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Influence of Experience on Browsing Sagebrush by Cattle and Its Impacts on Plant Community Structure

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Abstract

Mechanical and chemical methods used historically to rejuvenate sagebrush-steppe landscapes are cost prohibitive. A low-cost alternative is to fashion systems of management in which locally adapted animals use sagebrush as fall and winter forage to reduce feeding costs and to enhance the growth of grasses and forbs during spring and summer. We evaluated the practicality of fall browsing of sagebrush (*Artemisia tridentata* ssp. *tridentata*, ssp. *wyomingensis*) by cattle. To do so, we assessed 1) the foraging behavior and body weights of cattle with varying levels of experience browsing sagebrush, and 2) the ensuing responses of sagebrush, grasses, and forbs to cattle grazing. In spatially and temporally replicated trials from 2007 to 2009, cattle were challenged to eat sagebrush. Pregnant cows with calves (2007 and 2008), bred yearling heifers (2008), and first-calf heifer/calf pairs (2009), supplemented with protein and energy, learned to eat sagebrush as a significant portion of their diet (up to 63% of scans recorded during grazing). Experienced animals consistently ate more sagebrush and lost less weight, or gained more weight, than naive animals in 2008 and 2009 ($P < 0.05$). Cover, production, and percent composition of grasses and forbs maintained or dropped slightly from 2007 to 2008 but then rebounded sharply in 2009 to much greater levels than in 2007 or 2008 ($P < 0.05$). A corresponding reduction in shrub cover, production, and percent composition accompanied the increase in forbs and grasses ($P < 0.05$). Our research suggests grazing by cattle during fall and winter can be effective, biologically and economically, and can lead to habitat renovation and resilience by creating locally adapted systems of management in ways that landscape manipulations with chemical and mechanical treatments or prescribed fire cannot.

Key Words: body weight, holistic management, local adaptation, plant regrowth, targeted grazing

INTRODUCTION

Sagebrush steppe is one of the largest eco-regions in North America, covering millions of acres in Utah, Nevada, Wyoming, Oregon, Washington, Idaho, and Montana (West 1983). During the past century, people attempted to eliminate sagebrush (*Artemisia tridentata* spp. Nutt.) with the goal of stimulating growth of grasses and forbs to suit presumed needs of wild and domestic animals during spring and summer (Winward 1991). Contrary to long-standing beliefs, complete removal of sagebrush adversely affects biodiversity and results in little long-term benefits for perennial grasses and forbs. Indeed, forage production may eventually decline when sagebrush is removed (Winward 1991). Many groups now recognize the multiple year-round benefits of sagebrush for the integrity of soil, plants, animals, and people.

A low-cost alternative to mechanical and chemical removal of sagebrush is to develop systems of management that use sagebrush as a forage resource and to select for domestic animals that use sagebrush as fall and winter forage. These practices can enhance growth of grasses and forbs during spring and summer while maintaining sagebrush as an important part of biodiversity (Provenza et al. 2003; Provenza 2008). While sheep can rejuvenate sagebrush-steppe (Dziba et al. 2007), sheep numbers have declined in the West to the point that they may not be available to rejuvenate sagebrush steppe in many areas. As cattle are abundant in the Great Basin, we sought to determine if they could also revitalize sagebrush steppe.

Three factors help livestock rejuvenate sagebrush steppe. First, experience can help animals develop morphologically, physiologically, and behaviorally in ways that better enable them to increase consumption of a particular food. Experiences in utero and early in life enable animals to better use forages in environments in which they are conceived, develop, and live over generations (Provenza 2003; Provenza et al. 2003). Second, supplemental nutrients mitigate the adverse impacts of terpenes in sagebrush and increase the success of using livestock at high density to rejuvenate landscapes dominated by sagebrush (Dziba et al. 2007; Woodland 2007; Guttery 2010). Third, animals can positively influence rejuvenation of sagebrush steppe communities through foraging and nutrient inputs to soil in the form of urine and feces derived from supplements and forages (Hobbs 1996; Provenza et al. 2003). Increasing resource availability (water and nutrients) through inputs of carbon and nitrogen, as well as water, can enhance the production and nutritional quality of herbaceous plants while reducing terpene concentrations in plants like sagebrush (Bryant et al. 1983; Herms and Mattson 1992).

Our objectives were to evaluate the practicality of fall browsing of sagebrush (*Artemisia tridentata* ssp. *tridentata*, and ssp. *wyomingensis*) by cattle. To do so, we evaluated 1) use

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Table 1. Cells grazed during adaptations and trials from 2007 (22 October–10 November), 2008 (21 October–8 November), and 2009 (28 October–16 November).

	2007			2008		
Cell number[1]	2	3	4	8	9	10
Prescription	Adaptation	Trial	Trial	Trial	Adaptation	Trial
Number days	13	6	6	7	11	7
Cattle	20 pairs	20 pairs[2]		22	44	22
Class	Naïve cows w/calves	Naïve cows w/calves	Naïve cows w/calves	4 pairs experienced cows[3] w/calves, 4 pairs naïve cows w/calves, 3 experienced bred heifers[4], 3 naïve bred heifers	7 pairs experienced cows[3] w/calves, 9 pairs naïve cows w/calves, 6 experienced bred heifers[4], 6 naïve bred heifers	3 pairs experienced cows[3] w/calves, 5 pairs naïve cows w/calves, 3 experienced bred heifers[4], 3 naïve bred heifers
Number/class scanned	10 pairs	10 pairs		2 pairs experienced cows[3] w/calves, 2 pairs naïve cows w/calves, 2 experienced bred heifers[4], 2 naïve bred heifers	4 pairs experienced cows[3] w/calves, 4 pairs naïve cows w/calves, 4 experienced bred heifers[4], 4 naïve bred heifers	2 pairs of experienced cows[3] w/calves, 2 pairs naïve cows w/calves, 2 experienced bred heifers[4], 2 naïve bred heifers
Stock density (weight $kg \cdot h^{-1}$)	62 501	31 250		38 275	76 810	38 535
Stocking rate ($AUM \cdot h^{-1}$)[6]	47	22		16	49	16

[1]Control cells with no grazing: 1, 5, 6, 7, 11, and 15.
[2]Twenty pairs (40 head) grazed together—the fence dividing the two replication cells was removed because cattle repeatedly broke the wires between the pastures.
[3]These cows were in trials in 2007.
[4]These animals were calves in trials in 2007.
[5]These first-calf heifers were calves in 2007 and bred heifers in 2008.
[6]Animal-unit-months per hectare.

of sagebrush foliage and bark and body weight responses of cattle with varying levels of experience browsing sagebrush, and 2) the ensuing responses of grasses, forbs, and sagebrush to cattle grazing. Late fall and winter are good times for grazing to increase abundance of grasses and forbs and reduce sagebrush because terpene concentrations, which limit intake of sagebrush (Gade and Provenza 1986; Villalba et al. 2002; Dziba and Provenza 2008), are lower during those seasons than during spring, summer, and early fall (Kelsey et al. 1982), and perennial forbs and grasses have matured and are mostly senescent. We determined use of sagebrush and body weights of cow/calf pairs, bred heifers, and heifer/calf pairs supplemented with protein and energy to mitigate the effects of terpenes in sagebrush (Villalba et al. 2002). We assessed the effects of age and experience on use of sagebrush by mature cows and calves as they aged.

MATERIALS AND METHODS

Study Area

The study was conducted on the Cottonwood Ranch in O'Neil Basin, Northern Elko County in Northeast Nevada. The main current and historical use of this area is grazing by cattle and horses in summer and fall. The study site is within an area comprised of Loamy Bottom and Ashy Loam ecological sites. Soils are variable from deep silt loams to gravelly clay loams (US Department of Agriculture–Natural Resources Conservation Service 1990). The majority of annual precipitation in the area, which averages 259 mm, comes during winter and spring as snow, with limited growing season precipitation from summer thunderstorms. Wyoming and Basin big sagebrush dominate the site, with Douglas rabbitbrush as a subdominant shrub, along with a variety of perennial grasses and forbs and sparse amounts of cheatgrass and mustards. The area supports numerous species of insects and wildlife including sage-grouse, many passerine birds, mule deer, and pronghorn antelope.

The study site was 3.0 ha divided by electric fence into 15 cells of 0.2 ha each. Each cell was 27 m×72 m. During our study, cattle were confined to the described cells and provided supplements to help them use sagebrush in fall. We monitored use of sagebrush and other plant species by cattle, and the impacts of grazing on sagebrush and forbs and grasses.

Study Animals

The cattle used in our study were obtained from the Cottonwood Ranch cow-calf herd. They had both Angus and Hereford (among other) bloodlines, sired by multiple range-ready bulls. We used cows, yearling heifers, and calves from this herd in trials from 2007 to 2009. Throughout the remainder of the year, when not being used in our trials, all cattle were on hay meadows and sagebrush-steppe rangelands. Thus, while we did not control for the many factors that affect food and habitat selection throughout the year, all cattle were living in the same environments as a herd when they were not being used in our trials.

Grazing Trials

Trials occurred on 15 adjacent cells (0.2 ha each) in late October and early November from 2007 to 2009 (Table 1). We used five cells each year in October and November of 2007, 2008, and 2009: one cell to adapt animals to experimental conditions and two replications of two treatments (grazed or not grazed) for trials. Cattle grazed in new cells each year for 3

Table 1. Extended.

2009		
12	13	14
Trial	Adaptation	Trial
5	14	5
22	42	20
2 "double" experienced heifers[5] w/first calves, 3 naïve heifers w/first calves, 6 pairs of naïve cows w/calves	4 "double" experienced heifers[5] w/first calves, 6 naïve heifers w/first calves, 11 pairs of naïve cows w/calves	2 "double" experienced heifers[5] w/first calves, 3 naïve heifers w/first calves, 5 pairs of naïve cows w/calves
2 "double" experienced heifers[5] w/first calves, 3 naïve heifers w/first calves	4 "double" experienced heifers[5] w/first calves 6 naïve heifers w/first calves	2 "double" experienced heifers[5] w/first calves, 3 naïve heifers w/first calves
34 906	66 139	31 239
9.5	50	8.5

yr. The annual selection of cells for adaptation, grazing, and control was randomly generated.

Each year, cattle first grazed in an adaptation cell and then grazed in trial cells once they began to eat sagebrush. We provide a detailed description of the study layout, treatments, and animal numbers in Table 1. To encourage use of sagebrush, cattle were confined at high stock densities (from 62 501 $kg \cdot ha^{-1}$ to 76 810 $kg \cdot ha^{-1}$ live weight) and provided supplements. Even at high stock densities, animals still had ample room to move about calmly, and trampling of sagebrush was not an issue. To determine how experience affected foraging behavior, we placed experienced cattle (those included in the 2007 trials) with naïve cattle (those not included in the 2007 trials) in 2008 and 2009 and compared how readily each group ate sagebrush.

Supplementing Cattle

We fed grass hay grown at Cottonwood Ranch to cattle at a rate that ranged from 5.9 to 7.3 kg hay · 454 kg live weight · d^{-1} during adaptation. We gradually reduced the daily amount as cattle began eating sagebrush and other forages. We fed hay on the ground each morning and evening.

We fed a strategically formulated cube (ground mix of 50% beet pulp, 30% corn, 5% soybean meal, and 15% alfalfa hay) at a rate that ranged from 1.4 to 1.8 kg cubes · 454 kg live weight · d^{-1} during adaptation. We maintained the same rate of supplementation during trials to help cattle eat sagebrush. Cattle were fed cubes on the ground each morning and evening.

We provided natural rock salt with trace minerals ad libitum during the grazing trial, but not during adaptation, in 2007, and during both the adaptation and grazing trial in 2008. Natural rock salt was not available in 2009, so we used white block salt without trace minerals. Salt was placed on the opposite end of the cells from where the water and the hay and cube supplements were fed. Quality drinking water was provided ad libitum to cattle in 3 785 L troughs in each cell. The water was filled from existing stockwater pipelines, originating from a ranch well.

Cattle Foraging Behavior

We used scan sampling (Altman 1974), at 10-min intervals for 9 h · d^{-1}, to monitor diet selection and other behaviors in 2007 (13-d adaptation, 6-d trial), 2008 (11-d adaptation, 7-d trial), and 2009 (14-d adaptation, 5-d trial). Approximately half of the cattle, predesignated according to age class for scan sampling, were marked with ear tags each year (see Table 1 for actual animal numbers in each cell for each experience/age combination). Their feeding behaviors were classified as: 1) "S" for eating sagebrush foliage and/or twigs/branches at or near the top of the shrub; 2) "B" for eating sagebrush bark from along the trunk of the shrubs; 3) "U" for eating any forage in the plant community understory including grasses, forbs, and Douglas rabbitbrush; and 4) "O" for any other kind of activity such as drinking, licking salt, standing, and bedded/ruminating. We did not differentiate between the two subspecies (*Artemisia tridentata* ssp. *tridentata*, and ssp. *wyomingensis*) of big sagebrush for scan sampling.

Cattle Weights

The same cattle scanned for feeding behaviors (Table 1) were weighed in the evening before and after the study in all 3 yr. While it is preferable to weigh cattle after an overnight fast without food or water, we had to weigh cattle at the ranch corrals, where they had free access to grass hay and water. We weighed cattle of different ages (calves, heifers, and pregnant cows); pregnant cows were in the first trimester of gestation, so changes in fetal weight during the trials were nil. We present changes in weights as absolute values and as percentage change in weights. The data we generated are valuable as a relative indication of the degree to which grazing sagebrush during fall affected experienced and naïve calves, heifers, and pregnant cows.

Response of Vegetation to Grazing

We established baseline plant community conditions before the trials began and then documented responses of vegetation to grazing by cattle. We monitored plant cover, number of species, production, and percent composition (by weight) each summer for 3 yr.

We used point intercept transects to estimate foliar cover and determine the number of species. Transects were marked with a wooden stake in the middle of the southern edge of each cell. The "0" point was re-established for each reading by using a predetermined length from a wooden marker in a northern bearing. Data collection protocols, including forms, equipment, and data collection instructions, were according to Herrick et al. (2005).

To estimate production and percent composition by weight, we sampled along transects that were delineated based on a predetermined and consistent distance and bearing from a wooden stake marker located in the middle of the southern edge of each cell. The starting point for the weight estimate transect was re-established for each reading by using a predetermined length and bearing. Forms, equipment, and

Table 2. Scan samples (% of scans) for use of sagebrush foliage and bark by naïve and experienced cattle during adaptation periods and trials from 2007 to 2009.

Year	Cows		Calves or heifers			
	Naïve	Experienced	Naïve	Experienced	$P \geq F$	SEM
2007[1]						
13-d adaptation						
Foliage	15	—	12	—	0.53[5]	2.7
Bark[2]	—	—	—	—	—	—
6-d trial						
Foliage	7	—	11	—	0.11[5]	2.0
Bark	33	—	56	—	< 0.01[5]	4.5
2008[3]						
11-d adaptation						
Foliage	10	4	4	4	0.28[6]	2.7
Bark	16	36	44	52	0.06[6]	6.8
7-d trial						
Foliage	10	11	5	13	0.17[6]	2.6
Bark	16	35	44	52	0.39[6]	6.8
2009[4]						
14-d adaptation						
Foliage	—	—	3	3	0.96[5]	1.5
Bark	—	—	33	40	0.15[5]	3.1
5-d trial						
Foliage	—	—	1	11	0.12[5]	1.3
Bark	—	—	9	16	0.15[5]	2.4

[1]Naïve cows and their calves.
[2]Not measured during the adaptation period.
[3]Heifers exposed *in utero* in 2007.
[4]First-calf heifers exposed *in utero* in 2007 and as calves in 2008.
[5]Experience main effect.
[6]Age × experience interaction.

data collection instructions for the point intercept method followed protocols in Bureau of Land Management (1996).

We obtained precipitation data from the Gibbs Ranch weather station, which is at the same elevation as Cottonwood Ranch and located approximately 24 km to the south. Precipitation varied significantly from 2007 to 2009, so we used precipitation indices to adjust herbage production to better illustrate the effect of treatments on vegetation production. The index represents a percentage of "normal" or mean precipitation, which is converted to a yield index used to calculate percent of median herbage production values (US Department of Agriculture–Agricultural Research Service 1983). We present both unadjusted and adjusted herbage production values.

Statistical Analyses

All analyses were done with the MIXED procedure of SAS/STAT (SAS Institute, Inc, Cary, NC; version 9.1.3 for Windows). The selected within-cell covariance matrix (autoregressive order-1, compound symmetry, variance components) always provided the best fit for the data according to the Schwarz's Bayesian criterion (Littell et al. 1998). Model diagnostics included testing for normal distributions of error residuals and homogeneity of variances. All data met these norms. Means were analyzed using pairwise differences of least squares means. We consider $P < 0.10$ significant, given the low number of replications in our trials.

For scan sampling in 2008 and 2009, percentage of scans recorded on grazing sagebrush leaves, sagebrush bark, and other plants relative to the total number of scans recorded was analyzed using a mixed-effects model that accounted for the random effect of cells (two replicated cells) and the fixed effects of experience grazing sagebrush (yes or no) and age (cow vs. yearling [bred] heifer vs. calf) and their interaction. Day was a repeated measure (Littell et al. 1998). During 2007, we were unable to use replicated cells, so we analyzed effects due to age (cow vs. calf) and day (13-d adaptation and 6-d trial) with animals ($n = 10$) nested within each age class.

For cattle weights, we conducted separate analyses for each year. In 2007, age (cow vs. calf) was the main effect and animals were nested within each age class ($n = 10$). In 2008, the main effects were age (cow vs. yearling [bred] heifer vs. calf), experience grazing sagebrush (yes or no) and their interaction; animals ($n = 4$) were nested within age/experience class. In 2009, the main effects were age (first-calf heifer vs. calf), experience grazing sagebrush (yes or no), and their interaction; animals ($n = 4$) were nested within age/experience class.

For vegetation sampling, the repeated measures design for the analysis of variance had two replications in 2008 and 2009. The main effects were exposure to grazing (yes or no) and plant type (sagebrush, shrubs, grass, and forbs) and their interactions. We conducted separate analyses for cells 1–5 and cells 6–10 because monitoring occurred over a varying number of years for cells 1–5 (3 yr, 2007–2009) and cells 6–10 (2 yr, 2008–2009). Cells 11–15 were used only for the grazing trials in 2009, and no plant response data were collected. Response variables were plant cover (%), production (kg/ha), plant composition (%), and number of species.

RESULTS

Cattle Foraging Behavior

In what follows, we describe main effects and interactions for use of sagebrush foliage and bark, as well as for understory plants, during adaptation periods and trials from 2007 to 2009. We highlight effects of age and experience in Table 2, which is a summary of key main effects for 2007 and 2009 and key interactions for 2008.

Cows and Calves 2007. During the first 5 d of adaptation, cows and calves used grasses, forbs, and shrubs such as Douglas rabbitbrush, but little sagebrush foliage. As these forages diminished on days 6 to 13, cows and calves increased their use of sagebrush foliage, though not at the same time (age × day effect, $P = 0.02$): calves began using sagebrush foliage sooner than cows, but they ended up using the same amount of foliage during adaptation ($P = 0.53$; Table 2). Calves spent more time than did cows grazing during adaptation (19% vs. 9%; $P < 0.01$).

During the 6-d trial, when animals were put in two separate cells, cows repeatedly broke through the fence, so we combined all animals into one group that grazed both cells. Calves used more sagebrush foliage ($P = 0.11$) and bark ($P < 0.01$) than cows (Table 2), especially as the trial progressed (age × day effect, $P=0.08$), and they ate less understory than cows (33% vs. 60%; $P<0.01$). Calves and cows spent similar time grazing during the trial (41%; $P=0.99$).

Experienced or Naïve Cows and Yearling (Bred) Heifers 2008. During the 11-d adaptation, use of sage foliage did not differ by experience ($P=0.25$), age ($P=0.21$), or day ($P=0.33$); no interactions were significant ($P=0.28$; Table 2). Use of sagebrush bark was greater for experienced than naïve cows and yearlings ($P=0.06$; Table 2). Calves used bark more than cows, especially as the trial advanced (age×day effect; $P=0.01$). Use of understory declined over time but varied by experience and age: experienced cows used understory more than naïve cows (21% vs. 15%), while experienced heifers used understory less than naïve heifers (31% vs. 43%; $P=0.02$). For total time grazing, experienced animals grazed more than naïve animals (13% vs. 7%; $P=0.04$) and heifers grazed more than cows (15% vs. 5%; $P<0.01$).

During the 7-d trial, use of sagebrush foliage increased with time ($P<0.01$). Age did not affect use of sage foliage ($P=0.63$). Experienced and naïve cows used sagebrush foliage similarly, but experienced heifers tended to use more foliage than naïve heifers ($P=0.17$; Table 2). Experience and age tended to interact as experienced and naive cows ate similar amounts of foliage, whereas experienced yearling heifers ate more foliage than did naive yearling heifers ($P=0.17$; Table 2). Experienced animals used sagebrush bark more than did inexperienced animals (44% vs. 30%; $P=0.06$), and age and experience did not interact ($P=0.39$; Table 2). Use of understory declined over time ($P<0.01$). For total time grazing, there was a tendency for experience animals to graze more than naïve animals (47% vs. 39%; $P=0.22$), and for heifers to graze more than cows (49% vs. 38%; $P=0.14$).

Cows vs. Calves 2008. Use of sagebrush foliage was similar for calves and cows in the 11-d adaptation (6% vs. 7%; $P=0.58$) and the 7-d trial (10% vs. 10%; $P=0.92$). Calves ate more sagebrush bark than did cows in adaptation (53% vs. 26%; $P<0.01$), but not during the trial (52% vs. 42%; $P<0.44$). Calves used understory more than cows during adaptation (36% vs. 18%; $P<0.01$), but not during the trial (39% vs. 47%; $P<0.31$). Calves grazed more than cows during adaptation (15% vs. 5%; $P<0.01$), but not during the trial (43% vs. 38%; $P=0.59$).

Experienced vs. Naïve First-Calf Heifers 2009. Neither experience ($P=0.96$) nor day ($P=0.26$) affected use of sagebrush foliage until the trial at the end of the 14-d adaptation period. During the trial, experienced heifers used sagebrush foliage more than did naïve heifers ($P=0.12$; Table 2), especially as the trial proceeded (experience×day effect, $P<0.01$). Compared with naïve animals, experienced first-calf heifers tended to use bark more during adaptation ($P=0.12$), and during the trial ($P=0.15$; Table 2). Experienced and naïve animals used similar amounts of understory during adaptation (55% vs. 52%; $P=0.43$), but experienced heifers used less understory than did naïve animals during the trial (73% vs. 90%; $P=0.03$). Experienced heifers grazed more than naïve heifers during adaptation (15% vs. 7%; $P<0.01$), but not during the trial (40% vs. 43%; $P=0.54$). Experience and day interacted for total time grazing during adaptation ($P<0.01$), but not during the trial ($P=0.66$).

First-Calf Heifers vs. Calves 2009. During the 14-d adaptation, first-calf heifers and their calves did not differ in use of sagebrush foliage (3% vs. 2%; $P=0.32$) or bark (36% vs. 36%; $P=0.95$), and both groups increased use of sagebrush foliage ($P<0.01$) and bark ($P<0.01$) in adaptation. During the 5-d trial, first-calf heifers tended to use sagebrush foliage more than their calves (5% vs. <1%; $P=0.19$), but they did not differ in use of bark (12% vs. 18%; $P=0.32$). First-calf heifers used understory less than their calves in adaptation (53% vs. 60%; $P=0.12$), but not in the trial (83% vs. 82%; $P=0.74$). First-calf heifers grazed less than their calves in adaptation (10% vs. 17%; $P=0.02$), but not in the trial (42% vs. 39%; $P=0.38$).

Table 3. Weight of cattle in experiments from 2007 to 2009.

Year	Weight[1]	Change[1]	$P \geq F$	SEM	Change (%)	$P \geq F$	SEM
2007							
Naïve cow	457	−10.7	0.04	3.9	−2.1	0.09	1.2
Naïve calf	154	+1.1	0.04	3.9	+0.8	0.09	1.2
2008							
Exp cow[2]	536	−25.0	0.01	8.6	−4.5	0.01	3.3
Naive cow	568	−44.0	0.01	8.6	−7.6	0.01	3.3
Exp calf[3]	138	−1.7	0.01	8.8	−0.7	0.01	3.3
Naive calf	173	−16.4	0.01	8.8	−8.2	0.01	3.3
Exp heifer[4]	350	−8.5	0.01	8.8	−2.4	0.01	3.3
Naive heifer [5]	320	−42.5	0.01	8.8	−13.2	0.01	3.3
2009							
Exp calf[6]	123	+3.4	0.06	7.8	+2.0	0.09	3.3
Naive calf	112	+8.7	0.06	7.0	+7.1	0.09	2.7
Exp Heifer[7]	393	+15.9	0.06	7.8	+3.8	0.09	3.3
Naive Heifer	370	−7.6	0.06	7.0	−2.1	0.09	2.7

[1]Mean initial body weights and changes (kg).
[2]Exposed to sagebrush during trials in 2007.
[3]Exposed to sagebrush *in utero* in 2007.
[4]Bred, yearling heifers exposed to sagebrush with their mothers as calves in 2007.
[5]Bred, yearling heifers.
[6]Exposed to sagebrush *in utero* in 2008.
[7]Bred, yearling heifers exposed to sagebrush with their mothers as calves in 2007.

Cattle Weights

In 2007, naïve cows lost 10.7 kg during adaptation and trials, while their naïve calves gained 1.1 kg, and the percent change differed for cows (–2.1%) and calves (+0.8%; Table 3).

In 2008, experienced animals lost less weight than did naive animals (–11.7 kg vs. –34.2 kg; $P=0.01$), and they lost a lower percent of initial body weight (–2.1% vs. –9.6%; $P=0.01$). Age and experience did not interact for weight change or for percent weight change: experienced cows (–25 kg, –4.5%, respectively) and their calves (–1.7 kg, –0.7%) lost less weight than naïve cows (–44 kg, –7.6%) and their calves (–16.4 kg, –8.2%), and the same was true for experienced (–8.5 kg, –2.4%) and naïve yearling heifers (–42.5 kg, –13.2%; Table 3). Calves lost less weight than did yearling heifers, and yearling heifers lost less weight than did cows (–9 vs. –26 vs. –34 kg; $P=0.03$; $P=0.01$). As a percent of initial body weight, however, calves, yearling heifers, and cows did not differ in weight loss (–3.7% vs. –7.8% vs. –6.0%; $P=0.48$).

Table 4. Vegetation responses to cattle grazing in 2007 in cells 1–5.

	2007		2008		2009	
	No graze	Graze[1]	No graze	Graze	No graze	Graze
Cover (%)[2]						
Grass	27	28	29	29	36	50
Forb	9	5	8	9	10	11
Shrub	49	50	41	30	40	26
Sagebrush	42	39	36	22	35	23
Number species[3]						
Grass	4.5	3.0	3.5	2.5	4.5	4.5
Forb	3.5	2.5	4.5	2.5	4.5	2.5
Shrub	2.5	2.5	2.0	2.0	2.0	2.0
Sagebrush	1.0	1.0	1.0	1.0	1.0	1.0
Production ($kg \cdot ha^{-1}$)[4]						
Grass	439 (303)	603 (416)	251 (209)	236 (197)	421 (556)	774 (1 021)
Forb	162 (112)	158 (109)	240 (199)	234 (194)	189 (249)	359 (474)
Shrub	1 225 (845)	1 046 (722)	1 366 (1 134)	644 (535)	810 (1 069)	417 (550)
Sagebrush	1 107 (764)	920 (635)	1 196 (993)	497 (412)	733 (967)	251 (331)
Composition (%)[5]						
Grass	24	33	13	22	30	50
Forb	9	9	13	22	14	24
Shrub	67	58	74	56	56	27
Sagebrush	61	51	65	42	51	16

[1]Values in this column are data collected prior to grazing.
[2]$P=0.10$ graze × plant × year effect (SEM 7.6).
[3]$P=0.09$ graze (SEM 0.2) and $P<0.01$ for plant (SEM 0.3).
[4]$P<0.01$ graze × plant effect (SEM 62); $P=0.04$ graze × year effect (SEM 54); we used precipitation indices to adjust herbage production to better illustrate the effect of treatments on vegetation production. The index represents a percentage of "normal" or mean precipitation, which is converted to a yield index used to calculate percent of median herbage production values; unadjusted values are in parenthesis.
[5]$P=0.03$ for graze × plant × year effect (SEM 5.5).

In 2009, first-calf heifers with experience grazing sagebrush, as calves in 2007 and as yearling heifers in 2008, gained weight (+15.9 kg, +3.8%) compared with naive first-calf heifers that lost weight (–7.6 kg, –2.1%; Table 3). Calves grazing with experienced first-calf heifers gained less weight (+3.4 kg, +2.0%) than calves grazing with naive first-calf heifers (+8.7 kg and +7.1%; age × experience interaction effect, $P=0.06$ for weight and $P=0.09$ for %).

Response of Vegetation to Grazing

In cells 1–5 (Table 4), cover of grasses increased in grazed compared with ungrazed plots, especially in 2009. Cover of forbs was similar in grazed and ungrazed plots during the study ($P>0.10$). Cover of shrubs including sagebrush decreased in grazed relative to ungrazed plots from 2007 to 2009 ($P \leq 0.10$). Production of grasses, forbs, and shrubs declined for grazed compared with ungrazed plots from 2007 to 2008. Production of grasses and forbs increased on grazed compared with ungrazed plots in 2009, while production of shrubs declined in 2008 and 2009. The number of species of grasses, forbs, or shrubs was not affected ($P>0.10$). The abundance of grass and forbs increased relative to shrubs from 2007 to 2009 ($P \leq 0.10$).

In cells 6–10 (Table 5), cover of grasses increased in grazed compared with ungrazed plots from 2008 to 2009 ($P \leq 0.10$). Cover of forbs was lower in grazed than ungrazed plots in 2009 ($P \leq 0.10$). Cover of shrubs including sagebrush declined in grazed compared with ungrazed plots from 2008 to 2009 ($P \leq 0.10$). Production of grasses, forbs, and shrubs declined for grazed compared with ungrazed plots from 2008 to 2009 ($P \leq 0.10$). The number of species of grasses, forbs, and shrubs did not change in grazed compared with ungrazed plots ($P>0.10$). The abundance of grass and forb increased relative to shrubs from 2008 to 2009 ($P \leq 0.10$).

DISCUSSION

We evaluated the foraging behavior and body weights of cattle with varying levels of experience browsing sagebrush and the effects of foraging on sagebrush, grasses, and forbs. Cattle with experience generally used more sagebrush and maintained better weights. While the results for cattle foraging behavior were not always highly significant statistically ($P<0.10$), they were obtained consistently with few replications ($n=2$). We also expect the differences to have been larger had naïve and experienced animals not grazed together, as social influences greatly affect foraging behavior (Ralphs and Provenza 1999). Cattle grazing decreased abundance of sagebrush and increased abundance of grasses and forbs.

Cattle Foraging Behavior

During trials from 2007 to 2009, pregnant cows with calves (2007), bred yearling heifers and pregnant cows with calves

Table 5. Vegetation responses to cattle grazing in 2008 in cells 6–10.

	2008		2009	
	No graze	Graze[1]	No graze	Graze
Cover (%)[2]				
Grass	6	15	9	23
Forb	11	6	12	7
Shrub	45	52	49	35
Sagebrush	38	35	45	28
Number species[3]				
Grass	4.0	5.0	4.5	5.5
Forb	4.0	1.5	3.5	3.5
Shrub	4.5	2.0	2.0	2.0
Sagebrush	1.0	1.0	1.0	1.0
Production ($kg \cdot ha^{-1}$)[4]				
Grass	140 (116)	195 (162)	120 (158)	116 (153)
Forb	178 (148)	217 (180)	145 (192)	114 (151)
Shrub	1 140 (946)	828 (687)	450 (595)	242 (319)
Sagebrush	1 026 (851)	688 (571)	408 (538)	187 (246)
Composition (%)[5]				
Grass	10	15	17	24
Forb	12	18	20	24
Shrub	78	67	63	51
Sagebrush	70	55	58	39

[1]Values in this column represent data collected prior to grazing.
[2]$P < 0.01$ graze × plant × year effect (SEM 5.3).
[3]$P = 0.03$ graze × plant effect (SEM 0.27).
[4]$P = 0.03$ graze × plant effect (SEM 43); we used precipitation indices to adjust herbage production to better illustrate the effect of treatments on vegetation production. The index represents a percentage of ''normal'' or mean precipitation, which is converted to a yield index used to calculate percent of median herbage production values; unadjusted values are in parenthesis.
[5]$P = 0.10$ graze × plant effect (SEM 4.7).

(2008), and first-calf heifer/calf pairs (2009), supplemented with protein and energy to increase use of sagebrush by mitigating the effects of terpenes in sage (Villalba et al. 2002; Dziba et al. 2007), learned to eat sagebrush. Compared with naïve animals, experienced cows, calves of experienced cows, and experienced yearling heifers generally ate more sagebrush and lost less weight, or gained more weight, than naive animals in 2008 and 2009 (Tables 4 and 5). Experiences *in utero* and early in life influence subsequent food and habitat selection by insects, fish, birds, and mammals, including livestock (Provenza and Balph 1988, 1990; Provenza 1995, 2003; Provenza et al. 2003; Davis and Stamps 2004).

We did not evaluate the use of supplements for cattle, but they are essential for effective use of sagebrush by sheep (Dziba et al. 2007). Supplemental protein and energy enhance detoxification processes and better enable sheep and goats to eat sagebrush (Villalba et al. 2002). While sagebrush contains adequate levels of protein and energy relative to cattle requirements in late fall and early winter (8.4% crude protein and 60% total digestible nutrients [TDN]), as well as in late winter and early spring (11.3% crude protein and 74% TDN; wet-lab analyses of sagebrush collected at the research site in March 2006 and December 2007), terpenes in sagebrush elevate requirements for nutrients. The nutritional costs of detoxification occur during a two-step process involving conjugation, often with nitrogenous compounds such as glycine or glucuronic acid, and excretion of detoxified products (Foley et al. 1995; Illius and Jessop 1995). Nitrogen is lost through increased ammonium excretion buffering high acid loads from compounds such as glucuronic acid (Foley et al. 1995). Higher nutritional plane and particularly higher ratios of dietary protein/energy help animals cope with secondary compounds, as they can better withstand the acid loads associated with detoxifying secondary compounds (Illius and Jessop 1995). The pellets, hay, and salt we provided likely helped cattle use sagebrush.

Moreover, their consistent use of sagebrush bark may have helped cattle use sagebrush. In our studies, bark provided crude protein (4.8%) and energy (61.2% TDN; wet-lab analyses of bark collected at the research site in March 2006 and December 2007). Bark likely increased production of saliva, which would buffer acid loads from detoxifying terpenes in sagebrush foliage (Foley et al. 1995). Bark also contains tannins, which enhance protein nutrition and enable animals to eat plants with alkaloids and terpenes (Lyman et al. 2008, 2012; Villalba et al. 2011; Owens et al. 2012a, 2012b). By binding with terpenes, tannins in bark may enable domestic and wild herbivores to better cope with the terpene-rich foliage of sagebrush (Mote et al. 2008). This hypothesis is consistent with landscape-level studies that show ewes with a high preference for sagebrush, a shrub high in terpenes, also consume more bitterbrush, a shrub high in tannins, compared with ewes that have a lower preference for sagebrush (Seefeldt 2005).

In addition to supplemental hay, pellets, and salt, complementarities among forages likely influenced foraging behavior as cattle learned to use sagebrush steppe vegetation. The increased proportion of Douglas rabbitbrush in cells 6–15 compared with cells 1–5, may have decreased use of sagebrush in 2008 (cells 6–10) and 2009 (cells 11–15) as cattle grazed rabbitbrush before sagebrush. While rabbitbrush at the study site contained only modest levels of crude protein (4.4%), it was high in energy (72% TDN; wet-lab analyses of rabbitbrush from the research site in March 2006 and December 2007) and may have enabled cattle to better use sagebrush.

Responses of Vegetation to Grazing

Responses of vegetation varied due to grazing and precipitation. Crop year precipitation, measured from September of the preceding year through June of the following year, increased from 173 mm in 2007, to 198 mm in 2008, to 291 mm in 2009. Differences in vegetation response between cells 1–5 and 6–10, described below, likely reflect timing and amount of precipitation—less precipitation in 2007 and 2008 compared with 2009. Grazing created the opportunity for rejuvenation of sagebrush-steppe, which occurred when environmental conditions became optimal for growth and as plants recovered from use.

In cells 1–5, cover, production, and percent composition of grasses and forbs maintained or declined slightly from 2007 to 2008 and then rebounded to higher levels in 2009. Conversely, shrub cover, production, and percent composition declined from 2007 to 2009 due to cattle use of sagebrush foliage and bark, which caused some mortality of sagebrush. Grasses and forbs in cells grazed in fall 2007 recovered in 2009, likely aided by increased precipitation as well as animal impacts including nutrient inputs (dung and urine) from supplements.

In cells 6–10, the cover and number of grasses and forbs increased as shrub cover and production decreased in cells 1–6 from 2008 to 2009, as occurred with cells 1–5 in 2008 to 2009. Conversely, grass and forb production decreased in cells 6–10 from 2008 to 2009, as occurred with cells 1–5 from 2007 to 2008. The percent composition of grasses and forbs increased in cells 6–10 from 2008 to 2009, similar to that in cells 1–5 from 2008 to 2009, while shrubs showed large drops in percent composition. The changes in cells 6–10 from 2008 to 2009 likely reflect the effects of cattle grazing as well as the amount and timing of precipitation.

In general, fall and winter are good times for livestock to rejuvenate sagebrush-steppe because perennial forbs and grasses are less morphologically and physiologically vulnerable to grazing than in spring and summer. However, severe and repeated fall and winter grazing can remove green tillers, which initiate growth in late summer and early fall, and would otherwise overwinter as green foliage. Grazing can also harm buds in the crowns of grasses and forbs. Both factors can reduce the vigor of plants the following spring and summer, especially in the absence of adequate precipitation and optimal conditions for plant re-growth (Briske and Richards 1994).

In a 2-yr study following encouraging results by Staggs (2006), who used sheep to rejuvenate sagebrush steppe, Woodland (2007) found that 1) the abundance of Wyoming big sagebrush was reduced 66% by grazing with sheep during fall; 2) the number of age classes of Wyoming big sagebrush increased slightly even 1 yr following grazing; 3) the relative abundance of herbaceous species increased (grasses 43%, forbs 60%, total [grasses+forbs] 51%); and 4) plant species diversity increased 61% overall. During a 4-yr study from 2006 to 2009, Guttery (2010) found that 1) big sagebrush cover was reduced by 69% by sheep grazing; 2) grass and forb cover decreased below initial levels in 2006 (–10.6% ± 0.84) and 2007 (–8.1% ± 0.61), and then increased in both 2008 (+9.6% ± 0.72) and 2009 (+14.3% ± 1.22). Guttery (2010) concluded sheep grazing can improve sage-grouse brood-rearing habitat.

Moisture and temperature regimens during and after grazing affect the degree to which grazing positively or adversely affects production of forbs and grasses the year after grazing. Woodland (2007) found that fall grazing increased grasses and forbs by 43% and 60%, respectively, the year after grazing. His results are consistent with our findings in cells 1–5 and cells 6–10 in 2008–2009. On the other hand, our findings in cells 1–5 in 2007–2008, and those of Guttery (2010), suggest that fall grazing decreased production of perennial forbs and grasses the year after grazing and increased production thereafter. These differences likely are due at least in part to dissimilar growing conditions. Regardless, we caution against grazing the same areas repeatedly during fall and winter due to possible cumulative adverse impacts on over-wintering tillers and subsequent growth of grasses and forbs. Given the amount of sagebrush landscape that needs rejuvenating, that is not an issue. Finally, all of the aforementioned findings are consistent with the fact that winter browsing of shrubs repeatedly by mule deer and elk leads to landscapes dominated by grasses and forbs, while grazing by cattle in late spring and early summer encourages stands of shrubs to the detriment of grasses and forbs (Austin 2000).

Livestock as a Management Alternative

Grazing is an alternative to costly conventional methods of sagebrush control. Typical cost $\cdot$ hr^{-1} is high for chaining ($190), rotary mechanical ($100), prescribed fire ($110), herbicide ($70), and disking ($170; Nevada National Resources Conservation Service). These traditional brush management methods are not only cost-inefficient, they must be repeated as sagebrush re-establishes. Mechanical and chemical practices can be detrimental to ecological health, they depend on costly fossil fuel inputs, and they are often risky from a public safety standpoint. In addition, fire is either risky or poses a public safety conundrum due to threat of wildfire and smoke management.

A low-cost alternative is to fashion systems of management in which locally adapted animals use sagebrush as fall and winter forage to reduce costs of feeding and to enhance growth of grasses and forbs during spring and summer. Rather than feeding hay on meadows, which many ranchers do during winter, feeding hay on sagebrush-dominated landscapes during fall and winter can facilitate pasture-wide use of sagebrush as a forage resource for cattle. Such practices enable ranchers to feed roughly half the hay (7 vs. 13 kg $\cdot$ head $\cdot$ d^{-1}), which greatly reduces winter feeding—the principal cost of ranch operations (Gerrish 2010). Sagebrush becomes a forage resource to be valued rather than a "weed" to be eliminated at great cost, as Matt Carter has found in Oregon (Matt Carter, Crown Cattle Company, personal communication).

We propose livestock grazing as an ongoing part of managing sagebrush-steppe. In that sense, livestock are no longer viewed as a "tool" to "target graze" a landscape. By using sagebrush-steppe annually, creating herds of livestock that can use sagebrush, and moving the locations where they forage across the landscape, livestock can create mosaics of habitat—greatly increasing patchiness and edge effects—to meet needs of cattle and various species of wildlife at different times of the year. Strategically rejuvenating as little as 5% of the sagebrush-steppe landscape for both wildlife and livestock had large economic benefits at Deseret Land & Livestock (Rick Danvir, personal communication). The secondary benefits from improved rangeland condition and productivity include more resilient local ecosystems that provide sustainable, long-term habitat benefits for both livestock and wildlife (Provenza 2008).

The key to maintaining and improving sagebrush ecosystems is disturbance—graze it to save it—and our results suggest that can be accomplished with cattle as well as sheep. We have removed the main disturbances that shaped sagebrush steppe ecosystems historically, namely fire and large herbivores, leading to a loss of biodiversity and ability of rangeland systems to respond favorably to wildfire and other natural disturbances. The removal of fire as a major disturbance, combined with historic and currently repetitious livestock grazing during the critical growth stages of perennial forbs and grasses, has shifted the composition of sagebrush steppe plant and animal communities (Winward 1991). Unlike outcome-based chemical and mechanical brush management methods, which must be repeated at great cost and pay no attention to managing processes, grazing can be integrated into the annual cycles of livestock and landscape management to create mosaics across landscapes to improve habitat for wildlife including sage-grouse (Guttery 2010). While grazing kills some shrubs, it also prunes shrubs that can then respond favorably to moisture, resulting in reduced shrub cover while retaining live shrubs. Using livestock mouths, rather than steel and chemicals, can benefit plants, animals, and people.

The timing of breeding/calving will determine if cattle can be used for winter grazing and brush management treatments. For cattle managers who calve in winter, this approach is less likely to work due to high demands for energy and other nutrients during late gestation and lactation. For managers who calve in late spring and early summer, however, cattle are in their first and second trimesters of pregnancy during fall and winter, so their nutritional requirements for fetal growth are low. Native herbivores such as deer and elk that calve in May and June eat mature forbs and grasses and as much as one-third of their diet is sagebrush during winter, as is the case with sheep (Gade and Provenza 1986). Calves exposed *in utero* to high fiber diets consume and digest more high-fiber diets than calves exposed *in utero* to low fiber diets (Wiedmeier et al. 2012). Greater digestible dry matter intake is important for pregnant cows and their offspring that winter under extensive conditions on dormant forages where their energy requirements are only marginally satisfied for many months. Experiences *in utero* and early in life likely enable cows and their offspring to better use dormant forages during winter. Our findings suggest the same is true for cattle that learn to eat sagebrush in fall and winter.

MANAGEMENT IMPLICATIONS

Our research and the findings of others suggest that grazing by livestock in fall and winter can be effective, biologically and economically, and can increase grasses and forbs while decreasing sagebrush. In contrast to chemical and mechanical treatments or prescribed fire, integrating livestock grazing into landscapes is a way to fashion systems of management in which locally adapted animals use sagebrush and other shrubs as fall and winter forage to reduce the costs of feeding and to enhance the growth of grasses and forbs during spring and summer.

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