

EFFECTS OF CATTLE GRAZING ON NORTH AMERICAN ARID ECOSYSTEMS: A QUANTITATIVE REVIEW

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ABSTRACT.—A quantitative review was conducted of the effects of cattle grazing in arid systems on 16 response variables ranging from soil bulk density to total vegetative cover to rodent species diversity. Various studies from North American arid environments that used similar measures for assessing grazing effects on the same response variables were used for the review; each study was assigned to serve as a single data point in paired comparisons of grazed versus ungrazed sites. All analyses tested the 1-tailed null hypothesis that grazing has no effect on the measured variable. Eleven of 16 analyses (69%) revealed significant detrimental effects of cattle grazing, suggesting that cattle can have a negative impact on North American xeric ecosystems. Soil-related variables were most negatively impacted by grazing (3 of 4 categories tested were significantly impacted), followed by litter cover and biomass (2 of 2 categories tested), and rodent diversity and richness (2 of 2 categories tested). Vegetative variables showed more variability in terms of quantifiable grazing effects, with 4 of 8 categories testing significantly. Overall, these findings could shed light on which suites of variables may be effectively used by land managers to measure ecosystem integrity and rangeland health in grazed systems.

Key words: grazing, grazing effects, arid ecosystems, meta-analysis, rangeland conservation.

The debate regarding ecological effects of domestic livestock grazing on arid rangelands of the western U.S. is far from over, and many conservation biologists have become sufficiently concerned about the issue to join the debate (Brussard et al. 1994, Noss 1994). One can observe abundant examples of apparent overgrazing in North American arid systems (Fleischner 1994). Conservation biologists, however, may be skeptical of grazing literature, especially those studies conducted in the past. Nonetheless, I suggest that there is valuable information available in this abundant body of literature on effects of cattle grazing.

To those familiar with grazing literature, it is clear that there is still no scientific consensus regarding potentially detrimental effects of livestock grazing on arid rangelands (Brussard et al. 1994, Fleischner 1994, Noss 1994). The lack of consensus probably stems in part from inconsistencies in the grazing literature. Results of studies done in different plant communities, or at different sites representing the same community, often contradict one another. For example, a grazing study conducted in an arid shrub/bunchgrass community in central

Utah found that total vegetation cover was greater in grazed areas (Brotherson and Brotherson 1981), whereas another study in shrub/bunchgrass habitat in the adjacent valley reported that total vegetative cover was greater in ungrazed areas (Johansen and St. Clair 1986).

Traditional qualitative literature reviews do little to resolve such controversial issues, as they are subject to biases of the reviewer. For example, Fleischner's (1994) review of effects of grazing in western North America almost exclusively cites prior studies demonstrating detrimental effects of grazing. A range scientist with a contrary bias could easily cite as many studies demonstrating insignificant, and beneficial, effects of grazing. Though Fleischner's study sought to make the case against grazing rather than present a comprehensive review of grazing literature, I cite this example to illustrate that literature reviews can sometimes be a front for specific agendas. A more recent, more comprehensive grazing review completed by Belsky et al. (1999) qualitatively summarizes major effects of livestock grazing on stream and riparian systems in the West.

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This review was less biased than Fleischner's in that it used a more systematic approach in searching the literature.

The purpose of this paper is to present results of a quantitative synthesis of effects of cattle grazing on arid western rangelands. Quantitative reviews provide an alternative to traditional literature reviews and can take many forms. One of the more widely used methods is meta-analysis, which utilizes statistics to synthesize research results and draw general interpretations from a collection of original studies on a common topic (Hedges and Olkin 1985, Gurevitch and Hedges 1993).

A formal meta-analysis in this case would require means and variances of paired grazed and ungrazed sites from a set of similar studies. From these means and variances, one could calculate an effect size for each study, which is a standardized measure of the effect of grazing. However, of 112 studies screened for inclusion in the analyses, only 26 (23%) presented either a measure of variation along with means or data that would allow calculation of variability; thus, it was impossible to use formal meta-analysis for this quantitative review. Furthermore, other methods for quantitative review such as combined probability tests (i.e., Fisher 1932) were inappropriate because most studies screened failed to report exact *P*-values.

Because of these limitations, I grouped papers that used similar measures for assessing effects of grazing on the same response variables, and each study was used as a single data point in paired comparisons of grazed versus ungrazed sites. A similar approach was used by Milchunas and Lauenroth (1993) to assess relative roles of different environmental factors in determining differences between grazed and ungrazed sites worldwide. In yet another similar approach, Milchunas et al. (1998) synthesized published and unpublished data on various guilds of organisms from grazing studies performed at an experimental range in Colorado. While these 2 examples focused on community-level functional responses at first the global and then local level, this paper aims to shed light on the more basic issue of general effects of cattle grazing on arid western rangelands.

The objective of this study was to quantitatively synthesize effects of cattle grazing on

arid western rangelands. This was accomplished by grouping individual grazing studies into different categories, based on similarities in response variables measured, and using outcomes of these studies as single data points in paired comparisons of grazed versus ungrazed sites.

METHODS

Various databases were searched for primary research articles in journals, symposia volumes, and technical government publications concerning effects of livestock grazing on arid rangelands of the western U.S. AGRICOLA and BIOSIS were the primary databases used. Searches were done for the years 1945–1996. The literature was searched using the terms *grazing*, *cattle grazing*, or *livestock grazing* as primary key words and *effect* or *effects* as secondary key words. Studies were rejected that included grazers other than cattle. In addition, only studies that simultaneously compared grazed areas with nearby ungrazed controls were included. This eliminated all studies that compared only different intensities or levels of grazing (i.e., that lacked an ungrazed control) and studies that made temporal comparisons of the same sites before and after grazing.

Only studies conducted in arid environments of the western U.S. and with site descriptions that included xeric vegetation types were included in the analyses. Most studies used were conducted west of the Rocky Mountains, but a few occurred in arid shrub/grasslands of the western Great Plains or the Southwest. Studies pooled for analysis included sites from Oregon to Kansas and from Montana to Texas, and covered an elevational gradient from alpine to desert ecosystems. Vegetation types in these study areas ranged from forest ecosystems to grasslands. It was necessary to combine data from seemingly disparate study areas in order to achieve pooled sample sizes large enough to analyze. Again, any overall effects revealed through combining these data, despite differences in community type, would constitute general evidence of grazing effects in arid landscapes.

Similarly, it was necessary to lump studies that used different systems of grazing (independent from stocking rates, which are discussed below). Some studies used in my analysis

utilized a spring, summer, or winter grazing regime, or even a combination of these seasons. Others used a deferred-rotation system. Some studies reported multiple years of different grazing systems over time, while others did not report the grazing regime at all. With such a wide range of systems used among studies considered for inclusion in my analysis, it was necessary to combine different types to achieve pooled categories of sufficient size for analysis. Again, any overall effects seen through combining data from many different studies would constitute considerable evidence of grazing effects in western North America.

One hundred twelve studies were initially located on effects of grazing on fauna, flora, and soil properties, but after applying the above criteria for inclusion of studies, 54 were selected for the analyses. Several papers included appropriate data for more than a single analysis, such as articles with data on both vegetation and wildlife in grazed versus ungrazed sites (e.g., Bock et al. 1984, Medin and Clary 1989, 1990). Some papers also contributed 2 or more observations to a given analysis. Examples include those that assessed effects of grazing using the same vegetation variables measured independently in distinctly different community types or sites (e.g., Pieper 1968, Wheeler et al. 1980, Roundy and Jordan 1988). However, when non-independent observations were reported, such as a certain response variable being measured in the same grazed and ungrazed locations at different times or subsampling within the same grazed and ungrazed experimental units, these were reduced to single observations by calculating mean values. In some papers investigators compared ungrazed sites with 2 or more sites that were grazed at different intensities. In such cases the lower intensity grazing data were used to represent grazing effects when 2 levels of grazing were used (i.e., "lightly grazed" rather than "heavily grazed" data were used for comparison with an ungrazed control); data for the intermediate grazing intensity were used when 3 levels of grazing were used (i.e., "moderately grazed" was used rather than "lightly grazed" or "heavily grazed" for comparison with an ungrazed control).² I was unable to analyze grazing intensity categories (i.e., heavily and lightly grazed categories) separately because the analysis would have resulted in data pools too small for analysis.

The following response variables were separately analyzed: rodent species diversity, rodent species richness, vegetation diversity, total vegetation cover, shrub cover, grass cover, forb cover, total vegetation biomass, tree seedling survival, non-tree seedling survival, cryptogamic crust cover, litter cover, litter biomass, soil bulk density, infiltration rate, and soil erosion. Rodent species diversity measurements used the standard H' index. Rodent species richness was measured as total number of rodent species present per site. Vegetation diversity values were standard diversity indices (H') calculated according to percent cover of the 3 broad vegetation types (shrubs, grasses, and forbs) within the study areas. Total vegetation biomass was measured using various methods but always reported as weight per unit area.

Quantitative analysis for these 16 categories included data from several papers grouped by similar response variables and measures that were used to assess effects of grazing on these response variables. Each analysis included 4–18 data points (i.e., paired comparisons of grazed vs. ungrazed areas) taken from 3–16 different studies. Several response variables from the literature review were not analyzed because I did not find sufficient comparable data (i.e., I found <4 data points), or because data from too many papers did not meet the above criteria for inclusion.

Data to be included in each analysis were first tested for normality using the Shapiro-Wilks statistic (SAS 1987). Statistics designed for paired comparisons were used in all analyses of grazing effects. In all cases treatment means for each study were treated as fixed quantities, with no consideration of within-site variation (which generally was not reported in the individual studies). Raw data sets that were normally distributed (12 of 16 analyses) were tested using t tests for paired comparisons. Of the remaining 4 data sets, 3 (seedling survival for non-tree plant species, and litter cover and biomass) were normalized by standardizing differences between ungrazed and grazed measures by dividing by the ungrazed measures (i.e., [ungrazed – grazed] / ungrazed).

²Studies that defined "heavy," "moderate," and "light" grazing described heavy grazing as 0.5–2 ac AUM⁻¹ (or 50–80% herbage utilization), moderate grazing as 1.5–2.5 ac AUM⁻¹ (or 30–45% herbage utilization), and light grazing as 2–4 ac AUM⁻¹ (or <30% herbage utilization).

These transformed data sets, which reflect the relative reduction due to grazing of the 3 standardized measures, were also analyzed with paired-comparisons *t* tests. Neither raw nor transformed data were normally distributed from 1 data set (infiltration rates), so a non-parametric Wilcoxon matched-pairs signed-ranks test was applied to this analysis (Siegel 1956).

In all analyses the null hypothesis that grazing has no effect on the measured variables was tested against the 1-tailed alternative. This entailed testing for significant positive or negative deviations from 0 in ungrazed-grazed paired comparisons. For example, grazing would generally be considered detrimental if it caused reduced plant or animal diversity, reduced cover or biomass of plant litter or cryptogamic crusts, reduced seedling survival, or reduced infiltration rates of water into soil. However, for 2 variables analyzed, soil bulk density and erosion, grazing-induced increases would instead be considered detrimental effects, while grazing-induced decreases would be considered positive effects of grazing.

RESULTS

For each of 16 response variables analyzed, Table 1 shows numbers of papers and data points included in the analysis, identity of each paper included, and statistical results of the analysis. Table 2 shows treatment and control means (grazed versus ungrazed) and difference of the means for each analysis category. Eleven of 16 analyses (69%) revealed significant detrimental effects of livestock grazing on arid rangelands. With a type I error rate of 0.05, only 1 test would be expected to yield significance by chance (i.e., $16 \times 0.05 = 0.80$); the actual number of statistically significant analyses (11/16) was significantly greater than this ($\chi^2 = 130.1$, $df = 1$, $P \ll 0.001$). In addition, many of the other 5 analyses were quite close to being significant (i.e., the largest *P*-value for the null hypothesis of no grazing effect was 0.111). Furthermore, if a 2-tailed test that grazing had no detrimental effect on the various categories had been used instead, 7 of 16 analyses (44%) would have been significant, and none of these would have indicated beneficial effects.

Overall, the 3 broad categories of variables (soil-related, vegetation-related, and animal-related variables) showed a varied response to

grazing influences. Soil-related variables in particular seemed to reflect detrimental effects of grazing. Among paired grazed and ungrazed areas, the former had significantly reduced cryptogamic crust cover ($P = 0.021$) and infiltration rates (Wilcoxon: $P = 0.002$) and significantly greater soil loss to erosion ($P = 0.007$). Analysis of vegetation variables indicated that grazed areas had significantly reduced litter biomass ($P = 0.009$) and cover ($P = 0.046$), seedling survival (non-trees, $P = 0.028$), total vegetation biomass ($P = 0.005$), and grass and shrub cover ($P = 0.016$ and 0.013 , respectively) than paired ungrazed areas. Rodent categories, the only vertebrate categories for which I was able to gather sufficient data, indicated reduced species diversity ($P = 0.039$) and richness ($P = 0.034$) in response to grazing.

DISCUSSION

My analyses of data gleaned from the literature suggest that livestock grazing may have detrimental effects on North American arid ecosystems. Because the data are drawn from various studies conducted at different times and in different environments, these effects may be applicable to North American xeric systems in general, rather than to specific locations and/or study periods. Of course, this does not preclude the likely possibility that spatial and temporal heterogeneity in these arid environments play a role either in further exacerbating or in ameliorating these detrimental effects. Moreover, the analyses did not take into account certain details of individual studies, such as stocking rates and intensity and timing of grazing, that could affect measured impacts.

This later issue may be considered problematic because different kinds of grazing systems can result in differential impacts to the land. For example, a particular rotational system developed with great ecological sensitivity may work better in arid lands than perhaps systems that have been "transplanted" from the Midwest. In fact, some range management textbooks (i.e., Heady and Child 1994, Holecheck 1998) give sound evidence of this. However, to effectively take this particular variable into account in this analysis would have required locating many more studies that use the same system and stocking rate and that address the same response variables. Only then would further analysis be feasible.

TABLE 1. Results of tests for detrimental effects of livestock grazing on arid ecosystems.

Category	N		Test ^a	P	Observations with a decrease in dependent variable ^b	Literature sources ^c
	Source	Observations				
Rodent species diversity (H')	8	15	t	0.039	13(87%)	3, 18(7), 19, 25, 29, 30, 33(2), 45
Rodent species richness	8	17	t	0.034	10(59%)	3, 16(3), 18(7), 25, 29, 30, 33(2), 45
Vegetation diversity (shrubs, grasses, forbs)	13	15	t	0.086	7(47%)	3, 4, 11, 15, 20, 22, 29, 30, 38(3), 40, 45, 49, 50
Shrub cover (%)	16	18	t	0.013	10(56%)	3, 4, 7, 11, 15, 20, 21, 22, 29, 30, 38(2) 40, 45, 46(2), 49, 50
Grass cover (%)	15	17	t	0.016	12(71%)	3, 4, 7, 11, 15, 20, 22, 29, 30, 31, 38(3), 40, 45, 49, 50
Forb cover (%)	15	17	t	0.111	9(53%)	3, 4, 7, 11, 12, 20, 22, 29, 30, 31, 38(3), 40, 45, 49, 50
Total vegetation cover (%)	14	16	t	0.051	8(50%)	1, 4, 6, 7, 11, 20, 21, 23, 27, 38(3), 40, 43, 44, 49
Total vegetation biomass (kg ha ⁻¹)	7	11	t	0.005	10(91%)	8, 14, 16(2), 24, 31(2), 37, 38(3)
Seedling survival, trees (%)	5	8	t	0.098	6(75%)	10, 17, 26, 48, 52(4)
Seedling survival, non-trees (%)	3	4	ts	0.028	4(100%)	32(2), 35, 47
Cryptogamic crust cover (%)	6	6	t	0.021	5(83%)	1, 2, 7, 21, 23, 40
Litter cover (%)	9	12	ts	0.046	6(50%)	2, 7, 12, 14, 23, 34, 38(3), 40, 46(2)
Litter biomass (kg ha ⁻¹)	6	7	ts	0.009	6(86%)	5, 12, 16(2), 27, 41, 42
Soil bulk density (g cm ⁻³)	7	9	t	0.094	2(22%)	8, 27, 28(2), 31(2), 34, 42, 51
Soil/water infiltration rate (cm hr ⁻¹)	12	15	Wilcoxon	0.002	12(80%)	5(2), 8, 9, 13, 14, 27, 31(2), 36(2), 39, 42, 51, 53
Soil erosion (kg ha ⁻¹)	7	9	ts	0.007	0(0%)	13, 14, 31(2), 36(2), 39, 51, 54

^aStatistical tests employed were paired-comparisons *t* tests on actual data (t), paired-comparisons *t* tests on data standardized by ungrazed means (ts), or Wilcoxon matched-pairs signed ranks test.

^bPercentages of observations (usually individual studies) that experienced a decrease in dependent variable due to grazing treatment.

^cNumbers within parentheses indicate numbers of observations or data points utilized per literature source; no parentheses indicate only 1 observation was utilized. All other numbers identify literature sources utilized as follows: (1) Anderson et al. 1982, (2) Beymer and Klopatek 1992, (3) Bock et al. 1984, (4) Brady et al. 1989, (5) Branson et al. 1962, (6) Brotherson and Brotherson 1981, (7) Brotherson et al. 1983, (8) Brown and Schuster 1969, (9) Buckhouse and Gifford 1976, (10) Conroy and Svejcar 1991, (11) Cottam and Evans 1945, (12) Dady et al. 1998, (13) Dunford 1954, (14) Gamougoun et al. 1984, (15) Gardner 1950, (16) Grant et al. 1982, (17) Hall et al. 1992, (18) Hanley and Page 1981, (19) Heske and Campbell 1991, (20) Holecheck and Stephenson 1983, (21) Jeffries and Klopatek 1987, (22) Jepson-Innes and Bock 1989, (23) Johansen and St. Clair 1986, (24) Johnson 1956, (25) Johnson 1982, (26) Kingery and Graham 1991, (27) Knoll and Hopkins 1959, (28) Laycock and Conrad 1967, (29) Medin and Clary 1989, (30) Medin and Clary 1990, (31) Meeuwig 1965, (32) Milchunas et al. 1992, (33) Oldemeyer and Allen-Johnson 1988, (34) Orodho et al. 1990, (35) Owens and Norton 1992, (36) Packer 1953, (37) Pearson 1965, (38) Pieper 1968, (39) Pluhar et al. 1987, (40) Rasmussen and Brotherson 1986, (41) Reardon and Merrill 1976, (42) Rhoades et al. 1964, (43) Rich and Reynolds 1963, (44) Robertson 1971, (45) Rosenstock 1996, (46) Roundy and Jordan 1988, (47) Salihi and Norton 1987, (48) Schmidt and Stubbendieck 1993, (49) Schuster 1964, (50) Smith and Schmutz 1975, (51) Thompson 1968, (52) Wheeler 1980, (53) Wood 1982, (54) Wood and Blackburn 1981.

TABLE 2. Treatment and control means by category, with difference of means.

	Means (M)		$M_{\text{ugr}} - M_{\text{gr}}$
	Ungrazed (M_{ugr})	Grazed (M_{gr})	
Rodent species diversity (H')	0.564	0.438	0.126
Rodent species richness	5.94	4.70	1.24
Vegetation diversity	0.284	0.261	0.023
Shrub cover (%)	11.01	9.56	1.45
Grass cover (%)	25.33	20.19	5.14
Forb cover (%)	8.77	8.23	0.54
Total vegetation cover (%)	32.06	27.48	4.58
Total vegetation biomass (kg ha^{-1})	1935.8	1478.7	457.1
Seedling survival, trees (%)	41.6	36.0	5.6
Seedling survival, non-trees (%)	24.78	11.67	13.11
Cryptogamic crust cover (%)	34.46	19.29	15.17
Litter cover (%)	30.36	28.0	2.36
Litter biomass (kg ha^{-1})	2573.3	1034.0	1539.3
Soil bulk density (g cm^{-3})	1.17	1.22	-0.05
Soil/water infiltration rate (cm hr^{-1})	9.85	6.0	3.85
Soil erosion (kg ha^{-1})	288.74	525.91	-237.17

Furthermore, nearly 54 studies analyzed were found to be *quasi-experiments* (no randomization, but other experimental qualifications are met) rather than strict experiments in which experimental units are randomly assigned to control and treatment. Because of this, I do not infer causation between results presented in this review and western rangelands in general. I view these results as a basis for understanding which features of North American arid environments are most likely to suffer general impacts of grazing rather than as evidence relevant to the issue of the sustainability (or lack of it) of livestock grazing on western rangelands.

Various features of xeric soils appear to be sensitive to effects of cattle grazing (Table 1). Of those variables reflecting potential changes in soils that are generally attributed to trampling and compaction by cattle (Fleischner 1994), such as physical structure (bulk density) and functional properties (erosion, infiltration, cryptogamic crusts), there was statistical evidence for an effect of grazing on all 3 of the latter.

Although there may be some correlation between increase in erosion in grazed areas and a significant decrease in vegetation cover in grazed areas, the analyses, nevertheless, did appear to detect potential impacts of grazing on plant communities. Livestock grazing had significant effects on vascular plants for 4 of 8 vegetation response variables analyzed. Cover of grasses and shrubs, as well as total vegetation biomass, was reduced significantly by

grazing. The indication that shrub cover may be reduced by grazing contradicts other studies (Archer 1989, Schlesinger et al. 1990). However, many of these studies cite grazing as part of a complex of factors (i.e., fire suppression and climate change) that lead to increased shrub abundance.

Because many studies included in the analyses provided data only for vegetation categories such as shrubs, forbs, or grasses, analyses were necessarily limited to such broad categories. Although forb cover and vegetation diversity were statistically similar between grazed and ungrazed areas, much of this apparent lack of response to grazing may simply be an artifact of lumping plant species into broad vegetation categories. For example, lack of a grazing effect on forbs might occur even though palatable species of these plants are depleted by grazing, if this depletion is compensated by increases in unpalatable species or grazing-adapted, exotic weeds. The vegetation diversity category would have had more useful implications for range scientists and managers if it had been possible to include grazing studies that reported vegetation diversity in terms of numbers of native and nonnative species. I urge future investigators of grazing effects to collect and present vegetation data on a species-specific basis.

Rodents also seemed to react negatively to grazing influences. While in rare cases rodent diversity increased in grazed systems (i.e., Grant et al. 1982, Bock et al. 1984), the fact that meta-analysis of published literature

revealed negative overall impacts on rodents suggests that grazing is generally unfavorable for rodent communities on arid rangelands. Effects of domestic grazers on rodents are probably manifested indirectly through associated effects on soils and/or vegetation. For example, some desert rodent species specialize in foraging for seeds in certain soils and thus prefer particular soil properties (Price and Waser 1985, Price and Longland 1989). Grazing-induced changes in physical properties of soils could thus lead to loss of such specialized species or their replacement by a species more suited to the new edaphic conditions. Similarly, reduction in organic litter due to grazing may explain the loss of some species; western harvest mice (*Reithrodontomys megalotis*), for example, exhibit a strong affinity for grass litter (Clark and Kaufman 1991). Moreover, analyses indicated that grazing in these arid ecosystems reduces total vegetation biomass as well as shrub and grass cover (Table 1). Both natural ecotonal transitions from grass- to shrub-dominated habitats (Schroder and Rosenzweig 1975) and experimentally imposed changes in grass, shrub, and/or total vegetation cover (Rosenzweig 1973, Price 1978, Longland 1994) can have profound effects on desert rodent densities and species composition. Thus, it is quite possible that reduced vegetation cover in grazed areas drives the responses of the local rodent community.

The tentative conclusion that North American arid systems may be sensitive to livestock grazing is perhaps unsurprising. Whereas large herbivores that might be considered ecological counterparts to domestic livestock are native to many other arid regions of the world, there is a paucity of large, native grazers in contemporary North American xeric environments. American bison (*Bison bison*), for example, occurred very rarely in the arid West (Mack and Thompson 1982, Berger and Cunningham 1994, Kay 1994). In a worldwide review of effects of grazing by large herbivores, Milchunas and Lauenroth (1993) concluded that an evolutionary history involving grazing animals and the local environment was the most important factor in determining negative impacts of grazing on productivity. North American arid rangelands lack such an evolutionary history. Until Europeans introduced cattle and other grazers to our arid rangelands, the western range was relatively free of large grazing mammals

for 10,000 years (Berger 1986, Berger and Cunningham 1994). Arguments that these plant communities are adapted to grazing because they supported a diverse herbivore fauna during the Pleistocene (Burkhardt 1996) are probably irrelevant to this issue, as plant communities have most certainly changed in the intervening time and there have been few selective agents favoring retention of grazing tolerance.

Certainly, distinguishing effects of herbivory by native species versus livestock grazing is a concern to range scientists. However, it is notable that native grazers such as jackrabbits (*Lepus* spp.) and native browsers such as mule deer (*Odocoileus hemionus*) and pronghorn (*Antilocapra americana*) are usually allowed access to grazing enclosures such as those used in studies compiled in this review. Hence, the absence of grazing and browsing by native herbivores should rarely confound assessments of cattle grazing effects.

When biologists are faced with an abundance of very disparate studies or individual studies that yield no significant effects (as often found in the grazing literature), quantitative analysis allows detection of broad patterns due to a consistent direction of differences among those disparate studies. I used this tool to glean more objective information from the grazing literature than has been revealed in the past. It seems that soil-related variables and vegetative cover variables are most sensitive to grazing in arid systems. These findings may prove useful to rangeland managers, who traditionally have used only 1 or 2 metrics to assess rangeland health, with the most common criterion being soil condition. Perhaps investigation of a whole suite of connected variables, such as cryptogamic crust cover, soil infiltration rates, and litter cover, will give managers a more complete picture of ecosystem integrity in grazed landscapes.

It is imperative that conservation biologists work more closely with range managers and scientists. Livestock grazing is the most widespread land management practice in western North America. Seventy percent of the western U.S. is grazed, including wildlife refuges, wilderness areas, and part of our National Park System. The influence of grazing on arid ecosystems is just beginning to be realized. Conservation biologists could do much toward identifying potential impacts of grazing on biodiversity and ecosystem function by executing

more sophisticated grazing studies. A more traditional meta-analysis was unsuitable for this review because most studies used in this analysis were quasi-experiments, and many failed to present any measure of variability. This suggests that, although the literature is rich in studies of grazing effects, there is much room for improved experimental design and data presentation in this area of research.

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