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Case Study

Adaptive Grazing Management at Rancho Largo Cattle Company

By Grady Grissom and Tim Steffens

On the Ground

- Goal-driven ecologically based grazing management moved a ranching operation from negative economic returns to profit.
- Management adaptively manipulated the duration, seasonality, and frequency of grazing with a goal to recruit cool-season midgrasses. A change to recovery periods based on plant physiology of goal species was a key adaptation.
- Recruitment of both cool- and warm-season midgrasses improved water cycling, extended the grazing season, and eventually increased sustainable stocking rates.
- Flexible stocking rates were central to improved profit.

Keywords: adaptive management, flexible stocking rates, case study, seasonality of grazing, frequency of grazing, western wheatgrass recruitment, winterfat recruitment, diverse cattle enterprises.

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In this case study we relate a rancher's efforts to make a living and pay the mortgage on 14,020 acres of shortgrass steppe in southeastern Colorado. Grady Grissom (manager) and a partner acquired Rancho Largo Cattle Company (RLCC) in late 1995. Grissom had good knowledge of day-to-day ranch operations from ranch employment experience, but no experience in strategic (longer-term) management decisions such as stocking rates, ecological sustainability, or enterprise selection. Our story illustrates the learning curve as Grissom gained that experience.

Initially, we viewed maximum economic stocking rates (land efficiency) and environmentally adapted cattle (livestock efficiency) as the keys to economic success. The efficiency model, which included a method-driven grazing system, was unprofitable. In hindsight, the grazing system was ecologically unsound, but sparked an interest in grazing ecology. When economic peril forced us to discard the efficiency strategy we focused on grazing ecology.

Eventually we educated ourselves on grazing ecology through seminars, management publications, scientific literature, and interactions with progressive grazing managers. Over several years we initiated adaptive management focused on ecological goals of improved water cycle and plant species diversity. Using iterative loops of adaptation, we achieved our desired ecologic and economic outcomes.

Our objectives in this paper are to illustrate: 1) how managers adapt grazing systems and how management paradigms evolve; and 2) how our experiences over 17 years were consistent with, and in some ways analogous to, scientific progress on grazing management. A method-driven grazing system was ineffective, but adaptive strategies specific to our goals and a particular ecologic setting resulted in desired outcomes.

The Rancho Largo Cattle Company

Rancho Largo Cattle Company (RLCC; lat 37°46′N, long 104°20′W) is 60 miles southwest of La Junta, Colorado. RLCC lies between 5,400 feet and 6,000 feet elevation and contains 14,020 acres in the shortgrass steppe ecoregion. Mean annual precipitation over the last 60 years was 11.4 inches. Approximately one-third of the ranch has mixed piñon-juniper and shortgrass prairie habitat around small canyons in the Dakota Sandstone and two-thirds of the ranch is open shortgrass steppe. RLCC consists mostly of loamy plains and sandy plains ecological sites in Major Land Resource Area 69.

Records and Assessments

Precipitation measurements were averaged from the Rocky Ford and Fowler weather stations. Managers maintained animal performance and grazing records through our study (Table 1). Annual economic records were synthesized through a

Table 1. Annual precipitation, stocking rate, livestock performance, and rotation characteristics from 1996 to 2012. Precipitation was averaged from NOAA weather station records from Rocky Ford, CO and Fowler, CO. Stocking rates are based on a 1000-pound standard animal unit for 1 year (AUY). Over the course of the study some cows included in the conception rates did not spend the entire year at RLCC. At times we supplemented with corn stocks to winter some cows or leased summer pasture. Only cows that spent more than 6 months in a given year at RLCC were included in the analysis. Stocking rate per unit precipitation is the RLCC annual stocking rate divided by annual precipitation in inches. Average daily gains (ADG) for yearlings are based on in and out weights for lots of cattle that spent the growing season (March Through October) at RLCC. After 2004, deferral values with an * indicate actual days of deferment based on plant physiological goals

Year	Annual precipitation (inches)	RLCC stocking rate on 14,020 acres (AU/year)	Stocking rate per unit precipitation (AUY/inch)	Cow herd conception rate (%)	Yearling daily gain (pounds/day)	Annual grazing periods per pasture	Planned deferral (days)*
1996	11.5	304	26.4	80	–	3.4	40–60
1997	17.3	321	18.6	89	–	2.9	40–60
1998	13.6	260	19.1	87	–	2.3	40–60
1999	16.9	380	22.5	64	–	3.7	40–60
2000	10.6	300	28.3	83	–	3.4	40–60
2001	12.4	253	20.4	89	–	3.0	40–60
2002	3.7	44	11.8	–	–	1.2	40–60
2003	8.8	174	19.8	93	–	1.9	100
2004	15.4	325	21.1	96	–	2.2	100
2005	10.6	308	29.1	92	–	1.8	138*
2006	14.3	412	28.8	–	1.5	1.1	182*
2007	13.6	351	25.8	93	2.0	1.7	162*
2008	9.2	330	35.9	87	1.0	1.6	214*
2009	11.2	314	28.0	–	1.6	1.4	295*
2010	13.0	311	23.9	94	1.9	1.2	263*
2011	5.9	217	36.8	90	–	0.8	386*
2012	5.0	147	29.4	89	–	1.0	433*

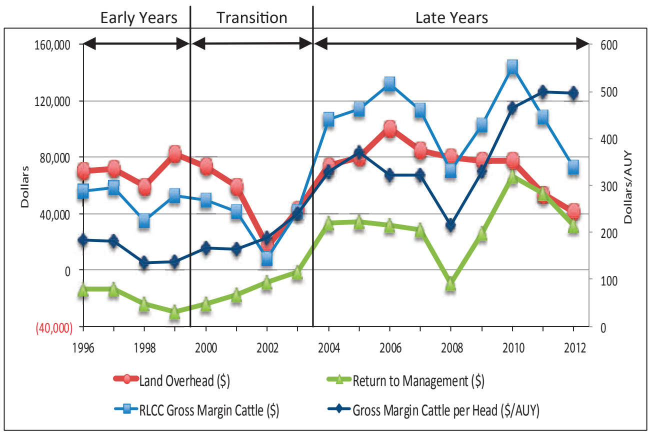

Figure 1. Gross margin, land overhead, and return to management plotted on the left axis and gross margin per head plotted on the right axis. The horizontal axis is divided into three management time periods. The average return to management for the late years was $53,373 higher than in the early years. On a per head basis, average returns were $160 in the early years, $189 in the transition years, and $372 in the late years.

Cattle gross margin per head = [(ending breeding stock inventory at fixed value/head + ending trading cattle inventory at market value + sales) − (beginning breeding cattle inventory at fixed value/head + beginning trading cattle inventory at market value + purchases + cost of sale + cost of feed + trucking cost + veterinary cost)] / operation-stocking rate (AUY). The operation-stocking rate includes some cattle run on leased land adjacent to RLCC for portions of some years.

Cattle gross margin = (cattle gross margin per head) × (RLCC stocking rate). Cattle gross margin calculated in this manner applies only to the deeded land at RLCC.

Land overhead = (RLCC stocking rate (AUM) × $17) + (land taxes + land maintenance cost).

Return to management = (cattle gross margin) − (land overhead).

gross margin analysis described in Figure 1. Breeding stock was held at fixed value in the analysis in order to minimize market factors. During the study, resale stockers and yearlings (with a cost basis) were commonly mixed with retained calves (without a cost basis). Year-end inventories of stockers and yearlings did not distinguish resale cattle from retained cattle so we could not delineate a fixed cost per head, or per pound, for resale cattle. Hence, all stockers and yearlings (retained and resale) were valued at market prices in this analysis. Fluctuating markets likely had minimal effect on the analysis of the resale cattle component of gross margins because purchase prices would fluctuate with sales prices. However, fluctuating markets likely had a significant effect on the calf or retained calf component of gross margins.

Ecological assessments evolved as we became increasingly focused on the ecology and set ecological goals. We only made general observations before 1999 but our assessment became more systematic over time. All of our assessments were qualitative and intended only for our internal decision-making. We found that touring a pasture and mentally integrating observations into a pasture average gave internally consistent and repeatable results that better fit our needs than time-consuming but more rigorous transect methods.

Annual pasture assessments of residual cover, litter, and major grass species composition were made most years in the fall beginning in 2000 (Table 2). We also estimated the percentage of plants that produced seed heads for each common species. Periodically, these assessments were repeated for the same pasture to check internal consistency. Estimates for the relative abundance of blue grama (*Bouteloua gracilis*) versus western wheatgrass (*Pascopyrum smithii)* varied by no more than 10%. Estimates of seed production varied by no more than 15%. Repeat assessments consistently classified residual cover and litter as low, medium, or high. We also noticed the recruitment of species in particular locations and began to map those locations with photos and GPS records (Table 3) when touring pastures.

The fall assessments and GPS/photo records became our primary long-term method to evaluate progress toward ecological goals. We also developed a protocol for short-term assessments that characterized grazing periods and informed decisions about cattle movements. We estimated the percentage of plants for each plant species defoliated during a grazing period and indicated the severity of defoliation by comparing the average height of undefoliated versus defoliated plants. We assessed plant recovery by flagging some defoliated plants at the end of grazing periods[1] and revisiting them.

Management Decisions and Adaptations

The thought processes behind our management decisions were derived from manager's reports written one to four times annually. We divide the management into three time periods: 1) the early years, characterized by a focus on economics and stocking rates; 2) the transition years, when an ecological focus was shaped; and 3) the late years of adaptive grazing decisions driven by plant recovery goals.

The Early Years (1996–1999)

Our decisions in the early years were focused on economies of scale. We expected a relatively small ranch (200–300 cows) to pay a land mortgage and support a full-time manager; managerial overhead was much of our total costs. We attempted to overcome high overhead by using leased land to increase the scale of the cattle operation and by maximizing production per acre through high stocking rates (Table 1). A long-term study in shortgrass steppe receiving slightly more precipitation (13.4 inches) showed heavy utilization at comparable stocking rates.[2] We did not assess residual cover in the early years, but we infer low residuals and high utilization based on memory and photos (Fig. 2).

Heavy stocking was associated with poor conception rates (average of 80%, Table 1) and low gross margin per head (Fig. 1) from 1996 to 1999. In late 1996 we realized that we had likely surpassed the optimum stocking rate[3] (*also see Frasier and Steffens, this issue*) where losses from poor animal performance outweighed additional production per acre. However, we persisted with high stocking rates and attempted to improve low conception rates by: 1) using cattle breeds better

Table 2. Annual fall ecological assessments. Residual cover was estimated as low, medium, or high by mentally integrating observations of leaf height through a pasture for common species. Average leaf heights of >3 inches for blue grama and >8 inches for western wheatgrass and Galleta indicated high residuals. Average leaf heights less than 2 inches for blue grama and 4 inches for western wheatgrass or Galleta indicated low residuals. Litter was visually estimated and integrated for each pasture as low =<20% coverage of bare ground by litter and high =>50% coverage of bare ground by litter. Relative amounts of blue grama and western wheatgrass were also visually estimated by pasture. Patches (10–50 yards) dominated by blue grama are shorter and a different color from patches with significant western wheatgrass. The relative amounts were estimated by visually appraising the percentage of patches for each species. This method gives much higher percentages of western wheatgrass than a canopy or ground cover assessment because western wheatgrass patches contain significant amounts of blue grama but not vise-versa. All assessments by pasture were averaged to reach a ranch-wide value. Asterisks indicate ranch-wide values that do not include all pastures. NA indicates no assessment was performed

Year	Residual cover	Litter	Relative species abundance (%)	
			Blue grama	Western wheatgrass
1996	NA	NA	NA	NA
1997	NA	NA	NA	NA
1998	NA	NA	NA	NA
1999	NA	NA	NA	NA
2000	Low	Low	80	20
2001	Med.*	Med.*	NA	NA
2002	Low*	Low*	80	20
2003	Med.*	Low*	70*	30*
2004	High	High	55	45
2005	Med.*	Low*	55*	45*
2006	High*	Med.*	45*	55*
2007	High*	Med.*	NA	NA
2008	Med.	Low	45	55
2009	High*	Med.*	50*	50*
2010	High	High	40	60
2011	Low	Low	50	50
2012	Low	Low	45	55

Table 3. Summary of GPS and photo mapping for recruitment of grass and shrub species from 2000 to 2012. All species except four-wing saltbush increased from 2000 to 2010. Galleta and sand dropseed decreased in the drought years of 2011–2012

Species	Description 2000	Description 2010	Description 2012
Galleta (*Pleuraphis jamesii*)	Estimated <5% total forage	Estimated 15% total forage	Estimated 5% total forage
Green needle grass (*Nassella viridula*)	Not observed	2006: first observation	No change from 2010
		2010: occurred in every major draw and some minor draws (23 of 36 pastures)	
Four-wing saltbush (*Atriplex canescens*)	Isolated locations	Isolated locations	Isolated locations
New Mexico feather grass (*Hesperostipa neomexicana*)	Common on rocky canyon edges	Common on rocky canyon edges, areal extent 3 times greater than 2000	No change from 2010
Sand dropseed (*Sporobolus cryptandrus*)	Estimated <5% total forage	Estimated 10% of total forage	Estimated <5% of total forage
Sideoats grama (*Bouteloua curtipendula*)	Occurred in Isolated locations on sandy soils at canyon edges	Occurred in isolated locations on sandy soils at canyon edges, Increased areal extent by factor of 2 since 2000	No change from 2010
Silver bluestem (*Bothriochloa saccharoides*)	Occurred in 2 draw bottoms, 2 of 36 pastures	Occurred in all major draw bottoms, some minor draw bottoms, 2 upland locations, 22 of 36 pastures	No change from 2010
Vine mesquite (*Panicum obtusum)*	Not observed	2004: first observation	No change from 2010
		2010: occurred in some major draw bottoms, 6 of 36 pastures,	
Winterfat (*Krascheninnikovia lanata*)	Small patches in lime-rich soils (10-yard scale), 7 of 17 pastures, none dispersed in uplands	2 large patches (100-yard scale), numerous small patches (10-yard scale), 36 of 36 pastures, dispersed in all uplands	3 large patches (100–500-yard scale), numerous small patches (10-yard scale), 36 of 36 pastures, dispersed in all uplands

adapted to our environment, 2) selecting replacement heifers for fertility, 3) increasing winter and spring supplements, 4) switching to a later calving season, and 5) using a calendar-based rotational grazing system with short nongrazing periods. Conception rates improved somewhat in 1997 and 1998 but fell to very low levels in 1999 (Table 1).

The Transition Years (2000–2003)

By 2000, poor financial performance forced us to re-evaluate our management strategy. The effort to stock right at the economic optimum, where animal performance balanced with production per acre, left no margin for error and no flexibility.[4] We decided to reduce stocking rates and directly

Figure 2. Repeat photographs from 1999 (left) and 2008 (right) at Rancho Largo Cattle Company in southeastern Colorado. The 1999 photo shows conditions with low residual plant and litter cover and a plant community dominated by blue grama. The 2008 photo shows greater residual plant and litter cover and recruitment of western wheatgrass (10- to 50-yard patches).

address overhead by reducing the management salary. We sold cows in 2000 to reduce the stocking rate but because precipitation was low, stocking rate per inch precipitation increased (Table 1) and conception rates were only 83%. In 2001 we again sold cows, but with precipitation near normal, stocking rate per inch precipitation dropped and conception rates improved (89%). Drought followed these decisions in 2002, so we drastically destocked in June by selling some cows and sending most to year-round leased pasture. We returned some cattle to RLCC in 2003 at moderate stocking rates and again saw improved conception rates (93%). Gross margin per head climbed slightly from 2001 through 2003 as conception rates improved, but cattle gross margin dropped as we destocked, especially in the drought of 2002 (Fig. 1).

Our initial efforts at rotational grazing from 1996 to 1999 had failed to improve animal performance at high stocking rates. Initial rotations were "method-driven" with no explicit mental model of plant–animal interactions, no goals, and no ecological assessment to guide livestock movements. Our desired outcome, high livestock production per acre, was economic with no reference to ecological conditions or processes. Deferral periods of 40 days in the spring and 60 days in the summer were calendar driven. We assumed that utilizing compensatory regrowth by rotating animals among pastures and grazing multiple times in a growing season (Table 1) facilitated higher stocking rates.

The initial rotational system did not meet our expectations but it did plant the seeds that grew into adaptive management. By concentrating cattle in a single herd in one pasture, we focused attention on plant–animal interactions and changed our mental model of grazing to an ecological perspective. Rotations create a natural laboratory to compare ungrazed pastures adjacent to grazed pastures, animal selection entering a "fresh" pasture at different seasons, and changes in animal selection as preferred species become heavily defoliated. Our observations prompted efforts at research that yielded two conclusions: 1) Successful grazing management requires ecological assessment to inform adaptation; and 2) Successful grazing management requires *specific* ecological goals.

We initiated ecological assessments in 2000 (Table 2) that revealed low residual plant cover and litter, and a blue grama dominated plant community (Fig. 2). We knew that water cycle is primarily a function of residual plant cover and litter[5] and inferred that we had a poor water cycle. We established an ecological goal to improve water capture, infiltration, and storage in the soil using residual cover and litter assessment metrics. We initially reduced stocking rates for economic reasons (discussed above), but we now intended reduced stocking to improve residual cover. Residual cover and litter (Table 2) increased in 2001, were low in the 2002 drought, and increased again in 2003.

After a failed attempt to improve the mineral cycle (Table 4), we began in 2001 to focus on plant species diversity as an index of ecological improvement. Specifically, we expected recruitment of western wheatgrass to improve nutrition available to cattle in the spring and fall months. We hoped recruitment of a midgrass would improve water capture and infiltration through additional residual cover and litter. We felt the goal was obtainable because cool-season species decrease at high grazing intensity in shortgrass steppe[6] and because pastures near RLCC with limited water, and therefore intermittent and low-intensity grazing, showed visual appraisals with 50–60% of the ground having a western wheatgrass component. In contrast, the 2000 estimate at RLCC was 20% (Table 2).

Our short-term assessments comparing pastures grazed at different times of year became important as we looked for ways to recruit western wheatgrass. We flagged defoliated plants to assess regrowth, which led us to several conclusions. First, plant growth is sporadic during the growing season and closely tied to precipitation events (*see Steffens et al., this issue*). Second, midgrass species like western wheatgrass can grow more than one inch per week in ideal conditions but blue grama never grew more than 0.3 inches per week. Third, plants defoliated during the growing season very rarely reached maturity to produce seed even in "good" years.

Lack of seed production after defoliation suggested that western wheatgrass needed season-long deferral in the RLCC environment to reach maturity. We expected that allowing plants to reach maturity would promote plant vigor and enhance both vegetative and sexual reproduction. In 2003 we increased recovery periods to a minimum of 100 days (Table 1) because our observations indicated that western wheatgrass starts growth in March and reaches maturity the end of May (90 days). The extended recovery periods left about 65% of the western wheatgrass plants on the ranch undefoliated during the critical spring growth period each year.

The potential for fast regrowth of western wheatgrass required reasonably short grazing periods (2 to 3 weeks) under optimal growing conditions to avoid repeated defoliations and to allow some recovery of plants grazed early in the spring growth period. Electric fencing, eventually installed to form 36 pastures, allowed annual grazing of all pastures with extended recovery and reasonably short grazing periods.

Table 4. Summary of failed and short-term grazing adaptations. These are examples of specific actions nuanced for specific goals in our operation

Year	Hypothesis and/or assessment observation	Adaptive management response	Follow-up assessment and action
2000	High stock densities can improve the efficiency of the mineral cycle.[5]	We installed cross fencing in some pastures that increased stocking density from 0.2 AU/acre to 0.6 AU/acre. (Stocking densities attained in this study were 2 orders of magnitude lower than densities reported by Peterson et al., this issue.)	Assessment showed no visual difference in manure distribution or plant trampling associated with the density increase. Manure and trampling were heavy at watering points and in draw bottoms but sparse in uplands. We discontinued efforts on stocking density and focused on plant diversity.
2005	Plant selection by cattle varies drastically with grazing season. Western wheatgrass is heavily defoliated (commonly 90–100% of the plants) in the spring or fall and rarely defoliated in the summer or dormant season.	A pasture grazed in the spring year 1, the summer year 2, and the spring or fall year 3 will give 2 years between defoliation of western wheatgrass (i.e., one can graze a pasture in the summer and still allow cool-season grasses to recover).	We observed recruitment of cool-season grasses so we continued to plan around seasonal selectivity of cattle.
2006 to 2008	Yearlings in summer begin to graze less, stay at water points longer, and look less full when 50% of blue grama plants are defoliated.	Over several years we found that moving yearlings at 50% blue grama defoliation resulted in good daily gains. In 2008 we grazed to 60 or 65% defoliation and yearling gains were only 1.0 pounds/day.	This practice was successful and was continued. We found several other benchmarks of % species defoliation that were used in the spring, winter, and fall.
2007	Palatability varies seasonally for most species but all winterfat plants were defoliated in every grazing period year-round. Plant species respond differently to defoliation and seasonal grazing. Typically 80–90% of the winterfat plants in pastures grazed before July 1 produce seed. Only 10–20% of the plants grazed after July 1 produced seed.	We added winterfat as a goal species. In locations where winterfat recruitment was desired we grazed before midsummer.	Observed more young plants in pastures grazed before midsummer so management action continued.
2008	Four wing saltbush was not responding to deferral of even 300 days. We were not losing plants but saw no evidence of recruitment.	Tried 2-year deferral in some pastures with good potential for four-wing saltbush recruitment.	Modest success with a few new plants in pastures of 300–400 acres. Continued 2-year deferrals when possible but it is economically difficult to defer for 2 years regularly.

In the fall of 2003 we realized an increase in the presence of western wheatgrass from 20 to 30%. Annual precipitation was below average but spring precipitation was above long-term averages.

The Late Years (2004–2012)

Season-long recovery was a management change that correlated with recruitment of a goal species in the first year. However, our fall assessments of seed production indicated that in dry years few western wheatgrass plants reached maturity, even with no grazing. We began to realize that recovery is not strictly a function of time, but rather depends on ecological conditions and growth characteristics of individual species. For instance, cool-season flagged plants under a late May defoliation followed by October defoliation effectively had no recovery because late May is the end of the spring growth period and October begins fall growth period. Hence, 120 days of nongrazing in summer allowed no effective physiological recovery for cool-season plants. We observed the same for a fall grazing period followed by a spring grazing period.

Our observations led us to adapt by again shifting our grazing strategies. Before 2005, one annual grazing plan was developed each year, assuming that a given period of time allowed adequate recovery. After 2005, we assessed all pastures in the spring (early April), midsummer (July), and fall (October). We used defoliation records from the previous grazing period and a visual assessment to choose pastures available for grazing based on plant physiology and available forage. A key criterion for return to a pasture was whether goal species had completed their life cycle (produced seed) since the last grazing period. The second adaptation in Table 4 allowed us to use all pastures each year and still meet these recovery criteria when precipitation was normal.

We estimated whether the available pastures would carry existing stock until the next planning assessment. We assumed no future forage growth except in an April planning session preceded by heavy March snows. When projected forage demand exceeded availability we destocked either by finding leased pasture or selling stock. If we estimated extra forage we either acquired cattle or saved the forage for dormant season use.

As we employed this planning method we were immediately faced with either removing cattle or putting them in pastures that were not fully recovered. To alleviate this problem we changed the structure of our cattle operation. Cow numbers were decreased by 65% and we added retained calf, yearling, and custom grazing enterprises. However, we did not buy or commit to take custom cattle until *after* each planning session. This point was critical since we no longer asked the question: Do we lease pasture or sell cattle? Instead, with forage in hand, we asked: Is there a class of cattle we want to own? Or, should we take custom cattle? Or, should we save forage for winter? Cattle are always available, but forage is commonly in short demand. After 2005 we no longer leased land or sold cattle *because we had to.* We also usually had forage available when we saw opportunities in the cattle markets.

Recovery based on plant physiology, seasonal grazing plans, and a diverse cattle operation were fundamental long-term adaptations. We also identified a number of minor adaptations that were very specific to plant species, grazing seasons, or cattle behavior (Table 4). We realized that our grazing system in the early years was ineffective because it lacked tactics specific for individual plant species or animal behaviors.

Ecological assessments from 2004 to 2012 indicated progress toward our goals of improved water cycle and increased species diversity (Table 2). Residual cover and litter, reflecting increased water capture and reduced evaporation, remained at medium or high levels from 2004 to 2010 with the exception of low litter observed in 2005 and 2008. Residual cover and litter both dropped to low levels in the drought of 2011–2012. Presence of western wheatgrass increased rapidly in 2004 (a wet year) followed by a slow increase through 2010 and a slight drop in the drought of 2011–2012.

Photo and GPS assessments indicated recruitment of a variety of other midgrass species between 2000 and 2010 (Table 3). Observations in 2012 indicate most midgrasses maintained populations in the 2011–2012 drought; exceptions were Galleta and sand dropseed. From 2000 to 2012 we also observed widespread recruitment of winterfat (*Krascheninnikovia lanata*), a highly palatable but relatively rare shrub that became a goal species in later years (Table 3). Recruitment increased when we adapted management based on observations of winterfat reproduction (Table 4). Observations of four-wing saltbush (*Atriplex canescens*), another palatable shrub, indicated only slight recruitment after 2008 (Table 3 and 4).

After the decrease in the transition years, stocking rates per acre and per inch precipitation were high from 2004 to 2010 (Table 1). In the drought (2011–2012) stocking rates per acre were low while stocking rates per inch precipitation were high. Economic performance (Fig. 1) and animal performance (Table 1) were generally high in the late years with notable spikes in 2008 and 2011–2012. In 2008, stocking rate per inch precipitation spiked upward (Table 1) while animal performance, gross margin per head, and gross margin cattle greatly declined (Fig. 1). We believe that in 2008 stocking rates surpassed the economic optimum for available forage, causing animal performance and thus economic performance to decline. Note in 2006–2008 (Table 4) that we grazed to higher utilization of blue grama for yearlings in the summer and had results similar to those seen in the early years.

We believe the upward spike of gross margin per head from 2010 to 2012 (Fig. 1) was related to a contemporary increase in the cattle market. Note that animal performance was relatively flat or down trending from 2010 to 2012 (Table 1). As gross margin per head spiked up from 2010 to 2012 gross margin cattle declined greatly (Fig. 1) because we reduced stocking rates due to drought.

Narrative Summary

The early years (1996–1999) and the late years (2004–2012) have starkly contrasting outcomes from two different management paradigms. Between 1996 and 1999 management used a flawed economic model (*see Frasier and Steffens, this issue*) and a method-driven grazing system. High stocking rates accompanied poor animal performance, low gross margin per head, and negative return to management in the cattle enterprise. Low residual herbage, litter, and plant diversity were normal under the early management paradigm (Fig. 2).

An ecological focus and adaptive grazing management characterized the late years. Stocking rates (relative to precipitation) were high but animal performance, gross margin per head, and return to management were improved. In short, more cattle were grazed on less average annual rainfall *while maintaining good animal performance*. The late years were characterized by improved species diversity with higher residual cover and litter.

Discussion

This narrative of our management decisions illustrates several points about adaptive management in a private sector production setting. Early adaptations were of the ad-hoc nature: "It's not working so we'll try something else." But after management focused on ecology, adaptations became more focused. Our research and observations of the landscape initiated subsequent goals. Ecological assessment and research helped us form a hypothesis on how to reach the goal. Hypothesis formulation involved finding the key ecological goal limiting process, and the management action that could alter that process. For us, the key process was initially improving western wheatgrass reproduction. Our management decision was to allow extended deferral for plants to reach maturity between defoliations. Ongoing assessments provided additional hypothesis and adaptations. Some were fundamental and long-term, such as recovery defined by plant physiology, tri-annual grazing planning, and diversification of the cattle business. Others were failed forks in the road or minor adaptations that nuanced grazing methods for particular species or changing conditions (Table 4). All the adaptations presented here are specific to one socio-ecological system, but the strategy to *find the ecological process that limits goal attainment and ways to alter that process* can be applied anywhere.

The narrative of management decisions contains a causal chain. Poor economic performance in the early years precipitated a search for alternatives.[7] A method-driven grazing system created an interest in grazing ecology. An ecological interest caused managers to research grazing ecology and start ecological assessments. Research and assessments led management to fundamentally change grazing strategy and the structure of the livestock business. Eventually, attainment of desired outcomes from adaptive management created beliefs (mental models) about grazing ecology and economics. Our discussions with other producers suggest to us that this causal chain of management thought is not unusual.

Experience over 17 years created the management belief that animal selectivity and the timing, seasonality, and duration of grazing can be manipulated toward desired ecological and economic outcomes. Science has shown that *system-driven* control of time-related grazing variables is generally ineffective to increase forage or animal production.[8] The failed grazing system in the early years of this case study is consistent with that conclusion. However, the range science community continues to test the idea that adaptive manipulation of time-related grazing variables can, directly or indirectly, produce desired ecological and economic outcomes.[9]

Manipulation of time-related variables to produce desired ecological and economic outcomes is a complex problem that requires *both* process-based science and adaptive management, along with effective communication between the two.[10] We suggest part of effective communication entails evaluating specific management adaptations and resulting beliefs in the context of science. That is, understanding the response of the dependent variable perceived by management in a case study, and asking how it is consistent with quantitative studies of the same variables.

This case study example provides several adaptations for comparison. We diversified our cattle business to gain flexibility of stocking rates and believe this caused economic improvement. Torell et al.[4] modeled the positive economic response of diverse cattle enterprises to achieve flexible stocking. Torell's model supports our belief that matching interannual stocking rates to forage availability is economically effective.

We changed grazing protocols to season-long recovery periods eventually defined by plant physiology. *Within the boundaries set by weather events*, we believe these changes caused recruitment of midgrasses and some shrubs. Our beliefs are consistent with a number of scientific conclusions including: 1) plant physiology studies showing that a number of species from short grass steppe require extended recovery;[11] 2) a study documenting sporadic plant growth in semiarid rangelands;[12] and 3) the unified vegetation response to grazing[8] that "Species composition of plant communities can be modified in response to the frequency, intensity, and seasonality of grazing." The consistency of our adaptation with replicated science supports our belief that adaptive control of time-related grazing variables directly caused recruitment of goal species.

We believe that during this study recruitment of midgrass species directly caused an increase of forage production, residual cover, and litter, which in turn improved water cycle. In a northwestern Texas study, grass standing crop and mulch was much higher (200%) for midgrass communities versus shortgrass communities.[13] And midgrass communities (39% western wheatgrass by weight) produced 64% more forage than shortgrass communities (9% western wheat by weight) in South Dakota.[14] A body of science indicates that water capture and storage increase with residual cover and litter.[5]

Taken individually, our primary adaptations and our associated mental models are consistent with scientific studies. These consistencies support our belief that improved water cycle and increased midgrasses can increase economically and ecologically sustainable stocking rates. We realized economic sustainability from good animal performance through the late years. We infer ecological sustainability in the late years from adequate residual cover and increasing diversity of the plant community.

Science cannot imitate the "whole" of adaptive management[9] but perhaps effective communication entails comparing the "parts" (individual adaptations) of adaptive management to science. Effective communication has several components: 1) Management uses available process-based science to create "successful" adaptations; 2) Case studies compare perceived management results with scientific results; and 3) Discrepancies create hypothesis for research.[15] In this context we suggest that increased sustainable stocking through the recruitment of midgrasses in shortgrass steppe is a hypothesis worthy of investigation in other management areas.

Implications

1) Adequate recovery refers to plant physiology of specific plants.
2) Stocking rate (grazing intensity) is not the only important grazing variable. Within the limits of uncertain and ever-changing events, the timing, frequency, distribution, and selectivity of grazing are also important.
3) Adaptive grazing management requires a focus on ecology.
4) Effective adaptive management identifies and modifies the "goal limiting process" associated with desired outcomes.

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