Natural Resources and Environmental Issues

Volume 17 *Threats to Shrubland Ecosystem Integrity* Article 23

2011

Moderating Livestock Grazing Effects on Plant Productivity, Nitrogen and Carbon Storage

John Carter
Environmental and Engineering Solutions, LLC

Julie Chard
Castilleja Consulting, Inc.

Brandon Chard
Castilleja Consulting, Inc.

Moderating Livestock Grazing Effects on Plant Productivity, Nitrogen and Carbon Storage

John Carter Ecologist, Environmental and Engineering Solutions, LLC, Mendon, Utah; **Julie Chard** Plant Scientist, and **Brandon Chard** Environmental Engineer, Castilleja Consulting, Inc., Hyrum, Utah

ABSTRACT

Multi-year studies of plant communities and soils in the Bear River Range in southeastern Idaho and northeastern Utah found reduced ground cover and herbaceous production in areas grazed by livestock when compared to reference values or long-term rested areas. Reductions in these ecosystem components have lead to accelerated erosion and losses in stored carbon and nitrogen. Restoration of these ecosystem components, with their associated carbon and nitrogen storage, is possible by application of science-based grazing management.

In Monaco, T.A. et al. comps. 2011. Proceedings – Threats to Shrubland Ecosystem Integrity; 2010 May 18-20; Logan, UT. Natural Resources and Environmental Issues, Volume XVII. S.J. and Jessie E. Quinney Natural Resources Research Library, Logan Utah, USA.

INTRODUCTION

During the past two decades, the role of carbon emissions in climate change has heightened interest in carbon sequestration as a means of mitigating climate change (FAO 2009). Forests sequester 86 percent of the planet's above-ground carbon and 73 percent of the planet's soil carbon (Sedjo 1993). Studies conducted on the Wasatch-Cache National Forest in the Bear River Range in Idaho and Utah found that ground cover and herbaceous vegetation production were reduced at sites grazed by livestock when compared with sites that had been rested for long periods or with reference values. Additionally, the loss of ground cover in grazed areas has led to accelerated soil erosion. Studies of soil organic matter, carbon, and nitrogen were conducted since erosion of the surface soils could have resulted in loss of these constituents or displacement to other locales, where mineralization could be increased by greater exposure to oxygen, light and water. For example, carbon losses from soil erosion can occur by reductions in soil productivity in the eroding areas (Schuman and others 2002).

Worldwide, soil organic matter contains three times as much carbon as the atmosphere (Allmaras and others 2000; ESA 2000; Flynn and others 1960). Rangelands have been estimated to store 30 percent of the world's soil carbon with additional amounts stored in the associated vegetation (Grace and others 2006; White and others 2000). Past rangeland use in the United States has led to losses in soil carbon (FAO 2009; Follett and others 2001). It is estimated that 73 percent of rangelands worldwide have suffered soil degradation (WOCAT 2009). This is significant in the eleven western states (Arizona, California, Colorado, Idaho, Montana, New Mexico, Nevada, Oregon, Utah, Washington, and Wyoming), where 305,000,000 acres of public land (National Forests, National Parks, National Wildlife Refuges, Bureau of Land Management, state and county lands) are leased for grazing livestock. An additional 220,000,000 acres of Indian reservations and private lands in these states are also grazed by livestock (Wuerthner and Matteson 2002).

Soil organic carbon is an important source of energy that drives many nutrient cycles. Increases in soil organic matter lead to greater pore spaces and more soil particle surface area which retains more water and nutrients (Tisdale and others 1985). Soil organic carbon, which makes up about 50 percent of soil organic matter, is correlated with soil fertility, stability, and productivity (Herrick and Wander 1998). Soil organic carbon and nitrogen decline in concentration from surface to subsoil with the highest rates of mineralization activity occurring in the top 2.5 cm of soil and beneath vegetation (Charley and West 1977; Yang and others 2010).

The loss of topsoil as a result of accelerated erosion resulting from livestock grazing has been well documented and affects these more organic and nutrient-rich surface layers first. Livestock grazing can compact the soil, reduce infiltration, and increase runoff, erosion, and sediment yield (Ellison 1960; Warren and others 1985). White and others (1983) found that sediment yield was 20-fold higher in a grazed watershed than in an un-grazed watershed. Numerous studies have observed severe erosion in the western United States when comparing heavily grazed areas to un-grazed areas (Cottam and Evans 1945; Gardner 1950; Kauffman and others 1983; Lusby 1979). There are also a number of extensive literature reviews on this topic that describe the impact of livestock grazing on soil stability and erosion (Fleischner 1994; Gifford and Hawkins 1978; Jones 2000). Removal of plant biomass and lowered production resulting from livestock grazing can reduce soil fertility and organic matter content (Trimble and Mendel 1995).

The grazing of livestock accelerates the rate of conversion of vegetation to gaseous forms of emissions. West (1983) noted that grazing and fire serve to accelerate the recycling of ash elements and result in gaseous losses of nitrogen. West (1981) noted that nearly all the nitrogen returned in animal feces and urine is lost in gaseous forms. Worldwide, livestock production accounts for about 37 percent of global anthropogenic methane emissions and 65 percent of anthropogenic nitrous oxide emissions. Methane emissions from cattle range from 6 to 7 percent of forage consumed (FAO 2006).

METHODS

Study Area

The Bear River Range occurs in the Caribou-Targhee National Forest in Idaho and in the Uinta-Wasatch-Cache National Forest in Utah (figure 1). The Utah portion contains 28 allotments that are grazed by cattle or sheep. The portion of the Bear River Range in Idaho contains 26 allotments grazed by cattle or sheep. Livestock have grazed here since the late 1800's. Grazing management has relied on increasing the number of water developments or rotation grazing systems. Authorized utilization levels range up to 55 percent (USDA 2004; USDA 2005). In the North Rich allotment, where the production and soil chemistry data were collected, a three pasture rest-rotation grazing system was implemented in the 1970's and abandoned a few years later due to fence maintenance issues. In a 2004 Forest Service decision (USDA 2004), the system was reinstated, but has not yet been implemented on the ground. The permitted stocking rate has remained essentially unchanged with season-long grazing since the 1960's with some year-to-year variation based on drought or permittee needs and the short-term implementation of the rest-rotation system.

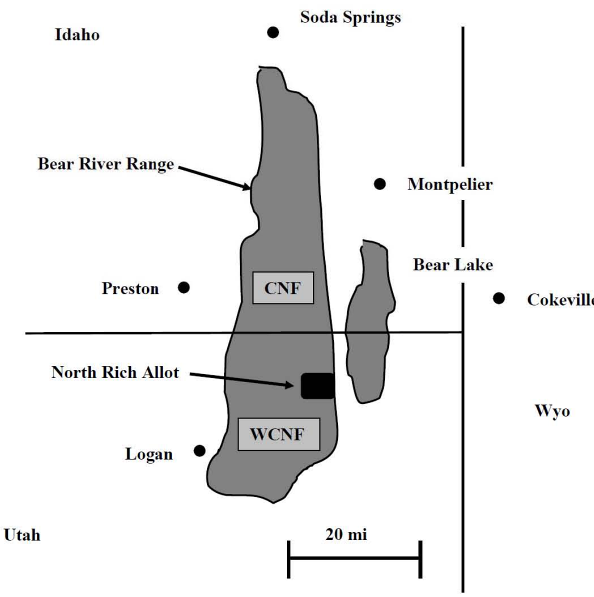

Figure 1. Map of Study Area.

Elevations range from 5,000 to near 10,000 feet with precipitation ranging from 12 inches at lower elevations to 40 inches at the higher elevations. Geology is a combination of karst and sedimentary types with dominant vegetation consisting of Douglas fir, mixed-conifer, aspen, mountain big sagebrush and mountain brush. Topography is steep with narrow valley bottoms and large, open basins on the crest of the range with rolling foothills in sagebrush-steppe at lower elevations (USDA 2003a; USDA 2003b). Under constant grazing pressure by livestock, plant communities have been altered with sensitive native bunchgrasses being replaced by more grazing-tolerant grasses and forbs being dominated by less palatable species.

Ground Cover Studies

Ground cover and soil surveys were conducted during the period 1990 to 2008. These were initially focused on two allotments in the Utah portion of the Bear River Range and then were expanded in 2001 to include locations in the Idaho portion of the Range. Locations were selected in mountain big sagebrush, aspen or mixed-conifer representative of lands accessible to cattle with gentle slopes and available water. Two methods of measuring ground cover were used. A rapid assessment method using a 34-inch diameter hoop placed at 10 yard intervals along a 100 yard transect was used for most data collection due to the large number of sites measured. Ground (basal) cover of grasses, forbs, shrubs, litter, rock, crust and bare ground were estimated to the nearest 1 percent. Ocular estimates were calibrated using a standard area card that was 1 percent of the plot area for comparison. A second method employed a nested frequency frame to collect more intensive data and to validate the ocular estimates. Five 100-foot radial transects were oriented from the center point. Along each transect, a nested frequency frame with eight points was placed at five foot intervals, recording ground cover "hits" for each point. A total of 800 points were recorded for each site surveyed. Sites surveyed by both methods gave similar results. Time savings by using the ocular method were significant in that the ocular method took approximately 30 minutes at a site, while the nested frequency method took over two hours at a site.

Production Studies

Herbaceous (grass and forb) production was determined by clipping plots at each site. Plots were clipped in the North Rich allotment in 2001 (five plots per site), 2004 (three plots per site) and 2005 to 2007 (one caged plot per site). The 2001 and 2004 plots were clipped prior to livestock entry into the allotment. The 2005 to 2007 plots were clipped after the grazing season. These plots were protected inside utilization cages and represent un-grazed samples. Adjustments for plant phenology were applied to the plot data from the 2001 and 2004 samples. Post-grazing samples needed no phenology adjustments since the growing season was complete prior to sampling. A 36" x 36" plot frame was used. Samples were clipped to 1/2" above the soil surface, placed in Ziploc™ bags and returned to the office for air drying. Samples were initially air dried to a constant weight in a warm space at about 80° F resulting in the clipped samples being brittle and easily broken. Subsequent samples were air dried to this textural endpoint. Based on oven-drying of subsamples, the air-dried samples contained about 5 percent moisture. Once dry, samples were weighed on an electronic balance sensitive to 0.1 gram.

Soil Studies

Soil samples were taken of the top 4 inches below the litter layer. Triplicate subsamples were taken at each ground cover transect location and combined. These were placed in bags and kept in a cooler with ice until delivered to the Utah State University Analytical Laboratory in Logan, Utah. Methods of analysis included determination of soil organic matter by loss on ignition, total organic carbon by the combustion method and total nitrogen by the Kjeldahl method (Miller and others 1997). Soil pits were excavated at each site and inspected for root density, soil stability and organic matter.

RESULTS

Literature - Ground Cover and Production Data

A search of agency records was used to determine the potential and historical basal ground cover of grasses, forbs, shrubs, litter, rock, biological crust, and herbaceous production for the plant communities of interest including aspen, conifer and mountain big sagebrush. These are presented and used for comparison with the results of surveys for ground cover, herbaceous production and soil chemistry recently conducted in the Bear River Range.

Ground Cover

The Wasatch-Cache National Forest (WCNF) provided data from nested frequency transects considered representative of potential ground cover (USDA 1996). Potential ground cover values for aspen ranged from 90 to 98 percent and mountain big sagebrush ranged from 81 to 96 percent (table 1). There were no potentials given for mixed-conifer forest. Caribou National Forest (CNF) plot data for percent bare soil (average of maximum values, average of all values, and average of minimum values) were summarized from historical range analyses (1959 to 1976) for the Montpelier Ranger District, which includes the Bear River Range (USDA 1997). The maximum ground cover values found in those range analyses are consistent with the highest values used as reference in the WCNF and appear to represent potential values of 98 percent for aspen, 94 percent for mountain big sagebrush and 98 percent for mixed conifer (table 1).

Table 1. Forest Service ground cover determinations, percent.

Source/Vegetation Type	Aspen	Mountain Big Sagebrush	Conifer
	Reference or Potential Values – Ungrazed Areas		
WCNF (USDA 1996)	90 – 98	81 – 96[a]	--
USDA (1997)	98	94	98
	Grazed Areas		
WCNF (1962)	79	59/70[b]	75
WCNF (USDA 2004)	67	36 – 87	--
CNF (USDA 1997)	98/62/85[c]	94/39/70	98/67/87

[a]Includes Silver sagebrush (*Artemisia cana*) and mountain big sagebrush (*Artemesia tridentata vaseyana.*
[b]*Hinger* number is from “unsuitable” lands that received lower grazing intensity due to slope or distance to water.
[c]Maximum / minimum / average from CNF range analysis plots. Maximum and minimum plots averaged from all locations. Average is the average for all plots across all locations.

Ground cover conditions in these plant communities during Forest Service range analysis surveys in areas grazed by livestock were well below these potentials (table 1). Ground cover in aspen communities in the North Rich allotment (1961 and 1962) was 79 percent, while mountain big sagebrush was 59 percent and conifer was 75 percent. Historical data for sites in areas grazed by livestock in the CNF averaged 85 percent ground cover in aspen, 70 percent in mountain big sagebrush, and 87 percent in conifer sites, with much lower values at many sites. Range analysis data for the North Rich allotment from the 1970’s for sagebrush, meadow and aspen communities, averaged across all sites, had average ground cover of 56 percent (USDA 1989). WCNF data collected in 2002 for the North Rich allotment found 67 percent ground cover in aspen and 36 to 87 percent in mountain big sagebrush (USDA 2004).

Production

Potential herbaceous plant community production values (table 2) were taken from Natural Resources Conservation Service (NRCS) ecological site descriptions that best matched the aspen and mountain big sagebrush sites surveyed (USDA 1992a,b,c). Based on these descriptions, during average precipitation years, mountain stony loam aspen communities produce 2,150 to 2,250 lbs/acre consisting of 45 percent grass and 30 percent forbs. Mountain loam mountain big sagebrush communities produce 1,600 to 2,000 lb/acre with 80 percent grasses and 5 percent forbs. Mountain shallow loam mountain big sagebrush communities produce 1,000 to 1,100 lb/acre with 50 percent grass and 5 percent forbs. No ecological site descriptions directly applicable to the mixed-conifer were found.

Given the maximum, average, and minimum production values published by the CNF (USDA 1997) and the average grass and forb percentages from the source data (table 2), herbaceous production was calculated for the Caribou National Forest. Based on this calculation, aspen communities produced a maximum of 1,297 lb/acre per year with an average of 654 lb/acre and a minimum of 297 lb/acre. Mountain big sagebrush communities produced a maximum of 914 lb/acre per year with an average of 453 lb/acre and a minimum of 153 lb/acre. Conifer communities produced a maximum of 780 lb/acre per year with an average of 348 lb/acre and a minimum of 107 lb/acre. Historical data from the 1961 and 1962 range analyses for the North Rich allotment found that aspen communities produced 241 lb/acre grasses and 443 lb/acre forbs for a total herbaceous production of 684 lb/acre. Mountain big sagebrush communities produced 122 lb/acre of grass and 163 lb/acre of forbs for a total herbaceous production of 285 lb/acre. Mixed-conifer communities produced 157 lb/acre grass and 253 lb/acre forbs for a total herbaceous production of 410 lb/acre.

Ground Cover Surveys

Surveys of ground cover conditions were conducted throughout the Bear River Range in Idaho and Utah (table 3). In 2001, 41 grazed and three un-grazed mountain big sagebrush locations were surveyed in the CNF. Mountain big sagebrush locations grazed by livestock had an average of 46.7 percent ground covercompared to 85.2 percent ground cover in un-grazed (livestock inaccessible or long-term rested) locations. Basal cover of grasses averaged 5.2 percent in grazed locations compared to 12.9 percent in un-grazed locations.

Table 2. Potential and historical herbaceous production, lb/acre.

Vegetation Type	Favorable Yr	Average Yr	Low Yr
Mountain stony loam aspen (USDA 1992a)	2900 – 3000 45/30[a]	2150 – 2250 45/30	1400 – 1500 45/30
CNF Aspen (USDA 1997)[b]	--	1908/962/437 20/48	--
Mountain loam mountain big sage (USDA 1992b)	1800 – 2200 80/5	1600-2000 80/5	1200 – 1500 80/5
Mountain shallow loam mountain big sage (USDA 1992c)	1600 – 1700 50/5	1000 – 1100 50/5	500 – 600 50/5
CNF Mountain big sage (USDA 1997)[b]	--	1758/872/295 15/37	--
CNF Conifer (USDA 1997)[b]	--	1182/527/162 19/47	--
WCNF Aspen[c]	--	--	241/443/684
WCNF Mountain big sage[c]	--	--	122/163/285
WCNF Conifer[c]	--	--	157/253/410

[a]Percent production by grasses/forbs.
[b]CNF data are from 1959 – 1976 period and are assumed to represent the long-term average. Data are maximum/average/minimum production, including grasses, forbs and shrubs. Percent production by grasses and forbs are the average across all sites.
[c]Values for the WCNF are from range analysis data sheets for the North Rich allotment for 1961 and 1962 and are in order: grasses/forbs/total herbaceous production. These data are from a below average precipitation year.

Additional locations were surveyed in the Utah portion of the Bear River Range in 2001, 2004 and 2005. These were principally in the North Rich allotment. They included three long-term un-grazed sites and 10 grazed sites in mountain big sagebrush; six grazed sites in mixed-conifer, three of which had been logged decades earlier and as a result had open canopy, and three with high canopy cover; and six grazed sites in aspen. Results of ground cover determinations at these locations are provided in table 3, while reference values are found in table 1. Grazed mountain big sagebrush locations had average ground cover of 61.8 percent compared to 94.4 percent in the un-grazed sites and 96 percent in reference sites. Grass basal cover in grazed locations averaged 3.6 percent compared to 38.9 percent in un-grazed locations. Six grazed aspen sites had 59.6 percent average ground cover compared to 98 percent for reference sites. Three mixed conifer sites that had been logged and continued to be grazed had average ground cover of 61.1 percent while three grazed closed-canopy mixed conifer sites had average ground cover of 92.2 percent. The only data available for comparison in mixed-conifer was the CNF maximum ground cover average of 98 percent in coniferous timber. The values for all grazed sites were much lower than those for either the un-grazed sites or the reference values in table 1

Vegetation Production Surveys

Three surveys have been conducted to determine production of herbaceous vegetation in the North Rich allotment. In 2001, the survey included measurement of ground cover and plot clippings to determine production of herbaceous vegetation in mountain big sagebrush and open canopy mixed-conifer areas. In 2004, ground cover and production was assessed in additional aspen, mountain big sagebrush and high canopy mixed-conifer locations. During the period 2005 to 2007, utilization cages were installed in additional aspen, mountain big sagebrush and mixed-conifer locations to assess utilization. Caged plots were located in sites representative of average grass cover and clipped to determine production.

Table 3. Results of 2001 to 2005 ground cover surveys, percent.

Vegetation Type/Forest/Yr	Rock	Crust	Litter	Grass	Forbs	Bare Ground	Total Ground Cover
Ungrazed Reference Areas							
Mtn big sage (CNF 2001 n=3)[a]	1.4	3.5	63.6	12.9	3.9	14.8	85.2
Mtn big sage (WCNF 2001 n=3)	2.6	0.3	41.8	38.9	10.9	5.6	94.4
Grazed Areas							
Mtn big sage (CNF 2001 n=41)	2.0	0.1	34.6	5.2	5.0	53.3	46.7
Mtn big sage (WCNF 2001, 2004, 2005 n=10)	0.9	0	53.7	3.6	3.6	38.2	61.8
Aspen (WCNF 2004, 2005 n=6)	2.5	0.3	70.7	1.7	2.3	40.4	59.6
Conifer (2001 n=3)[b]	1.1	0	42.5	7.7	9.8	38.9	61.1
Conifer (2004 n=3)[c]	1.0	0.1	89.6	0.6	0.9	7.8	92.2

[a] n = number of transect locations.
[b]Conifer area logged and thinned in prior years, low canopy cover.
[c]Conifer with no recent thinning, high canopy cover.

Table 4. Grass and forb production (lb/acre) in the North Rich Allotment compared to potentials.

Vegetation Type and Year	Ppt.	Grass			Forb		
		Potential	Measured	Percent of Potential	Potential	Measured	Percent of Potential
Ungrazed Reference Areas							
Mtn big sage - 2001 (n=1)[a]	<Avg	1080	2104	195	68	94	139
Mtn big sage - 2001 (n=2)[b]	<Avg	275	432	157	28	38	138
Grazed Areas							
Mtn big sage - 2001 (n=3)	<Avg	275	118	43	28	154	560
Mtn big sage - 2004 (n=3)	Avg	525	98	19	53	159	303
Mtn big sage - 2005 (n=4)	>Avg	825	447	54	83	384	465
Mtn big sage - 2006 (n=3)	Avg	525	178	34	53	108	206
Mtn big sage - 2007 (n=2)	Avg	525	210	40	53	89	170
Aspen - 2004 (n=3)	Avg	990	140	14	660	--	--
Aspen - 2005 (n=3)	>Avg	1328	536	40	885	291	33
Aspen - 2007 (n=1)	Avg	990	160	16	660	96	15
Conifer - 2001 (n=3)[c]	<Avg	--	107	--	--	204	--
Conifer - 2004 (n=3)[d]	Avg	224	14	6	556	101	18
Conifer - 2006 (n=2)[d]	Avg	224	6	3	556	76	14
Conifer - 2007 (n=1)[d]	Avg	224	0	0	556	4	1

[a]Mountain loam site.
[b]Mountain shallow loam sites.
[c]Open canopy mixed-conifer.
[d]Closed canopy mixed-conifer.

Precipitation records for climate stations in or adjacent to the Bear River Range were reviewed to find a station with complete data for the period of interest. Based on this review, the Richmond, Utah, station provided the most complete record, indicating that 2001 was a below average precipitation year, while 2005 was above average (WRCC 2010). The other years were near average, being slightly above or below the long-term average. Comparisons of measured production to potential were based on this determination.

Current herbaceous production in grazed areas (table 4) was compared to potential and historical Forest Service values (table 2). Grass production measured in aspen communities during the 2000's in the North

Rich allotment ranged from 140 to 160 lb/acre during average precipitation years compared to a potential of 990 lb/acre. Forest Service range analysis data collected in the 1960's found an average of 241 lb/acre (WCNF 1962). Forb production in aspen communities was measured at only one site during an average year, finding 96 lb/acre compared to a potential of 660 lb/acre and the 1960's Forest Service data of 443 lb/acre. Mountain shallow loam big sagebrush communities produced 98 to 210 lb/acre of grass during average years compared to a potential of 525 lb/acre and the 1960's Forest Service amount of 122 lb/acre. Forb production was 89 to 159 lb/acre compared to potential of 53 lb/acre and the historical amount of 163 lb/acre during the 1960's Forest Service range analysis surveys. Mixed-conifer communities produced 0 to 14 lb/acre of grasses per year compared to the 1960's Forest Service amount of 157 lb/acre, while forbs were measured at 4 to 101 lb/acre compared to the historical amount of 253 lb/acre. If the maximum values found in the CNF range analysis for conifer were used as potentials, current production in the North Rich allotment mixed-conifer would be well below those values. It should be emphasized that the 1960's Forest Service data from the North Rich allotment was collected during below average precipitation years, yet in most cases exceeded what is found today during average precipitation years, indicating that a decline in production may have occurred since the 1960's.

The only un-grazed, or long-term rested sites surveyed for herbaceous production were in mountain big sagebrush vegetation types (table 5). The un-grazed mountain loam site produced a total of 2,198 lb/acre total herbaceous vegetation in 2001, a below average year, compared to potential of 1,148 lb/acre. The un-grazed mountain shallow loam sites produced 470 lb/acre during a below average year compared to potential of 303 lb/acre. Grazed sites in mountain shallow loam produced 272 lb/acre in 2001, a below average year, with a range of 257 to 299 lb/acre during average years, compared to potential of 578 lb/acre. No data were collected in grazed mountain loam mountain big sagebrush areas.

Table 5. Herbaceous production surplus or deficit (lb/acre) compared to potential.

Vegetation Type and Year	Ppt.	Total Herbaceous Production		Surplus or Deficit lb/acre
		Potential	Measured	
Ungrazed Reference Areas				
Mtn big sage - 2001 (n=1)[a]	<Avg	1148	2198	1051
Mtn big sage - 2001 (n=2)[b]	<Avg	303	470	168
Grazed Areas				
Mtn big sage - 2001 (n=3)	<Avg	303	272	-31
Mtn big sage - 2004 (n=3)	Avg	578	257	-321
Mtn big sage - 2005 (n=4)	>Avg	908	831	-77
Mtn big sage - 2006 (n=3)	Avg	578	286	-292
Mtn big sage - 2007 (n=2)	Avg	578	299	-279
Aspen - 2004 (n=3)	Avg	1650	--	--
Aspen - 2005 (n=3)	>Avg	2213	827	-1386
Aspen - 2007 (n=1)	Avg	1650	256	-1394
Conifer - 2001 (n=3)[c]	<Avg	--	311	--
Conifer - 2004 (n=3)[d]	Avg	780	115	-665
Conifer - 2006 (n=2)[d]	Avg	780	82	-698
Conifer - 2007 (n=1)[d]	Avg	780	4	-776

[a]Mountain loam site.
[b]Mountain shallow loam sites.
[c]Open canopy mixed-conifer.
[d]Closed canopy mixed-conifer.

Table 6. Soil organic matter, carbon, nitrogen and nitrate-N.

Year	Vegetation Type	Organic Matter percent	Organic Carbon percent	Total Nitrogen percent	Nitrate-N ppm
1992	Mtn big sage – grazed (n=7)	9.9/71[a]	--	--	--
1992	Mtn big sage – ungrazed (n=3)	14.0	--	--	--
1995	Mtn big sage – grazed (n=5)	12.5/69	--	0.3/60	6.4/56
1995	Mtn big sage – ungrazed (n=2)	18.0	--	0.5	11.4
2001	Conifer – heavy grazing (n=2)	--	2.85/50	0.12/46	1.35/56
2001	Conifer – moderate grazing (n=2)	--	4.25/75	0.21/81	1.7/71
2001	Conifer – ungrazed (n=2)	--	5.65	0.26	2.4

[a]This value is 71% of the ungrazed value, similar for each /value.

Soil Chemistry Surveys

Soil samples were taken in 1992 and 1995 in mountain big sagebrush type, and in 2001 in mixed-conifer (table 6). In 1992, only soil organic matter (OM) was determined, with the un-grazed reference sites containing 14 percent OM and the grazed sites containing 9.9 percent OM. In 1995, sampling found 18 percent OM and 0.5 percent total nitrogen (N) in un-grazed reference sites compared to 12.5 percent OM and 0.3 percent N in the grazed sites. The mixed-conifer sites showed similar patterns of reduced soil organic matter, total nitrogen and nitrate as well as reductions in litter in grazed sites when compared to un-grazed sites. The heavily grazed site was nearest the water source (500 ft), with the moderately grazed site more distant from water (2000 ft), and the un-grazed control was in an area not accessed by livestock approximately 10,000 ft from the water source. The un-grazed site averaged 5.65 percent organic carbon compared to 4.25 percent in the moderately grazed site and 2.85 percent in the heavily grazed site. Soil total nitrogen ranged from 0.26 percent in the un-grazed site to 0.21 percent in the moderately grazed site and 0.12 percent in the heavily grazed site. Nitrate-nitrogen averaged 2.4 ppm at the un-grazed site, 1.7 ppm at the moderately grazed site and 1.35 ppm at the heavily grazed site. Litter depth averaged 2 inches in the un-grazed site, 0.8 inches in the moderately grazed site and 0.5 inches in the heavily grazed site. Both grazed sites had areas of bare soil, while ground cover was 100 percent at the un-grazed site. Only the un-grazed site had a mycorrhizal layer at the litter/soil interface.

DISCUSSION

Forest Service reference data and NRCS ecological site descriptions provided a basis for comparison to current ground cover and herbaceous vegetation production in the Bear River Range. Ground cover potential values were obtained from the Wasatch Cache National Forest Rangeland Health EIS (USDA 1996), which presented ranges of ground cover for various plant communities including mountain big sagebrush and aspen. Data collected at sites that have been rested from grazing for long periods provided additional information for ground cover at or near potential. Maximum ground cover data from the Caribou National Forest's "Hierarchical Stratification of Ecosystems for the Caribou National Forest" (USDA 1997) sites were also considered as potentials. These closely aligned with the upper limits of reference published by the WCNF (USDA 1996). These were provided in table 1.

Grazed areas surveyed in mountain big sagebrush, aspen and previously thinned mixed-conifer forest had ground cover ranging from 46.7 percent to 61.8 percent, compared to potential values of greater than 90 percent. Only high canopy mixed-conifer forest, at 92.2 percent ground cover, approached potential. This was likely due to the absence of sufficient forage to attract livestock and thereby reduced the presence of livestock and associated grazing and trampling, which allowed litter to accumulate and cover the soil. When current ground cover was compared to historical Forest Service values from the 1960's, conditions did not appear to be improved and may have declined (table 1; table 3). When measurements were taken with increasing distance from water, ground cover increased, indicating that reduced grazing intensity was correlated with increased ground cover (figure 2).

These reduced levels of ground cover lead to increased soil erosion as predicted by the literature. Analysis of two allotments in the Bear River Range in Idaho used tree and shrub canopy measurements, ground cover data, precipitation values and the

Universal Soil Loss Equation (Ruhe 1975) to determine relative erosion rates at different ground cover values (Carter et al. 2006). The analysis determined that the reduced levels of ground cover in the Bear River Range result in high rates of erosion. At the Caribou National Forest ground cover standard of 60 percent, erosion was up to 15 times higher than background. The levels of ground cover found in this study were near this level and would result in similar high levels of erosion (table 3).

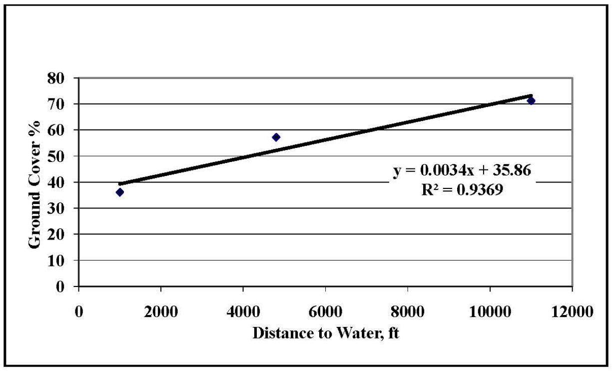

Figure 2. Ground cover vs. distance to water (2004 data).

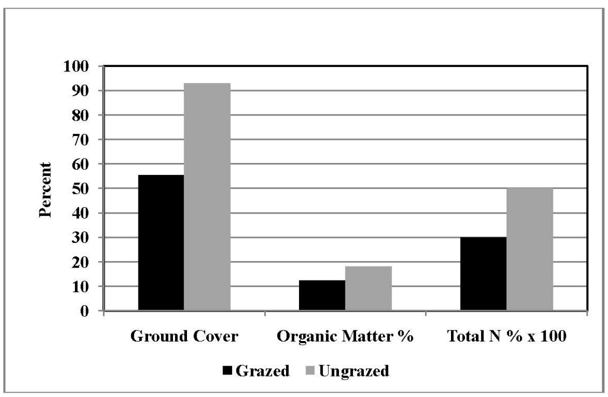

Figure 3. Ground Cover vs. Soil Organic Matter and Total Nitrogen (1995 data).

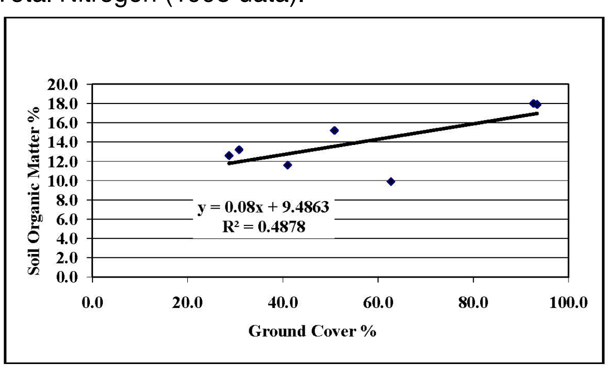

Figure 4. Soil organic matter vs. ground cover (1995 data).

This accelerated erosion carries the nitrogen and carbon contained in surface soils down-gradient, thereby reducing the pool of carbon and nitrogen stored in the forest. Soil samples taken in un-grazed and grazed mountain big sagebrush locations in the Bear River Range in 1992 and 1995 showed that organic matter was reduced by approximately 30 percent, total nitrogen by 40 percent and nitrate-N by 44 percent in grazed areas compared to un-grazed areas (table 6; figure 3). When the 1995 data for soil organic matter and nitrogen were plotted against ground cover, a positive correlation was found, indicating higher ground cover was associated with higher soil organic matter and total nitrogen (figures 4 and 5). A similar pattern of decline of soil organic carbon, total nitrogen, nitrate-nitrogen and litter depth occurred in samples taken from grazed sites in mixed-conifer forest compared to an un-grazed site (table 6; figure 6). The heavily grazed site, when compared to the un-grazed site, showed a decline in organic carbon of 50 percent, total nitrogen by 54 percent, and nitrate-N by 44 percent. Litter depth in the heavily grazed site was 25 percent of that in the un-grazed site and only the un-grazed site had an evident and complete mycorrhizal layer at the litter and soil interface.

Production measurements and comparisons to potential were provided in Table 4. Grass production in un-grazed mountain big sagebrush sites ranged from 157 to 195 percent of potential, while forbs were at 138 to 139 percent of potential. In grazed mountain big sagebrush sites, grass production ranged from 19 to 54 percent of potential, while forbs ranged from 170 – 560 percent of potential, reflecting dominance by non-palatable species, or increasers, which are avoided by livestock. Grasses in grazed aspen sites ranged from 14 to 40 percent of potential production, while forbs ranged from 15 to 33 percent of potential. If the CNF historical maximums were used for comparison, mixed-conifer grass production ranged from 0 to 14 percent of potential and forbs ranged from 1 to 18 percent of potential. When the 2004 grass production data was plotted against ground cover, a positive correlation was found, indicating that grass production increased as distance from water increased. This reflected the reduced intensity of grazing further from the water source (figure 7).

The surplus or deficit of total herbaceous production compared to potential was provided in table 5. The un-grazed site in mountain loam mountain big sagebrush produced a surplus of 1,051 lb/acre and a surplus of 168 lb/acre in the shallow loam sites. No grazed sites produced a surplus compared to potential. The deficit in grazed mountain big sagebrush communities ranged from 77 to 321 lb/acre. The deficit in aspen communities ranged from 1,386 to 1,394 lb/acre. Mixed-conifer, when compared to the maximum values found in the CNF had deficits ranging from 665 to 776 lb/acre. These figures don't take into account the belowground portion of plants.

Holechek and others (2004) reported that total nitrogen in Australian livestock forage ranged from 1.4 to 2.2 percent. Haferkamp and others (2005) found nitrogen concentrations in mixed grass prairie varied through the seasons, ranging from 1.7 percent in spring to 0.75 percent in fall for mixed grasses and forbs. Qiji and others (2008) found that grasses and forbs in lightly degraded areas had carbon content of 42.0 and 42.5 percent and nitrogen content of 1.34 and 1.41 percent, while in heavily degraded areas, carbon declined to 37.3 and 40.5 percent with nitrogen values of 1.31 and 1.38 percent respectively. Based on these literature values for carbon and nitrogen in livestock forage, values of 43 percent carbon and 1.4 percent nitrogen contained in herbaceous plants were used to estimate the potential pool of carbon and nitrogen present in the above-ground portion of herbaceous vegetation sampled. According to West (1983) root masses can constitute up to half the biomass present in sagebrush vegetation types.

The values for carbon and nitrogen content in herbaceous vegetation were applied to the literature values for potential production of herbaceous vegetation in the plant communities found in the Bear River Range to estimate potential storage. Based on this, significant potential for carbon and nitrogen storage exists within the plant communities (table 7). Calculated carbon and nitrogen values based on potential herbaceous production for each vegetation type were compared to long-term un-grazed sites and grazed sites. Long-term un-grazed sites were in a surplus for both carbon and nitrogen while grazed sites were in a deficit. The surplus in mountain big sagebrush un-grazed sites ranged from 72 to 451 lb C/acre and 2.3 to 14.7 lb N/acre. The deficit for mountain big sagebrush sites in grazed areas ranged from 13 to 138 lb C/acre and 0.4 to 4.5 lb N/acre. The deficit in grazed aspen ranged from 596 to 600 lb C/acre and 19.4 to 19.5 lb N/acre. The deficit for mixed-conifer (based on CNF maximum production values) ranged from 286 to 333 lb C/acre and 9.3 to 10.8 lb N/acre.

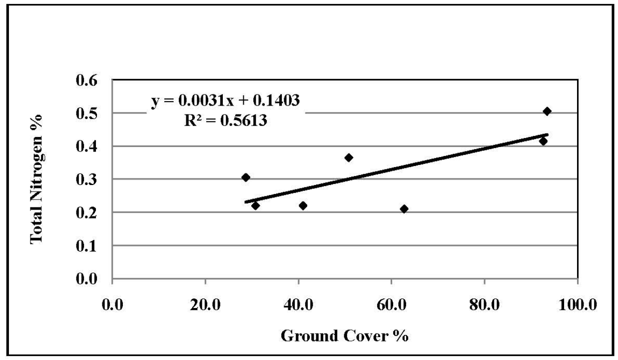

Figure 5. Soil total nitrogen vs. ground cover (1995 data).

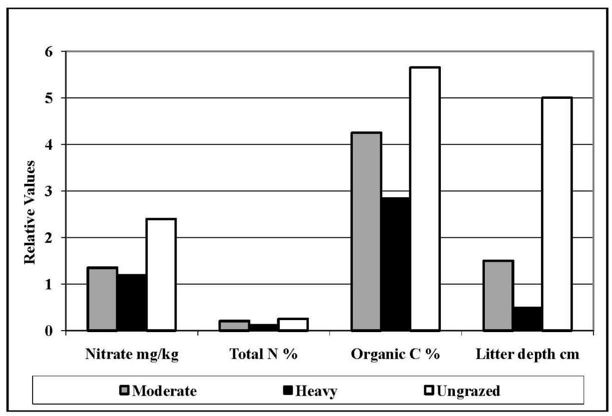

Figure 6. Soil conditions vs. grazing intensity.

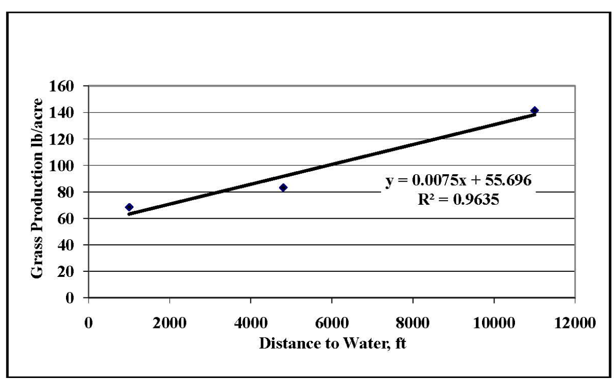

Figure 7. Production of grasses vs. distance to water (2004 data).

Table 7. Surplus or deficit of organic carbon and nitrogen compared to potential.

Vegetation Type	Ppt.	Potential Organic C lb/acre	Estimated Organic C lb/acre	Surplus or Deficit OC lb/acre	Potential Total N lb/acre	Estimated Total N lb/acre	Surplus or Deficit N lb/acre
Ungrazed Reference Areas							
Mtn big sage - 2001 (n=1)[a]	<Avg	494	945	451	16.1	30.8	14.7
Mtn big sage - 2001 (n=2)[b]	<Avg	130	202	72	4.2	6.6	2.3
Grazed Areas							
Mtn big sage - 2001 (n=3)	<Avg	130	117	-13	4.2	3.8	-0.4
Mtn big sage - 2004 (n=3)	Avg	249	111	-138	8.1	3.6	-4.5
Mtn big sage - 2005 (n=4)	>Avg	390	357	-43	12.7	11.6	-1.1
Mtn big sage - 2006 (n=3)	Avg	249	123	-126	8.1	4.0	-4.1
Mtn big sage - 2007 (n=2)	Avg	249	129	-120	8.1	4.2	-3.9
Aspen - 2004 (n=3)	Avg	710	--	--	23.1	--	--
Aspen - 2005 (n=3)	>Avg	952	356	-596	31.0	11.6	-19.4
Aspen - 2007 (n=1)	Avg	710	110	-600	23.1	3.6	-19.5
Conifer - 2001 (n=3)[c]	<Avg	--	134	--	--	4.4	--
Conifer - 2004 (n=3)[d]	Avg	335	49	-286	10.9	1.6	-9.3
Conifer - 2006 (n=2)[d]	Avg	335	35	-300	10.9	1.1	-9.8
Conifer - 2007 (n=1)[d]	Avg	335	2	-333	10.9	0.1	-10.8

[a]Mountain loam site.
[b]Mountain shallow loam sites.
[c]Open canopy mixed-conifer.
[d]Closed canopy mixed-conifer.

These data show that in areas of the Bear River Range surveyed, ground cover, herbaceous production, carbon and nitrogen storage have been reduced below potential and likely continue to decline, whereas areas rested from livestock grazing for long periods have ground cover and production at or near potential and contain a significant reservoir of stored carbon and nitrogen. Rest from grazing has not been provided in the study area, yet is essential to recover degraded plant and soil communities. For example, native bunchgrass species, such as bluebunch wheatgrass (*Pseudoroegneria spicata*) and Idaho fescue (*Festuca idahoensis*), which are key species in sagebrush-steppe ecosystems, require several years of rest following each period of grazing in order to restore their vigor and productivity (Anderson 1991; Clary and Webster 1989; Hormay and Talbot 1961; Mueggler 1975). The recovery of degraded plant and soil communities can take many years, even under total rest (Anderson and Inouye 2001; Orr 1975; Owens and others 1996; Trimble and Mendel 1995).

Grazing management in the study area has relied upon installation of water developments and grazing systems. For example, the North Rich allotment contains over 130 water developments yet ground cover, herbaceous production, soil carbon and nitrogen are well below potential. Stocking rates have not been adjusted to reflect current forage availability and forage consumption rates, yet research has shown that it is reductions in stocking rate that lead to increased production, not grazing systems (Briske and others 2008; Clary and Webster 1989; Holechek and others 1999; Van Poolen and Lacey 1979). Utilization rates commonly used by the Forest Service and other agencies have remained near 50 percent in spite of research that shows utilization levels in the range of 25-30 percent should be used to maintain productivity (Galt and others 2000; Holechek and others 2004).

The Forest Service has not conducted forage capacity surveys since the early 1960's. Galt and others (2000) recommended that grazing capacity surveys should take place at intervals of no more than 10 years and that grazing capacity determinations take into account slope (<30 percent) and distance to water (< 1 mile) limitations. Forage consumption rates currently used by the Forest Service and other agencies underestimate the demand from today's larger cattle by using 26 lb/day, or 780 lb/month forage consumption for an animal unit month (AUM), which is considered to be one cow/calf pair or five sheep with lambs. Today's cow/calf pair weighs approximately 1,680 pounds, while a ewe/lamb pair weighs 275 pounds (Carter 2008). Cattle consume 3 percent of their body weight in air-dry forage per day (USDA 2003c), while sheep consume 3.3 percent (USDA 1965). Applying these rates to the combined weight of the cow/calf pair gives a forage consumption rate of over 50 lb/day or 1,532 lb/month air-dry forage. A similar analysis for sheep leads to a consumption rate of 9.1 lb/day for each ewe/lamb pair, which for five ewe/lamb pairs is 1,380 lb/month air-dry forage. These values are nearly twice those used by the land management agencies for an AUM.

CONCLUSIONS

The analysis presented here illustrates the current degraded state of plant communities and soils in grazing allotments in the Bear River Range. The lack of science-based livestock grazing management has resulted in the loss of native grass and forb production, shifts to less palatable and more grazing-tolerant species, and large decreases in ground cover from potential. The consequence has been increased soil erosion and the loss of carbon and nitrogen storage in soils as well as in the herbaceous components of plant communities. This observed loss in native plant productivity as a result of livestock grazing practices is not unique to the Bear River Range (Catlin and others in press).

Implementing restoration practices and science-based grazing management on the 305,000,000 acres of public lands and 220,000,000 acres of Indian Reservations and private lands grazed by livestock in the eleven western states has the potential to restore native plant communities and store significant amounts of carbon and nitrogen to mitigate the impacts of climate change. Other benefits would include improved watershed function, enhanced water supplies, lowered water treatment costs, and healthy fish and wildlife populations. The costs of continued livestock grazing should be evaluated against the value of these and other restored ecosystem services. Reliance on failed livestock grazing strategies must be reversed and mechanisms must be found to provide for long-term rest sufficient to recover these degraded systems to potential. This can be accomplished through allotment and/or pasture closures through voluntary action, mandate, or by permit buyouts. Education of livestock producers and providing incentives for carbon storage on private lands and Indian Reservations, much like the Conservation Reserve Program or Grassland Reserve Program managed by NRCS may have the potential to offset some of the losses from those lands.

Where livestock grazing continues on public lands, the series of steps below must be taken to ensure that it is sustainable and the plant and soil communities are restored to potential with their associated potential ground cover, production of native species, carbon and nitrogen storage.

Determine available grazing capacity based on surveys of current forage production by desirable herbaceous species and factors such as slope (<30 percent) and distance to water (<1 mile) with areas of sensitive or high erosion hazard soils being eliminated from stocking rate calculations.

Update stocking rates based on conservative utilization rates of 25 to 30 percent and current forage consumption rates of cattle and sheep.

Manage all livestock by herding instead of relying on additional pasture fencing and water developments, which have not succeeded and have resulted in increased range degradation where these have been installed.

Provide adequate rest for plants to recover vigor and productivity after being grazed and before being grazed again. This can require several years of rest for each grazing period. Productivity should be monitored prior to grazing to ensure recovery.

Provide long-term rest for recovery of degraded soil and plant community productivity. Where multiple pastures already exist, single pastures could be excluded from grazing until restored, then grazed again under the preceding principles. When areas are closed, stocking rates must be adjusted downward based on the remaining capacity of the allotment.

REFERENCES

Almaras, R.R.; Schomberg, H.H.; Douglas, C.L. 2000. Soil organic carbon sequestration potential of adopting conservation tillage in U.S. Croplands. Journal of Soil and Water Conservation. 55(3): 365-373.

Anderson, J.E.; Inouye, R.S. 2001. Long term vegetation dynamics in sagebrush steppe at the Idaho National Engineering and Environmental Laboratory. Ecological Monographs. 71: 531-556.

Anderson, L.D. 1991. Bluebunch wheatgrass defoliation, effects and recovery – a review. BLM Technical Bulletin 91-2. Bureau of Land Management, Idaho State Office, Boise, Idaho.

Briske, D.D.; Derner, J.D.; Brown, J.R.; Fuhlendorf, S.D.; Teague, W.R.; Havstad, K.M.; Gillen, R.L.; Ash, A.J.; Willms, W.D. 2008. Rotational grazing on rangelands: reconciliation of perception and experimental evidence. Rangeland Ecology and Management. 61: 3-17.

Carter, J.G. 2008. Updating the animal unit month. Western Watersheds Project, Hailey, Idaho. 7p.

Catlin, J.; Carter, J.; Jones, A. (In press). Range management in the face of climate change. Proceedings of a symposium; 2010 May 18 – 20; Logan, Utah; Utah State University Wildland Shrub Symposium.

Carter, J.; Brawer, J.; Haak, A.; Mayfield, M. 2006 Presentation. Spatial analysis of Forest Service capability criteria for watershed management and soil conservation. Proceedings of an international conference; 2006 July 22 – 26; Keystone, Co. Soil and Water Conservation Society.

Charley, J.L.; West, N.E. 1977. Micro-patterns of nitrogen mineralization activity in soils of some shrub-dominated semi-desert ecosystems of Utah. Soil Biology and Biochemistry. 9: 357–365.

Clary, W.P.; Webster, B.F. 1989. Managing grazing of riparian areas in the Intermountain Region. Gen. Tech. Rep. INT-263. USDA, Forest Service, Intermountain Research Station, Ogden, Utah. 15p.

Cottam, W.P.; Evans, F.R. 1945. A comparative study of the vegetation of grazed and un-grazed canyons of the Wasatch Range, Utah. Ecology. 26: 171-181.

ESA. 2000. Carbon sequestration in soils. Ecological Society of America. Washington D.C. Online at http://www.esa.org/education_diversity/pdfDocs/carbonsequestrationinsoils.pdf. Accessed July 26, 2009.

Ellison, L. 1960. Influence of grazing on plant succession of rangelands. Botanical Review. 26: 1-78.

FAO. 2006. Livestock's long shadow environmental issues and options. Publishing Management Service; Food and Agricultural Organization of the United Nations. Rome. Online at ftp://ftp.fao.org/docrep/fao/010/a0701e/a0701e.pdf. Accessed July 26, 2009.

FAO. 2009. Review of evidence on drylands pastoral systems and climate change implications and opportunities for mitigation and adaptation. Land Tenure and Management Unit Land and Water Division; Food and Agricultural Organization of the United Nations, Rome. Online at ftp://ftp.fao.org/docrep/fao/012/i1135e/i1135e00.pdf. Accessed July 26, 2011.

Fleischner, T.L. 1994. Ecological costs of livestock grazing in western North America. Conservation Biology. 8: 629-644.

Flynn, A.J.; Alvarez, P.; Brown, J.R.; George, M.R.; Kustin, C.; Laca, E.A.; Oldfield, J.T.; Schohr, T.; Golley, F.B. 1960. Energy dynamics of a food chain of an old field community. Ecological Monographs. 30: 187-206.

Follett, R.F.; Kimble, J.M.; Lal, R., eds. 2001. The potential of U.S. grazing lands to sequester carbon and mitigate the greenhouse effect. Boca Raton: Lewis Publishers. 457p.

Galt, D.; Molinar, F.; Navarro, J.; Joseph, J.; Holechek, J. 2000. Grazing capacity and stocking rate. Rangelands. 22(6): 7-11.

Gardner, J.L. 1950. The effects of thirty years of protection from grazing in desert grassland. Ecology. 31: 44-50.

Grace, J.; San Jose, J.; Meir, P.; Miranda, H.; Montes, R. 2006. Productivity and carbon fluxes of tropical savannas. Journal of Biogeography. 33: 387–400.

Gifford, G.F.; Hawkins, R.H. 1978. Hydrologic impact of grazing on infiltration: a critical review. Water Resources Research. 14: 305-313.

Haferkamp, M.R.; MacNeil, M.D.; Grings, E.E. 2005. Predicting nitrogen content in the northern mixed-grass prairie. Rangeland Ecology and Management. 58: 155-160.

Herrick, J.E.; Wander, M.M. 1998. Relationships between soil organic carbon and soil quality in cropped and rangeland soils: the importance of distribution, composition and soil biological activity. Pages 405-425 In:Lal, R.; Kimble, J.; Follett, R.; Stewart, B.A., eds. Advances in Soil Science: Soil Processes and the Carbon Cycle. Boca Raton, Fl. CRC Press LLC.

Holechek, J.L.; Gomez, H.; Molinar, F.; Galt, D. 1999. Grazing studies: what we've learned. Rangelands. 21(2): 12-16.

Holechek, J.L.; Pieper, R.D.; Herbel, C.H. 2004. Range management principles and practices, Fifth Edition. Upper Saddle River, N.J. Pearson Prentice Hall. 607 p.

Hormay, A.L.; Talbot, M.W. 1961. Rest-rotation grazing a new management system for perennial bunchgrass ranges. USDA, Forest Service Production Research Report No. 51.

Jones, A.L. 2000. Effects of cattle grazing on North American arid ecosystems: a quantitative review. Western North American Naturalist. 60: 155-164.

Kauffman, J.B.; Krueger, W.C.; Vavra, M. 1983. Effects of late season cattle grazing on riparian plant communities. Journal of Range Management. 36: 685-691.

Lusby, G.C. 1979. Effects of grazing on runoff and sediment yield from desert rangeland at Badger Wash in western Colorado, 1953-1973. Water Supply Paper 1532-1. U. S. Geological Survey.

Miller, R.O.; Kotuby-Amacher, J.; Rodriguez, J.B. 1997. Western states laboratory proficiency testing program soil and plant analytical methods. 133p.

Mueggler, W.F. 1975. Rate and pattern of vigor recovery in Idaho fescue and bluebunch wheatgrass. Journal of Range Management. 28(3): 198-204.

Orr, H.K. 1975. Recovery from soil compaction on bluegrass rang in the Black Hills. Transactions of the American Society of Agricultural Engineers. 18: 1076-1081.

Owens, L.B.; Edwards, W.M.; Van Keuren, R.W. 1996. Sediment losses from a pastured watershed before and after stream fencing. Journal of Soil and Water Conservation. 51(1): 90-94.

Qiji, W.; Shixionga, L.; Zengchuna, J.; Wenying, W. 2008. Response of carbon and nitrogen content in plants and soils to vegetation cover changes in alpine Kobresia meadow of the source region of Lantsang, Yellow and Yangtze Rivers. Acta Ecologica Sinica. 28(3): 885-894.

Ruhe, R.V. 1975. Geomorphology: geomorphic processes and surficial geology. Boston: Houghton-Mifflin Co., Boston. 246p.

Schuman, G.E.; Janzen, H.H.; Herrick, J.E. 2002. Soil carbon dynamics and potential carbon sequestration by rangelands. Environmental Pollution. 116 (3): 391–396.

Sedjo, R.1993. The carbon cycle and global forest ecosystem. Water, Air, and Soil Pollution. 70: 295-307.

Tisdale, S.L.; Nelson, W.L.; Beaton, J.D. 1985. Soil fertility and fertilizers (fourth ed.). New York: Macmillan. 754 pp.

Trimble, S.W.; Mendel, A.C. 1995. The cow as a geomorphic agent, a critical review. Geomorphology. 13: 233-253.

USDA. 1964. R-4 Range Analysis Handbook. United States Forest Service, Intermountain Region.

USDA. 1989. Grazing impact analysis data sheets for 1978–1989. USDA, Wasatch-Cache National Forest, Logan Ranger District, Logan, Utah.

USDA. 1992a. Draft ecological site description mountain stony loam (aspen thicket) 047AY458UT. Natural Resources Conservation Service. Online at ftp://ftp-fc.sc.egov.usda.gov/UT/Range/E47XA/047AY458UT.pdf. Accessed July 26, 2009.

USDA. 1992b. Draft ecological site description mountain shallow loam (mountain big sagebrush) 047AY446UT. Natural Resources Conservation Service. Online at ftp://ftp-fc.sc.egov.usda.gov/UT/Range/E47XA/047AY446UT.pdf. Accessed July 26, 2009.

USDA. 1992c. Draft ecological site description mountain loam (mountain big sagebrush) 047AY446UT. Natural Resources Conservation Service. ftp://ftp-fc.sc.egov.usda.gov/UT/Range/E47XA/047AY469UT.pdf. Accessed July 26, 2011.

USDA. 1996. Wasatch-Cache National Forest Rangeland Health Forest Management Plan. US Forest Service, Intermountain Region, Wasatch-Cache National Forest.

USDA. 1997. A hierarchical stratification of ecosystems of the Caribou National Forest. US Forest Service, Caribou National Forest.

USDA. 2003a. Final environmental impact statement for the Caribou National Forest Revised Forest Plan. US Forest Service, Caribou-Targhee National Forest.

USDA. 2003b. Final environmental impact statement Wasatch Cache National Forest. USDA, Wasatch-Cache National Forest. Online at http://www.fs.usda.gov/Internet /FSE_ DOCUMENTS/stelprdb5076935.pdf. Accessed July 26, 2009.

USDA. 2003c. National range and pasture handbook revision 1. US Natural Resources Conservation Service, Grazing Lands Technology Institute. Online at http://www.monocounty.ca.gov/cdd%20site/Planning/Documents/NCRSHandbook_CompleteHandbook.pdf. Accessed July 26, 2009.

USDA. 2004. North Rich allotment final environmental impact statement. US Forest Service, Wasatch-Cache National Forest. Logan Ranger District, Logan, Utah.

USDA. 2005. Record of decision South Bear River Range AMP revision project. US Forest Service, Caribou-Targhee National Forest.

Van Poolen, H.W.; Lacey, J.R. 1979. Herbage response to grazing systems and stocking intensities. Journal of Range Management. 32: 250-253.

Warren, S.D.; Merril, M.B.; Blackburn, W.H.; Garza, N.E. 1985. Soil response to trampling under intensive rotation grazing. Soil Science Society of America Journal. 50: 1336-1341.

WCNF. 1962. Range analysis data sheets for 1961 and 1962. USDA, Logan Ranger District, Uinta-Wasatch-Cache National Forest.

West, N.E. 1981. Nutrient cycling in desert ecosystems. Pages 301-324 In Arid Land Ecosystems: Structure, Functioning and Management Volume 2. International Biological Programme 17. Cambridge University Press.

West, N.E. 1983. Western intermountain sagebrush steppe. Pages 351-373 In West, N.E., ed. Temperate Deserts and Semi-Deserts. Amsterdam: Elsevier Scientific Publishing Company.

White, R.K.; VanKeuren, R.W.; Owens, L.B.; Edwards, W.M.; Miller, R.H. 1983. Effects of livestock pasturing on non-point surface runoff. EPA-600/S2-83-011. U.S. Environmental Protection Agency, Robert S. Kerr Environmental Research Laboratory, Oklahoma. 6p.

White, R.; Murray, S.; Rohweder, M. 2000. Pilot analysis of global ecosystems: Grassland Ecosystems. Washington, D.C., World Resources Institute. 112 p.

WOCAT. 2009. Benefits of sustainable land management. World overview of conservation approaches and technologies; Swiss Agency for Development and Cooperation, FAO, Centre for Development and Environment.

WRCC. 2010. Richmond, Utah (427271) period of record monthly climate summary. Western Regional Climate Center. Reno, Nevada.

Wuerthner, G.; Matteson, M. 2002. Welfare ranching: the subsidized destruction of the American West. Sausalito, California: Foundation for Deep Ecology and Island Press. 346p.

Yang, Y.H.; Fang, J.Y.; Ji, C.J.; Ma, W.H. 2010. Vertical patterns of soil carbon, nitrogen and carbon: nitrogen stoichiometry in Tibetan grasslands. Biogeosciences Discuss. 7: 1-24.