains and annual forage production) between fixed grazing treatments implemented over fine spatial and temporal scales. However, ranchers make decisions and adapt management for multiple outcomes across numerous scales in response to the dynamic social–ecological systems within which their ranch enterprises are embedded (see Fig. 1 in Lubell et al., 2013). In the adaptive decision-making process, place-based expertise, trial-and-error learning over time,

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and heuristics passed through generations and local knowledge networks all function to determine agricultural strategies and perceptions of management successes or failures (Brunson and Burritt, 2009; Didier and Brunson, 2004; Knapp and Fernandez-Gimenez, 2008, 2009; Lai and Kreuter, 2012; Lubell et al., 2011; Sorice et al., 2012; Teague et al., 2013).

We argue that characterizing on-ranch grazing strategies, as well as understanding the social, economic, and ecological variables driving ranchers' grazing strategy preferences, is an essential first step towards reconciling the discrepancies between *experimental research-based* and *experiential management-based* perceptions of grazing strategy effectiveness. The fundamental questions that need to be answered in the process of resolving this dilemma require communication and collaborative research efforts between scientists and grazing managers. For example, we need to determine how the types of grazing systems studied by the research community thus far actually compare to on-ranch grazing management strategies. We also need to determine how variables such as ranchers' goal prioritization, number of livestock, local environment, and views on risk and experimentalism determine their grazing strategy preferences and perceptions of management successes and failures.

Here we build on the adaptive management decision-making framework, outlined by Lubell et al. (2013), to characterize on-ranch grazing strategies and the variables that influence strategy adoption as steps toward 1) interpreting existing grazing systems research results in the context of actual on-ranch grazing strategies, and 2) providing guidance for new stakeholder participatory research on the effectiveness of place-based, expert-managed grazing strategies for multiple social, economic, and ecological outcomes. We use social survey methods to quantify on-ranch grazing management practices across two common rangeland agroecosystems: Wyoming, which represents perennial, summer growing season systems; and California, which represents annual, winter growing season systems. We used statistical classification of on-ranch grazing management practices to identify general grazing strategies, followed by regression analysis to examine whether ranchers' grazing strategy preferences are related to operator and operation characteristics, information sources and social networking, and personal attitudes and values variables (Fig. 1).

Methods

Rangeland Decision Making Survey

We included questions in the Rangeland Decision Making Surveys of California and Wyoming ranchers to better understand on-ranch grazing strategies and variables influencing their adoption. These surveys are fully described in Kachergis et al. (2013) and Lubell et al. (2013). We developed these mail surveys using the membership list of the California Cattlemen's Association (CCA) and the Wyoming Stock Growers Association (WSGA). CCA and WSGA are nonprofit trade organizations serving ranchers across California and Wyoming—well representing our target sampling frame of production livestock ranchers (Lubell et al., 2013). The mail survey included sections on operation and operator characteristics, individual goals, management practices, information sources, and social values and perspectives. Survey questions were developed based on previous research, informational interviews with 22 ranchers, and pretesting at agricultural stakeholder meetings in both states. As discussed in Lubell et al. (2013) and Kachergis et al. (2013), we used the same multicontact approach to engage ranching communities and develop awareness of the survey in both states (Dillman, 2007). The California survey was delivered to 1 727 addresses in March–June 2011, and the Wyoming survey was delivered to 749 addresses in January–March 2012. The California response rate was 33% (Lubell et al., 2013), and the Wyoming response rate was 49% (Kachergis et al., 2013). There were 473 California and 292 Wyoming surveys eligible for the analyses presented in this paper; the number of responses (n) per question is noted throughout.

Grazing Practices and Strategies

To classify on-ranch grazing strategies practiced by ranchers, we developed 5 survey questions patterned after (Briske et al., 2008) to quantify the following core grazing practices: 1) number of pastures, 2) number of livestock herds, 3) duration of grazing, 4) livestock density, and 5) timing of rest from grazing. We asked respondents to describe how they applied these strategies specifically to the largest area of private rangeland (owned or leased) they managed in order to focus responses on place-based grazing strategies where

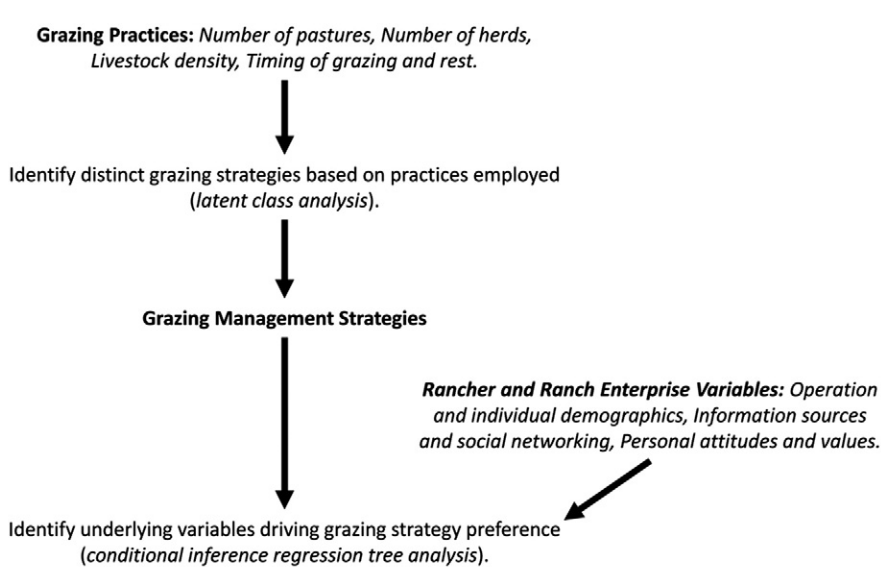

Fig. 1. Data analysis pathway followed to first characterize on-ranch grazing strategies and then associate strategy preference with rancher and ranch enterprise features.

they had decision-making capacity. California and Wyoming ranches are complex enterprises comprised of multiple land types (i.e., private owned, private leased, and public leased) located across different rangeland ecosystems and climate regimes; therefore, it was necessary to have respondents focus on specific parts of their operations, given that grazing strategies might vary across parcels.

Operation and Operator Demographics

Operation and operator characteristics are critical variables in most theories of adaptive agricultural decision making (Buttell and Newby, 1980; Didier and Brunson, 2004; Gosnell et al., 2007; Huntsinger and Fortmann, 1990; Kachergis et al., 2013, 2014; Kreuter et al., 2004; Lubell et al., 2013). We asked questions to determine respondents' dependence on ranch income (on a 1 to 5 scale, ranging from "fully disagree" to "fully agree"), total number of livestock, generations of family working in ranching (with a range of 5 levels: 1 = first-generation rancher; 2 = parents were ranchers; 3 = grandparents were ranchers; 4 = great-grandparents were ranchers; and 5 = great-great-grandparents were ranchers), and if the ranch operation included publicly leased land. Based on mailing ZIP code, we determined the U.S. Environmental Protection Agency Level III Ecoregion for each respondent (Table 1). Ecoregions broadly capture geographical similarities in resource potential and variability among ecosystems, as well as similarities in capacity to respond to disturbances such as grazing (Bryce et al., 1999).

Information Sources and Social Networking

Social networks are key in disseminating new information and facilitating adoption of innovations (Brodt et al., 2004; Didier and Brunson, 2004; Farmar-Bowers and Lane, 2009; Huntsinger and Hopkinson, 1996; Kreuter et al., 2006; Lubell and Fulton, 2008; Lubell et al., 2013; Marshall et al., 2011). Formal and informal education can affect issue awareness, which may ultimately alter the range of decisions available to an individual (Kurz, 2002). The survey included numerous questions about respondents' information resources, including the extent of education received (on a 1 to 7 scale ranging from "did not graduate high school" to "advanced degree").

Table 1
Variables hypothesized to influence individual ranchers' grazing strategy preferences. Questions were from a rangeland decision-making mail survey delivered in March—June 2011 to 1 727 producer members of the California Cattlemen's Association and in January—March 2012 to 749 producer members of the Wyoming Stock Growers Association.

Question	Value
Operation and operator demographics	
USEPA Level III Ecoregion	Categorical
Dependence on ranch as a source of income	1—5 scale[1]
Total number of livestock	0—22 000 count
Number of generations ranching	1—6 count
Operation includes publicly leased land	Yes/No
Information sources and social networking	
Educational level	1—7 scale[2]
Number of good or excellent information sources	0—14 count
Opinion leadership	1—5 scale[1]
Information sharing with other ranchers	1—5 scale[1]
Operator personal attitudes and values	
Views on experimenting with new strategies/practices	1—5 scale[1]
Views on economic viability and environmental protection	1—5 scale[1]
Views on risk taking	1—5 scale[1]
Rank of livestock production goal	1—9 rank[3]

[1] Likert-scale ranging from 1 = "fully disagree" to 5 = "fully agree".
[2] Scale ranges from 1 = "did not graduate high school" to 1 = "advanced degree".
[3] Rank among 8 other identified goals (forage production, carbon sequestration, invasive weed management, recreation, riparian/meadow health, soil health, water quality, and wildlife).

We asked respondents about the number of information sources they used and the perceived quality of each source (Table 1). Response categories for each information source were on a 1 to 4 scale that ranged from "never use" to "use and excellent quality information." Analysis was conducted on summative scales evaluating the total number of good and/or excellent sources; for example, a respondent would receive a score of 2 if they mentioned two information sources that provided good or excellent information. Social networking was measured using two separate attitude statements (based on a 5-point disagree-agree Likert scale) shown to be associated with different measures of network centrality: 1) "I share information with groups of ranchers who would not otherwise communicate with each other," and 2) "I think most ranchers in California/Wyoming consider me to be an opinion leader in the industry."

Operator Attitudes and Values

Personal attitudes and values are often argued to shape beliefs and, ultimately, individual decisions and adoption of management goals and practices (Brodt et al., 2004; Brunson and Burritt, 2009; Didier and Brunson, 2004; Farmar-Bowers and Lane, 2009; Kreuter et al., 2006; Lubell, 2007; Lubell et al., 2013; Marshall et al., 2011; Smith et al., 2007). We collected responses to a number of personal attitude statements, using a 1 to 5 scale that ranged from "fully disagree" to "fully agree" (Table 1). Questions were derived to assess attitudes toward experimenting with new strategies/practices, economic viability and environmental protection, and risk taking. We asked ranchers to rank specific agricultural and natural resource management goals from highest to lowest priority to quantify the relative importance respondents placed on production (e.g., livestock, forage) versus noncommodity ecosystem services (e.g., carbon sequestration, invasive weed management, recreation, riparian health, soil health, water quality, and wildlife).

Data Analysis

Our analysis approach was to first determine, using Latent Class Analysis (LCA) (Linzer and Lewis, 2011), the classes of grazing strategies actively practiced by ranchers based on their responses to grazing practice questions (i.e., number of pastures, number of herds, duration of grazing, livestock density, and timing of rest from grazing). After we established the grazing strategy classes via LCA, individual respondents were assigned a probability of membership, or loading, to each strategy. We then used conditional inference regression models (Hothorn et al., 2006) to determine rancher and ranch enterprise characteristics; use of information sources and social networking; and personal attitudes and values driving membership probabilities for each grazing strategy (Fig. 1). The basic idea behind this approach is to identify which attributes of ranchers and ranch operations are more likely to predict preference for a particular class of grazing strategy. California and Wyoming responses were analyzed independently.

Latent Class Analysis (LCA)

To determine distinct classes of grazing strategies for each state, we employed latent class models using the poLCA package in R (Linzer and Lewis, 2011). LCA analyzes response patterns, allowing enumeration of underlying classes and the strength of class membership for each individual respondent. Individuals were assigned to a latent class based on their predicted probability of membership. The best fit LCA was determined using the lowest Akaike Information Criteria (AIC) and Bayesian Information Criteria (BIC) (Linzer and Lewis, 2011). Class memberships resulting from LCA are analogous to finger prints; each rancher develops and implements a unique grazing management strategy, yet there are identifiable patterns in these strategies among classes of ranchers.

Conditional Inference Regression Trees

We used conditional inference regression tree analysis to determine the variables (Table 1) associated with rancher preference for each of the grazing strategy classes identified via LCA for California and Wyoming. We used the R statistical package extension 'party' (Hothorn et al., 2006) for this analysis. This analysis uses tree-structured regression to identify variables likely to predict respondents' membership probabilities (continuous response variable) for each class of grazing strategy determined from the LCA analyses. This analysis accommodates nonparametric data and large numbers of candidate predictor variables, is appropriate in cases that include data collected in categorical and nominal forms, allows examination of data that potentially interact in a complicated and nonlinear fashion, and recursively partitions the overall variance to form groups of similar responses (Cutler et al., 2007; De'ath and Fabricius, 2000; Herr, 2010; Hothorn et al., 2006; Strobl et al., 2009).

Results

Three Classes of On-Ranch Grazing Strategies Emerge for each State

California

Analysis of California respondents resulted in a final latent class model consisting of 3 on-ranch grazing strategies which can be described as 1) rotational (46% of respondents); 2) growing season-long continuous (35% of respondents); and 3) yr-long continuous (19% of respondents) (Table 2). Loadings for each grazing practice question (i.e., conditional probabilities of observing each response to each question) indicate the 3 California on-ranch grazing strategies differentiate primarily on duration of grazing and timing of rest (see bolded response probabilities in Table 2). The average class assignment probability, or degree of correspondence between predicted class membership and the characteristics of a respondent, was above 88% in all 3 classes, indicating a high quality of classification.

Respondents assigned to each class varied in terms of individual practices (Table 2). For the rotational class, individuals spanned the entire range of pasture numbers (1 to > 10) and grazing durations (short to continuous throughout the year) with median responses of 6–10 pastures and moderate (a few wk at a time) grazing period durations, respectively. Responses for the timing of rest for the rotational class included all seasons—growing season rest and dormant season rest—with a median response of growing season rest and no individuals reporting no rest.

For the season-long continuous class, individuals also spanned the entire range of pasture numbers and grazing durations, but median responses were 2–5 pastures and long (several mo) grazing period durations, respectively. Timing of rest responses for the season-long continuous class included all seasons—growing season rest and dormant season rest—with a median response of dormant season rest and no individuals reporting no rest.

For the yr-long continuous class, individuals spanned the entire range of pasture numbers, with a median response of 2–5 pastures. The majority (93%) of respondents assigned to this class reported yr-long continuous grazing durations. Respondents also reported some growing season rest (35%) or no rest from grazing at all (65%).

Wyoming

Analysis of Wyoming respondents also resulted in a final latent class model consisting of 3 on-ranch grazing strategies which can be described as 1) rotational with few (≤5) pastures (53% of respondents), 2) rotational with many (6+) pastures (35% of respondents), and 3) high livestock density with short grazing duration (12% of respondents) (Table 3). Grazing practice loadings indicate the Wyoming on-ranch grazing strategies differentiate primarily on number of pastures, duration of grazing, and livestock density (see

Table 2

Results of latent class analysis to classify California on-ranch grazing strategies based on responses to grazing practice questions from a rangeland decision-making mail survey delivered in March—June 2011 to 1 727 producer members of the California Cattlemen's Association. For interpretation, bolded values highlight primary practice differences among classes.

Grazing Practice Question	Proportion of Respondents[1]	Class of Grazing Strategy[2]		
		Rotational	Season long continuous	Yr-long continuous
Number of pastures (n = 461)				
1	7%	0.02	0.09	0.15
2—5	48%	0.38	0.53	0.62
6—10	24%	0.32	0.19	0.13
>10	21%	0.27	0.18	0.11
Number of herds (n = 456)				
1	43%	0.38	0.47	0.49
2—5	43%	0.47	0.40	0.38
6—10	7%	0.08	0.05	0.08
>10	7%	0.07	0.08	0.06
Duration of grazing (n = 471)				
Short - A few days at a time	4%	0.09	0.00	0.01
Moderate - A few weeks at a time	45%	**0.78**	0.26	0.00
Long - Several months	28%	0.05	**0.68**	0.09
Continuous throughout year	23%	0.09	0.06	**0.90**
Livesotck density (n = 464)				
<5 acres/animal unit	23%	0.33	0.18	0.11
6—11 acres/animal unit	32%	0.25	0.44	0.29
11—20 acres/animal unit	25%	0.17	0.26	0.41
>20 acres/animal unit	20%	0.25	0.12	0.20
Timing of rest (n = 462)				
All seasons	17%	0.32	0.02	0.02
During growing season	46%	**0.63**	0.30	0.33
During dormant season	25%	0.05	**0.68**	0.00
No rest	12%	0.00	0.00	**0.65**

[1] Proportion of respondents selecting response to each grazing practice question.
[2] Conditional probabilities of observing each response under each grazing practice.

Table 3
Results of latent class analysis to classify Wyoming on-ranch grazing strategies based on responses to grazing practice questions from a rangeland decision-making mail survey delivered in January—March 2012 to 749 producer members of the Wyoming Stock Growers Association. For interpretation, bolded values highlight primary practice differences among classes.

		Class of Grazing Strategy[2]		
Grazing Practice Question	Proportion of Respondents[1]	Rotational with few pastures	Rotational with many pastures	High density short duration
Number of pastures (n = 282)				
1	7%	0.13	0.00	0.00
2—5	38%	**0.65**	0.00	0.13
6—10	25%	0.18	**0.40**	0.16
>10	30%	0.04	**0.60**	**0.71**
Number of herds (n = 280)				
1	28%	0.46	0.00	0.19
2—5	56%	0.52	0.56	0.74
6—10	8%	0.00	0.24	0.00
>10	8%	0.02	0.19	0.07
Duration of grazing (n = 274)				
Short - A few days at a time	5%	0.01	0.00	**0.48**
Moderate - A few weeks at a time	38%	0.38	0.30	**0.52**
Long - Several months	56%	**0.59**	**0.70**	0.00
Continuous throughout year	1%	0.02	0.00	0.00
Livesotck density (n = 221)				
<5 acres/animal unit	20%	0.14	0.06	**0.50**
6—11 acres/animal unit	29%	0.23	0.16	0.38
11—20 acres/animal unit	25%	0.17	0.29	0.05
>20 acres/animal unit	26%	**0.45**	**0.48**	0.07
Timing of rest (n = 269)				
All seasons	32%	0.19	0.44	0.59
During growing season	53%	0.59	0.47	0.41
During dormant season	14%	0.20	0.09	0.00
No rest	1%	0.02	0.00	0.00

[1] Proportion of respondents selecting response to each grazing practice question.
[2] Conditional probabilities of observing each response under each grazing practice.

bold response probabilities in Table 3). Similarities in livestock density and grazing duration between rotational grazing with few (2 980 ha) and many (9 477 ha) pastures and differences in ranch size and total livestock numbers (few pastures = 573 head, many pastures = 1 309 head) indicate this division is driven by operation size (Tables 3 and 4). The average class assignment probability was above 84% in all three classes, indicating a high quality of classification.

Respondents assigned to each class varied in terms of individual practices (Table 3). For the rotational with few pastures class, individuals spanned the entire range of pasture numbers (1 to > 10), grazing duration (short to continuous throughout yr), and livestock densities, with median responses of 2–5 pastures, long (several mo) grazing period durations, and 11–20 acres·animal unit, respectively. Timing of rest responses for this class spanned all categories (all seasons, growing season rest, dormant season rest, and no rest) with a median response of growing season rest.

For the rotational with many pastures class, all individuals used at least 6 pastures, with 59% using more than 10 pastures. The majority (74%) of respondents assigned to this class reported long (several mo) grazing durations, and the remaining 26% reported moderate (few wk) grazing durations. Livestock density responses spanned all categories, with a median response of 11–20 acres·animal unit. Timing of rest responses for the rotational with many pastures class included all seasons, growing season rest, and dormant season rest with a median response of growing season rest and no individuals reporting no rest.

For the high density short duration class, respondents reported 2 or more pastures, with 79% of respondents using more than 10 pastures. Fifty-three percent of respondents assigned to this class reported short (few days) grazing durations, and the remaining 47% reported moderate (few wk) grazing durations. Livestock density responses spanned all categories, with a median response of < 5 acres·animal unit. Respondents assigned to this class reported some rest during all seasons (59%) or growing season rest only (41%).

Variables Linked to Ranchers' Grazing Strategy Preference

California

Three conditional inference regression trees (Fig. 2A—C)—one tree for each of the three on-ranch grazing strategies classified by latent class analysis (Table 2)—resulted from analysis of California re-

Table 4
Characteristics of ranchers and ranches assigned to grazing strategies emergent for California and Wyoming based on latent class analysis of grazing practice questions in a rangeland decision-making mail survey delivered in March—June 2011 to 1727 producer members of the California Cattlemen's Association and in January—March 2012 to 749 producer members of the Wyoming Stock Growers Association.

State	Strategy	Percent of Respondents Assigned	Mean Total Number of Livestock	Mean Total Private Hectares in Ranch Enterprise	Mean Total Hectares in Ranch Enterprise
California	Rotational	46	636	7 507	19 574
	Season-long continuous	35	949	5 992	43 480
	Yr-long continuous	19	219	3 184	3 861
Wyoming	Rotational with few pastures (≤5)	53	573	7 364	23 775
	Rotational with many pastures (6+)	35	1 309	23 417	39 787
	High-density short duration	12	949	13 911	32 316

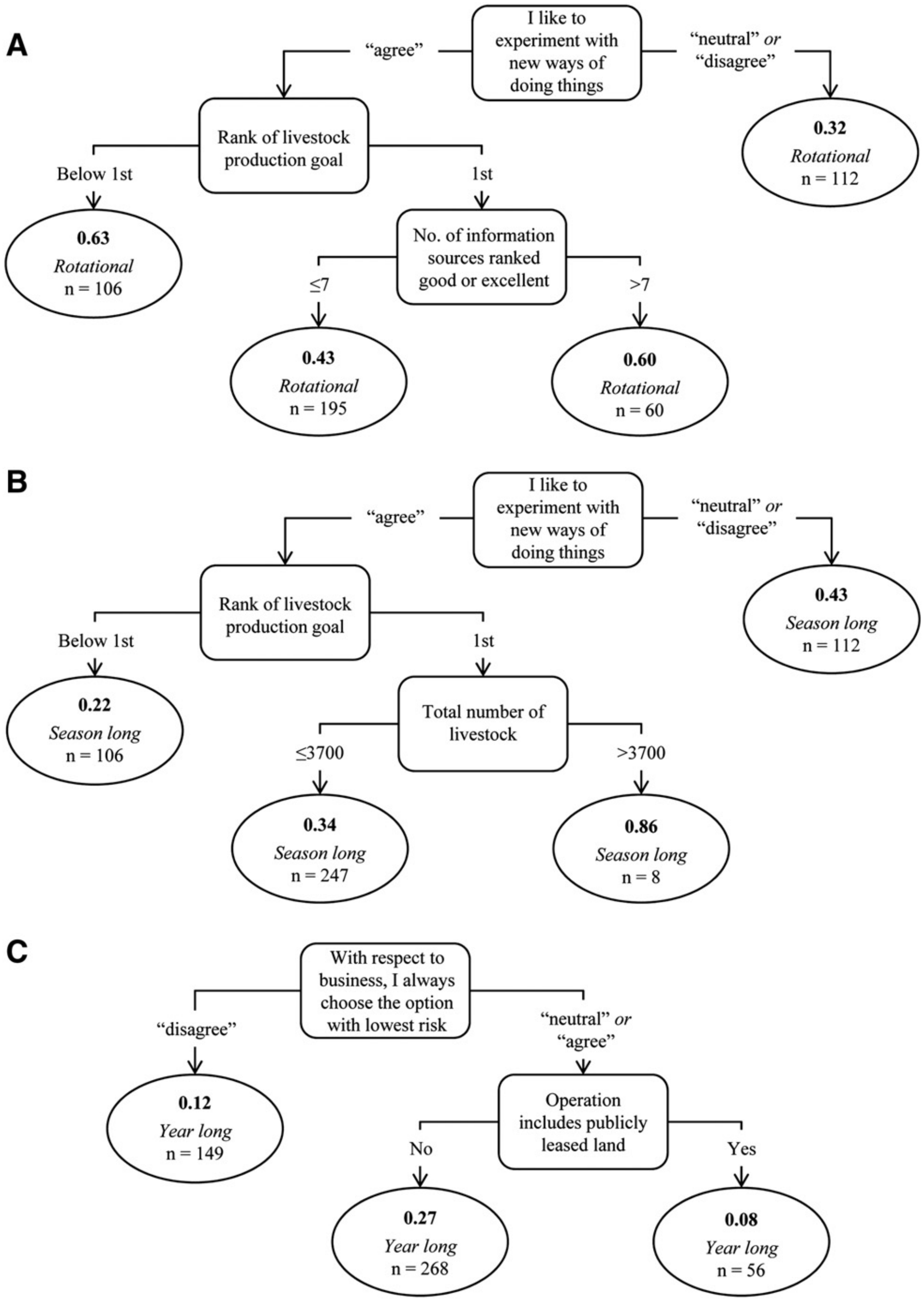

Fig. 2. Conditional inference tree models for **A,** rotational, **B,** season long continuous, and **C,** yr-long continuous grazing strategies identified in latent class analysis (LCA) for California rancher survey data. The conditional inference regression models explain variation in respondents' (n = 473) 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 the $P < 0.05$ level.

sponses. The conditional inference tree for the rotational grazing strategy contained three significant splits ($P < 0.05$) producing four terminal nodes (Fig. 2A). The first split partitioned respondents based on agreement with the attitude statement, "I like to experiment with new ways of doing things." Respondents neutral or disagreeing with this statement were least likely to adopt a rotational grazing strategy (probability of adopting = 0.32; Fig. 2A). Among the self-reported experimenters, those that *did not* rank livestock production as their first goal had the highest probability (0.63) of adopting rotation. Of the remaining experimenters who *did* list livestock production as their first goal, those identifying more than seven "good" or "excellent" information sources were more likely (0.60) to adopt a rotational grazing strategy than those identifying seven or fewer "good" or "excellent" information sources (probability of adopting = 0.43) (Fig. 2A).

The conditional inference tree for the season-long continuous grazing strategy also contained three significant splits ($P < 0.05$) producing four terminal nodes (Fig. 2B). The first split partitioned respondents based on agreement with the attitude statement, "I like to experiment with new ways of doing things." Respondents neutral or disagreeing with this statement had a 0.43 probability of adopting a season-long continuous grazing strategy (Fig. 2B). Among the self-reported experimenters, those who *did not* rank livestock production

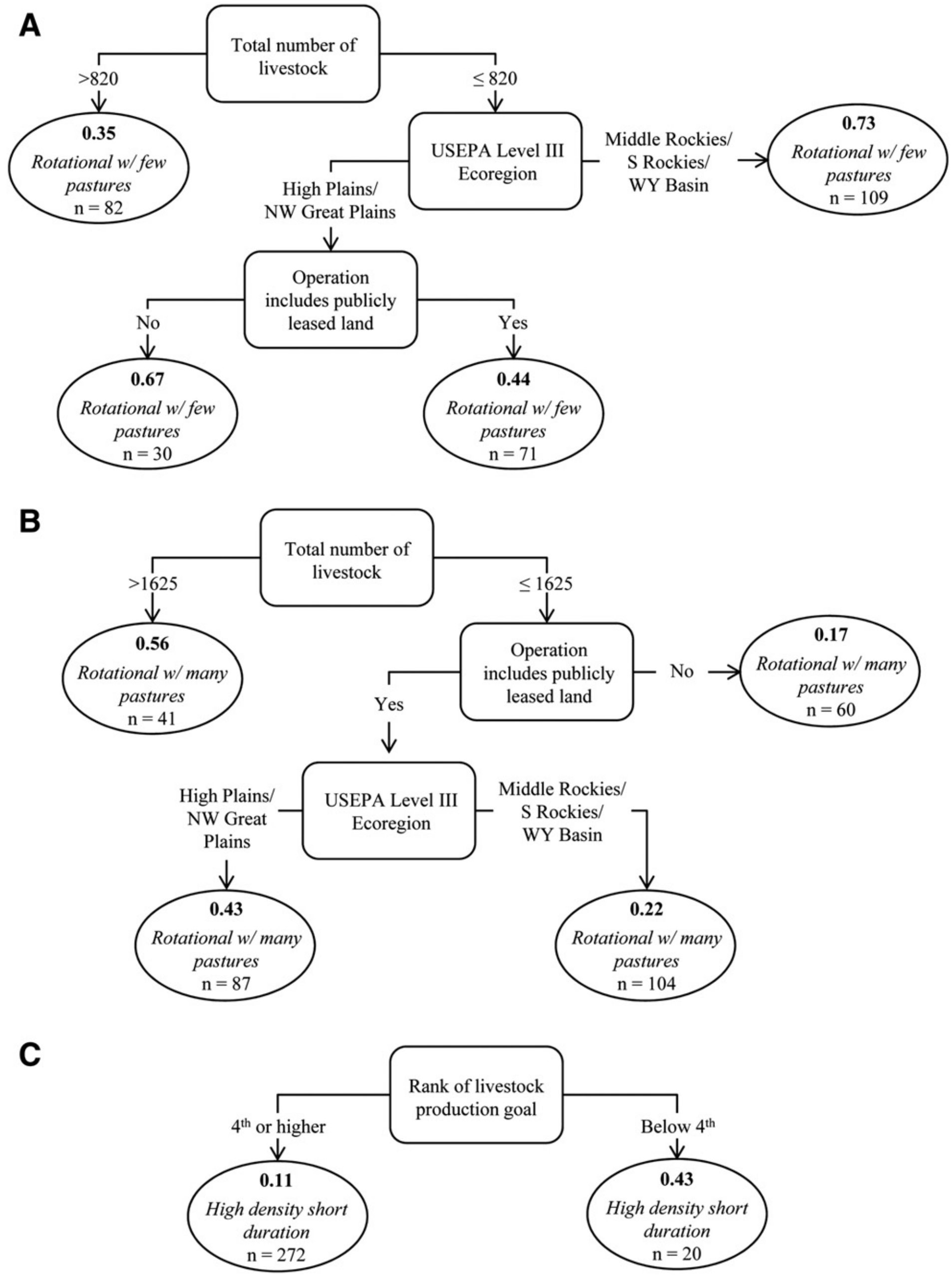

Fig. 3. Conditional inference tree models for **A,** rotational with few pastures, **B,** rotational with many pastures, and **C,** high-density, short-duration grazing strategies identified in latent class analysis (LCA) for Wyoming rancher survey data. The conditional inference regression models explain variation in respondents' (n = 292) membership probabilities acquired from LCA. Bolded values are predicted mean probabilities of respondents with the preceding characteristics adopting each strategy. Respondents were surveyed between January—March 2012, and were producer members of the Wyoming Stock Growers Association. All splits are statistically significant at the $P < 0.05$ level.

as their first goal had the lowest probability (0.22) of adopting the season-long continuous grazing strategy. Experimenters who ranked livestock production as their first goal and reported more than 3 700 head of livestock were the most likely (0.86) to adopt a season-long continuous grazing strategy (Fig. 2B).

The conditional inference tree for the yr-long continuous grazing strategy produced two significant splits ($P < 0.05$) and three terminal nodes (Fig. 2C). The first split partitioned respondents based on their agreement with the attitude statement, "With respect to business, I always choose the option with the lowest risk." Respondents disagreeing with this statement had a 0.12 probability of adopting a year-long continuous grazing strategy (Fig. 2C). Among ranchers neutral or agreeing with this statement, those whose ranch enterprise *did not* include publicly leased land were the most likely (0.27) to adopt year-long continuous grazing strategy, and those whose ranch enterprise *did* include publicly leased land were the least likely (0.08) to adopt year-long continuous grazing strategy (Fig. 2C).

Wyoming

Three conditional inference regression trees (Fig. 3A—C)—one tree for each of the three on-ranch grazing strategies classified by latent class analysis (Table 3)—also resulted from analysis of Wyoming responses. The conditional inference tree for the rotational grazing with few pastures (≤5) strategy contained three significant splits ($P < 0.05$) producing four terminal nodes (Fig. 3A). The first split partitioned respondents based on number of livestock. Respondents with 820 or fewer livestock whose ranches were located in the Middle Rockies, Southern Rockies, or Wyoming Basin ecoregions were the most likely (0.73) to adopt the rotational grazing with few pastures grazing strategy. Ranchers with 820 or fewer livestock who were located in the High Plains or Northwest Great Plains and did not have access to publicly leased lands were the second most likely (0.67) to adopt this strategy. Ranchers with 820 or fewer livestock who were located in the High Plains or Northwest Great Plains and had access to publicly leased lands had a lower probability of adoption (0.44). Ranchers with more than 820 livestock had the lowest probability of adoption (0.35) (Fig. 3A).

The conditional inference tree for the rotational grazing with many pastures (6+) strategy contained three significant splits ($P < 0.05$) producing four terminal nodes (Fig. 3B). The first split partitioned respondents based on number of livestock. Respondents with more than 1 625 head of livestock were the most likely (0.56) to adopt this strategy. Respondents with 1 625 or fewer livestock whose operations included publicly leased land and were located in the High Plains or Northwest Great Plains ecoregions were the second most likely (0.43) to adopt the rotational grazing with many pastures strategy. Respondents with 1 625 or fewer livestock whose operations included publicly leased land and were located in the Middle Rockies, Southern Rockies, or Wyoming Basin ecoregions were less likely to adopt this strategy (probability of adoption = 0.22). Respondents with 1 625 or fewer livestock whose operations did not include publicly leased land had the lowest probability of adoption (0.17) (Fig. 3B).

The conditional inference tree for the high density short duration grazing strategy contained only one significant split ($P < 0.05$) producing two terminal nodes (Fig. 3C). Ranchers ranking livestock production below fourth place (among nine goals) were the most likely (0.43) to adopt the high density short duration grazing strategy. Ranchers ranking livestock production fourth place or higher were the least likely (0.11) to adopt this emergent intensive rotational grazing strategy (Fig. 3C).

Discussion

Our results provide strong empirical evidence supporting the theorized origin, persistence, and resolution of the grazing systems dilemma as introduced by Briske et al. (2008; 2011a; 2011b). Two-thirds of 765 ranchers responding from across two western states and 15 ecoregions reported on-ranch use of rotational grazing strategies. This adoption rate confirms that ranchers do perceive social, economic, and/or ecological benefits which have not been documented in scientific comparisons of rotational and continuous grazing systems (Briske et al., 2011a; Grissom and Steffens, 2013; Teague et al., 2011, 2013).

However, only 5% of respondents used intensive rotational grazing on rangelands, and no classes of intensive rotational grazing strategies emerged for California. Briske et al. (2011a) reported that almost 50% of scientific grazing system comparisons focused on *intensive* rotational versus continuous grazing strategies. Our results indicate that the primary focus of ranchers (62% of all respondents and more than 93% of all rotational grazers) is on *extensive* intragrowing season rotational strategies with moderate (a few wk to mo) grazing period durations, moderate (2.4–8 ha·animal unit) livestock densities, and growing season rest periods. Furthermore, we identified an intergrowing season rotational strategy in California, in which pastures are predominantly grazed throughout the growing season and rested during the dormant season (e.g., when cattle are moved in a seasonal cycle from low-elevation, winter-grazed annual grasslands to high-elevation, summer-grazed pastures). These results suggest that development of research efforts on integrated social, economic, and ecological aspects of extensive rotational strategies would be relevant to working ranches. The limited on-ranch adoption of intensive rotational strategies also indicates that considerable agreement – not debate – exists between experiential and experimental perceptions about the success of this particular strategy for achieving *primary livestock production goals*.

As found by others, ranchers' grazing management decisions were predicted by a combination of social, economic, and ecological variables (Coppock and Birkenfeld, 1999; Didier and Brunson, 2004; Jakoby et al., 2014; Kachergis et al., 2013, 2014). Significant variables spanned scales from the individual human dimension (goal setting, experimentation, risk tolerance, information network), to the ranch enterprise (total number of livestock, land types comprising ranch), to the ecoregion in which the ranch was located (Figs. 2 and 3). Most of these variables and the adaptive management decision making framework they comprise (Lubell et al., 2013) have not been well integrated into grazing system experiments in terms of experimental design; treatment selection, implementation, and adaptation; or selection of diverse metrics for comparisons of grazing system effectiveness. This could lead to mismatched value assessments and seemingly polar perceptions of successes versus failures (i.e., the grazing systems dilemma). For example, Wyoming ranchers who ranked livestock production below fourth place (out of nine) had the greatest probability of adopting intensive rotational grazing (Fig. 3C). Ranchers adopting this strategy are likely making decisions to meet alternative ecosystem service goals (e.g., forage production, soil health), and their perceptions of success are not based on the traditional livestock production metrics that the scientific community commonly uses to compare grazing systems.

Grazing systems research has largely been conducted at spatial and temporal scales that are orders of magnitude finer than conditions under which on-ranch adaptive grazing management strategies have been developed. For example, median pasture area, overall study area, and study duration for the research-based comparisons referenced by Briske et al. (2011a) were 12.7 ha, 60 ha, and 5 yr, respectively. Median grazing area reported by our rancher respondents was 931 and 4 220 ha in California and Wyoming, respectively. Over 70% of respondents had three or more family generations of experience in ranching, and had a median age of more than 60 yr. Therefore, it is not surprising that there are discrepancies in results between on-ranch and experimental grazing systems when attempting to translate between orders of magnitude of temporal and spatial complexity (Briske et al., 2008; Jacobo et al., 2006; Teague et al., 2011, 2013).

Also key is understanding the larger context of ranch enterprises, including the structural features, resource options and capacity, and the policy and agro-ecological landscape. As an example, public lands play a critical role in shaping rancher decision-making on private rangelands (Brunson and Huntsinger, 2008; Gentner and Tanaka, 2002). In our survey, 77% (n = 277) of Wyoming respondents and 20% (n = 461) of California respondents used publicly leased lands within their ranching operations, which significantly affected rancher grazing strategy preferences (Figs. 2 and 3). In both Wyoming and California, the number of livestock-grazing federal forests and rangelands has drastically declined: for the period from 2000 to 2013, Wyoming and California have experienced 52% and 28% reductions in animal unit months, respectively (USFS, 2013). These and other changing parameters of rangeland social-ecological systems clearly demand further research on critical linkages among social, economic, and ecological factors that drive decision-making. This work highlights important questions for future research, including socio-economic linkages between public and private land management decision making and the economic and ecological significance of enterprise components (e.g., private lands, public leases, and diverse ecoregions) to on-ranch grazing management.

Implications

We found that ranchers do adopt and value rotational grazing strategies, in spite of limited scientific support for the benefits of rotation. The emergence of rotational grazing as a dominant on-ranch management strategy indicates social, economic, and/or ecological benefits from rotation are perceived within the spatial and temporal scales at which ranchers make adaptive management decisions. A substantial proportion of grazing systems research has been focused on assessing the claimed benefits of *intensive* rotational grazing systems, when in actuality the vast majority of reported on-ranch rotational grazing is *extensive* in nature. A renewed research focus on extensive rotational grazing would better align research with on-ranch management. Ranchers' grazing system preferences – and likely their perceptions of successes – are not solely driven by the livestock production variables commonly examined in grazing systems research. Resolving this evident grazing systems dilemma will require enhanced communication and coordination between scientists and managers. Scientists must work with ranchers to identify and quantify the social, economic, and/or ecological benefits ranchers are deriving from their grazing strategies. Managers must become active participants in the design, implementation, and interpretation of grazing studies conducted at scales relevant to on-ranch conditions, decision making, and adaptation. Novel, large-scale, participatory research approaches are required to advance our collective understanding of on-ranch adaptive grazing strategies and the mechanisms by which these place-based strategies provide the goods and services managers expect.

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