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Economic Impacts of Increasing Seasonal Precipitation Variation on Southeast Wyoming Cow-Calf Enterprises☆

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ABSTRACT

Knowledge regarding the economic impacts of predicted increases in seasonal precipitation variability on cow-calf enterprises, through influences of precipitation on both forage and cattle productivity, is needed by land managers for developing risk management strategies. Here we use existing forage production and cattle performance data from the northern mixed-grass prairie, coupled with spring precipitation and economic data, in a ranch-level mathematical programming model. We estimate economic impacts across a 35-yr planning period with 100 iterations of different price cycles including five levels of increasing spring precipitation variation (10%, 20%, 30%, 40%, and 50% increases), examining the impact of resulting forage production and calf gain. Annual expected profit variability increases largely due to the increase in herd number variability rather than variability in calf gains. Overall, as seasonal precipitation variation increases, higher annual expected profit variability results in greater risk of negative returns from cattle. An important implication from our results is that the positive benefits of wet years do not overcome the negative impacts of the dry years given relationships among precipitation, forage production, and calf gains used in our model. Results indicate greater profitability in generally maintaining lower herd numbers as seasonal precipitation becomes more variable. The results also illustrate the need for producers to diversify their operation and/or income sources if they are to cope with increased precipitation variability even if mean annual precipitation remains constant.

Introduction

Given the dependence of forage and cattle production on precipitation (Derner and Hart, 2007; Derner et al., 2008; Reeves et al., 2013a, 2013b), economic stability of the livestock industry could be negatively impacted by predicted increases in precipitation variability (National Research Council, 2010; Hatfield et al., 2014). Increases in precipitation variability, coupled with cattle cycle dynamics, create complexity for livestock producers trying to manage risk given positive and negative impacts on location, timing, and productivity of cattle production systems (Walsh et al., 2014). These impacts include destocking (reducing herd numbers) to accommodate lower levels of forage production in drought years (Bastian et al., 2009; Kachergis et al., 2014) and deliberately slow restocking through heifer retention or purchase of breeding stock during favorable weather years (Torell et al., 2010). These stocking and liquidation (or destocking) decisions before and during drought periods greatly impact long-term economic outcomes for cow-calf operations (Thomas et al., 2015). Increasing precipitation variability would increase the frequency and severity of drought and lead to greater occurrence of destocking decisions often made during unfavorable price levels, thereby directly reducing the economic viability of cow-calf operations (Bastian et al., 2009; Ritten et al., 2010a).

Changes in weather and climate can translate into direct and indirect effects on cattle performance (Ojima et al., 2013). Direct effects resulting from changes in precipitation on cattle include changes in the forage quantity and quality of rangeland vegetation that influence animal growth (Hatfield et al., 2008; Calvosa et al., 2009; Mader and Gaughan, 2010; Miller, 2011) through feed intake (Craine et al., 2010). Indirect effects resulting from changes in precipitation, unfortunately, are not well understood as the feedbacks from the influence of

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precipitation on forage production to cattle performance are often nonlinear with more pronounced effects in dry compared with wet years (Reeves et al. in review), as forage limitations in dry years negatively impact weight gains, whereas extra forage production in wet years does not translate to greater animal performance. Enhancing the knowledge of seasonal-weather-related decision making for land managers is necessary for adaptive management (Reeves et al., 2015).

The major objective of this study is to show the ranch-level impacts of, and optimal response to, increasing variation in growing season precipitation. We hope this knowledge will improve decision making by land managers and increase the resilience of cow-calf operations to improve economic sustainability given predicted increases in precipitation variability associated with altered climate. Specifically, we use existing forage production and cattle performance data from the northern mixed-grass prairie, coupled with precipitation and economic data, in a ranch-level mathematical programming model to estimate economic impacts for three scenarios across a 35-yr planning period. We include 100 iterations of different price cycles, as well as five levels of increasing spring precipitation variation (10%, 20%, 30%, 40%, and 50% increases). Although it is impossible to separate the impacts of climate on forage and calf performance, we also aim to determine the economic importance of these impacts separately to better understand potential management priorities in the face of altered precipitation patterns. Therefore, initially, we examine separately the impact of resulting forage production from precipitation variability (scenario 1) and the impact of precipitation variability on calf gains (scenario 2) as it relates to the likelihood of negative returns. For the remainder of the manuscript we examine the impacts of these two factors combined (scenario 3).

Methods

Representative Ranch Characteristics

Our data regarding precipitation, forage production, and cattle production are based on research conducted at the US Department of Agriculture (USDA)-Agricultural Research Service (ARS), High Plains Grasslands Research Station (HPGRS) station located in Laramie County in southeastern Wyoming (Derner and Hart, 2007; Derner et al., 2008; Reeves et al., 2013b, 2015).

Land composition for a case ranch was modeled from a six-county region (Albany, Converse, Goshen, Laramie, Niobrara, and Platte Counties) in southeastern Wyoming to simulate average resources and related operating procedures in this area. Bastian et al. (2005) indicate that while variations across counties do exist, this region is relatively homogeneous in terms of livestock production, average productivity of range resources, and average ranch carrying capacity. Average carrying capacity of ranches sold ($n = 147$) in these counties for this region ranged between 159 and 162 Animal Units during the study period of 2002 − 2004 (Bastian et al., 2005). Although average operations across the counties are similar, as expected, heterogeneity does exist. For example, operations ranged from 1 to 19 head per operation for 2012 to operations with more than 500 head in the counties for the study area for our analysis (NASS, 2012). However, given the objective of the study, we model our case ranch on the basis of average characteristics for the region of interest.

The total number of hectares of each land type according to the Bureau of Land Management (BLM, 2014) in each county coupled with the total number of operators in each county according to Wyoming 2012 Agricultural Statistics data were used to estimate a simple average of land resources for an individual operation in the region (NASS, 2012). Our case operation consists of 1 461 ha. On the basis of the above-average calculations, this land base consists of 1 114 ha of deeded rangeland, 125 ha of state land, 139 ha of federal land lease, and 83 ha of privately leased land. Ranches in Wyoming are typically characterized by multiple land ownerships/leases (Kachergis et al., 2013).

The deeded land produces just over 1 385 animal unit months (AUM), state land provides 150 AUM, federal lands provide 168 AUM, and leased land provides 100 AUM, resulting in a total of forage available for grazing on the ranch of 1 803 AUM. Again, on the basis of reported averages for the area, the representative ranching operation in the study area produces both irrigated meadow and alfalfa hay, with 70 and 91 ha of each, respectively. Hayed lands also offer the availability of grazing after harvest, incorporating alfalfa and meadow hay land aftermath grazing potential of 0.33 and 1.57 AUM$\cdot$ha^{-1}, respectively, according to previous research for the area (Torell et al., 2002; Strauch, 2008). This provides an additional 410 AUM of grazing after harvest.

On the basis of the ranch characteristics reported earlier and the ability to feed hay through winter months, the representative ranch has the potential to carry a maximum of 180 head of cows (with calves), including the required number of bulls and replacement heifers. A typical ranch in southeastern Wyoming consists of a combination of enterprises that often include cow-calf and hay enterprises. Many operations have other farming (e.g., small grains) or yearling cattle enterprises that, when combined, tend to make the whole ranch more viable than just haying or raising calves (Kachergis et al., 2013). However, because of the cow/calf production lag due to heifer development, this sector of the industry is the least flexible in terms of responses to forage supply. Our model isolates and focuses on the cow/calf enterprise to understand the impact of changes to variation in precipitation on this type of business with other enterprises or off-ranch income expected to contribute to the ranch.

A multiperiod linear programming model was used to estimate optimal management strategies for the operation. The model was originally developed as part of a regional effort and has been widely used and adapted for evaluation of management strategies and grazing management assessments (Torell et al., 2002; Rimbey et al., 2003; Taylor et al., 2004, 2005; Torell et al., 2013). The base for this model is that used in Ritten et al. (2010b). We altered the model to represent our case ranch using the previously mentioned land resources, production practices, and representative costs and represented it conceptually in Figure 1. The model was solved using the MINOS solver in Generalized Algebraic Modeling System (GAMS) (Rosenthal, 2008).

The model maximizes the net present value of future profits over a T-year planning horizon subject to a series of constraints defining the ranch resource limitations and transfer resources from one year to the next. The decision variables under the land manager's control include herd size (mainly through liquidating/restocking decision) and land use (amount and timing). For each model iteration, initial herd size was set at 180, but the model is free to adjust herd size in subsequent years. Major constraints include animal production limitations (conception/weaning rates, required bull/cow ratios, interyear transfers), and forage supply (total supply, seasonal use restrictions). A 35-yr planning horizon corresponds to available precipitation and production data from the HPGRS. The model consists of equations that transfer animals and cash from one year to the next. The model is constrained by both total annual forage supply and seasonal land constraints. The operation is also required to maintain a minimum cash reserve of $500. Although some previous applications of this model tend to use a higher amount (e.g., Torell et al., 2010 require a $10,000 cash reserve), we are interested in determining the impact of increasing precipitation variation on bankruptcy. This requirement is simply used to ensure a positive cash position (in line with the original application of this model, which also uses a $500 minimum cash reserve, Torell et al., 2002).

Forage Production and Constraints

The model consists of six seasons determined by important ranch activities (e.g., calving, marketing, weaning) (Torell et al., 2010) and land availability (federal land permit restrictions). The season dates can be seen in Table 1. Forage availability is constrained by both total annual production and seasonal availability. For example, public lands are

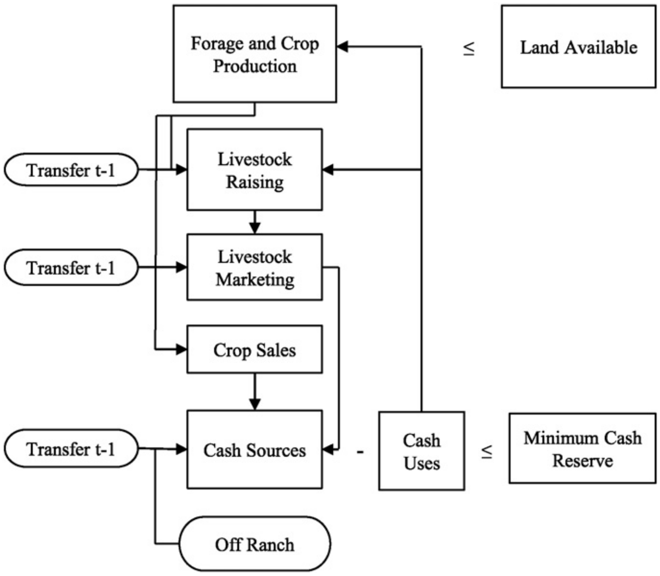

Figure 1. Conceptualization of model. (From Torell et al., 2013.)

available only in seasons 2, 3, and 4. Likewise, aftermath grazing of hay lands is not available until after harvest, beginning in season 4. Fed hay is the primary source of feed in seasons 1 and 6. Forage demand is flexible as long as the specific class of land is available, and seasonal forage availability is not exceeded by forage demand. Hay is fed when deemed economically feasible by the model but can only be fed November through April. Previous work by Ritten et al. (2010c) have examined providing hay in other seasons mainly as a drought reaction strategy with minimal positive impacts. Therefore, we limit hay feeding to the season when it is more common in the study area.

The model determines forage availability through various parameters already mentioned and is constrained by a land use equation (Eq. (1)) that establishes that the annual amount of each land class used in each season and the annual amount of each land class not used in each season cannot exceed the annual total amount of land available of that class.

$$\sum_{Season} Land\ \ Used + Land\ \ Not\ \ Used = Land\ \ Available \tag{1}$$

The AUM availability equation (Eq. (2)) constrains the model to feed the number of AUMs that can be supported by the amount of land available for grazing. It converts all livestock that are grazing to their equivalent AUMs and converts all land classes available for feeding to AUMs. The AUM available equation (Eq. (2)) specifically states that the number of AUMs required for grazing in the current year cannot exceed the number of AUMs that can be supported by the available land. Eq. (2) also calculates the number of months of grazing allowed per season and restricts grazing accordingly.

$$\sum_{Animal\ \ Class} AUM \le \sum_{Land\ \ Class} AUMs \tag{2}$$

Table 1
Dates and lengths of grazing seasons

	Season 1	Season 2	Season 3	Season 4	Season 5	Season 6
Grazing on date	1 Apr	1 May	15 Jun	15 Oct	1 Nov	15 Jan
Grazing off date	30 Apr	14 Jun	14 Oct	31 Oct	14 Jan	1 Apr
Duration	1	1.5	4	0.5	2.5	2.5

Table 2
Economic characteristics of the representative ranch

		Units	Number of units	Cost per unit ($)
Land resources owned	Deeded rangeland	AUMs	1 385	15.44
	Alfalfa hayland (w/aftermath grazing)	Acres	172	573
	Meadow hayland (w/aftermath grazing)	Acres	225	259
Land resources leased or purchased	State	AUMs	150	19.32
	BLM	AUMs	100	19.32
	USFS	AUMs	68	19.32
	Privately leased	AUMs	100	18.70
Livestock resources (initial year)	Brood cows	Head	180	107.60
	Yearling replacement heifers	Head	29	107.60
	Bulls	Head	13	Included in cow costs
	Horses	Head	3	Included in cow costs
Miscellaneous expenses	Fixed ranch expenses	$	45 000	
	Required minimum cash reserve	$	500	
Efficiency measures	Calf crop	%	90	
	Calf deathloss	%	4	
	Cow deathloss	%	2	
	Bull deathloss	%	1	
	Bull-to-cow ratio	Ratio	1:18	

AUM indicates animal unit months.

The livestock sales equation (Eq. (3)) depends on livestock numbers and sale weights specified in the model.

$$Total\ \ Sale\ \ Weight_{Animal\ \ Class} \le (100 - \%Deathloss_{Animal\ \ Class}) * (\#Sold\ \ Animals_{Animal\ \ Class}) * Sale\ \ Weight_{Animal\ \ Class} \tag{3}$$

The case ranch has a savings equation. Any savings that have been accumulated may be used to cover operating cash shortages (see Eq. (4)). Savings or wealth (AccumSav [T]) in period t is equal to savings from the previous period, plus any accumulated interest, plus net income from that period (NET [T]), plus off-ranch income or income from other enterprises other than the cow-calf enterprise (OFFRANCH) plus short-term borrowing (STBORROW [T]). The model allows annual borrowing but requires all borrowing in any given year be paid back during the following year, as is common practice with operating loans. Interest on borrowed money is 9% based on the average Federal Reserve bank prime loan rate[1] (Board of Governors of the Federal Reserve System, 2013). As costs and prices are in real terms, all debt is in 2012 dollars and estimated interest on any debt is in 2012 dollars. This 9% rate is used to represent a higher short-term interest rate as compared with a longer-term rate and the discount rate used for our model. This approach is consistent with Torell et al. (2010). Continuous annual borrowing is allowed as long as the debt obligations from the previous year are paid off. Borrowing is not allowed during the last year, and all debt must be paid off in the last year. Income is supplemented by "off-ranch" income, which was defined for our model as any source of income other than the cow-calf enterprise. Although we did not specify where this additional income comes from, some sources may include other enterprises on the farm/ranch (e.g., other classes of livestock such as yearlings or other farming activities) or wages earned off the ranch. Off-ranch income is then used to meet debt obligations in the event the income and savings from the ranch are unable to do so as debt must be zero by the end of the planning horizon. Kachergis et al. (2013) state that incorporating other activities on the ranch and earning

[1] Bank loan rates are calculated as average of rates posted of top 25 insured US-chartered commercial banks. Rate is calculated as average of 1975 – 2012 to correlate with weather and production data.

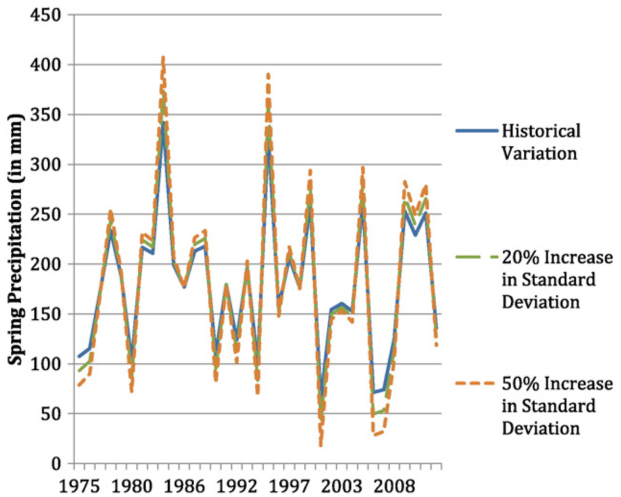

Figure 2. Spring precipitation amounts for observed data and estimates with standard deviation increases of 20% and 50%.

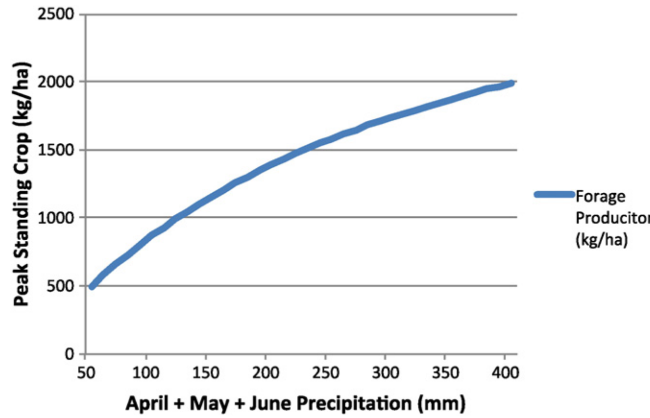

Figure 3. Relationship of spring precipitation and peak standing crop.

income off the ranch are the prominent drought-coping strategies in Wyoming. Rather than use an arbitrary value, we solved for the minimum annual off-ranch income required to prevent bankruptcy over the planning horizon.

$$\text{AccumSav(T)} = \text{AccumSav(T-1)} * (1 + \text{savrate}) + \text{NET(T)} + \text{OFFRANCH} + \text{STBORROW(T)}. \quad (4)$$

Objective Function

The objective function of the model maximizes the discounted total profits (NPV) over a planning period of T years (Eq. (5)).

$$Max\ \ NPV = \sum_{t=1}^{T} (DF_t * ((Revenue_t - Costs_t) + TERM_T)) \quad (5)$$

The objective function is the sum of discounted returns over the planning period. The main decision variables are the amount of breeding stock, which can fluctuate by culling cows and buying or retaining additional replacement heifers, and amount and timing of land use. The model is constrained by both land use and livestock transfer constraints to ensure forage demand does not exceed forage supply in any year or season. A discount factor ($DF_t = \frac{1}{(1+r)^t}$) was used to calculate for the present value of future net returns. A discount rate of 7% is based on an estimated 4% real return on investment plus a 3% risk premium to account for risk on agricultural investments (Torell et al., 2010). Profit over the planning horizon is defined as net present value of the difference between annual revenue and costs, plus a terminal component. $Revenue_t$ is calculated as the revenue received from the sale of livestock in year t. Livestock revenue is calculated on the basis of cattle weight, market price, and number of animals sold. While hay is produced on the ranch, in order to isolate the impact of precipitation variation in the cow-calf enterprise, the cost and revenues associated with excess hay sold off the ranch is not included in this analysis. Removing the costs and returns of the hay enterprise isolates the costs and returns of the cow-calf enterprise. However, the costs of hay fed to the cow herd are included as a variable cost of the cow-calf enterprise.

The objective function is substantially influenced by the livestock prices used in the model. Livestock price series were calculated using a Monte Carlo analysis by Torell et al. (2013) in order to consider the effect of price variability on economic variables and optimal management strategies. Prices were generated for each of the 35 years over 100 different iterations. The use of 100 iterations ensures that the model must be solved over a suite of price forecasts and cattle cycles. Each iteration of prices accounts for the beef price cycle, trends in prices, and relationships between sex and class of livestock. Prices were normalized so that the mean real 2012 adjusted (using the Producer Price Index, PPI) price for each livestock class (weight and sex), during the month of sale, was equal to the 1980 − 2012 mean real price recorded by CattleFax (Torell et al., 2013).

Total costs *($Costs_t$)* consist of all variable and fixed costs associated with the cow-calf enterprise in a given year. Variable costs include costs associated with animal and forage production, as well as crop harvesting and feed expenses. Variable expenses are costs of production and vary with the level of production and use of cattle, forage, and that portion of the hay crop that is fed on the ranch (including purchased feed). The ranching operation in the study area produces irrigated meadow and alfalfa hay. Costs of production of meadow hay were retrieved from Nebraska budgets (Klein et al., 2014c). Costs of production for irrigated alfalfa hay were based on Wyoming enterprise budgets (Hewlett and Bastian, 1992a, 1992b).[2] Federal and state rangeland grazing costs were retrieved from Eisele et al. (2011) and Strauch (2008). Brood cow, cull cow, and replacement heifer costs of production were retrieved from Eisele et al. (2011). These livestock classes are generally comingled until sorting for sale occurs and incur the same costs. Production costs include salt/mineral, protein supplement, veterinary, labor, and transportation for marketing from Eisele et al. (2011). Fixed ranch expenses are $45,000 and include facility maintenance, machinery maintenance, depreciation, insurance, taxes, professional services, and the cost of leasing federal and state land (Eisele et al., 2011). As with livestock prices, all costs were deflated to 2012 values using PPI to be consistent with prices used in the analysis. See Table 2 for a more detailed list of production costs.

The objective function also includes a terminal value ($TERM_T$) component that takes into account the value of cows after the 35-yr planning horizon is completed. The terminal value accounts for the value of the breeding stock after the planning period is done or the value a breeding cow generates by producing a calf every year after the period ends. If the terminal value component was not included in the objective function, the model would sell all livestock the last year in order to maximize the objective function.

[2] In evaluating the budgets for alfalfa establishment and alfalfa production, we found operations and inputs were similar to those reported for alfalfa production reported for Nebraska in 2014. When we inflated the costs from Hewlett and Bastian (1992a, 1992b), the costs of production were ($127/ton), and when compared with the Nebraska budget, we found the costs to be similar ($126/ton) (Klein et al., 2014a and Klein et al., 2014b). Thus, given Hewlett and Bastian (1992a, 1992b) were based on interviews and data from the study area, we used these inflated costs.

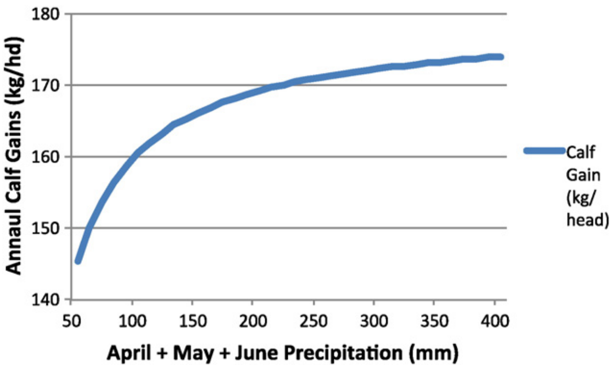

Figure 4. Relationship of spring precipitation and annual calf gains.

Impacts of Seasonal Precipitation

To better understand the effects of spring precipitation variability on economic outcomes, we examined the impact of five levels of increasing precipitation variability on forage production alone (scenario 1), calf gains alone (scenario 2), and the combination of impacts on forage production and calf gains (scenario 3) by running the model across our planning period and price iterations. Figure 2 shows observed spring precipitation, as well as estimated spring precipitation for the scenarios that increase the standard deviation by 20% and 50% to illustrate the impacts of increasing the variation. The impact of precipitation variation is determined by examining the change in optimal herd size, forage use, land use, and economic returns across both years and model iterations (35-yr optimal solutions). Descriptive statistics are estimated across the resulting outcomes of each of the scenarios. Additionally, means are compared across scenarios and precipitation levels using a multiple means Tukey comparison in SAS (Statistical Analysis System, 2003) and an alpha value of 0.05.

Annual Forage Production Given Precipitation Variation

Weather variation impacts on cattle production in southeast Wyoming were analyzed through the impacts of spring precipitation variation on forage production, using spring (April-June) precipitation, to estimate peak standing forage production through a hyperbolic function for moderate stocking. The functional format is the same as Derner and Hart (2007) but includes more recent data. Spring precipitation influences not only forage availability but also economic outcomes in Wyoming (Smith et al., 2005; Bastian et al., 2009). Peak standing crop was estimated according to Eq. (6). The relationship of spring precipitation to peak standing crop can be seen in Figure 3.

$$Y_t = \frac{3501.8 * p_t}{304.2 + p_t} \left(R^2 = 0.44\right) \tag{6}$$

Where Y_t is peak standing crop (kg·ha^{-1}), and p_t is the sum of April, May, and June precipitation, in mm. Total kg·ha^{-1} of forage production was estimated using historical precipitation for years 1975 − 2012. Forage available for grazing was calculated assuming a 35% utilization rate (439 kg·ha^{-1}) of total forage available (1 254 kg·ha^{-1}), which represents a light to moderate grazing level for this rangeland system. The available forage for grazing in a given year then impacts the AUMs available for grazing (Eq. (2)) and the forage available per unit of land area for each land type (Eq. (1)). This then defines model constraints for grazing on an annual basis. In this way the model incorporates annually impacted forage production (again constrained by seasonal use restrictions) when making profit-maximizing decisions over the planning horizon.

Reliable forecasts for changes in growing season precipitation specific to the study were difficult to obtain. Therefore, increases in variation in growing season precipitation are modeled around the historical (1975 − 2012) mean. Using the historical data for the study area, we simulated increases in precipitation variation by keeping mean precipitation constant but increased the standard deviation around the mean in 10% increments. Precipitation scenarios were analyzed for historical precipitation variation and increases in precipitation variation by 10%, 20%, 30%, 40%, and 50% (see Figure 2). These precipitation profiles were then used in the estimation of forage yield (Eq. (6)) and then incorporated into the model as previously explained.

Table 3
Impact of increasing precipitation variability on available forage (in kg·ha^{-1})

	Mean	Min	Max	Std. Dev.
Historical variation	439	214	649	110
10% Increase in climate variation	436	180	662	122
20% Increase in climate variation	433	146	676	135
30% Increase in climate variation	430	128	683	141
40% Increase in climate variation	424	69	702	160
50% Increase in climate variation	419	27	713	175

Note: No statistically significant difference between means. $\alpha = 0.05$.

Annual Calf Gain Variation

Weather variation impacts on cattle productivity were analyzed through the impacts of precipitation variation on calf gain variation. Spring precipitation (April − June) is the best weather-related determinant of calf weight gain (kg·head^{-1}) for this rangeland ecosystem (Derner et al., 2008). Livestock weight gain over summer grazing season (approximately 125 days) is a hyperbolic function of spring (April − June) precipitation, again following the previous work of Derner et al. (2008). Annual calf gains were estimated according to Eq. (7). The relationship of spring precipitation to annual calf gains can be seen in Figure 4.

$$G_t = \frac{179 * p_t}{11.56 + p_t} \left(R^2 = 0.65\right) \tag{7}$$

Where G_t is annual calf gains (kg·head^{-1}), and p_t is the sum of April, May, and June precipitation, in mm. Weaning weight is impacted by calf gains and is incorporated into the model through total sales weight (Eq. (3)), which in turn affects gross returns of livestock via the livestock sales equation. In order to incorporate weaning weight variation, scalars were used to adjust annual livestock sale weights used in the model on the basis of adjusted calf gain weaning weights, which in turn impacts gross returns. A benefit of using estimated weather impacts on calf gains is that the data were readily available for the study area, and the same precipitation data profiles used to estimate forage production were used to estimate calf gains (Eq. (7)), which in turn affected the sales weights and revenues in this analysis.

In order to account for change in prices received as weaning weights change, a price slide regression was used to adjust prices according to the differences in weights as dictated by precipitation levels in any given year. The regression was estimated by Ritten et al. (2010a) and calculates price as a function of calf weight and corn prices. The price slide was incorporated in the model by adjusting price estimates by Torell et al. (2013) for the differing calf weights.[3] Lighter calves received a higher price per cwt and heavier calves received lower prices per cwt. The impact of differences in calf weight was therefore partially offset by a "slide" in the price per weight. Thus, the gross returns account for both altered sale weights and related price effects.

[3] We used the historical mean corn price as reported by Ritten et al. (2010a) when calculating the price slide to remove any impact varying corn prices would have on livestock prices from our model.

Table 4
Impact of increasing precipitation variability on calf weaning weights (in kg)

	Mean	Min	Max	Std. Dev.
Historical climate	237	219	245	6
10% Increase in climate variation	236	213	245	8
20% Increase in climate variation	235	205	245	10
30% Increase in climate variation	234	191	246	12
40% Increase in climate variation	233	168	246	17
50% Increase in climate variation	230	115	246	26

Note: No statistical significant difference between means. $\alpha = 0.05$.

Results

Forage Production

The hyperbolic relationship between forage production and growing season precipitation results in forage production estimates that are negatively skewed with increasing forage variation. Increases in variation of precipitation levels cause increases in forage production variation (Table 3). Mean forage production does not statistically significantly change while the minimum decreases by a larger amount than the maximum increases, implying that as precipitation variation increases, the occurrence and severity of drought events will also increase. Decreases in precipitation at the lower levels of precipitation result in larger negative impacts to forage production than increased precipitation at high levels of precipitation have positive impacts to forage production.

Calf Gains

Similar to the forage production estimate, the hyperbolic relationship between calf gain and growing season precipitation results in weaning weight estimates that are negatively skewed. Increases in precipitation variation cause increases in weaning weight variation, with drought having stronger effects than favorable precipitation (Table 4). Mean weaning weights show no statistically significant change across precipitation scenarios, while the minimum decreases by large amounts and the maximum does not change greatly. As precipitation variation increases, the likelihood of observing low weaning weights increases.

Impacts of Forage Production and Calf Gain on Likelihood of Negative Returns

While climatic impacts on forage production and animal performance occur simultaneously for a ranch, we were interested in discerning the relative impact each of these had on economic outcomes. Therefore, in order to understand the magnitude of forage production variation and calf gain changes from variable precipitation on the potential for negative annual returns to the ranch, spring precipitation variation impacts on ranch outcomes given altered forage production and calf gains were initially analyzed separately. When looking only at the impacts of precipitation on forage production (with static weaning weights, scenario 1), the chance that expected annual profits (discounted net returns) from the cattle enterprise would be negative in any given year is 15.3% with precipitation varying in a historical (1975 − 2012) pattern (Table 5). The chance of negative expected annual returns increases to 25.5% when precipitation variability is increased by 50%. This increase in negative returns is driven by the ranch being forced to destock in dry years as forage limitations influence herd size. This results in lower sales of livestock during dry years and increased costs after dry years as the ranch restocks.

When only including spring precipitation variation impacts on calf performance (with static annual forage production, scenario 2), the chance that expected annual profits from cattle are negative is 10.2% with historical precipitation variation (see Table 5). Discounted net returns from cattle will be negative by only 0.5% more (10.7%) of the time when precipitation variation increases by 50%. The differences in likelihood of negative returns in any given year between the forage production and calf gain models are due to 1) forage production is not impacted in this scenario and therefore the need to destock and restock the ranch is eliminated, and 2) lighter calves do receive slightly higher prices, partially reducing the negative impacts of dry years. Overall, this comparison demonstrates that forage production impacts economic outcomes for the ranch much more dramatically than changes in calf weights.

When the impacts to calf performance and forage production are modeled simultaneously (scenario 3), the resulting probability of negative returns more closely follows the forage production model (see Table 5). Again, decreased forage supply has a major impact on ranch profitability. The chance that expected annual profits from the cattle enterprise would be negative in any given year is 14.3% with historical variation, and that probability increases to 31.2% when precipitation variation reaches 50%. As expected, this value is higher than the impacts of spring precipitation variability on forage production alone (scenario 1, 25.5%). The two effects combined, however, do not result in the simple sum of the previously mentioned percentage changes for altered forage production and calf weights. This is because the final scenario accounts for the change in number of animals sold, price effects associated with altered sale weights, and changes in costs associated with both impacts occurring simultaneously. Overall, our analysis indicates forage production has the potential to more directly impact long-term profitability as spring precipitation becomes more variable compared with the direct impacts of precipitation variability on cattle gains.

Cow Numbers

When considering precipitation impact on both forage and calf performance, the relatively large impact on probability of negative profits emanates mostly from the impacts to forage production and the related optimal stocking decisions made in the model. Optimal mean annual cow herd numbers are used as an indicator of these stocking decision impacts from precipitation variation. Each level of increased precipitation variation indicates a statistically different mean level of cows. The average number of cows over the planning horizon decreases from 84 head with historical precipitation variation to 50 head (a 40% reduction) when precipitation variation is increased by 50% (Fig. 5, Table 6). Moreover, relative variability in cow numbers increases with increases in precipitation variability as indicated by a change in the coefficient of variation from 0.26 (historical variation) to 0.70 (50% increase in

Table 5
Frequency of annual returns being less than zero

	Proportion <0:		
Weather scenario	Forage production impacts only (scenario 1)	Calf performance only (scenario 2)	Combined impacts (scenario 3)
Historical variation	15.3%	10.2%	14.3%
10% Increase	16.2%	10.3%	16.3%
20% Increase	16.8%	10.7%	19.6%
30% Increase	19.7%	9.2%	20.3%
40% Increase	21.1%	9.2%	23.9%
50% Increase	25.5%	10.7%	31.2%

Note: Frequency is calculated over 3 500 observations.

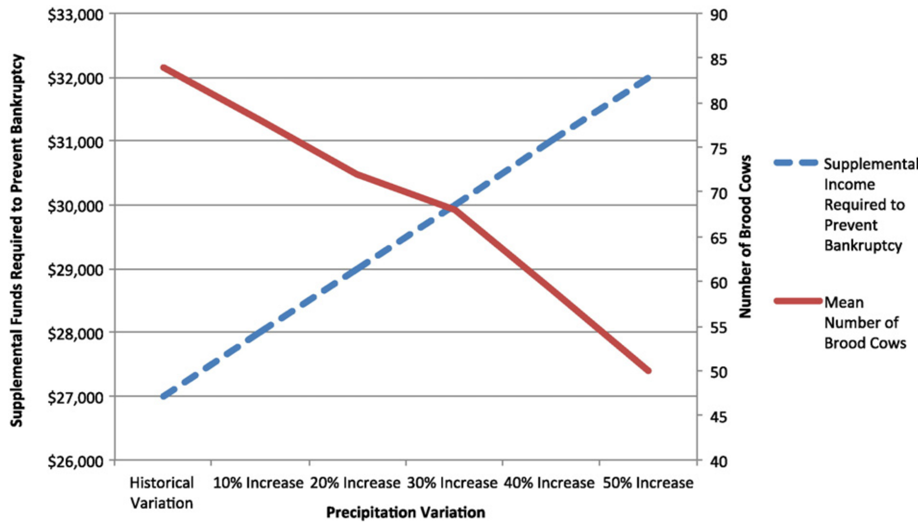

Figure 5. Supplemental funds required to prevent bankruptcy and mean number of brood cows over increasing amounts of precipitation variation.

variation). Decreases in forage production in more severe drought years with increasing precipitation variability results in the need to destock more severely. Results indicate that it is not optimal to fully restock with cows following drought to take advantage of increased forage production in wet years. Figure 6 shows optimal stocking decisions over the planning horizon for historic climate, as well as increases of 20% and 50% in variation. Even though all scenarios are initially endowed with the same number of cows, as variation in seasonal precipitation is increased cow numbers begin to decline. The increased severity of dry years results in optimally responding by carrying smaller herds over the planning horizon. While cow numbers do increase by larger amounts in wet years as variation is increased, the herd numbers never reach the same level when compared with the historical climate scenario. The variability of cow numbers and the probability of negative profits are indicators of the overall impacts on profitability associated with greater precipitation variability.

Profit Variability

Annual expected profit (gross returns from the cow-calf enterprise) variability increases as precipitation variation intensifies beyond 20% due to altered herd size (Table 7). The coefficient of variation increases from 1.57 with 20% increase in precipitation variability to 1.87 at the 50% level. As drought becomes more severe with greater precipitation variability, the number of cattle that can be supported in these drought years decreases, intensifying the variability of herd numbers and profits, and increases the chance of negative returns from cattle. Mean gross returns and net discounted returns decline as precipitation variability increases. Results indicate the inclusion of precipitation variability makes the model less sensitive to price cycle dynamics, and trade-offs are made between managing for cattle price cycle dynamics and managing for precipitation variation. If there is a 50% increase in precipitation variation, net discounted returns from the cow-calf enterprise are reduced by 27%.

Supplemental Funds

When analyzing the impacts of precipitation variability on both forage production and calf performance, the minimum amount of annual supplemental income required to prevent bankruptcy is $27 000 for historical precipitation and increases by $1 000 for each 10% increase in precipitation variation (see Fig. 5). With a 50% increase in precipitation variation, 19% more annual off-ranch income ($32 000) is necessary than with historical variation ($27 000).

Discussion

Results indicate that increases in spring precipitation variation negatively impact cow/calf operations in southeastern Wyoming when considering changes in forage production and calf performance. Negative impacts of dry years are ultimately greater than the positive impacts of wet years for the ranch given the nonlinear production relationships among precipitation, forage production, and calf gains. Positive economic impacts for cow-calf enterprises associated with increased forage production and calf gains when precipitation is increased cannot overcome the more pronounced negative impacts from years with less precipitation.

When modeling the combined impacts of precipitation variability on forage production and calf performance, annual expected profit variability increases with precipitation variation largely due to the increase in herd number variability resulting from forage production variability. Overall, higher annual expected profit variability results in greater risk of negative returns from cattle as drought has large negative impacts on forage production and calf gain and resulting economic and management variables. Managers likely need to reduce average herd numbers in order to maximize profits if precipitation variability increases from climatic change. The mean number of cows the operation can stock decreases by up to 40% as precipitation variation increases to its maximum level (50%) in our analysis. This suggests greater profitability in

Table 6
Cow numbers given off-ranch income and precipitation variation impacts on forage production and calf gain

Mean annual value of:	Historical variation	10% Increase	20% Increase	30% Increase	40% Increase	50% Increase
Number of cows	84[1] (22)	78[2] (22)	72[3] (23)	68[4] (25)	59[5] (31)	50[6] (35)
Percent change in cows from historical variation	—	7%	14%	19%	30%	40%
Coefficient of variation of brood cows	0.26	0.28	0.32	0.37	0.53	0.70

Note: Cow numbers are means of years 6—35, allowing the model to stabilize to initial price and precipitation impacts. Numbers in parentheses are standard deviations. Superscripts across columns indicate significant differences between values ($\alpha = 0.05$).

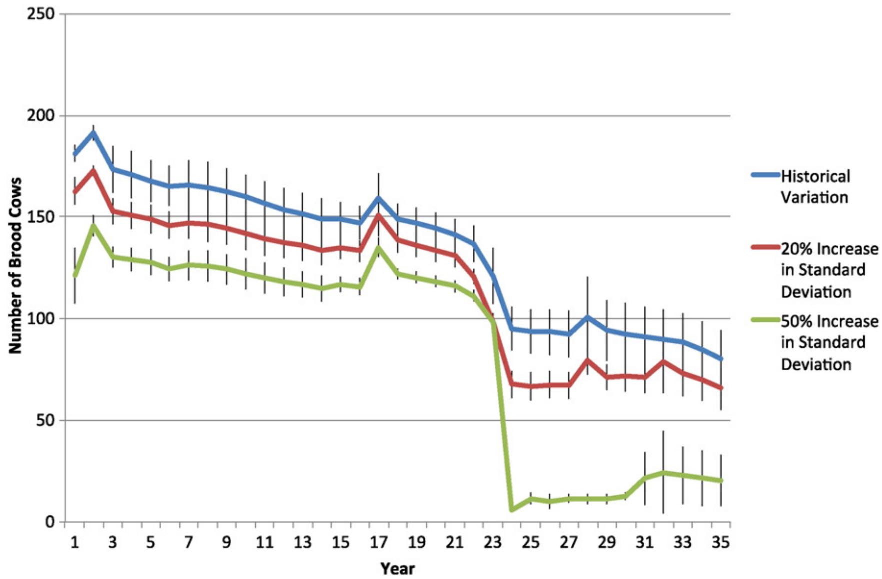

Figure 6. Average number of cows by year for historical variation in seasonal precipitation and standard deviation in seasonal precipitation of 20% and 50%. Vertical bars represent the standard deviation.

maintaining lower herd numbers in preparation for drought rather than destocking during drought events and restocking during following wet years for a cow-calf operation. Additional needs for supplemental funds for the cow-calf enterprise in the face of increased precipitation variation further illustrates the need for producers to diversify their operation and/or income sources if they are to adapt and survive increased variability even if mean annual precipitation remains constant. Our analysis suggests it may become less economically viable for cattle producers to remain in ranching if increased precipitation variability occurs. However, it is likely that many producers will diversify or infuse more off-ranch income to stay on their land as profit maximization is likely not the only motivation for ranchers (Torell et al., 2001).

Implications

Cow-calf producers in southeastern Wyoming are expected to be more negatively impacted economically by increased precipitation variation with effects driven primarily through resultant forage production responses to precipitation rather than calf performance. Adaptive management will become increasingly important regarding flexibility in herd numbers to mitigate negative impacts associated with more frequent and severe droughts. Furthermore, producers will need to evaluate the applicability of additional management strategies to mitigate economic and ecological risks associated with increased precipitation variability that were not included in our model, such as including carrying calves over as yearlings, using grass banking for forage reserve, leasing additional forage in dry years, or renting out excess forage to others in wet years (e.g., Kachergis et al., 2014). It is important to note, however, that if leasing becomes a widely used adaption strategy, there will likely be market impacts as there will be excess forage available in wet years and a shortage of available grazing land in dry years. Addition of a yearling enterprise will reduce the cow herd numbers but provides flexibility to use excess forage production in good years and sell yearlings rather than breeding stock in dry years, which cumulatively increases the profitability of the ranching operation (Torell et al., 2010). This strategy of employing diversity in animal groups (yearlings + cow-calf pairs) could provide additional adaptive capacity for decision making to match forage demand to forage availability compared with continual restocking/destocking with only a cow-calf enterprise.

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Table 7
Cow/Calf enterprise returns and costs given off-ranch income and seasonal precipitation variation impacts on forage production and calf gain

Average annual value of:	Historical variation	10% Increase	20% Increase	30% Increase	40% Increase	50% Increase
Gross returns from cow/calf enterprise ($)	41 579[1] (15 521)	38 595[2] (15 084)	35 880[3] (15 498)	33 962[4] (16 189)	29 906[5] (17 433)	25 947[6] (18 814)
Variable cost of cattle ($)	28 015[1] (14 953)	25 710[2] (13 900)	23 799[3] (13 423)	22 770[4] (13 342)	20 018[5] (13 734)	17 539[6] (14 341)
Discounted net returns from cattle ($)	4 275[1] (6 941)	4 185[1] (6 514)	4 024[1] (6 304)	3 789[1,2] (6 246)	3 491[2,3] (5 998)	3 134[3] (5 862)
Percent change in discounted net returns from cattle from historical variation	–	−2%	−6%	−11%	−18%	−27%
Coefficient of variation of discounted net returns from cattle	1.62	1.56	1.57	1.65	1.72	1.87

Note: Numbers in parentheses are standard deviations. Same superscripts across columns signify no statistically significant differences between values ($\alpha = 0.05$).

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