Species Richness Inside and Outside Long-Term Exclosures

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Abstract: Recent environmental literature contains claims that livestock grazing has caused reduction in species diversity on Western rangelands. Data of species richness (number of species) is presented from inside and outside 24 long-term exclosures in Montana, Utah, and Wyoming. For the average of all exclosures there was no difference between species richness inside and outside the exclosures. Overlap of species (those found both inside and outside of the exclosures) was high (69 to 72 percent), and the species found either inside only or outside only did not reveal any trend related to grazing or successional status. The areas inside and outside eight exclosures in Wyoming were sampled in 2 successive years. Growing season moisture was above normal the first year and far below normal the second. Species richness sampled was more than 40 percent lower in the second year than in the first. The rather small difference in species richness inside and outside all of the exclosures indicates that neither grazing nor lack of grazing has much long-term influence on species richness. However, growing season moisture can greatly influence how many species are encountered when sampling an area.

Introduction

Some conservation biology and environmental literature contains claims that livestock grazing has caused and continues to cause reduction in species diversity on Western rangelands: Livestock have greatly lowered plant diversity in most of the West (Jacobs 1991). One of the ecological costs of livestock grazing is the "reduction of species richness" (Fleischner 1994). Livestock grazing is the most insidious and pervasive threat to biodiversity on rangelands (Noss and Cooperrider 1994). Livestock grazing has altered and diminished the presettlement diversity of native fauna and flora on many Western rangelands (Donahue 1999). Ehrlich (1990), Wuerthner (1990), and Noss (1994) made similar statements. Wuerthner (1994) lumped farming and pastoralism (grazing) together and suggested that agriculture is the most serious threat to biodiversity in the Western United States. In most of these publications, only anecdotal information was presented to back up the claims that grazing reduces species diversity.

Authors have not always clearly defined terms (like biodiversity, diversity, and species diversity) used in their publications. Because of this, some definition of terms may be useful at this point. West (1993) defined "biological diversity" (or "biodiversity") as:

> ...the variety of life and its processes, including the variety of living organisms, the genetic differences among them, the communities, ecosystems and landscapes in which they occur, plus the interactions of these components.

This definition specifically includes diversity at the genetic, species, community, or ecosystem and landscape or regional level. In a later publication, West (1995) suggested that the culture and indigenous knowledge of local people engaged in sustainable lifestyles should also be added to the definition of biodiversity.

Species diversity is usually expressed in one of two ways: richness, which is the number of species present in an area; and evenness or equitability, which is a measure of the abundance of each species present (West 1993). This paper deals with only one element of diversity, that is, that of plant species richness.

This paper compares species richness (number of plant species) inside and outside 24 long-term exclosures in Utah, Wyoming, and Montana. Only species richness is reported because the data were collected by different methods in each area and, in some cases, species lists were pooled from more than one sampling method, and species evenness or other indices of diversity could not be calculated. Species richness inside and outside the eight exclosures in Wyoming also was compared over 2 years with substantially different amounts of growing season precipitation. This illustrated how such precipitation can influence the number of species encountered in sampling.

Methods

The central Utah study included eight exclosures with quaking aspen (*Populus tremuloides*) vegetation communities. One exclosure was established in 1934, and the other seven were established between 1947 and 1974. The exclosures ranged in size from 0.3 to 1.0 ha. Cover of understory vegetation by species was estimated on 0.1-m^2 quadrats in 1995 or 1996. Overstory tree species were not included in the species richness numbers unless the tree species occurred in

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the understory. The overall comparisons for these exclosures were published by Kay and Bartos (2000), but the species richness data for each individual exclosure were obtained from file data.

In southwestern Wyoming, eight exclosures in sagebrush (*Artemisia tridentata* ssp. *Wyomingensis*) and/or salt desert shrub vegetation communities were studied. One was established in 1940, and the other seven exclosures were established between 1958 and 1963. The exclosures were either 0.4 or 0.8 ha in size. For shrubs, cover by species was sampled with line and belt transects. Herbaceous species were sampled with a point frame and density counts on 1.2-m^2 quadrats. Species lists from the various methods were pooled to calculate species richness. The same sampling methods were repeated by the same observer in 1993 and 1994. The species richness information for these exclosures were obtained from Johnson-Barnard (1995).

The southwestern Montana study included eight high-elevation exclosures: three in tall forb, three in open conifer, and two in mountain big sagebrush (*Artemisia tridentata* ssp. *vaseyana*) vegetation communities. Seven exclosures are 15.0 m^2 (0.02 ha) and were established in 1978. One of the open conifer exclosures is 0.09 ha in size and was established in 1960. For the open conifer type, only understory species were sampled, and the mature overstory tree species are not included in the number of species. Herbage production (biomass) by species was estimated in 1994 on 1.0-m^2 quadrats for sagebrush and 0.5-m^2 quadrats for other vegetation types. The species richness data for these exclosures were obtained from Klement (1997) and from file data.

All 24 exclosures had been protected from livestock grazing all or a majority of the time since establishment. The areas outside the exclosures had been grazed by livestock during the same seasonal period in each respective location: by cattle and/or sheep during the summer in Utah; by cattle and/or sheep either in summer or year round in Wyoming; and by sheep only during the summer in Montana. All areas were available for wildlife use. Plant species nomenclature follows that was used in each individual study.

Results and Discussion

Aspen Exclosures (Utah)

The understory plant communities in the aspen exclosures were not especially species-rich and had the fewest number of species of all the vegetation types studied (table 1). The average number of species detected by sampling was about the same both inside (9.3) and outside (9.1) the exclosures. Two exclosures had the most species found inside (12) and two different exclosures had the most species found outside (11). Three exclosures had more species inside the exclosure than outside, and four exclosures had more species outside the exclosure than inside. One exclosure had the same numbers of species inside and outside (table 2).

A total of 12 species were found inside one or more of the eight exclosures but not outside. Twelve species were found outside one or more of the eight exclosures but not inside (table 3). *Bromus ciliatus* and *Sitanion hystrix* were found inside but not outside at two exclosures, but these species were found both inside and outside at four other exclosures. All other species were found either inside only or outside only at just one exclosure.

The overlap of species, that is, the number of species found both inside and outside, averaged 7.5 species (69 percent) for

Table 1—Average number of plant species inside and outside aspen, shrub, and high-elevation exclosures.

		Vegetation type					
				High elevation (Montana)			
Location	**Life form**	**Aspen (Utah)**	**Shrub (Wyoming)**	**Tall forb**	**Sagebrush**	**Open conifer**	**All exclosures**
		Average number of species					
Inside exclosure	Shrub	1.9	7.0	0	2.5	0.3	0.8
	Grass	4.4	4.4	6.7	5.5	8.7	7.1
	Forb	3.0	2.6	27.7	21.5	22.0	24.0
	Total	9.3	14.0	34.4	29.5	31.0	31.9
Outside exclosure	Shrub	2.6	7.2	0	2.0	0	.5
	Grass	3.5	4.9	7.3	5.5	12.3	8.8
	Forb	3.0	2.4	29.0	24.5	25.7	26.6
	Total	9.1	14.5	36.3	32.0	38.0	35.9

Table 2—Number of exclosures with different numbers of species inside or outside for each vegetation type.

	Vegetation type					
			High elevation			
Location of different numbers of species	**Aspen**	**Shrub**	**Tall forb**	**Sagebrush**	**Open conifer**	**All exclosures**
	Number of exclosures					
More species inside than outside	3	3	1	0	0	1
More species outside than inside	4	4	2	2	3	7
Same number of species inside and outside	1	1	0	0	0	0

Table 3—Species found either inside or outside, but not both, for the eight aspen exclosures in Utah.

Species inside but not outside	
Shrubs	
	Chrysothamnus viscidiflorus
Grasses and grasslike	
	Bromus ciliatus
	Festuca idahoensis
	Festuca thuberi
	Sitanion hystrix
	Stipa comata
	Stipa lettermanii
Forbs	
	Aquilegia coerula
	Galium spp.
	Potentilla gracilis
Total species	
	Inside but not outside = 12
Species outside but not inside	
Shrubs	
	Artemisia tripartita
	Juniperus comunis
	Juniperus osteosperma
	Pushia tridentata
	Rosa woodsii
	Symphoricarops oreophilus
Grasses	
	Muhlenbergia wrightii
	Poa pratensis
Forbs	
	Antennaria microphylla
	Castilleja linariafolia
	Taraxacum officinale
Total species	
	Outside but not inside = 12

the eight exclosures (table 4). The lowest overlap was 58 percent, and the highest was 90 percent.

Species richness inside and outside the exclosures was almost identical and did not reveal any grazing effect. However, Kay and Bartos (2000) indicated that understory species composition of the aspen stands studied had been affected by ungulate herbivory. In the area available to mule deer but excluding livestock, tall forbs and shrubs were reduced, while grasses and unpalatable forbs increased. Cattle grazing tended to reduce grass cover. Both livestock and deer browsing affected aspen regeneration; aspen regenerated successfully in the livestock exclosure and combined use plots outside the exclosures only when mule deer populations were low. The species richness data did not reflect these composition changes in the vegetation in response to use by cattle and deer.

The aspen exclosures tended to be on drier sites, which may partially explain the low number of plant species sampled. A more detailed study of two aspen exclosures in Utah was published by Mueggler and Bartos (1977). One of these exclosures, Big Flat, was also sampled in 1995–1996 and was included in the Kay and Bartos (2000) study.

Shrub Exclosures (Wyoming)

The average number of species sampled was similar inside (14.0) and outside (14.5) the exclosures (table 1). Approximately half of the species were shrubs. The largest number of species found both inside and outside was 18 at different exclosures. More species were found inside the exclosure than outside at three exclosures, more species were found outside than inside at four exclosures, and the same number of species occurred inside and outside one exclosure (table 2).

When all eight exclosures were combined, 17 species were found inside but not outside a given exclosure, and 19 species were found outside but not inside. Most species were found only inside or only outside the exclosure at just one site, but one species was found inside only at two sites, one species was found outside only at two sites, and two species were found outside only at three sites.

One forb and two wheatgrass species were found inside only at one site and outside only at a different site. Five other forb species were found inside only at one exclosure, and one other forb species was found outside only at three exclosures. Two species of shrubs were found inside the exclosure only at one site and outside the exclosures only at two different sites. Six other species of shrubs were found inside one or more exclosures only but not outside, while seven completely different shrub species were found outside one or more exclosures only but not inside. Other than two wheatgrasses, no other grasses were found inside only, but five additional grass species were found outside only at one exclosure. The average overlap of species found both inside and outside was 11.9 species or 72 percent (table 4). The highest overlap of species occurring inside and outside the same exclosure was 83 percent, and the lowest overlap was 56 percent.

The number of species found either inside the exclosures only or outside only did not give any indication that grazing had a different effect on the vegetation of these shrub exclosures than 35 years of protection from grazing. Johnson-Barnard (1995) found no observable effect of grazing on cover, density, production, or species composition of shrub or

Table 4—Plant species overlap—average number of species per exclosure in common (present both inside and outside), found inside exclosures only and found outside exclosures only for the three vegetation types.

	Vegetation type					
			High elevation (Montana)			
	Aspen (Utah)	Shrub (Wyoming)	Tall forb	Sagebrush	Open conifer	All exclosures
	Number of species (percent)					
Species in common	7.5 (69)	11.9 (72)	30.7 (77)	26.0 (73)	26.7 (63)	28.0 (70)
Inside but not outside	1.8 (16)	2.1 (13)	3.7 (9)	3.5 (10)	4.3 (10)	3.8 (10)
Outside but not inside	1.6 (15)	2.6 (15)	5.7 (14)	6.0 (17)	11.3 (27)	7.9 (20)

herbaceous species for these exclosures. The only consistent difference between inside and outside was that shrub height was significantly (P = 0.05) greater inside all of the exclosures.

High-Elevation Exclosures (Montana)

The high-elevation exclosures in Montana had greater species richness than the Utah and Wyoming vegetation types sampled, averaging more than 30 species both inside and outside the exclosures (table 1). A great many of the species of grasses and forbs were the same in all three vegetation types for the high-elevation exclosures. The percentage of the total number of species made up by forbs was 68 to 81 percent for all of the vegetation types (table 1) (Klement 1997).

In the tall forb type, the highest number of species was 39 inside two exclosures and 42 outside one of the same exclosures. In the mountain big sagebrush type, one exclosure had 30 species inside and 32 species outside. This mountain big sagebrush type had more than twice the total number of species as the lower elevation Wyoming big sagebrush exclosures sampled in Wyoming.

In the open conifer type, the highest number of species was 41 outside and 38 inside the same exclosure. For all vegetation types, more species occurred outside than inside at seven of the exclosures (table 2), with an average of four more species outside. One of the tall forb exclosures had three more species inside than outside.

In spite of the rather large numbers of species found only inside or only outside the exclosures, the overlap (species found both inside and outside a given exclosure) was rather high for all of the high-elevation exclosures, ranging from an average 26.0 to 30.7 species in common, with an average overlap of 70 percent (table 4).

Even though more species generally were found outside of the exclosures than inside, species richness did not reveal any major differences in vegetation composition between the inside and the outside the exclosures in all three vegetation types. This agrees with Klement (1997) who, based on the biomass data, concluded that light summer grazing by sheep does not appear to be a factor in vegetation composition in these high-elevation vegetation types.

Effect of Growing Season Precipitation on Species Richness

The areas inside and outside the eight sagebrush and salt desert shrub exclosures in Wyoming were sampled by the same methods by the same observer in both 1993 and 1994. The 1994 data were summarized above. Late spring and early summer precipitation (May through July) from the nearest weather station (Kemmerer, WY) indicated that growing season precipitation in the 2 years were quite different. The long-term average for that period was 7.39 cm. Growing season precipitation was 31 percent above this average (9.70 cm) in 1993 and 73 percent below this average (2.77 cm) in 1994.

As might be expected, the number of shrub species sampled inside and outside were the same in 1993 and 1994. However the total number of herbaceous species sampled was 41 percent lower in 1994 than in 1993 (table 5) and the changes were similar both inside and outside the exclosures. The largest reduction in number of species was for forbs. The number of annual forb species sampled was 69 percent lower inside and 84 percent lower outside in 1994 than in 1993. The number of perennial forb species sampled was 48 percent lower inside and 45 percent lower outside. The reduction in number of grass species sampled in 1994 was smaller, 30 percent lower inside and 28 percent lower outside.

The species that were not found in 1994 presumably did not disappear from the community. The annual forb species may simply not have germinated in the dry conditions of 1994. The perennial forbs may have grown earlier when soil moisture was present but dried and were absent or unrecognizable at the time of sampling. The grass species absent in 1994 may have had so little growth that they were not recognizable at the time of sampling. The important point is that sampling in a year with low growing season precipitation can result in a lower number of species being detected than would be detected in a more favorable year. The 22 species that were present in 1993, but absent in 1994, inside exclosures at one or more sites and outside exclosures at one or more sites are listed in table 6.

Similar changes in numbers of species sampled as a result of differences in precipitation have been reported. On northern mixed grass prairie in North Dakota, Biondini and others (1998) reported an increase in the number of forb species sampled from 14 in 1988 at the end of a prolonged drought to 36 in 1995 after several years of above average precipitation. These changes occurred in pastures grazed moderately and heavily by cattle and also in exclosures. At the Cedar Creek Natural History Area in Minnesota, Tilman and El Haddi (1992) reported that the local species richness of four different grassland fields decreased an average of 37 percent during a 1988 drought. However, despite the return to more normal precipitation during the

Table 5—Sagebrush and salt desert shrub exclosures in Wyoming. Changes in richness of herbaceous species in 2 years with different precipitation.

Life form	1993		1994		1993–1994 change	
	Inside	Outside	Inside	Outside	Inside	Outside
	Average number of species					
Grass	6.3	6.8	4.4	4.9	–1.9	–1.9
Perennial forb	4.0	3.8	2.1	2.1	–1.9	–1.7
Annual forb	1.6	1.9	.5	.3	–1.1	–1.6
Total	11.9	12.5	7.0	7.3	–4.9	–5.2

Table 6—Sagebrush and Salt Desert Shrub Exclosures in Wyoming. Herbaceous species found in 1993 but not in 1994 inside exclosures at one or more different sites and outside exclosures at one or more different sites.

	Number of exclosures	
	Inside	Outside
Grasses		
Agropyron dasystachyum	5	6
Agropyron smithii	2	1
Agropyron spicatum	3	1
Oryzopsis hymenoides	1	1
Poa spp.	3	1
Poa canby	1	1
Poa fendleriana	1	1
Poa secunda	1	1
Sitanion hystrix	3	4
Stipa comata	1	2
Perennial forbs		
Allium textile	1	4
Antennaria dimorpha	2	2
Astragalus convallarius	1	1
Cryptantha fendleri	1	1
Eriogonum flavum	1	1
Eriogonum ovalifolium	1	1
Phlox hoodii	3	2
Phlox longifolia	3	3
Annual forbs		
Astragalus spp.	2	3
Descurainia pinnata	1	1
Halogeton glomeratus	1	1
Lappula redowskii	2	4

next 2 years, there was no significant recovery of species richness in the permanent plots. They concluded that "environmentally extreme conditions can limit species richness by causing the local extinction of rare species." However, they did not present long-term data to indicate that rare species had, indeed, become extinct in their permanent plots.

Conclusions

Because the sampling methods employed in this study were not primarily intended to compile a complete list of all species in the area, not every species present inside or outside each exclosure would have been encountered. To compile a comprehensive species list would have required sampling at different times during the growing season and additional searches for rare species outside the sample quadrats or lines. However, because the vegetation at each exclosure site was sampled by the same person, using the same methods and at the same time both inside and outside of each exclosure, comparisons of species richness between the two areas should be valid.

Species richness, by itself, may or may not be a good indicator of the effects of grazing on vegetation, depending on the situation. For the shrub areas in Wyoming and the high-elevation areas in Montana, the lack of difference in species richness inside and outside the exclosures agreed with the conclusions from analysis of cover or biomass data, that is, the vegetation inside and outside the exclosures was not different. However, for the aspen areas in Utah, the cover data revealed some differences caused by grazing or browsing by livestock or deer that the species richness comparison did not reveal.

The rather large impact that weather, mainly growing season precipitation, can have on the number of species encountered in a sample was shown by comparing samples taken in 2 successive years in Wyoming. The number of herbaceous species sampled in the dry summer of 1994 was more than 40 percent lower than the number sampled in the relatively wet summer of 1993. The majority of the species that were present in 1993 but not in 1994 were perennials that had not disappeared from the area. They either did not grow in 1994, or they may have been indistinguishable during sampling because they were too small or unidentifiable.

Collins (1987) reported that areas of tall grass prairie both burned and moderately grazed by cattle had the highest plant species diversity, while areas burned but not grazed had the lowest diversity. On shortgrass steppe vegetation in Colorado, Hart (2001) found that plant species diversity and evenness were greatest in lightly and moderately grazed pastures, least in exclosures, and intermediate in heavily grazed pastures. These pastures had been grazed by cattle at the same intensities for 55 years, and the exclosures had been protected from grazing during the same period.

Laycock (1994) suggested that either no grazing or very heavy grazing may reduce species diversity, but moderate grazing probably does not diminish diversity and may enhance diversity at both the species and landscape levels by promoting patchiness of vegetation.

Oba and others (2000) reviewed literature from African rangelands that suggested that grazing at moderate intensities on Mediterranean, sub-Saharan, and other subtropical rangelands increased plant species diversity and that, on Sahelan rangelands, neither continuous grazing nor long-term protection had a lasting effect on plant species diversity. Oba and others (2000) concluded that:

> Thus, the evidence suggests that the lack of grazing may degrade rangelands in sub-Saharan Africa. Long-term deferral of grazing results in either no significant changes in species composition or in lowered diversity caused by the disappearance of herbivory-adapted species. Therefore, if the removal of ungulate grazing results in the loss of principal species from the plant community, then this ecosystem may be considered to have been degraded in the absence of grazing.

The results of the present study agreed with published information summarized above that moderate livestock grazing does not cause plant species richness to decline. Thus, the claims that livestock grazing has reduced plant species richness on Western rangelands appear to be without merit at least for the vegetation types studied on these 24 sites.

Studies need to be conducted on many more rangeland vegetation types to determine the effects of livestock grazing on species richness or other elements of biodiversity. Previous studies have the potential to provide such information, but species richness or other measures of species diversity usually cannot be calculated from published results of grazing or exclosure studies because journals seldom allow the publication of complete species lists and often lump minor species as “Other.” Complete lists can be obtained from file data for previous studies or from complete species lists in unpublished theses or dissertations.

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