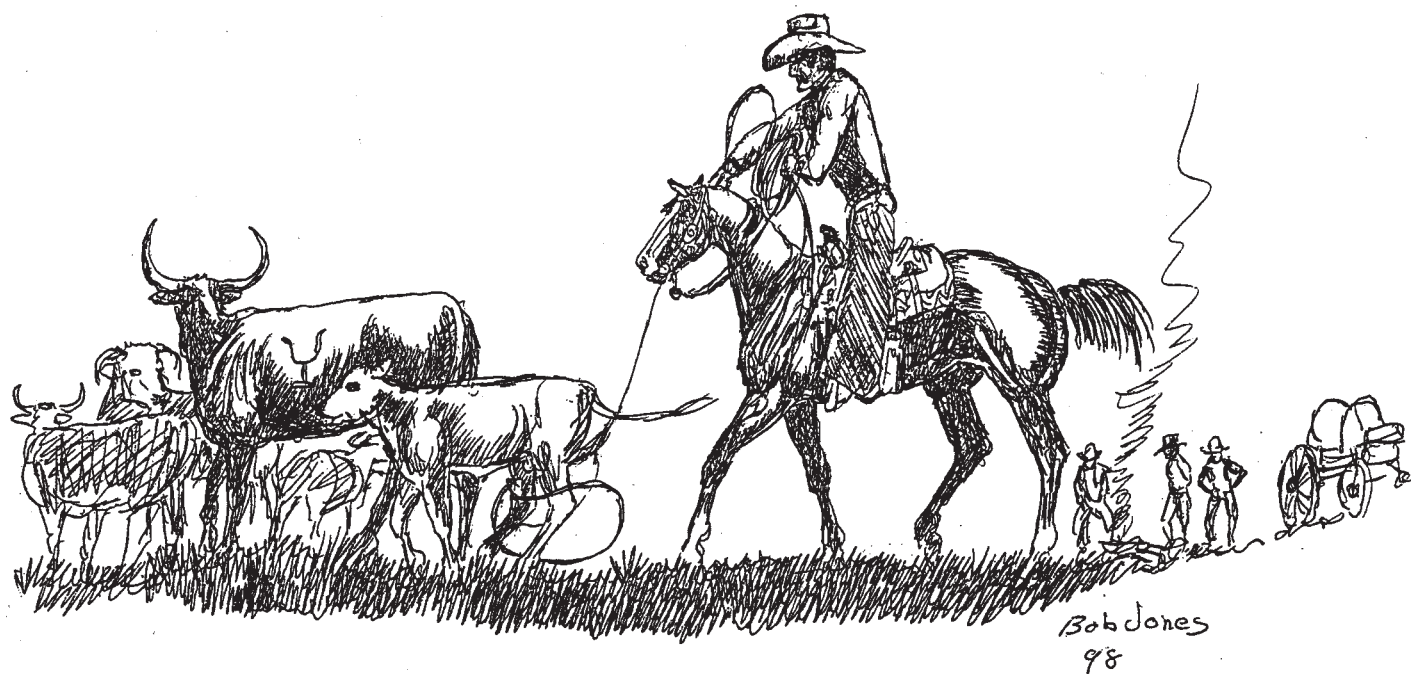


Impacts of Controlled Grazing Versus Grazing Exclusion on Rangeland Ecosystems: What We Have Learned



Range Improvement Task Force
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Impacts of Controlled Grazing Versus Grazing Exclusion on Rangeland Ecosystems: What We Have Learned

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Abstract

This paper examines the impacts of carefully controlled livestock grazing versus grazing exclusion on rangeland ecosystems, focusing on arid and semi-arid areas. Eighteen studies were found that evaluated the effects of controlled grazing versus grazing exclusion on rangeland vegetation. These studies provide evidence that controlled livestock grazing may enhance rangeland vegetation by altering plant succession, increasing plant diversity and productivity, and reducing plant mortality during drought. These positive impacts of livestock grazing are most likely to occur when grazing intensities are light to conservative. Although more than 30 studies consistently show that controlled grazing adversely impacts soils through increased compaction, reduced infiltration and increased erosion, these impacts are minor and are ameliorated by natural processes that cause soil formation, soil deposition and soil loosening. Plant seedling establishment and mineral cycling can be increased by livestock treading. Research from the Chihuahuan Desert indicates that moderately grazed mid seral rangelands support a higher diversity of wildlife species than those lightly grazed in near climax condition. Riparian habitat improvement has occurred under carefully timed grazing at light to conservative intensities. The impacts of controlled grazing on fish populations have not been well studied. In conclusion, there is limited scientific evidence that controlled grazing can play an important role in managing and maintaining rangelands in arid and semiarid regions for a variety of uses and ecosystem services. However, more and better designed research is needed on this subject.

Introduction

Conflict over management of public grazing lands in the western United States is becoming increasingly contentious; the land base there has shrunk due to rapid human population increase, urban sprawl, and changing social values. Through research, the impacts of controlled livestock grazing on rangeland ecosystems of the western United States have become better understood during the last 20 years. However, most of this research is in technical peer-reviewed journal articles that are generally not read by the public. A careful analysis of this research is needed to provide the public, ranchers, lawmakers, government planners, and conservationists with a sound basis for decision making. The focus of this review is the impact of controlled livestock grazing on rangeland health, emphasizing vegetation. Soil, watershed, and wildlife will be discussed briefly. Semiarid and arid areas will receive emphasis because livestock grazing on public rangelands of the western United States is under the greatest scrutiny (Donahue 1999).

Primary Sources of Information

All grazing studies of the western United States will not be exhaustively reviewed. Only those that have involved careful control of intensity, timing and frequency of grazing will be reviewed. However, influential reviews and “opinion articles” that examine livestock grazing from different perspectives will be identified.

The primary range management textbooks include Stoddart et al. (1975), Valentine (1990), Heady and Child (1994), and Holechek et al. (2004). These books draw heavily from peer reviewed science and focus on controlled grazing outcomes. Relevant, more specialized textbooks include Branson et al. (1981) on rangeland watershed management, Vavra et al. (eds.)

(1994) on grazing impacts on Western plant communities, Krausman (ed.) (1996) on rangeland wildlife, and Heitschmidt and Stuth (eds.) (1991) on rangeland ecology.

Another level of books and handbooks is directed toward the layman or rancher seeking applied information. These include Bell (1973), Savory (1999), and Sayre (2001). Bell (1973) provides an excellent overview of range management based on his experiences as a range conservationist with the USDA Soil Conservation Service. Sayre (2001) more closely ties his observations, case studies, and viewpoints to peer reviewed studies than Savory (1999).

Noteworthy anti-grazing books include Jacobs (1992) and Donahue (1999). Both books contain some factual information but also rely heavily on opinions and viewpoints.

The most comprehensive reviews of scientific information on grazing impacts on rangeland vegetation include Ellison (1960), Milchunas et al. (1988), and Milchunas and Lauenroth (1993). Reviews providing a defense for public land grazing include Holechek (1980) and Holechek (1981). Those that make the case against public land grazing include Fleischner (1994) and Jones (2000). Belsky et al. (1999) reviews various studies showing that uncontrolled livestock grazing degrades riparian ecosystems.

Problems with Grazing Exclusion Studies

Fleischner (1994) and Jones (2000) review a wide variety of grazing versus grazing exclusion studies that show livestock grazing has adverse impacts on vegetation diversity, vegetation structure, plant succession, soil stability, nutrient cycling, wildlife diversity, and riparian health. Neither of these reviews that involved more than 100 studies take into account critical details such as grazing intensity, timing, and frequency, which greatly influence experimental outcomes. Fleischner (1994) fails to consider any of the 35 long-term controlled

grazing studies later identified and summarized by Van Poolen and Lacey (1979), Holechek, et al. (1999) and Holechek, et al. (2004) as the foundations of range management. Only one of these foundational studies is mentioned by Jones (2000). Nearly all the studies considered in the Fleischner (1994) and Jones (2000) reviews have flaws (Brown and McDonald 1995), including inadequate descriptions of grazing treatments or practices, weak study designs, and/or lack of pre-treatment data.

Weak study designs typically include lack of replication in time and space, grazing treatments so poorly described they cannot be reconstructed, non-uniform experimental units, and excessively small experimental units that do not adequately reflect the area studied (Brown and McDonald 1995, Larsen et al. 1998). In the case of grazing versus grazing exclusion studies, very few provide information on grazing intensity, season of use, frequency of use, and use by native herbivores prior to construction. Consequently, the reader cannot discern the nature of the grazing impacts that impaired the area.

Controlled Grazing Studies

It has been known for over 100 years that sustained heavy to severe grazing intensities are harmful to soil, vegetation, and wildlife. Range scientists and ranchers have long acknowledged that damage to soil and vegetation occurred in the late 1800s and early 1900s because of severe grazing over much of the western United States. However, it is well established that steady improvement has occurred on both publicly and privately owned rangelands over the past 60 years due to better controlled grazing (Table 1). A quick review of the controlled grazing studies will be provided before consideration of controlled grazing versus grazing exclusion. The basis for this review is Holechek et al. (1999) and Holechek et al. (2004).

Table 1. Comparative percentages of Bureau of Land Management rangelands in excellent, good, fair, and poor condition between 1936 and 1998.

YEAR	EXCELLENT (CLIMAX)	GOOD (LATE SERAL)	FAIR (MID SERAL)	POOR (EARLY SERAL)
1936	1.5	14.3	47.9	36.6
1966	2.2	16.7	51.6	29.5
1975	2.0	15.0	50.0	33.0
1984 ^a	5.0	31.0	42.0	18.0
1993 ^a	4.0	33.0	38.0	14.0
1998 ^a	5.0	28.0	39.0	11.0

Source: USDI 184, 1994, 1998.

^a Less than 100% totals because some lands have not been rated as to range condition.

For more details on various controlled grazing studies, the reader is referred to Van Poolen and Lacey (1979), Lacey and Van Poolen (1981), Milchunas and Lauenroth (1993), and Vavra et al. (eds.) (1994).

What is Sustainable Grazing?

Various stocking rate studies characterize grazing intensity treatments as heavy, moderate conservative, and light. Klipple and Bement (1961) define heavy grazing as a degree of forage utilization that does not permit desirable forage species to maintain themselves. Moderate grazing is a degree of herbage utilization that allows the palatable species to maintain themselves but usually does not permit them to improve in herbage-producing ability. Light grazing is a degree of herbage utilization that allows palatable species to maximize their herbage producing ability.

The primary measure of grazing intensity used in long-term grazing studies has been percent use of palatable forage species. Although it has limitations as a measure of grazing intensity, percent use is more easily understood by ranchers and non-range professionals than other measurements such as stubble heights, percentage of grazed plants, or minimum residues (Jasmer and Holechek 1984). When several years of data have been collected, percent use of forage was well related to changes in productivity of primary forage plants, livestock performance, and financial returns (Holechek et al. 1999).

When all the stocking rate studies were averaged, Holechek et al. (1999) found heavy grazing averaged 57% use of primary forage species compared to 43% use for moderate and 32% use for light grazing (Table 2). Research was remarkably consistent in showing that moderate grazing involved about 45% use of forage (Johnson 1953, Klipple and Costello 1960, Beetle et al. 1961, Paulsen and Ares 1962, Houston and Woodward 1966, Launchbaugh 1967, Martin and Cable 1974, Skovlin et al. 1976, and Sims et al. 1976). In some years, use approached 60% while in others it was only 20%. Over long time periods, an average near 45% maintained vegetation productivity for arid to semi-arid range types (see also Milchunas and Lauenroth 1993).

Table 2. Summary of 25 studies on effects of grazing intensity on native vegetation and livestock production in North America.

	GRAZING INTENSITY		
	HEAVY	MODERATE	LIGHT
Average use of forage (%)	57	43	32
Average forage production (lbs./acre)	1,175 ¹ (1,065) ²	1,473 ¹ (1,308) ²	1,597 ¹
Forage production drought years (lbs./acre)	820 ¹	986 ¹	1,219 ¹
Range trend in ecological condition	down (92%) ³	up (52%) ⁴	up (78%) ⁴
Average calf crop (%)	72 ¹ (77) ²	79 ¹ (84) ²	82 ¹
Average lamb crop (%)	78	82	87
Calf weaning wt (lb)	381 ¹ (422) ²	415 ¹ (454) ²	431 ¹
Lamb weaning wt (lb)	57	63	----
Gain per steer (lb)	158	203	227
Steer/calf gain per day (lb)	1.83	2.15	2.30
Steer/calf gain per acre (lb)	40.0	33.8	22.4
Lamb gain per acre (lb)	26.0	20.4	13.8
Net returns per animal (\$)	38.06 ¹ (29.00) ²	51.57 ¹ (39.71) ²	58.89 ¹
Net returns per acre (\$)	1.29 ¹ (1.72) ²	2.61 ¹ (2.24) ²	2.37 ¹

Source: Holechek et al. 1999a.

¹ Average for those studies comparing heavy, moderate, and light grazing (studies comparing only heavy and moderate grazing excluded).

² Average for all studies.

³ Percentage of studies with downward trend.

⁴ Percentage of studies with upward trend.

Unlike stocking rate studies, research comparing continuous or season-long and rotation grazing systems has shown much inconsistency regarding influences on rangeland vegetation (Van Poollen and Lacey 1979, Holechek et al. 1999, Table 3). Across all studies, forage production was 7% higher under rotation compared to continuous grazing. In the semi-arid and desert range types, rotation grazing systems generally showed no advantage over continuous or season-long grazing. However, in the more humid range types, forage production averaged 20 to 30% higher under rotation grazing. Generally, rotation grazing has been more beneficial than

continuous grazing to desirable forage species in the humid types. However, in flat semiarid and arid areas, rotation has shown no definite advantage from a vegetation standpoint. In mountainous areas, rotation grazing systems provide easier access areas (riparian zones), opportunity for recovery, and can be advantageous over season-long grazing. More detailed discussions of the results from various grazing system studies are provided by Vallentine (1990), Heady and Child (1994), and Holechek et al. (2004).

Table 3. Summary of 15 studies on effects of rotation grazing systems on native rangeland vegetation and livestock production in North America.

CHARACTERISTIC	SEASON-LONG OR CONTINUOUS GRAZING	ROTATION GRAZING
Average use of forage (%)	41.8	42.4
Average forage production (lb/acre)		+7%
Range trend	up=61%, stable=31%, down=8%	up=69%, stable 85, down=23%
Average calf crop (%)	89.4	85.9
Calf weaning wt (lb)	504.6	494.1
Net returns (\$/acre)	6.60	6.37

Source: Holechek et al. 1999.

One point made by leading range managers should be emphasized; stocking is and always will be the major factor affecting the condition of rangeland resources (Pieper and Heitschmidt 1988). No grazing system can counteract the negative impacts of long-term overstocking. These conclusions are well supported by various long-term studies from North America (Holechek et al. 2001) and Africa (O'Reagan and Turner 1992).

More than 35 controlled grazing studies from North America and over 50 studies from other parts of the world (O'Reagan and Turner 1992, Milchunas and Lauenroth 1996, Ash and Smith 1996) show managed livestock grazing using scientific principles is sustainable and

generally results in rangeland improvement. Rather than focusing on what is well known (that unmanaged grazing damages rangelands), we must examine how controlled grazing at light to moderate intensities affects rangelands relative to ungrazed controls. We selectively review those studies judged to have adequate experimental design to separate controlled grazing from climatic, soil, and other environmental effects.

Vegetation Studies

Research Identification

In western North America, we have found 20 studies that compare vegetation responses of controlled grazing at moderate to light intensities with grazing exclusion. These studies are summarized in Table 4. Sixteen of these studies evaluated trend, 11 evaluated productivity, and 2 evaluated under managed grazing compared to grazing exclusion during drought. Only 7 of the studies involved arid rangelands.

Table 4. Studies comparing vegetation responses of controlled grazing at moderate to light intensities with grazing exclusion.

Range Type	Location	Vegetation Responses Studied	Grazing Treatment	Reference
Northern mixed prairie	Alberta, Canada	Production	Light grazing, Grazing exclusion	Johnston 1962
Northern mixed prairie	North Dakota	Trend	Moderate grazing, Grazing exclusion	Brand and Goetz 1986
Northern mixed prairie	Alberta, Canada	Trend	Grazing intensities, Grazing exclusion	Smoliak et al. 1972
Northern mixed prairie	Montana	Trend	Conservative stocking, Grazing exclusion	Vogel and Van Dyne 1966
Southern mixed prairie	Texas	Productivity, Trend	Stocking rates, Grazing systems, Grazing exclusion	Wood and Blackburn 1984
Southern mixed prairie	Texas	Trend	Stocking rates, Grazing systems, Grazing exclusion	Thurrow et al. 1986
Southern mixed prairie		Productivity, Trend	Stocking rates, Grazing exclusion	Heitschmidt et al. 1985
Southern mixed prairie	Texas	Productivity, Trend	Stocking rates, Grazing systems, Grazing exclusion	Reardon and Merrill 1976
Shortgrass prairie	Colorado	Productivity	Stocking rates, Grazing exclusion	Milchunas et al. 1994
Shortgrass prairie	Colorado	Trend	Stocking rates, Grazing exclusion	Hart and Ashby 1998
Coniferous forest	Colorado	Productivity, Drought response Trend	Stocking rates, Grazing exclusion	Johnson 1956, Smith 1967
Coniferous forest	Oregon	Productivity, Trend	Stocking rates, Grazing systems, Grazing exclusion	Skovlin et al. 1976
Palouse bunchgrass	Oregon	Productivity, Trend	Stocking rates, Grazing systems, Grazing exclusion	Skovlin et al. 1976
Sagebrush grassland	New Mexico	Trend	Moderate stocking, Grazing exclusion	Holechek and Stephenson 1983
Sagebrush grassland	Idaho	Trend	Timed grazing, Grazing exclusion	Bork et al. 1998
Sagebrush grassland	Oregon	Drought response	Grazing intensity, Grazing exclusion	Ganshopp and Bedell 1981
Chihuahuan Desert	New Mexico	Trend, Drought response	Grazing intensities, Grazing exclusion	Paulsen and Ares 1962
Chihuahuan Desert	New Mexico	Productivity, Trend	Conservative grazing, Grazing exclusion	Herbel and Gibbens 1996
Salt Desert	Utah	Trend	Grazing timing, Grazing exclusion	Alzerreca-Angelo et al. 1998
Mojave Desert	Utah/Arizona	Trend	Grazing intensity, Grazing exclusion	Jeffries and Klopatek 1987

Analysis of Trend Studies

Fourteen of the 18 studies evaluating trend had sufficient baseline information, where vegetation changes through time could be determined. In all 14 of these studies, ungrazed and moderately to lightly grazed treatments showed the same trend. Ten studies showed an upward trend, two showed a downward trend, and two showed no definite trend. Paulsen and Ares (1962) reported a downward trend on Chihuahuan Desert rangeland due to extended drought, while Skovlin et al. (1976) associated a downward trend on coniferous forest rangeland with increasing tree cover. In 6 of the 18 studies, plant species composition did not differ between grazed and ungrazed areas. Grazed, compared to ungrazed, areas were considered to be in higher ecological condition (more climax vegetation) in 5 studies and lower in 5 studies. Two studies (Paulsen and Ares 1962, Hart and Ashby 1998) merit special consideration because they involved long-time periods (more than 20 years), were well replicated in space, and provided detailed characterization of grazing intensity. In both studies, grazing was found to be sustainable at intensities that involved up to 40% utilization of forage.

On the Colorado shortgrass prairie, prickly pear cactus (*Opuntia Polyacantha* Haw.) biomass was lowered by 55 years of moderate grazing (40% use) compared to exclusion (Hart and Ashby 1998). Shrub biomass (mostly fringed sagewort [*Artemisia frigida* willd.], slender bush eriogonum [*Eriogonum microthecum* Nutt.], and broom snakeweed [*Gutierrezia sarothrae* Pursh]) was higher under exclusion than under grazing. The lower cactus and shrub component under grazing treatments were considered advantageous because these plants have low forage value for livestock and some wildlife species. Light and moderate grazing reduced cool-season graminoids but increased warm-season graminoids compared to exclusion. Forb biomass did not

differ among grazed and ungrazed treatments. It was concluded that moderate cattle grazing had been sustainable during the 55-year period of study.

In the Chihuahuan Desert of New Mexico, black grama (*Bouteloua eriopoda* Torr.) basal cover over a 37-year period was maintained at a higher level under conservative grazing (35% use) than under no grazing or heavier grazing levels (Paulsen and Ares 1962) (Figure 1). Black grama is the primary decreaser forage grass in the Chihuahuan Desert and dominates upland rangelands in high ecological condition. Tobosa (*Hilaria mutica* Buckley) is the second most important livestock forage grass in the Chihuahuan Desert; it is also important for a variety of wildlife species including ground-nesting birds, and dominates lowland flood plains. Tobosa had over twice as much basal area on long-term (15 years) conservatively and moderately grazed quadrats as those protected (Table 5). The authors stated that tobosa plants tend to stagnate when old growth is not removed. Thus, moderate grazing is desirable to maintain a vigorous tobosa stand. Findings from the Paulsen and Ares (1962) study are supported by additional follow-up research from the same study areas by Herbel and Gibbens (1996). These two Chihuahuan Desert studies provide strong evidence that managed livestock grazing at light to moderate levels is sustainable in arid environments.

Table 5. Average basal area of tobosa (cm^{-2}) on square meter quadrats receiving 4 different intensities of cattle grazing in the 1928 to 1943 period on Jornada Experimental Range in southern New Mexico (Paulsen and Ares 1962).

Grazing Intensity	Use of Forage (%)	Average Basal Area of Tobosa (cm^{-2})
Protected	0	1,191
Conservative	<40%	2,461
Intermediate (Moderate)	40-55%	2,718
Heavy	>55%	2,294

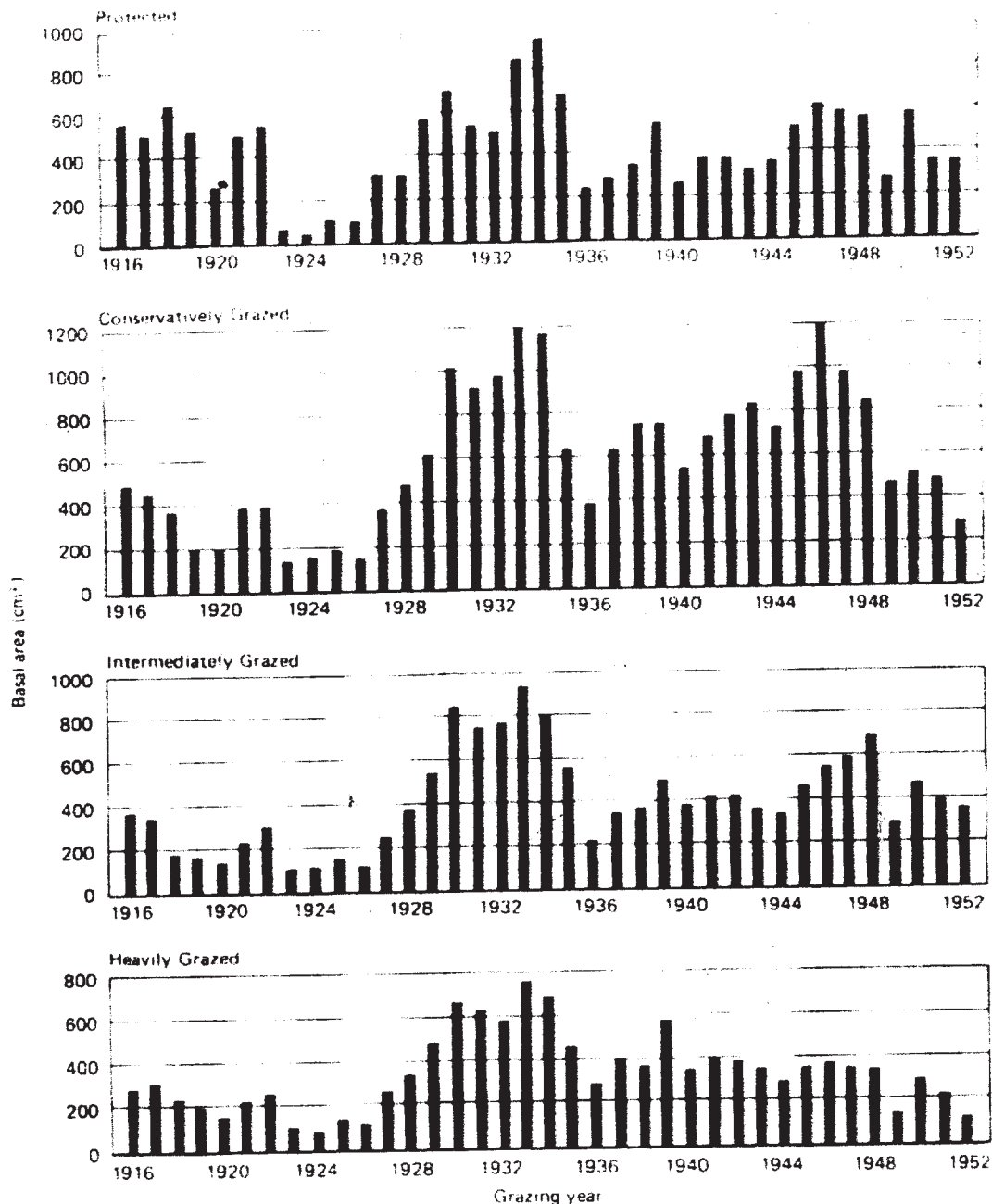


Figure 1. Basal area of black grama on meter-square quadrats protected from grazing and at three intensities of grazing on the Jornada Experimental Range, southern New Mexico, 1916-1953 (From Paulsen and Ares 1962.)

Further evidence that grazing is sustainable in arid environments is provided by Navarro et al. (2002). This study evaluated long-term (1952-1999) trend in ecological condition on 41 grazed sites distributed across Bureau of Land Management rangelands in the Chihuahuan Desert

of southern New Mexico. Over the 48-year study period, major changes occurred in rangeland condition due to fluctuations in precipitation. At the end of the study, however, average ecological condition score across sites was the same as the beginning. The average percent cover of primary forage grasses was the same. The authors concluded managed livestock grazing is sustainable on Chihuahuan Desert rangelands.

Plant Diversity

Very few studies have evaluated the effects of controlled grazing on plant diversity in arid and semiarid areas. In the Chihuahuan Desert of southern New Mexico, Smith et al. (1996) reported that vegetation diversity was higher on long-term, conservatively grazed late seral rangeland than on lightly grazed rangeland in near-climax condition. In another study in the same area, Nelson et al. (1997) reported that vegetation diversity was the same on moderately grazed mid seral and conservatively grazed late seral rangelands. On the shortgrass prairie of Colorado, Milchunas et al. (1988) found that plant diversity increased as grazing intensity decreased. However, the difference in plant diversity between ungrazed and lightly grazed areas was small.

Vegetation Productivity

Long-term managed grazing, compared to grazing exclusion, on average reduced grass production 13% and total vegetation production 4% across 11 different studies (Table 6). The Chihuahuan Desert study merits particular consideration because it involved two sites and 19 years of data collection (Herbel and Gibbens 1996). Grazing intensities were conservative (30-35% use of forage). On both sites in this study, managed grazing resulted in slightly higher grass production than exclusion. Grazing intensity was lower in this study than in the others cited

Table 6. Summary of studies evaluating vegetation productivity under controlled grazing and grazing exclusion in North America.

			Grass Productivity			Total Vegetation Productivity		%	Difference
			Grazed	Excluded		Grazed	Excluded		
			kg ha ⁻¹			kg ha ⁻¹			
									Difference
Johnston 1962	Alberta, Canada	Northern mixed prairie	1,390	1,625	-14	2,429	2,471	-2	
Brand & Goetz 1986	North Dakota	Northern mixed prairie	1,540	1,780	-13	1,908	1,908	-8	
Vogel & Van Dyne 1966	Montana	Northern mixed prairie	477	522	-9	655	733	-11	
Wood & Blackburn 1984	Texas	Southern mixed prairie	3,281	4,202	-22	-----	-----	-----	
Heitschmidt et al. 1986	Texas	Southern mixed prairie	1,152	1,430	-19	1,171	1,441	-19	
Reardon & Merrill 1976	Texas	Southern mixed prairie	1,211	1,015	+14	2,436	1,578	+54	
Milchunas et al. 1984	Colorado	Shortgrass	710	750	-5	-----	-----	-----	
Johnson 1956	Colorado	Coniferous forest	733	1,229	-40	982	1,637	-40	
Skovlin et al. 1976	Oregon	Coniferous forest	101	160	-37	280	337	-17	
Skovlin et al. 1976	Oregon	Palouse prairie	175	204	-14	374	350	+7	
Herbel & Gibbens 1996	New Mexico	Chihuahuan desert	215	206	+4	-----	-----	-----	
Average			999	1,193	-13	1,250	1,294	-4	

above. In arid areas, it appears that grazing at light to conservative levels may have no effect or a stimulative effect on forage production. This, however, needs to be better studied.

Two studies provide evidence that long-term grazing exclusion can result in vegetation stagnation. On chaparral rangeland in south-central Texas, Merrill and Reardon (1976) found that production of decreaser grasses was lower under grazing exclusion than under a moderately stocked four-pasture deferred-rotation grazing system. On desert shrub rangelands in Nevada, Tueller and Tower (1979) found productivity of desirable shrubs (bitterbrush) was lower, but that of grasses higher on grazing excluded compared to grazed areas. This study was not included in Table 6 because information on grazing intensity was vague.

Most of the productivity studies in Table 6 apparently did not use cages on grazed areas to account for herbage removed by livestock. Another problem encountered in reviewing the studies is that many of them do not clearly state whether old growth was separated from new growth. In the Herbel and Gibbens (1996) study, where grass production was slightly higher on grazed areas, the authors do state that their estimates involved only current year growth.

Drought Response

Three studies indicate that light to conservative grazing may actually benefit grass plants during drought compared to no grazing (Johnson 1956, Paulsen and Ares 1962, Ganskopp and Bedell 1981). In eastern Oregon, lightly grazed Idaho fescue (*Festuca idahoensis* Elmer) and bluebunch wheatgrass (*Agropyron spicatum* Pursh) had as much and in some cases more herbage, seed stalks, and final height than ungrazed plants following severe drought (Ganskopp and Bedell 1981). Similar observations were made for black grama on Chihuahuan Desert rangeland in New Mexico (Paulsen and Ares 1962). On coniferous forest rangeland in Colorado, Johnson (1956) found that moderately and lightly grazed pastures had less reduction in forage

production than plots excluded from grazing during drought. In their book, *Sonoran Desert*, researchers Bock and Bock (2000) reported that moderate livestock grazing reduced drought-caused mortality on perennial grasses in southeastern Arizona. In southeastern Montana, Eneboe et al. (2002) found that moderate grazing did not adversely affect primary native grasses (i.e., blue grama, western wheatgrass) during and after drought.

Positive Influences of Controlled Grazing

Possible positive influences of managed grazing compared to grazing exclusion on range plant productivity are reviewed by Holechek (1981), and Holechek et al. (2001). These include removal of excess vegetation that may negatively affect net carbohydrate fixation, maintaining an optimal leaf area index, reducing transpiration losses, reducing excess accumulations of standing dead vegetation and mulch, increased tillering in grasses, reducing apical dominance in shrubs and inoculating plant part with saliva to stimulate growth. Nearly all of the studies identifying these responses were conducted in greenhouses rather than under range conditions. Research by McNaughton (1983) in the African Serengeti provides one of the best validations that grazing does have positive or compensating effects on forage plant productivity, while Belsky (1986) reviews contradictory evidence. A major challenge for rangeland researchers in the 21st century will be to provide better information on this subject.

Soil and Watershed Studies

In contrast to vegetation, several (over 30) studies are available that have evaluated the effects of controlled grazing versus exclusion on rangeland soils and watershed properties. Various reviews of these studies include Gifford and Hawkins (1978), Branson et al. (1981), Blackburn (1984), Thurow (1991), Heady and Child (1994), and Holechek et al. (2004). Unlike

the studies on rangeland vegetation, the research on soils and watershed properties under controlled and grazing exclusion is remarkably consistent. These studies all show that light to moderate grazing reduces soil bulk density, increases water infiltration, decreases overland flow (Figure 2) and reduces soil erosion (Figure 3) relative to grazing exclusion. However, the effects of light to moderate grazing compared to grazing exclusion on soil properties have been of small magnitude and non-significant (Figures 2 and 3).

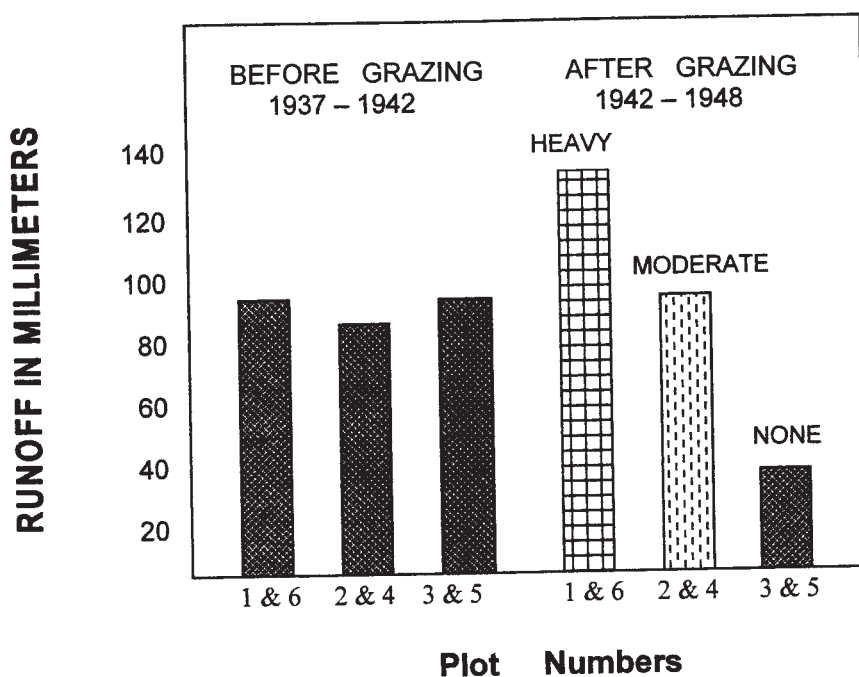


Figure 2. Runoff for bunchgrass rangeland in Colorado prior to grazing (1937-1942) and after (1942-1948) heavy and moderate grazing. (Adapted from Dunford 1949 by Branson et al. 1981.)

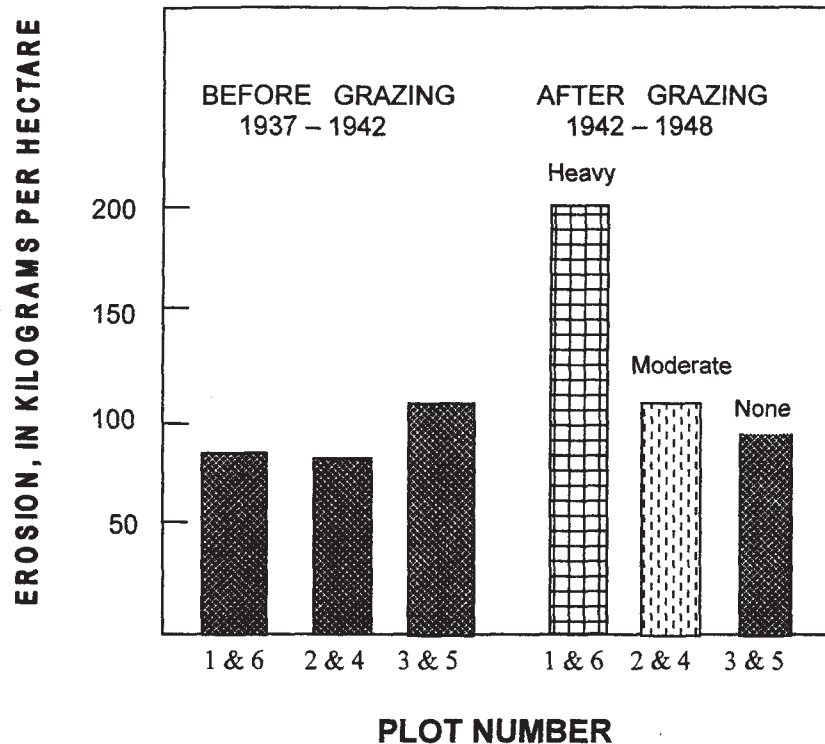


Figure 3. Average erosion from plots subject to different grazing intensities before grazing (1937-1942) and after grazing (1942-1948) on bunchgrass range in Colorado. (Adapted from Dunford 1949 by Branson et al. 1981.)

A popular belief has been that intensive grazing can loosen the soil surface during drying periods and increase infiltration (Savory and Parsons 1980). Several studies reviewed by Thurow (1991), Heady and Child (1994), and Holechek et al. (2004) are consistent in showing that heavy livestock grazing has caused the opposite effect; increasing compaction, reducing infiltration, and increasing erosion.

Short-duration heavy grazing involving concentrated livestock hoof activity for short time periods has been promoted for its capability to improve water infiltration into the soil and increase forage production. The most detailed evaluation of hydrologic responses under short-duration grazing was reported by Warren et al. (1986 a,b,c). They studied infiltration and

sediment production on a silty clay soil in Texas using a short-duration grazing system with moderate, double-moderate, and triple-moderate stocking rates. Short-duration grazing at all intensities reduced infiltration and increased sediment production compared to no grazing (Warren et al. 1986c) (Table 7). These deleterious effects were increased as stocking rate increased. The damage was augmented when the soil was moist at the time of treading. Thirty days of rest was insufficient to allow hydrologic recovery. Another part of the study evaluated seasonal changes in infiltration and sediment production under short-duration grazing at a moderate stocking rate (Warren et al. 1986a). The infiltration rate declined and sediment production increased following the short-term intense grazing periods inherent to this system. These effects were most severe during drought and dormancy, due to reduced vegetation standing crop. It was also found that there was no hydrologic advantage to increased stocking density via manipulation of pasture size and numbers (Warren et al. 1986b).

Table 7. Infiltration rate and sediment production in relation to stocking rate and soil water content at the time of trampling on the Edwards Plateau, Texas (from Warrant et al 1986c).

STOCKING RATE	TRAMPLED DRY	TRAMPLED MOIST
INFILTRATION RATE (MM/HR.)		
0	166	160
1X	140	133
2X	121	99
3X	117	96
SEDIMENT PRODUCTION (KG/HA)		
0	976	2,007
1X	2,827	2,875
2X	3,438	4,274
3X	4,788	5,861

1X = moderate stocking rate, 2X = double-moderate stocking rate, 3X = triple-moderate stocking rate.

Available research is consistent in showing that heavy short-duration grazing increases sediment production compared to moderate continuous grazing (McCalla et al. 1984, Thurow et al. 1986, Weltz and Wood 1986, Pluhar et al. 1987). The reduced vegetation standing crop and cover associated with short-duration grazing appeared to cause the higher sediment production.

Sediment production under various other specialized grazing systems has been compared with moderate continuous grazing (Wood and Blackburn 1981, Gamougoun et al. 1984, Pluhar et al. 1987). As in the case of infiltration, these studies show little difference between grazing systems other than heavy short-duration intensive grazing.

Although treading by livestock can have undesirable effects such as soil compaction, it can also have desirable effects. Treading incorporates standing dead material into the soil surface, increasing mineral cycling (Pieper 1974). It can reduce large accumulations of mulch and litter by incorporating these materials into the soil. Moderate treading by livestock appears to favor emergence and survival of perennial grass seedlings while heavy treading can favor forbs and shrubs (Hyder and Sneva 1956, Eckert et al. 1986). Like so many things, a small to moderate level of livestock hoof action can be beneficial while heavy amounts are destructive.

Discussions of the role of livestock grazing on mineral cycling are provided by Briske and Heitschmidt (1991), Haynes and Williams (1993), and Heady and Child (1994). Without question, livestock grazing increases the rate of nutrient flow and availability in rangeland ecosystems by biting, chewing, rumination, digestion, urination, and defecation. These processes cause a large proportion of essential nutrients otherwise tied up in plant material to more rapidly become available in mineral form to support plant growth. While this is a positive aspect of controlled grazing, a detailed discussion of mineral cycling by livestock is beyond the scope of this paper.

Various types of compensation ameliorate the impacts of light to moderate livestock grazing on rangeland soils. Soil formation is an ongoing process. Natural soil formation compensates to some extent for erosion that occurs under light to moderate grazing. Natural deposition of soil from overland flow of water replaces some of the soil loss from grazing. Activities of insects and burrowing mammals relieve soil compaction from grazing as does scratching and dusting by birds. Termite activity decomposes manure and accelerates nutrient cycling. Soil compaction by grazing animals occurs primarily in the first 5 cm of soil and seldom extends beyond 15 cm (Reynolds and Packer 1963). Alternate swelling and shrinking of soils from wetting, drying, freezing, and thawing can cause complete recovery from heavy treading within 2 to 3 years (Lusby 1970, Stephenson and Veigel 1987). Under light to moderate livestock treading, most rangeland soils are little impacted or recover within a year or less.

Impacts of Controlled Grazing on Rangeland Wildlife

The impact of livestock grazing on rangeland wildlife is largely dependent on the grazing management practices used. It is important to remember that it is impossible to make broad generalizations on the impact of livestock grazing on rangeland wildlife because each grazing situation is unique, and various wildlife species have different habitat requirements. Therefore, livestock grazing plans should be site-specific and based on the habitat needs of the wildlife species of interest. Important livestock grazing management variables that affect wildlife habitat include stocking rates, stocking density, the age and physiological condition of livestock, grazing season, forage selection, and livestock distribution. Other factors including range condition, soil type, temperature, and precipitation also can greatly effect the relationships between livestock grazing and habitat quality for rangeland wildlife.

During the last 20 years, a vast amount of research has become available on interactions between rangeland wildlife and livestock. However, it is also important to note that many scientific studies that have examined the effects of grazing (heavy vs. light or no grazing) tend to be compromised by lack of true controls, weak methodologies, and inaccurate or overly broad quantification of grazing intensity and ecological effects. Despite these limitations in the literature, comprehensive reviews on the interactions between livestock and rangeland wildlife include Holechek et al. (1982), Kie et al. (1994), Krausman (ed.) (1996), and Holechek et al. (2004).

The various ways properly managed livestock grazing can positively impact wildlife are summarized by Holechek et al. (1982), Launchbaugh et al. (1996) and Holechek et al. (2004). These include:

1. Increasing diversity of vegetation composition and improve forage availability and quality for early to mid successional wildlife species.
2. Creating patchy habitat with high structural diversity for feeding, nesting, and hiding.
3. Opening up areas of dense vegetation to improve foraging areas, including greater production of forbs, for upland gamebirds and songbirds.
4. Removal of rank, coarse grass to encourage re-growth and improve abundances of high quality forages for wild ungulates.
5. Stimulating browse production by reducing grass biomass.
6. Improving nutritional quality of browse by stimulating plant re-growth.

Various examples of these positive impacts on individual wildlife species are provided by Holechek et al. (1982), Krausman (ed 3.) (1994), and Holechek et al. (2004). However, actual studies evaluating the response of groups of wildlife species on particular rangelands to various grazing programs are limited. The primary research available on this issue comes from a series of studies in the Chihuahuan Desert of southern New Mexico. These studies compared mammal and

bird observations on lightly grazed rangeland in near climax condition, conservatively grazed rangeland in late-seral condition, and moderately grazed rangeland in mid-seral condition. Lightly grazed climax rangelands and conservatively grazed late-seral rangelands had similar songbird and total bird populations but pronghorn, jackrabbits, scaled quail, and mourning dove observations were lower on the climax rangeland (Smith et al. 1996). Overall wildlife diversity was higher on the conservatively grazed late-seral than the lightly grazed climax rangeland. In a follow up study, Nelson et al. (1997) found that total wildlife observations were greater on moderately grazed mid-seral Chihuahuan Desert rangelands compared to conservatively grazed late-seral rangelands (Table 8). Overall wildlife diversity did not differ between mid- and late-seral rangelands. A follow-up study by Joseph et al. (2003) further confirmed the findings of Nelson et al. (1997).

Nelson et al. (1999) evaluated wildlife preferences for grassland (late seral), shrub-grass (mid seral), and shrubland (early seral) communities in the Chihuahuan Desert of New Mexico. They found total observations for birds and mammals were higher in shrub-grass than in grassland or shrubland. Shrubland communities were preferred over grassland communities. In general, plant succession will move toward shrubland communities with heavy livestock grazing, shrub-grass communities with moderate grazing, and grassland communities with conservative to no grazing. These studies (Nelson et al. 1997, Nelson et al. 1999, Joseph et al. 2003) indicate that conservatively to moderately grazed areas in mid or late seral condition supported greater diversity of birds and large mammals than ungrazed areas in climax condition in the Chihuahuan Desert. Therefore, maintaining a patchwork of lightly, conservatively, and moderately grazed pastures appears to provide habitat that supports high wildlife diversity. However, these studies do not provide information on livestock grazing (i.e. grazing intensity) on population dynamics

for particular wildlife species, and some species associated with the Chihuahuan Desert require a high component of herbaceous vegetation for suitable habitat.

Table 8. Average wildlife sightings (sightings km²) on conservatively grazed late seral and moderately grazed mid seral rangelands in southern New Mexico (From Nelson et al. 1997).

Wildlife species	Late Seral/Conservatively Grazed	Mid Seral/Moderately Grazed
	----- (Sightings km ²) -----	
Pronghorn	9.3	0.5
Coyote	0.5	3.1
Jackrabbit	49.1	63.4
Cottontail	8.1	12.4
Total Mammals	67.1	79.6
Mourning dove	12.4	19.3
Scaled quail	8.1	16.2
Total Gamebirds	20.5	35.5
Meadow lark	5.2	14.9
Western kingbird	18.0	20.5
Loggerhead shrike	6.2	13.1
Sparrow/juncos	110.7	138.7
Mockingbird	6.2	14.9
Lark bunting	20.5	42.9
Other songbirds	4.9	23.9
Total songbirds	171.7	268.7
Total raptors	13.1	16.8
Ravens	10.1	11.8
Total other birds	10.6	12.4
Total birds	215.9	333.4
Total wildlife	282.0	413.0

Similar research has evaluated the response of birds and rodents to grazing exclusion and moderate cattle grazing in southeastern Arizona (Bock et al. 1984). In this study, the grazed area supported higher bird numbers during the summer, but densities did not differ in winter. Rodents

were more abundant in the grazing exclusion areas. It was concluded that moderate cattle grazing favors birds over rodents as a class.

With regard to managed livestock grazing systems on particular wildlife species, significant research has been conducted with upland gamebirds and large mammals. For example, Mearns quail and prairie chickens are upland gamebirds sensitive to livestock grazing. Adequate residual bunchgrass cover following the growing season is required for nesting and escaping predators. Grazing use levels of no more than 35% to 40% of forage appear necessary to maintain Mearns quail populations (Brown 1982). Recent research suggests that Mearns quail need a minimum of 20 cm height of bunchgrasses and at least 50% herbaceous cover (Bristow and Ockenfels 2003). Light to moderate cattle grazing can benefit Mearns quail by increasing availability of food plants (Brown 1982, Bristow and Ockenfels 2000). An intensive study of Mearns quail habitat in southeastern Arizona showed more Mearns quail coveys occurred on grazed than ungrazed rangelands (Bristow and Ockenfels, 2000). Grazing intensities were considered to be light to moderate on the areas studied. The investigators cautioned that heavy grazing would be harmful to Mearns quail as demonstrated by Brown (1982) through excessive removal of cover and food.

Studies in New Mexico (Campbell et al. 1973, Saiwana et al. 1998) have indicated that conservative to moderate grazing can benefit scaled quail by improving their mobility through opening up dense grass stands. However, on severely degraded rangelands, any benefits of livestock grazing to scaled quail are doubtful (Joseph 2001).

Livestock grazing can be used to enhance forage for elk, and grazing systems can be used to manage the distribution of elk across habitats within a herd's range. Managed livestock grazing can benefit elk by increasing availability of preferred grasses in early growth stages,

improving nutritive value of herbaceous vegetation, and improving accessibility of high quality grasses by removing surrounding litter. A variety of research projects also illustrate ways to coordinate livestock grazing and mule deer habitat needs. For example, managed livestock grazing and prescribed burning are common tools to maintain or increase shrub production for mule deer. Many rangelands can provide habitat for both pronghorn and livestock. The key is maintaining the rangelands in good ecological condition. Pronghorn thrive in subclimax habitats, but production decreases when excessive livestock grazing produces poor range conditions (Howard et al. 1990). In desert regions in poor ecological condition, the potential for competition between cattle and pronghorn is highest from March to August, when both species are grazing forbs and grasses. For all of these large mammals, carefully managed livestock grazing intensity and timing are critical in accomplishing the objective of maintaining or improving habitat quality.

Analysis of the literature shows many wildlife species are tolerant of moderate grazing, and many appear to benefit from light to conservative grazing. However, studies that clearly isolate grazing as the primary factor endangering specific species are scarce. This is largely due to the fact there have been very few studies designed to detect these relationships. Although there is certainly strong circumstantial evidence that heavy grazing can be a major factor resulting in the decline of several endangered rangeland wildlife species, carefully controlled studies are needed to better examine and understand the relationships between controlled grazing (i.e. light, conservative, and moderate grazing intensity) and endangered species in arid or semiarid environments.

Controlled Livestock Grazing Impacts on Riparian Habitat

Several studies reviewed by Ohmart (1996) and Belsky et al. (1999) have demonstrated that poorly managed livestock grazing can be destructive to riparian habitat. Only recently have studies become available comparing the effects of carefully controlled grazing and grazing exclusion on riparian habitat. In eastern Oregon (Shaw and Clary 1995) and central Idaho (Clary et al. 1999), carefully timed cattle grazing at light to moderate intensities had a similar effect on riparian vegetation as grazing exclusion. Many riparian improvements occurred under both controlled grazing and grazing exclusion in the Idaho study (Clary et al. 1999). It was concluded light to moderate cattle grazing in late spring is compatible with riparian habitat maintenance and improvement.

Unfortunately, in the southwestern United States, research evaluating the effects of controlled grazing on riparian habitat is limited. On the Montana Allotment on the Coronado National Forest in southeastern Arizona, a combination of rest rotation grazing and conservative stocking over a 10-year period resulted in rapid improvement of both riparian vegetation and bank characteristics (Fleming et al. 2001). Hundreds of riparian trees became established in riparian reaches where they had been absent 13 years ago. Based on a system using 10 indicators, riparian health on the Montana Allotment was judged to be excellent. This study shows that well-planned grazing can result in rapid riparian habitat improvement under some conditions in the southwestern United States.

However, in a recent study conducted in south-central New Mexico, Lucas et al. (2004) observed no negative impacts of grazing at light (20-30% forage utilization) and moderate (40-50% forage utilization) levels during the cool, warm, or dormant seasons as compared to areas excluded from grazing. No significant differences were detected between grazed and ungrazed

plots with respect to plant species diversity, runoff and sediment production, stream profiles, or cottonwood numbers and growth. The study observed increasing use of cottonwood saplings during cooler seasons and with increasing grazing intensity but concluded that grazing at these levels during these seasons were within the systems' ability to respond from grazing.

Controlled Livestock Grazing Impacts on Fish

Very little research addresses fish/grazing relationships in the western United States (Rinne 1999). Much of what is known about the effects of grazing on fishes is summarized by Platts (1991) and Rinne (1999). Scientific consensus, as summarized by Platts (1991), has been that grazing has irrefutably harmed fishes and their habitats. Despite this statement, Platt (1991) and Rinne (1999) both acknowledge that controversy exists because published, valid evaluations of grazing strategies as related to fishery productivity are lacking in the literature. Therefore cause and effect are not completely understood between livestock grazing and fishes. After reviewing 166 papers relating to fish and grazing, Rinne (1999) found only 30 that evaluated fish population responses to grazing. The rest were concerned primarily with grazing effects on riparian habitat attributes. After careful dissection, it was found only 3 of the 30 studies contained pretreatment data essential to separate grazing effects from natural variations in populations. Various other experimental limitations were found in these studies such as lack of replication in time and space. Lack of statistical analyses and failure to report in peer-reviewed publications were other important limitations.

Nearly all of the literature on grazing and fishes involves upper-elevation, mountain areas inhabited by coldwater salmonid species (Rinne 1999). Knowledge of grazing effects on salmonids (trout) cannot be readily applied to warm-water species (minnows and suckers)

occupying lower-elevation streams and rivers because their habitat requirements and behavioral traits differ (Rinne and Neary 1997). Several warm-water fish species are threatened or endangered such as the spinedace and Rio Grande sucker. However, lack of research prevents drawing definite inferences about the effects of controlled grazing on this category of fish. Rinne and Neary (1997) found that endangered cyprinid fish populations in the Verde River, Arizona actually disappeared when grazing was excluded. It can be conjectured that grazing strategies that result in riparian habitat improvement will generally benefit salmonid fish species but this may not apply to some warm-water fish species.

Conclusions

Several literature reviews have compared the impacts of unmanaged livestock grazing with grazing exclusion on various components of rangeland ecosystems. These reviews are consistent in showing that unmanaged grazing can be destructive to rangeland vegetation, soils and wildlife habitat. Unfortunately, reviews comparing the impacts of managed livestock grazing to grazing exclusion are limited. Analysis of 20 studies shows that carefully managed grazing can have neutral or in some cases positive effects on plant species composition, productivity, and drought survival.

Although claims have been made that intensive grazing can be beneficial to rangeland soils, over 30 studies are consistent in showing that grazing even at light to moderate intensities adversely impacts soils by increasing compaction, reducing infiltration, and increasing erosion. However, the magnitude of these adverse effects is ameliorated by natural forces that cause soil formation, soil deposition, and soil loosening. Treading of soil by livestock can improve grass seeding establishment and increase mineral cycling, particularly on highly degraded sites.

Managed grazing can be beneficial to some desirable wildlife species. Evidence that grazing at light to conservative intensities has harmed or endangered wildlife species is lacking. Recent research shows some riparian habitats can rapidly improve under properly timed grazing at light to conservative intensities. Poorly controlled grazing can harm habitat of various salmonids but impacts on warm-water fish species are uncertain. Research comparing the impacts of carefully controlled grazing versus grazing exclusion on fish populations is lacking. Habitat for salmonids can improve under controlled grazing, but grazing exclusion may give a faster rate of improvement.

The current literature, particularly that which is readily accessed by the general public (i.e., popular press), is replete with examples of poorly designed studies comparing controlled grazing versus grazing exclusion. Many peer-reviewed research studies that do exist have serious shortcomings. These include lack of pretreatment information, lack of replication in time, lack of replication in space, and failure to apply statistical tests, making it difficult to objectively evaluate many grazing studies conducted in the arid southwest. Well-designed long-term studies are needed that better evaluate the impacts of various grazing intensities and systems versus grazing exclusion on rangeland vegetation. Knowledge of how vegetation is impacted by controlled grazing versus grazing exclusion can be readily used in decisions regarding management of watersheds, wildlife habitat, and fish habitat.

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