

THE EFFECTS OF RIPARIAN GRAZING ENCLOSURES ON  
ADJACENT RIVERINE ECOSYSTEMS

by

Victoria Jeanne Bunn

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Dr. Duncan T. Patten, Chair &  
Dr. Geoffrey Poole, Co-Chair

Approved for the Department of Land Resources and Environmental Sciences

Dr. Tracy Sterling

Approved for The Graduate School

Dr. Carl A. Fox

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## ABSTRACT

In the western U.S., riparian ecosystems cover 1% of land area while supporting 70-80% of native species. 70% of this land area is available as range for livestock, who use riparian areas preferentially. Ecological concerns have led to numerous studies of the effects grazing has on these ecologically important, easily damaged ecosystems. Exclosure-based research has thoroughly examined the effects of livestock on riparian ecosystem health and function, but failed to investigate the potential for exclosures to intensify adverse effects of use at their boundaries, which could lead to overestimation of their benefits and impair their efficacy in management. This study attempts to supplement existing research by characterizing potential impacts, making exclosures a more informed and effective management strategy.

Study exclosures were located on grazed public lands in southwest Montana. Riparian vegetative cover and channel morphology response variables were measured inside the exclosure and in two grazed reaches, one placed 0 to 20 m and one >50 m from the exclosure to capture differences in the spatial extent and severity of any impacts due to differences in livestock behavior caused by the exclosure's influence.

Findings were that (1) results were consistent with previous exclosure studies using the same response variables to compare grazed and exclosed areas, (2) significant differences in herbaceous cover, bare ground cover, channel width, and bank angle between the two grazed subreaches were greater than corresponding grazed/exclosed comparisons, indicating that impacts to the subreach adjacent to the exclosure that are greater than corresponding improvements within, (3) spatially inconsistent impact zones within and among sites made it impossible to describe an overall impact zone adjacent to exclosures, but impacts to channel morphology, herbaceous cover, and bare ground occurred within 8 m of the exclosure, and within 2 m for bank angle, (4) data didn't support predicted relationships between impact severity and exclosure duration, size, or stocking rates, most likely due to the many other influencing factors that were not measured.

Evidence supporting existence of exclosure-caused impacts should inform exclosure use and make it a more effective management tool, especially when considered in the context of how these impacts might encumber specific management goals.

## INTRODUCTION

Riparian areas are the zones of transition between terrestrial and aquatic ecosystems. They connect streams, rivers, and lakes to adjacent uplands via surface and subsurface hydrology and influence the exchange of energy and matter between aquatic and terrestrial ecosystems. Healthy riparian areas provide a variety of environmental services, including reducing erosion by slowing the return of precipitation to stream channels (Chaney et al. 1993), removing pollutants from overland flow and shallow groundwater (NRC 2002), and providing breeding, wintering, and migration habitat for a variety of fish, birds, and mammals (Fleischner 1994).

Riparian ecosystems make up about 1% of the surface area in the eleven western United States (Montana, Wyoming, Colorado, New Mexico, and states westward), while supporting 70-80% of native species (Belsky et al. 1999). In these same states, approximately 70% of the land area is available for use as livestock range (Fleischner 1994). Livestock preferentially use the riparian areas of this arid landscape, especially in warm, dry weather (Armour et al. 1994). The damage that can result from this preferred use has been well documented, and several thorough reviews summarizing the different aspects of livestock impact to riparian ecosystems have been published (Kauffman and Krueger 1984; Osmund et al. 2007).

While the use of western public lands as range has been economically beneficial, improved understanding of its adverse effects, and of the important ecological role

riparian areas play in this arid landscape, has brought conservation priorities into step with economic priorities (Fleischner 1994). As a result, physical barriers that prevent livestock from accessing a portion of the riparian area within a pasture have become popular management tools. These ‘exclosures’, built to allow for protection of the riparian ecosystem, have simultaneously provided an opportunity to assess the impacts of grazing and potential for riparian ecosystem recovery in specific conditions, through comparisons with nearby grazed areas.

Exclosure-based research has addressed the effects of livestock on a diverse list of ecologic indicators, including riparian and instream vegetation, water quality, channel morphology, hydrology, riparian soils, and a variety of aquatic and riparian fauna (Belsky et al. 1999). Direct and incidental damage by livestock to riparian vegetation and channel morphology has been particularly well documented. Reduction in riparian vegetative cover has been shown to be the result of many livestock-related mechanisms, both direct and indirect. These mechanisms include grazing-induced environmental change (e.g. inadequate moisture as a result of a water table lowered by channel incision; Fleischner 1994), and direct removal by trampling and grazing (Belsky et al. 1999). Changes in stream channel morphology have also been shown to be the result of different livestock-related mechanisms, including grazing-induced channel instability (e.g. removal of stabilizing vegetation, more erosive peak flows due to soil compaction; Fleischner 1994), and direct change via trampling (Kondolf 1993).

Some exclosure studies have monitored a study reach through time (Clary 1999; Duff 1977; Kauffman et al. 1983; Nagle and Clifton 2003), but many have made a space-

for-time substitution, comparing grazed and rested reaches along the same stream. This requires the assumptions that the reaches vary only in use treatment, and that conditions in the reaches were identical prior to exclosure construction (Dahlem 1978; Fleischner 1994; McDowell and Magilligan 1997; Platts and Nelson 1989; Schulz and Leininger 1990).

Both types of studies have shown differences in their chosen response variables due to livestock removal via exclosure (Powell et al. 2000), but have failed to investigate the potential of an exclosure to alter livestock use patterns due to its presence, which may intensify the adverse effects of use (soil compaction, bank erosion, vegetation removal, etc.) at its boundaries. Further, many of these studies provide inadequate detail of their methods, making it difficult to determine whether their sample locations would have been likely to capture these effects if they exist. Changes due to exclosure presence seem feasible, as livestock tend to be attracted to the lush vegetation and shade that are likely to be produced by exclosed areas over time (USDA 1997), and to habitually follow fence lines (Leonard et al. 1997).

Failure to account for the detriments exclosures might cause could lead to overestimation of their benefits, and impair the efficacy of their use in management. In cases where exclosures are used to protect specific features like spawning habitat, for example, severe adverse effects could allow conditions immediately outside the protected area to degrade below the minimum conditions needed for trout passage. In cases where an exclosure is used to allow an area to recover, these adverse effects could cause the degradation of the immediately adjacent reach and negate any improvement achieved

inside. The emphasis of this study is to supplement existing research that emphasizes the benefits of exclosure use in riverine systems with a characterization of its potential impacts, ultimately making exclosure use a more informed and effective management strategy.

## HYPOTHESIS AND RESEARCH QUESTIONS

This research addresses the following hypothesis: Riparian grazing exclosures alter livestock utilization of the grazed areas surrounding them, and intensify the adverse effects of grazing in the adjacent riparian areas.

There are four associated research questions. (1) Does this study capture the differences between grazed and exclosed areas shown in previous studies? (2) Is there evidence of impact in the study subreach adjacent to the exclosure greater than that seen in the more distant subreaches? (3) If the subreach adjacent to the exclosure has greater impact than more distant subreaches, can a more specific 'zone of impact' be identified within it? (4) Do the age or size of the exclosure, or the density of livestock on the pasture riparian area affect the severity of impacts in the subreach immediately adjacent to the exclosure?

For study analyses related to Question 1, the following prediction was developed:

- Indicators of impact (i.e., reduced shrub cover, herbaceous cover, and bank angle, increased bare ground and channel width) will be greater outside the exclosure (50+ meters from exclosure border, the AWAY subreach) than inside the exclosure (the EXCL subreach) at the study sites.

For analyses related to Question 2, the following prediction was developed:

- Indicators of impact will be greater in the area adjacent to the exclosure (0-20 m away from exclosure border) than in the area farther away (50+ meters from exclosure border).

For analyses related to Question 3, the following prediction was developed:

- Significant differences will exist between means from the AWAY subreach and plots within the NEAR subreach that are closer to the exclosure, but not in plots farther from the exclosure.

For analyses related to Question 4, the following predictions were developed:

- Sites with newer exclosures will have smaller differences between adjacent and reference subreach response variables than sites with older exclosures.
- Sites with smaller exclosures will have smaller differences between adjacent and reference subreach response variables than sites with larger exclosures.
- Sites with lower pasture riparian area stocking densities will have smaller differences between adjacent and reference subreach response variables than sites with higher stocking densities.

Study findings will be discussed relative to their use in management recommendations, and their utility in maximizing the net benefits of exclosure use.

## METHODS

### Study Area

Study exclosures were located on Bureau of Land Management (BLM), Beaverhead-Deerlodge National Forest (BDNF) and Gallatin National Forest (GNF) land holdings north and west of Yellowstone National Park (Figure 1). This area is roughly 23,000 square kilometers, is bordered by the continental divide near Dell, MT to the southwest and extends to Livingston, MT in the northeast. The topography of the area is mountainous, and the study exclosures were at elevations ranging from 1860 to 2300 meters above sea level. The major rivers of the study area include the Yellowstone, Gallatin, Madison, Jefferson, Ruby, Beaverhead, and Big Hole rivers.

### Study Site Selection

A list of exclosures with potential for use as study sites was compiled from exclosure construction records on file at the BLM and Forest Service offices within the study area. Twenty two geographically and ecologically diverse study sites met the selection criteria: 1) exclosure fencing that completely isolated a portion of a perennially flowing stream and its associated riparian zone from livestock; 2) adequate space for the study reach to be contained within a single pasture (grazing treatment); 3) relative homogeneity in valley type throughout the study reach; 4) continuity of stream order throughout the study reach (no tributaries), and 5) a riparian area free of artificial

obstructions or alterations (i.e. culverts, roads, fences) other than the exclosure fence (Table 1).

A ‘site’ was defined as a stream segment within a riparian exclosure, paired with an immediately adjacent upstream or downstream stream segment. Study sites were defined in this way because very few exclosures met the study selection criteria at both their upstream and downstream reaches.

### Response Variable Selection

Previous exclosure studies have used a wide range of response variables for making comparisons inside and outside exclosures, many for the purpose of evaluating exclosure benefits as they relate to a specific management objective. The response variables used in this study; herbaceous and shrub cover, bare ground, channel width, and bank angle; are general ecologic indicators that are also *direct* consequences of livestock use, in contrast to indirect, goal-specific responses like wildlife population changes or habitat utilization. All were found to exhibit significant differences between use treatments by at least one previous study of livestock impacts in riparian areas (Table 2).

### Subreach, Plot, and Transect Layout

At each study site, three subreaches were delineated at predetermined linear distances along the stream channel from the exclosure’s riparian fenceline (Figure 2). The exclosure subreach (EXCL) consisted of ten 1x2 m plot pairs placed at random distances of one to six meters from the next, beginning at a distance of 2 m inside of the

exclosure fence. Outside of the exclosure, the adjacent subreach (NEAR) consisted of ten plot pairs placed immediately outside the exclosure fence (0 m) to 20 m. The reference subreach (AWAY) consisted of ten plot pairs placed at random distances of one to six meters from the next, beginning at a distance of 51 m from the exclosure fence.

Subreach and plot/transect placement within the grazed area at each study site was designed to capture differences in the spatial extent and severity of impact due to livestock behavior as a result of the exclosure's influence. The NEAR subreach was assumed to contain all portions of the channel that would be affected by the exclosure's influence, and study plots were placed contiguously to insure that even highly localized impacts were accounted for. The AWAY subreach was assumed to be far enough from the exclosure to be outside of its influence on livestock behavior, and because of its location in an area of 'uninfluenced' grazing, represents the experimental control in this study. Plots within the AWAY subreach were placed randomly in order to accurately characterize reference conditions. Any differences in the EXCL and NEAR subreaches, assessed relative to the AWAY subreach were assumed to be due to differences in livestock utilization in response to the presence of the exclosure.

Within each subreach, the 1x2 m plot pairs were placed along the channel, one on each side, with their lengths running parallel to the channel (Figure 3). The plot edge closest to the stream was aligned with the first rooted line of perennial vegetation adjacent to the stream, or 'greenline' (Cagney 1993), and was extended from areas where it could be clearly discerned through those where it was vague or absent due to trampling

or bank collapse. A channel morphology transect was placed across the channel, perpendicular to flow, between the center of each set of paired plots.

### Riparian Cover

Aerial cover for basal shrubs and herbaceous vegetation was estimated visually in each plot to the closest 5 percent. Cover of bare ground, large rocks, and litter were also estimated with this method. Herbaceous cover is reported as the proportion possible within the plot, in order to distinguish instances of low cover due to natural obstruction (e.g. a boulder or mature tree trunk within the plot) from those due to its removal. Possible herbaceous cover within the plot is the area not accounted for by basal shrub growth, trees, or large rocks.

### Channel Morphology

Channel width and bank angle were measured along each transect between the plot pairs with depth rods, line levels, and measuring tape. The break in slope along the banks, or 'banktop stage' was used as a surrogate for true bankfull stage (Harrelson et al. 1994), as the floodplain was frequently difficult to discern at the study sites. The vertical and horizontal distance between the wetted channel edge and banktop stage (rise and run) was measured on both sides of the channel for bank angle calculations, which are reported in degrees from horizontal. Channel width was measured as the horizontal distance between banktop stage on either side of the channel along each transect.

### Management Data

Pasture maps, and data on exclosure ages, reason for exclosure construction, and stocking records were collected for each study exclosure through interviews with the employees of the managing federal agency. Stocking records and interviews were used to calculate a five-year stocking average, reported in Animal Unit Days (AUD). The length of accessible, perennial stream bank within each pasture was estimated from pasture maps. The five-year stocking average and accessible stream bank data were used to calculate the average stocking rate per meter of stream channel within each study pasture (“livestock density”), which was used in testing  $H_6$  (Kauffman et al. 1983). This value was thought to be a more accurate predictor of grazing impacts to the riparian area than stocking alone, as the group of study sites varies greatly in size.

Table 1. List of study sites, including the location of the grazed reach relative to the enclosure, the reason and year the enclosure was constructed, the management agency responsible, and the approximate location and elevation.

Site #	Site Name	Up/Down stream	Sample Date	Reason Constructed	Year Built	Agency <sup>1</sup>	Lat.	Lon.	Elev. (m)
01	Basin Creek/1	Up	6/29/2010	study	1994	BDNF	44.8592	-111.9841	2130
02	Basin Creek/2	Up	6/29/2010	study	1994	BDNF	44.8592	-111.9841	2130
03	Basin Creek	Down	6/30/2010	study	1994	BDNF	44.8592	-111.9841	2130
04	Pole Creek/1	Down	7/6/2010	study	1985	BDNF	44.7744	-112.0580	2320
05	Pole Creek/2	Up	7/7/2010	study	1994	BDNF	44.7593	-112.0318	2170
06	Pole Creek/2	Down	7/7/2010	study	1994	BDNF	44.7593	-112.0318	2170
07	Shenon Creek	Down	7/8/2010	recovery	1982	BLM	44.9280	-113.2252	2040
08	Shenon Creek	Up	7/8/2010	recovery	1982	BLM	44.9280	-113.2252	2040
09	Old Tim Creek	Up	7/9/2010	recovery	1975	BDNF	45.4411	-113.2138	2300
10	Old Tim Creek	Down	7/9/2010	recovery	1975	BDNF	45.4411	-113.2138	2300
11	Muddy Ck@Trail Ck	Down	7/12/2010	protect/habitat	1968	BLM	44.6617	-112.8348	2010
12	Muddy Ck @ Johnson Ck	Down	7/12/2010	recovery	1966	BLM	44.6875	-112.8533	2060
13	Muddy Ck @ Johnson Ck	Up	7/12/2010	recovery	1966	BLM	44.6875	-112.8533	2060
14	Hansen Creek	Up	7/19/2010	protect/habitat	2000	BLM	44.8943	-113.0558	1970
15	Kate Creek	Up	7/20/2010	recovery	2004	BDNF	44.7518	-112.9624	2170
16	Warm Springs Creek	Down	7/20/2010	protect/morphology	1983	BLM	44.8102	-112.9878	2000
17	Muddy Creek Corridor	Up	8/19/2010	protect	1997	BLM	44.6537	-112.8296	2010
18	Lower Willow Creek	Down	8/20/2010	protect/habitat	1995	GNF	45.7698	-110.7358	1860
19	Lower Willow Creek	Up	8/20/2010	protect/habitat	1995	GNF	45.7698	-110.7358	1860
20	Pony Creek	Up	8/23/2010	protect	2005	BLM	45.6607	-111.9288	1890
21	Pony Creek	Down	8/23/2010	protect	2005	BLM	45.6607	-111.9288	1890
22	Upper Willow Creek	Down	8/25/2010	protect/habitat	1999	GNF	45.7672	-110.7393	1870

<sup>1</sup>BLM = Bureau of Land Mgmt., BDNF = Beaverhead-Deerfodge National Forest, GNF = Gallatin National Forest.

Table 2. Study response variables used as indicators of impact, and previous studies that found significant differences between grazed and ungrazed areas.

Response Variable	Exclosure Studies Finding Differences (not exhaustive)
Shrub cover	(Ammon and Stacey 1997), (Duff 1979)
Herbaceous cover	(Schulz and Leininger 1990), (Hoffman and Stanley 1978)
Bare Ground cover	(Schulz and Leininger 1990), (Hubert 1985)
Channel Width	(Hubert 1985), (Clary 1999), (Magilligan and McDowell 1997), (Platts and Nelson 1985), (Duff 1977)
Bank Angle	(Platts and Nelson 1989), (Platts and Nelson 1985)

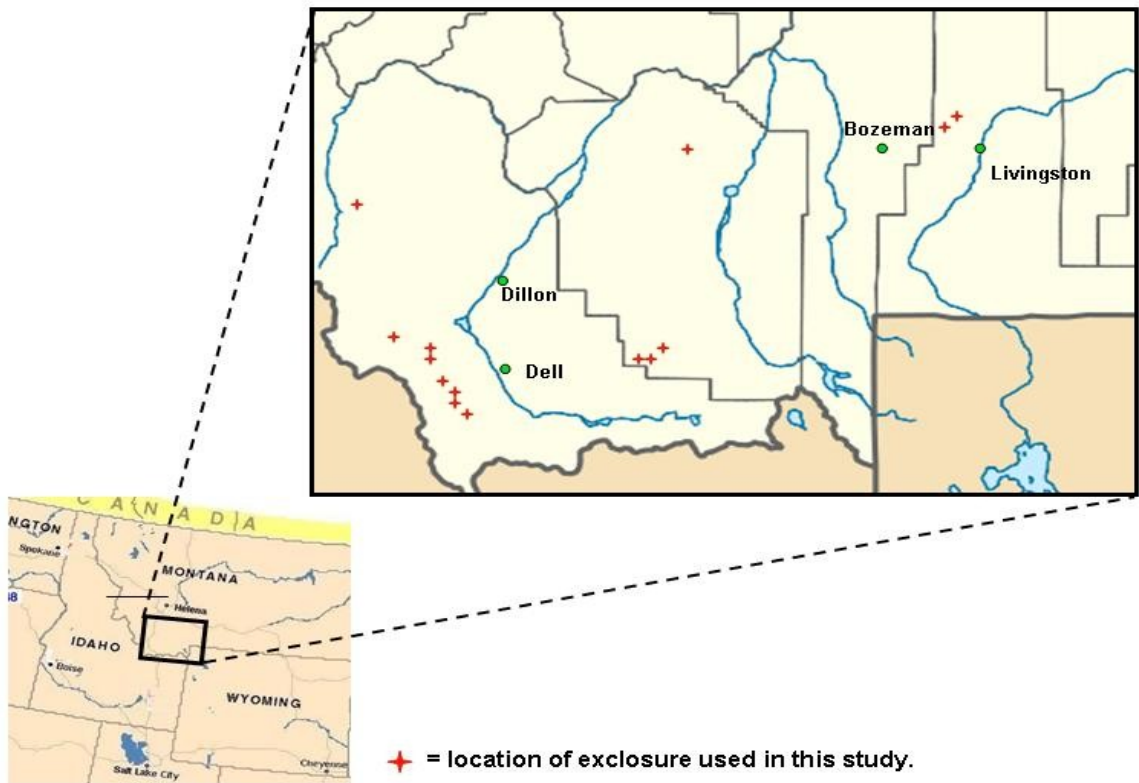


Figure 1. Map of project study area showing location of study sites in relation to Bozeman and other Montana cities.

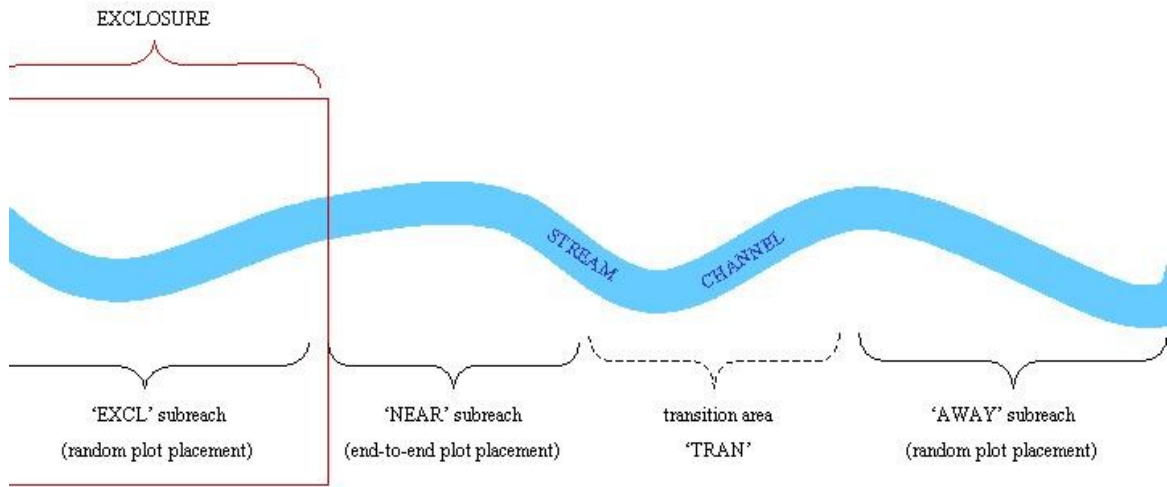


Figure 2. Diagram of site and sampling layout showing subreach placement relative to enclosure fence.

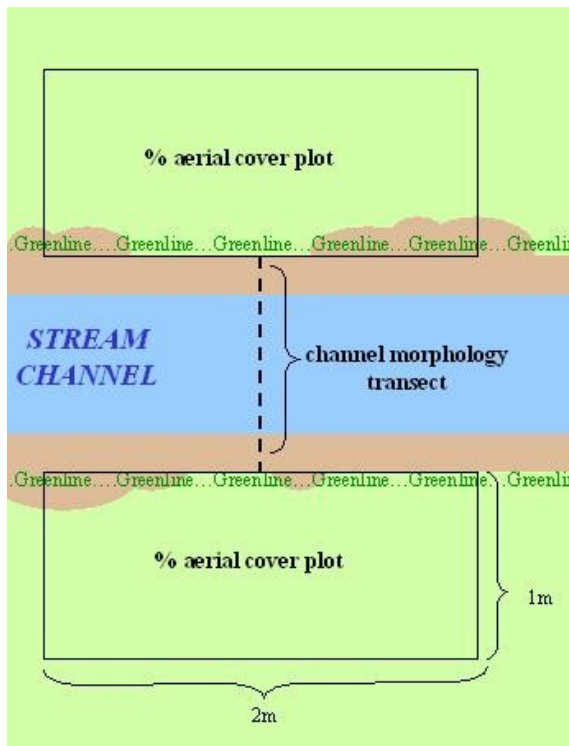


Figure 3. Diagram of one plot pair with the associated channel morphology transect. Each subreach consisted of ten.

## DATA ANALYSIS

Data analysis was organized in three parts.

1. Questions 1 and 2 were addressed by exploring differences between subreach response variable means (shrub cover, herbaceous cover, bare ground, bank angle, channel width) for the group of sites.
  - a) Confirming findings of previous research on inside vs. outside (EXCL and AWAY comparisons in this study).
  - b) Determining differences between adjacent and reference subreaches (NEAR and AWAY comparisons in this study).
2. Question 3 was addressed by exploring differences between plot-level response variable means (shrub cover, herbaceous cover, bare ground, bank angle, channel width) from the adjacent subreach and the reference subreach mean for the group of sites.
3. Question 4 was addressed by determining whether the age or length of the enclosure, or the density of livestock on the pasture riparian area affect the severity of impact seen in Part 1.

Parts 1 & 2: Exploring Differences Between Subreaches, and Describing a More Specific 'Zone of Impact' within the NEAR Subreach.

Data for all response variables failed the Shapiro-Wilk test for normality, and the Levene's test for homogeneity of variance. Attempts to transform the data were unsatisfactory. Due to the inapplicability of parametric tests, Kruskal-Wallis one-way

analysis of variance was used to detect differences among the three subreaches for each response variable, and the Mann-Whitney U test was used for subsequent pair-wise comparisons for Part 1.

For Part 2, Kruskal-Wallis tests were used to detect response variable differences between the plot-level means for each distance within the NEAR subreach and the AWAY subreach mean. Mann-Whitney U tests were used for subsequent pair-wise comparisons, and Kruskal-Wallis and Mann-Whitney tests were repeated as described for two length-based subgroups, to enable discussion of size-related management recommendations as it pertains to maximizing an enclosure's net benefits.

### Part 3: Determining whether Enclosure Age, Length, or Livestock Density Affect the Severity of Impacts.

This portion of the analysis is limited to herbaceous cover and channel morphology response variables, as shrub cover was not different between the NEAR and AWAY subreaches in Part 1, and changes in bare ground were correlated with changes in herbaceous cover, and therefore do not warrant separate discussion.

In this analysis, impact severity was defined as the difference between the response variable means for the AWAY and NEAR subreaches at each site. This difference was represented as a relative difference  $[(\text{AWAY}-\text{NEAR})/\text{AWAY}]$  for herbaceous cover (Table 3). Impact severity values were compared with enclosure age and length data, and livestock density calculations.

Since the predicted relationships might not be linear, and since independent variable data did not pass Shapiro-Wilk tests for normality, Spearman rank correlation

was used to assess relationships between impact severity and exclosure age, length, and livestock density. The results of Spearman rank correlation made further partial correlation or regression analysis unnecessary, and the absence of compelling relationships was confirmed visually with scatterplots.

Table 3. Summary of study site ages, exclosure lengths, stocking densities, and impact values.

Site ##	Exclosure Age (yrs)	Exclosure Length (m)	Livestock Density <sup>1</sup>	Impact Severity Values		
				Herbaceous Cover <sup>2</sup>	Bank Angle <sup>3</sup>	Channel Width <sup>4</sup>
01	16	125	5.23	0.06	14.97	0.38
02	16	155	5.23	0.21	5.62	0.51
03	16	155	5.23	0.19	11.56	0.68
04	25	150	1.19	0.19	-1.68	1.52
05	16	90	2.02	0.20	5.31	0.72
06	16	90	2.02	0.10	8.00	0.03
07	28	106	0.32	0.54	8.56	0.46
08	28	106	0.32	0.34	-1.55	1.91
09	35	60	0.31	0.07	7.04	0.56
10	35	60	0.31	0.08	2.91	1.14
11	42	100	0.02	0.41	13.32	-0.17
12	44	65	0.02	0.02	-1.25	0.57
13	44	65	0.02	0.01	-6.22	-0.03
14	10	145	8.40	-0.10	21.16	0.79
15	6	322	0.44	0.30	6.29	1.45
16	27	225	5.81	0.06	3.27	-0.46
17	13	300	0.02	0.19	-13.28	1.02
18	15	322	0.83	0.33	11.25	0.99
19	15	322	0.83	0.27	-1.00	0.18
20	5	120	0.35	0.31	-1.14	2.40
21	5	120	0.35	0.13	-3.36	1.80
22	11	322	0.83	0.35	26.96	0.68

<sup>1</sup> 5-yr avg. of AUD / m perennial channel in study pasture.

<sup>2</sup> Difference in AWAY and NEAR means, relative to AWAY mean  $[(\text{AWAY}-\text{NEAR})/\text{AWAY}]$ .

<sup>3</sup> Difference in AWAY and NEAR means (AWAY-NEAR)

<sup>4</sup> Difference in AWAY and NEAR means (NEAR-AWAY)

## RESULTS

### Part 1: Exploring Differences Between Subreach Response Variables Among Sites.

Kruskal-Wallis one-way analyses of variance indicated significant differences among the subreaches for all response variables ( $p < 0.001$ ). Mann-Whitney tests confirmed significant differences ( $p < 0.01$ ) between the AWAY and EXCL subreaches for shrub cover, herbaceous cover, and bare ground. Mann-Whitney test also confirmed significant differences ( $p < 0.01$ ) between the AWAY and NEAR subreaches for all response variables except shrub cover (Table 4).

Differences in the means of actual values used for AWAY/NEAR subreach comparisons were roughly five times greater than the differences in means for AWAY/EXCL comparisons of herbaceous cover and bare ground, and roughly four and eight times greater than AWAY/EXCL comparisons of channel width and bank angle, respectively. Differences in the actual means used for the AWAY/NEAR subreach comparison of shrub cover was only about half that of the differences in means for the AWAY/EXCL comparison.

### Part 2: Describing a More Specific 'Zone of Impact' within the NEAR Subreach.

Scatterplots of the plot-level response variable data indicated that the spatial patterns of impact vary among sites, as might be expected in a heterogeneous study group that includes enclosure sites of varying age, terrain, use history, etc. Additionally, the

plots and transects exhibiting the greatest impacts for the different response variables often varied spatially within individual sites, making description of an overall zone of impact for all response variables difficult at most individual sites, and unworkable for the study site group.

Kruskal-Wallis one-way analyses of variance indicated significant differences between the AWAY subreach and single plots within the NEAR subreach for all response variables except shrub cover ( $p < 0.001$ ). Mann-Whitney tests confirmed significant differences ( $p < 0.01$ ) between the AWAY subreach and all NEAR plots within 8 m of the enclosure for channel width, herbaceous cover, and bare ground. Mann-Whitney test also confirmed significant differences ( $p < 0.01$ ) between the AWAY subreach and the NEAR plot closest to the enclosure (0-2 m) for bank angle (Table 5).

Differences in the means of actual values used for comparisons of the AWAY subreach to significantly different plots within the NEAR subreach were roughly eight times greater than the differences in means for AWAY/EXCL comparisons of herbaceous cover and bare ground, and roughly six and fifteen times greater than AWAY/EXCL comparisons of channel width and bank angle, respectively.

Tests repeated with the length-based subgroups did not indicate any trends in the spatial extent of impacts due to enclosure size (Table 6). Channel width impacts spanned fewer plots for both subgroups than for the study group as a whole. Herbaceous cover and bare ground impacts were more spatially extensive in the short enclosure subgroup, and bank angle impacts remained the same in the long enclosure subgroup (0-2 m), while

differences in the NEAR subreach plots of short exclosures were not significant (Table 6).

Part 3: Determining whether Exclosure Age, Length,  
or Livestock Density Affect the Severity of Impacts.

Scatter plots provided no evidence of the predicted relationships between severity of impact and exclosure age, size, or livestock density (Figures 4-6). Spearman rank correlations confirm the absence of the predicted relationships. Correlations were never significant ( $p < 0.01$ ), and only four of the nine Spearman tests had a sign (positive or negative) consistent with the predicted outcome (Table 7). Two correlations, severity of impact to channel width and severity of impact to bank angle and livestock density, were significant at  $p < 0.05$ . However, the associated correlations (0.477 and 0.460) are not compelling, as Spearman correlation tests for any association between the variables being compared, not only one that is specifically linear.

Table 4. Kruskal-Wallis analysis of variance with Mann-Whitney post-hoc pairwise comparisons for enclosure (EXCL), reference (AWAY), and adjacent (NEAR) subreaches for all response variables.

	Herbaceous Cover (%) <sup>1</sup>	Bare Ground (%)	Shrub Cover (%)	Channel Width (m)	Bank Angle (deg)
<b>K-W chi squared<sup>2</sup></b>	203.334	259.993	71.414	115.059	31.121
<b>p =</b>	0.0000	0.0000	0.0000	0.0000	0.0000
<b>Post-Hoc Comparisons<sup>3</sup></b>					
<b>EXCL/AWAY<sup>4</sup></b>	3.22(3.63%)* <sup>5</sup>	-3.54(54.36%)*	7.91(44.68%)*	-0.41(10.74%)	0.69(2.15%)
<b>AWAY/NEAR<sup>6</sup></b>	-17.21(19.40%)*	17.12(262.37%)*	-4.47(25.29%)	1.59(41.96%)*	-5.31(16.37%)*

<sup>1</sup> n = 660 for Channel Width, n = 1320 for all other response variables. <sup>2</sup> d.f. = 2

<sup>3</sup> Mann-Whitney tests with Bonferroni correction. <sup>4</sup> reported values: mean<sub>EXCL</sub> - mean<sub>AWAY</sub> (% difference)

<sup>5</sup> \* = significant difference (p < 0.01) <sup>6</sup> reported values: mean<sub>NEAR</sub> - mean<sub>AWAY</sub> (% difference)

Table 5. Kruskal-Wallis analysis of variance with Mann-Whitney post-hoc pairwise comparisons for the reference (AWAY) subreach and distance-specific plots in the NEAR subreach for all response variables.

	Herbaceous Cover (%) <sup>1</sup>	Bare Ground (%)	Shrub Cover (%)	Channel Width (m)	Bank Angle (deg)
<b>K-W chi squared<sup>2</sup></b>	130.946	167.419	27.9708	81.3798	34.2124
<b>p =</b>	0.0000	0.0000	0.0018	0.0000	0.0002
<b>Post-Hoc Comparisons<sup>3</sup></b>					
<b>NEAR plot distances signif.<sup>4</sup> different than AWAY subreach</b>	0-8m	0-8m	N/A <sup>5</sup>	0-8m	0-2m
<b>Difference relative to mean<sub>AWAY</sub><sup>6</sup></b>	-27.69(31.23%)	28.59(438.33%)	N/A	2.41(63.69%)	-10.53(32.48%)

<sup>1</sup> n = 440 for Channel Width, n = 880 for all other response variables. <sup>2</sup> d.f. = 10

<sup>3</sup> Mann-Whitney tests with Bonferroni correction. <sup>4</sup> p < 0.01

<sup>5</sup> p value of K-W test did not justify post-hoc analysis.

<sup>6</sup> reported values: mean of signif. different NEAR plots - mean<sub>AWAY</sub> (% difference)

Table 6. Zones of impact for the entire study group (n = 22), long exclosures (n = 11), and short exclosures (n = 11), as determined by significant differences ( $p < 0.01$ ) in Kruskal-Wallis post-hoc analyses<sup>1</sup> between the reference (AWAY) subreach and distance-specific plots in the NEAR subreach for all response variables.

	Herbaceous Cover (%) <sup>2</sup>	Bare Ground (%)	Shrub Cover (%)	Channel Width (m)	Bank Angle (deg)
<b>STUDY GROUP</b>	0-8m	0-8m	N/A <sup>3</sup>	0-8m	0-2m
<b>SMALL EXCLOSURES</b> (mean length = 89 m)	0-4, 6-8m	0-4, 6-8m	N/A	0-2m	none
<b>LARGE EXCLOSURES</b> (mean length = 231 m)	0-4m	0-4m	N/A	0-6m	0-2m

<sup>1</sup> Mann-Whitney tests with Bonferroni correction.

<sup>2</sup> n = 220 for Channel Width, n = 440 for all other response variables.

<sup>3</sup> p value of K-W test did not justify post-hoc analysis.

Table 7. Spearman rank correlations between exclosure age, size and grazing density, and herbaceous cover, stream bank angle and channel width impact values (n=22).

	Impact Severity Values for:		
	Herbaceous Cover	Bank Angle	Channel Width
AGE	-0.208	-0.116	-0.477
p=	0.35	0.61	0.03
SIZE	0.346	0.187	0.115
p=	0.11	0.40	0.61
DENSITY	-0.162	0.460	-0.103
p=	0.47	0.03	0.06

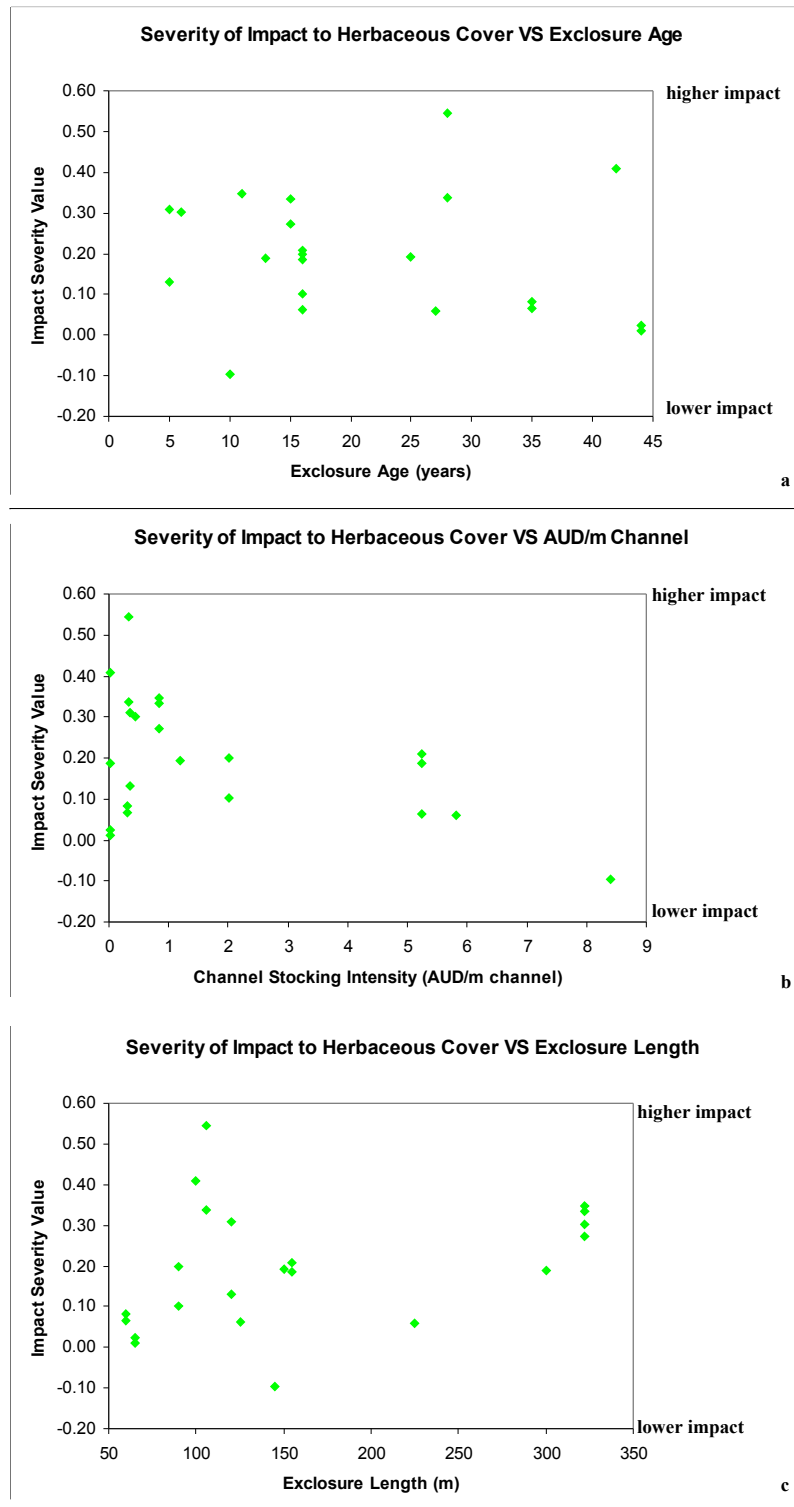
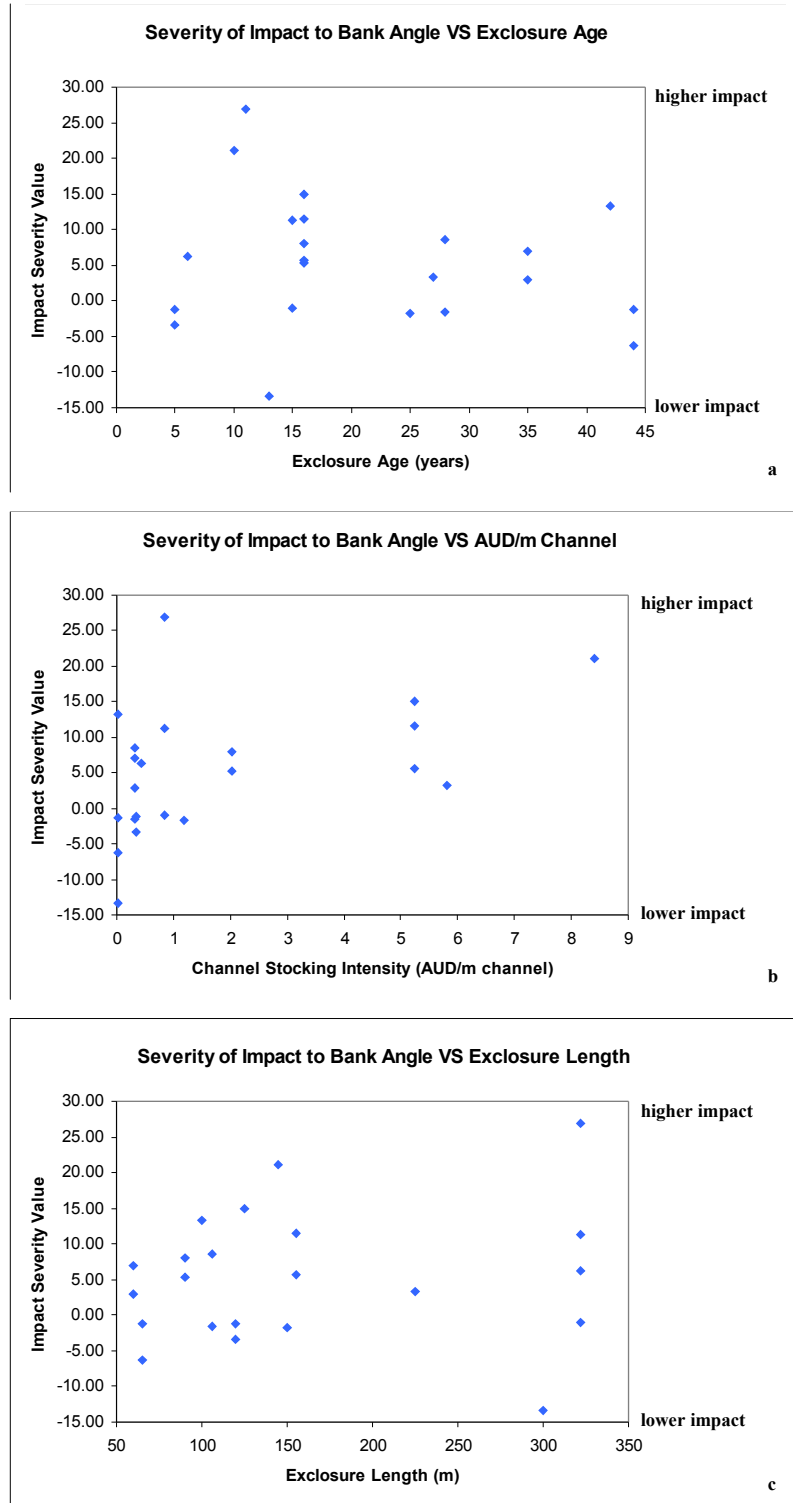


Figure 4. Severity of impact to herbaceous cover, the difference between the AWAY and NEAR subreach means relative to the AWAY subreach mean, for exclosures by (a) age, (b) stocking intensity per meter channel, and (c) length.



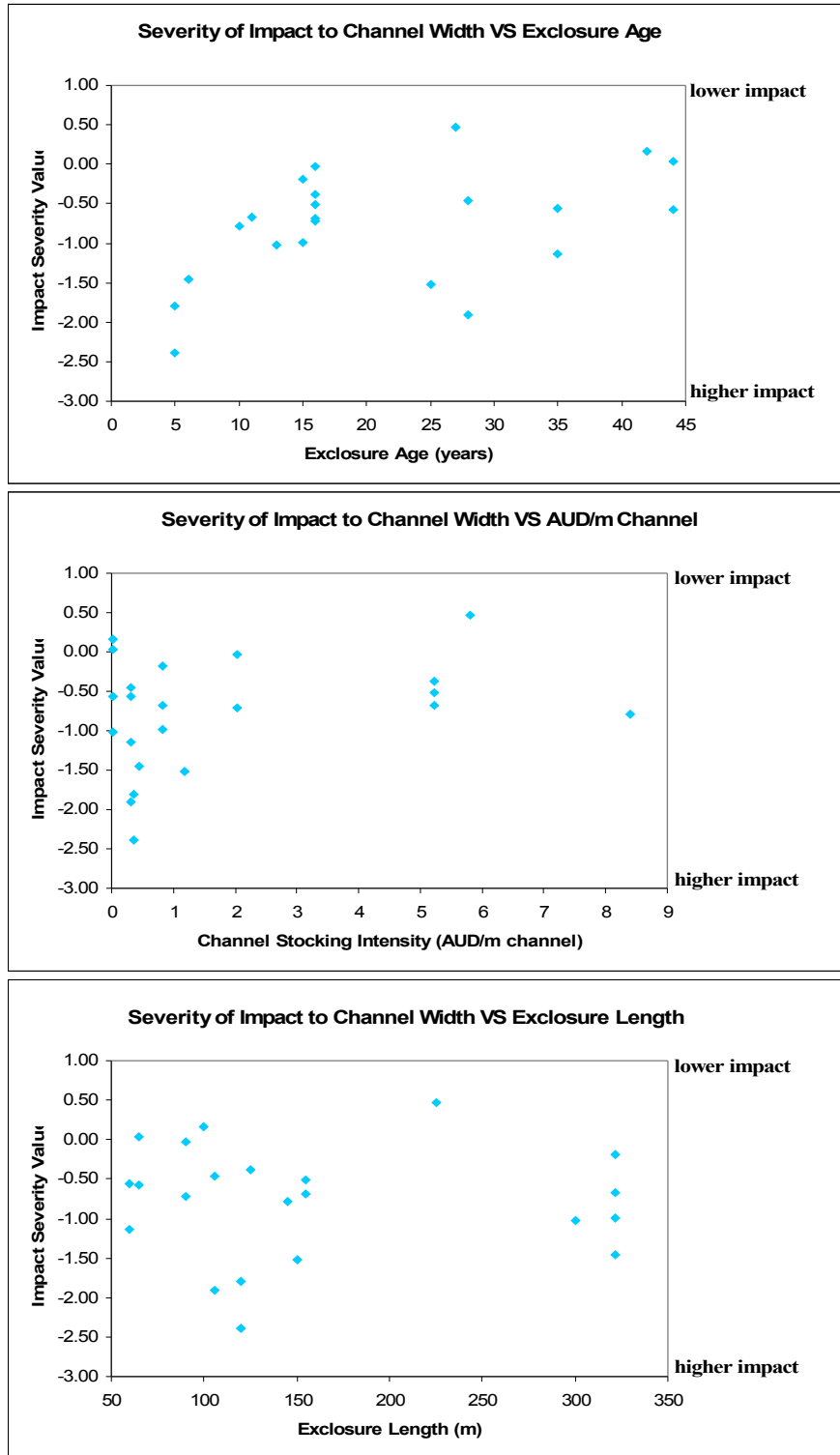


Figure 6. Severity of impact to channel width, the difference between the AWAY and NEAR subreach means, for exclosures by (a) age, (b) stocking intensity per meter channel, and (c) length.

## DISCUSSION

Part 1: Exploring Differences Between  
Subreach Response Variables Among Sites.

Riparian Vegetative Cover

Previous exclosure studies conducted on the grazed lands of the western U.S. have commonly shown differences in riparian vegetation response variables when comparing grazed areas to areas that have been rested five or more years. A northern Colorado study of 30 year-old exclosures reported significant differences ( $p < 0.05$ ) in herbaceous cover (11%), bare ground (26%), and shrub cover (23%). A 30-year exclosure in western Nevada reported differences in bare ground (7.2%) and ground vegetation cover (10.0%), although statistical significance was not discussed (Ammon and Stacey 1997). A southeastern Oregon study of yet another 30-year exclosure reported significant differences ( $p < 0.01$ ) in bare ground (10%), and a difference in total herbaceous cover (24%) that was only compared statistically by functional group (Dobkin et al. 1998).

Some studies have not found differences in riparian vegetation response variables when comparing grazed to rested reaches, but these are frequently associated with younger exclosures. An eastern Oregon study found no differences in herbaceous or shrub cover, or bare ground, but cover comparisons were based on a 3-year average that began only three years after exclosure construction (Clary et al. 1996). Another reported increased herbaceous cover and decreased bare ground in eight of eight exclosures more than six years old, and increased shrub cover in seven. In contrast, shrub and herbaceous

cover were similar and bare ground was greater in three study exclosures less than five years old (Kauffman et al. 2002).

Since this study used exclosures ranging in age from 5 to 44 years, the significant differences between ungrazed areas and grazed areas 50+ m from the exclosure (the EXCL and AWAY subreaches) for bare ground and the riparian vegetation response variables confirm the success of this study in capturing the differences reported by previous studies comparing grazed and exclosed areas for these response variables.

A marked contrast exists between the roughly 3% difference in mean herbaceous cover and bare ground seen in the EXCL/AWAY comparisons and the approximately 17% difference seen in the corresponding comparisons between the two grazed subreaches (NEAR and AWAY) for these response variables (Table 4). A difference of this magnitude provides evidence of impact in the subreach immediately adjacent to the exclosure greater than that seen in the more distant subreaches.

Several range studies that have found herbaceous cover to be responsive to differences in livestock use (Schulz and Leininger 1990, Ammon and Stacey 1997, Dobkin et al. 1998). This could be due to the ubiquitous nature of herbaceous growth in riparian areas, making its localized absence statistically 'noticeable'. In general, herbaceous species have shallower roots systems than mature shrubs and trees, which may make them more vulnerable to trampling via direct removal and reduced water availability in surface soils (Olson et al. 1997).

Shrub cover, while lower in the NEAR than in the AWAY subreach, was not significantly different in the two grazed subreaches (Table 4). This lack of statistical

significance could be due to basal shrub cover outside the study exclosures being primarily composed of the woody bottoms of mature shrubs that were likely to have been well established before the exclosures were built, already too large to be directly trampled and lacking recent growth below the browse line (Figure 7). In contrast, differences in the EXCL/AWAY subreach comparison are probably due to the basal growth of abundant new shoots typically seen within exclosures (Figure 8).

Response of different shrub species to the variety of grazing intensities at these sites may also result in the absence of significant differences in shrub cover between the grazed subreaches. Heavy browsing can harm most riparian shrub species (Mosley et al. 1997), but lower levels of browsing may stimulate above-ground production (Molvar et al. 1993). Additionally, the typically patchy distribution of shrubs (Miller et al. 2003), combined with inclusion of sites in which shrub growth was entirely absent, may reduce our ability to detect differences without a more intensive sampling regime.

Vegetative cover serves many important functions in riparian ecosystems. Rooted riparian plants stabilize streambanks, slow return flow, trap sediment and pollutants, and provide habitat and food for aquatic and riparian species (Belsky et al. 1999). However, incomplete knowledge of the ecological functions of riparian zones, particularly in the watershed and landscape contexts, makes the levels at which removal of riparian vegetation adversely affect aquatic ecosystems, riparian wildlife, and water quality difficult to quantify (Moore and Richardson 2003). While the ecologic significance of 3% greater mean herbaceous cover and lower mean bare ground within the exclosure, as compared to the reference reach, is debatable (Table 4), the shift of roughly 17% of mean

herbaceous cover to bare ground in the areas adjacent to exclosures warrants a more extensive evaluation of the net effects of exclosure use, done in the context of the specific management goal.

### Channel Morphology

The absence of significant differences in channel morphology in EXCL and AWAY subreach comparisons may be due to initially wider channel and shallower banks inside the exclosure, which violates the assumption of identical pre-exclosure conditions necessary for space-for-time substitutions, but cannot be confirmed without pre-exclosure data. Lack of pre-exclosure data was cited as a potential problem in an eastern Oregon study that found only eight of eleven study sites to have narrower channel widths within exclosures (McDowell and Mowry 2002). Similar reasoning was included in a study of exclosures throughout the Intermountain West when explaining their mixed results (McDowell and Magilligan 1997). In the case of an initially wider channel and lower banks inside the exclosure, improvements in response to removal of grazing would not be detected until they reached levels surpassing those in the grazed reach.

The wide range of exclosure ages represented by the study group may also explain the absence of significant differences in channel morphology in EXCL and AWAY subreach comparisons, as geomorphic adjustment may first require improvement in bank vegetation and the occurrence of channel-forming discharge (McDowell and Mowry 2002). A central Idaho study found no difference in bank angle between grazed and exclosed reaches, but the study exclosures had been in place only three years when comparisons began (Clary et al. 1996). A study of four exclosures in eastern Oregon

found narrower widths within all four, which ranged in age from 14 to 30 years, but statistical significance was not discussed (Magilligan and McDowell 1997). A central Oregon study also found channel widths within a 50-year old exclosure to be significantly narrower than in the paired grazed study reach (Clifton 1989).

The exclosures used in this study are situated on small, low order streams that are characterized by small contributing areas and high channel gradients. This placement makes the streams flowing through them unlikely to be slow or sediment-laden enough to allow exclosure vegetation to trap sediment and rebuild the channel, which might also explain the absence of significant differences in channel morphology in EXCL and AWAY subreach comparisons. Confirming this explanation would require a closer look at the study sites within the context of their watersheds. A California study that found no significant changes in channel morphology in a 24-year old exclosure discussed the contradictory and unpredictable effects that differences in upstream land use and contributing area within the watersheds that contain exclosures might have on channel morphology within them, stating that increased overland flows and sediment load could be trapped by riparian vegetation and encourage narrowing in some areas, while widening to accommodate the higher flows might occur in others (Kondolf 1993).

A marked contrast exists between the roughly 0.4 m narrower mean channel width seen in the exclosure and the 1.59 m wider mean channel width seen in adjacent subreach, relative to the reference (AWAY) subreach (Table 4). Similarly, an even greater difference in mean bank angle is seen in the NEAR/AWAY comparisons than in EXCL/AWAY comparisons. These significant differences provide evidence of impact in

the subreach immediately adjacent to the enclosure greater than the insignificant improvement that is seen within the enclosure, relative to the reference (AWAY) reach.

Changes in channel width and bank angle are known to have effects on riparian ecosystem function. Widening channels are increasingly disconnected from their floodplains, impairing return of moisture, nutrients, and bank-building sediments to the riparian corridor (NRC 2002). Altered bank geometry results in reduction of the overhanging banks and vegetation that are important habitat for salmonids and other aquatic species (Oswood and Barber 1982). However, the extensive list of ecological services provided by lotic systems and their associated riparian zones, the variety of riparian and aquatic wildlife that may benefit from them, and the different spatial and temporal scales on which they operate make the degree of channel response that constitutes ecological significance difficult to quantify.

The 11% decrease in mean channel width and 2% increase in mean bank angle within the enclosure, relative to the AWAY subreach, seem unlikely to represent significant improvements ecologically (Table 4), but considered in the context of the 42% increase in mean channel width and 16% decrease in mean bank angle in the grazed area immediately adjacent to the enclosure, relative to the AWAY subreach, these channel responses warrant closer evaluation of the net effects of enclosure use.

#### Part 2: Describing a More Specific 'Zone of Impact' within the NEAR Subreach.

The identical zone of impacts (0-8 m) and similar mean differences between subreaches for herbaceous cover and bare ground indicate correlation between these

response variables (Tables 4 and 5). Channel width impacts indicate a zone of widening and removal of vegetation, due the enclosure's influence, in the area within 0-8 m of the enclosure fence. As expected, the extent of impacts in this zone is of greater severity than within the NEAR subreach as a whole for these response variables, relative to the reference reach. Mean channel width within 0-8 m of the enclosure is more than 60% wider than within the AWAY subreach, and mean difference in herbaceous cover and bare ground of approximately 30% (Table 5).

Bank angles were different only within the immediately adjacent plot (0-2 m). It is likely because this was the only plot region where differences in this response variable were of a severity and spatial consistency to be captured by the methods employed in data collection, which seemed to be particularly difficult to collect accurately in plots with dense shrub cover. This idea is supported by the 32.48% difference in mean bank angle, relative to the AWAY subreach, represented by the significant test result (Table 5).

Division of the study site group into two length-based subgroups did not produce any trends in the spatial extent of impacts due to enclosure size (Table 6). Differences in the resulting impact zones are likely due to the effects of the smaller data sets, or the ranking process used in the nonparametric test. The absence of a size-based trend in the spatial extent of the impact zone indicates that, in the absence of differences in impact severity due to enclosure size (discussed in Part 3), the net benefits of an enclosure can be expected to increase with enclosure length.

Part 3: Determining whether Exclosure Age, Length,  
or Livestock Density Affect the Severity of Impact.

Increases in exclosure age, length and livestock density were predicted to increase the disparity in livestock utilization of the NEAR and AWAY subreaches. Older exclosures might lead to longer periods of preferred use by livestock within the NEAR subreach, and higher headcounts per meter of perennial channel within the pasture might lead to preferred use in the NEAR subreach by more animals. Similarly, longer exclosures might intercept more animals as they travelled toward the channel and funnel greater numbers toward the exclosure's riparian boundaries.

Herbaceous cover was thought likely to respond predictably to these differences, as greater utilization might impair regrowth via root removal and intensify compaction that could impair reestablishment after spring flooding disturbances. Channel morphology was also believed likely to respond to these differences, as slower recovery rates make channel shape prone to the cumulative effects of annual grazing regimes.

While the data don't support the predicted responses (Figures 4-6, Table 7), further examination of the possible effects of exclosure duration, size and pasture use intensity on the adjacent riparian ecosystem would be recommended, as several study-specific factors could be contributing to the absence of the expected relationships.

The records for the exclosures included in this study, on file with the Forest Service and Bureau of Land Management, are incomplete in many cases. Survey responses regarding exclosure ages, and the stocking rates and dates used to calculate density, were estimated when written records did not exist. These inaccuracies could be

obscuring correlation between impact severity and age and livestock density by shifting data points from their 'correct' place on the x-axis, particularly in the case of livestock density, where small errors in stocking rate data could lead to greater differences in the outcome of the calculation.

The study methods used to create the livestock density data might also be contributing to absence of the predicted relationships. Stocking rates were calculated with an average of only five years of data, which allows for misrepresentation of its actual effects on impact severity, particularly at sites with recent histories of reduced stocking rates and at older sites where the effects of additional years are ignored using this method. Pasture boundaries and stream channel within the pasture were estimated from maps, which creates the potential for additional inaccuracies in the livestock density calculation.

The absence of predicted relationships between impact severity and exclosure age, length and livestock density are most likely explained by the many potential influencing factors that were ignored in order to make comparisons within a complex system where multiple controls are acting simultaneously and unpredictably. Varying conditions at the study sites are the result of differences in topography, canopy cover, underlying soil types, and other characteristics, all of which have the potential to alter livestock behavior or affect the susceptibility of the riparian area to livestock impacts.



Figure 7. Photo of typical shrub growth in grazed areas. Note woody appearance and relative absence of new growth below browse line.



Figure 8. Photo of typical shrub growth in exclosed areas. Note abundant new growth below typical browse height.

## CONCLUSIONS

### Summary of Primary Research Objectives.

#### Did the Study Confirm the Differences in Grazed and Exclosed Areas Shown by Previous Studies?

Study findings are consistent with the results of previous exclosure studies. Significant differences in herbaceous cover, shrub cover, and bare ground between reference grazed and exclosed subreaches (EXCL/AWAY comparisons) are accordant with the majority of studies that used these response variables. Insignificant differences between reference grazed and exclosed subreaches for channel width and bank angle are in keeping with the inconsistent results of previous exclosure studies that have used these response variables, particularly in light of the range of exclosure ages represented by the study site group and their placement on small, low-order streams.

#### Did the Study Indicate More Intense Impacts in the Subreach Adjacent to the Exclosure than in the More Distant Reference Reach?

This study also found significant differences in herbaceous cover and bare ground between the two grazed subreaches. The differences in the NEAR/AWAY means were approximately five times greater than the corresponding EXCL/AWAY mean comparisons for these response variables. Differences in channel width and bank angle, not significant in comparisons of the EXCL/AWAY means for these response variables, were significant and approximately four and eight times greater, respectively, in NEAR/AWAY comparisons. These findings indicate that impacts are not only more

intense within the grazed subreach adjacent to the enclosure, but that detriments to these response variables within the NEAR subreach are greater than the corresponding improvements within the enclosure, when a comparison is made relative to the AWAY subreach.

Shrub cover, while significantly different in the comparison of grazed and enclosed subreach means, was not significantly different between the two grazed subreaches. This is most likely due to the naturally patchy distribution of shrub growth, combined with the presence of different shrub forms in the grazed and enclosed subreaches due to long-term differences in grazing pressure.

Can a More Spatially Specific 'Zone of Impact' be Described for the Response Variables that Exhibit Impact within the Subreach Immediately Adjacent to the Enclosure?

A zone of channel widening and reduced herbaceous cover occurs within the grazed area 0-8 m from the enclosure fence. The spatial extent of impact to bank angle is confined to the plot immediately adjacent to the enclosure fence (0-2 m), possibly due to the inability of the data collection methods to detect small differences in this response variable. Enclosure length does not appear to severely affect the spatial distribution of impacts, meaning that, in the absence of differences in impact severity due to enclosure size, the net benefits of an enclosure can be expected to increase with enclosure length.

Does the Age or Length of the Exclosure, or the Density of Livestock on the Pasture Riparian Area Affect the Severity of Impact in the Subreach Immediately Adjacent to the Exclosure?

While the data don't support the predicted responses, further examination of the possible effects of exclosure duration, size and pasture use intensity on the adjacent riparian ecosystem is recommended, as several study-specific factors could be contributing to the absence of the expected relationships. Chief among these are error due to incomplete or inaccurate exclosure records, error due to the limitations of the study methods used to create the livestock density data, and the many potential influencing factors that were ignored in order to make comparisons within a complex system in which multiple controls are acting simultaneously and unpredictably.

Study Findings as they Relate to Management Recommendations that Optimize the Net Benefits of Exclosures.

In the absence of size-related differences in the spatial extent or severity of impacts due to exclosure size, larger exclosures will maximize any exclosure benefits inside relative to the detriments they cause outside. If overall riparian ecosystem function were the singular management goal, complete removal of livestock from western riparian areas would be optimal. However, realistic management must balance the desire for optimally functioning riparian ecosystems with real-world goals, like the efficient use of limited funds and the historic and economically important uses of public lands.

Actual management goals that prescribe exclosure use typically involve 'benefits' that depend on improvement as it relates to achieving specific benchmarks within a specific area, like meeting the habitat requirements of a single species within the

boundaries of a single, contiguous land holding. The response variables used for this study, while good ecologic indicators, weren't collected with the intent of assessing a specific management issue. This makes them less than ideal metrics for calculating exclosure benefits as they pertain to any real-world management goal, but they can be used to illustrate how data collected in pursuit of a specific goal could be used to determine the minimum exclosure size needed to achieve a net benefit.

If 50% herbaceous cover within a pasture is the management goal, the minimum exclosure size (length of channel excluded) needed to achieve a net benefit can be calculated using the data in Tables 4 and 5. A 30% decrease in herbaceous cover can be expected in the 8 m immediately adjacent to both ends of the exclosure (Table 5), and a 4% increase can be expected inside (Table 4). These changes represent 35% herbaceous cover in the 16 m immediately outside the exclosure, and 52% herbaceous cover inside. To exceed a mean cover of 50% within the pasture, an exclosure would have to be at least 120 m in length.

If the goal of 50% herbaceous cover represented a small-scale habitat requirement, increased cover inside the exclosure would likely result in suitable habitat, regardless of a zone of decreased cover outside, and its effects on mean herbaceous cover for the pasture as a whole. An exclosure built in an effort to deepen and narrow a channel in an attempt to improve trout habitat will do little toward that goal if the channel in the adjacent grazed area experienced impacts severe enough to prevent fish from migrating through it. These examples illustrate that one unit of benefit and one unit of detriment

are unlikely to neatly ‘cancel each other out’, relative to a typically specific management goal.

It makes more sense to consider the level of detriment acceptable in any project on a case-by-case basis. While this makes the predictive value of this study minimal, the strong case presented in this paper that an exclosure-caused zone of impact exists should inform exclosure use and make it a more effective management tool, especially when considered in the context of the issues of concern within the watershed, and how concentrated areas of impact might encumber specific management goals, especially in vulnerable or ecologically critical areas.

#### Additional Recommended Research

While the findings of this study provide a strong case for the existence of exclosure-caused impacts, this knowledge creates a need for future research to better understand them. Simply knowing that these impacts exist, while important, should not be viewed as an end in itself. In particular, three recommendations regarding future exclosure research would serve to optimize this understanding.

1. An emphasis on comparison studies of grazed and exclosed areas that used response variables related to specific management goals, such as habitat improvement, with methods designed to capture these effects would shed light on how the benefit-versus-detriment equation translates to a concrete measure of success.

2. An emphasis on comparison studies that follow grazed and exclosed areas through time, with methods designed to capture these effects, would remove the need for the assumption of identical pre-exclosure condition, and clarify how both benefits and detriments develop as exclosures age.
3. An emphasis on how land use activities and exclosure placement within the watershed affect both benefits and detriments would shed light on the bigger-picture potential for effective exclosure use.

### Summary

The utility of an exclosure is the net ‘gain’ of all resulting responses within the system in which it was constructed, and is more difficult to evaluate than many previous studies would lead their readers to believe. Adjacent impacts have certainly been observed, as a description of my project in discussions with range conservationists has been met with some indication of “edge effects” as common knowledge. However, I am not aware of a published attempt to account for these effects. While more precise, goal-specific characterization of the severity and spatial extent of adjacent impacts will further the efficacy of exclosures as a management strategy, this study serves to document the existence of these impacts, and should make practitioners aware of the cautions and general limitations associated with exclosure use.

## LITERATURE CITED

- Ammon, E. M., and P. B. Stacey. 1997. Avian nest success in relation to past grazing regimes in a montane riparian system. *The Condor* 99:7-13.
- Armour, C., D. Duff, and W. Elmore. 1994. The effects of livestock grazing on western riparian ecosystem. *Fisheries* 19:9-12
- Belsky, A. J., A. Matzke, and S. Uselman. 1999. Survey of livestock influences on stream and riparian ecosystems in the western United States. *Journal of Soil and Water Conservation* 54:419-431.
- Cagney, J. 1993. Riparian management – greenline riparian-wetland monitoring. Denver, CO, USA: US Department of Agriculture, Bureau of Land Management Service Center, TR 1737-8, p. 11.
- Chaney, E., W. Elmore, and W.S. Platts. 1993. Managing change: livestock grazing on western riparian areas. Eagle, ID, USA: US Environmental Protection Agency, Northwest Resource Information Center, p. 8.
- Clary, W. P. 1999. Stream channel and vegetation responses to late spring cattle grazing. *Journal of Range Management* 52:218-227.
- Clary, W. P., N. L. Shaw, J. G. Dudley, V. A. Saab, J. W. Kinney, and L. C. Smithman. 1996. Response of a depleted sagebrush steppe riparian system to grazing control and woody plantings. Ogden, UT, USA: US Department of Agriculture, Forest Service, Research Paper INT-RP-492.
- Clifton, C. 1989. Effects of vegetation and land-use on channel morphology. *In*: R. E. Greswell, B. A. Barton, and J. L. Kershner, J. L. [EDS.]. Practical Approaches to Riparian Resource Management – An Educational Workshop; 8-11 May 1989; Billings, Montana, USA. U.S. Bureau of Land Management. BLM-MT-PT-89-001-4351. p. 121-129.
- Dahlem, E. A. 1978. The Mahogany Creek watershed—with and without grazing. *In*: O. B. Cope [ED.]. Proceedings of the Forum - Grazing and Riparian/Stream Ecosystems; 3-4 November 1978; Denver, CO, USA. Trout Unlimited, Inc. p. 31–34.
- Dobkin, D. S., A. C. Rich, and W. H. Pyle. 1998. Habitat and avifaunal recovery from livestock grazing in a riparian meadow system of the northwestern Great Basin. *Conservation Biology* 12:209-221

- Duff, D. A. 1977. Livestock grazing impacts on aquatic habitat in Big Creek, Utah. *In: J. W. Menke [ED.]. Proceedings of workshop on livestock and wildlife-fisheries relationships in the Great Basin; 3-5 May 1977; Sparks, NV, USA. Berkeley, CA, USA: University of California Agricultural Station, Special Pub. 3301. p. 129-142.*
- Fleischner, T. L. 1994. Ecological costs of livestock grazing in western North America. *Conservation Biology* 8:629-644.
- Harrelson, C. C., C. L. Rawlins, and J. P. Potyondy. 1994. Stream channel reference sites: an illustrated guide to field technique. Fort Collins, CO, USA: US Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station, GTR-RM-245. p. 33.
- Kauffman, J. B., G. Coleman, D. Lytjen, D. Nagy, and N. Otting. 2002. Riparian vegetation composition in paired grazed and ungrazed stream reaches in northeastern Oregon. *In: Research / evaluate restoration of NE Oregon streams. Portland, OR, USA: Bonneville Power Administration. Project No. 2000-05100, BPA Report DOE/BP-00006210-1.*
- Kauffman, J. B., and W. C. Krueger. 1984. Livestock impacts on riparian ecosystems and streamside management implications...a review. *Journal of Range Management* 37:430-438.
- Kauffman, J. B., W. C. Krueger, and M. Vavra. 1983. Impacts of cattle on streambanks in northeastern Oregon. *Journal of Range Management* 36:683-685.
- Kondolf, G. M.. 1993. Lag in stream channel adjustment to livestock exclosure, White Mountains, California. *Restoration Ecology* 1:226-230.
- Leonard, S., G. Kinch, V. Elsbernd, M. Borman, and S. Swanson. 1997. Riparian management: grazing management for riparian-wetland areas. Denver, CO, USA: US Department of the Interior, Bureau of Land Management, National Applied Resource Sciences Center, Technical Reference 1737-14. p. 17.
- Magilligan, F. J., and P. F. McDowell. 1997. Stream channel adjustments following elimination of cattle grazing. *Journal of the American Water Resources Association* 33:867-878.
- McDowell, P. F. and F. J. Magilligan. 1997. Response of stream channels to removal of cattle grazing disturbance: overview of western U.S. exclosure studies. *In: S. Y. Wang et al. [EDS.]. Proceedings of the Conference on Management of Landscapes Disturbed by Channel Incision; 19-23 May 1997; Oxford, MS, USA: University of Mississippi. p. 469-475.*

- McDowell, P. F. and A. Mowry. 2002. Geomorphic response to exclosures. *In: Research/valuate restoration of NE Oregon streams*. Portland, OR, USA: Bonneville Power Administration. Project No. 2000-05100, BPA Report DOE/BP-00006210-1.
- Miller, J. R., J. A. Weins, N. T. Hobbs, and D. M. Theobald. 2003. Effects of human settlement on bird communities in lowland riparian areas of Colorado (USA). *Ecological Applications* 13:1041-1059
- Molvar, E. M., R. T. Bowyer, and V. Van Ballenberghe. 1993. Moose herbivory, browse quality, and nutrient cycling in an Alaskan treeline community. *Oecologia* 94:472-479.
- Moore, R. D. and J. S. Richardson. 2003. Progress towards understanding the structure, function, and ecological significance of small stream channels and their riparian zones. *Canadian Journal of Forest Research* 33:1349-1351.
- Mosley, J. C., P. S. Cook, A. J. Griffis, and J. O'Laughlin. 1997. Guidelines for managing cattle grazing in riparian areas to protect water quality: review of research and best management practices policy. Moscow, ID, USA: Idaho Forest, Wildlife, and Range Experimental Station, ID State University, Policy Analysis Group Rep. 15. p. 19.
- Nagle, G. N., and C. F. Clifton. 2003. Channel changes over 12 years on grazed and ungrazed reaches of Wickiup Creek in eastern Oregon. *Physical Geography* 24:77-95.
- [NRC] National Research Council. 2002. Summary section. *In: Riparian areas: functions and strategies for management*. Washington, DC, USA: National Academy Press. p.1-22.
- Olson, B. E., R. T. Wallander, and P. K. Fay. 1997. Intensive cattle grazing of oxeye daisy (*Chrysanthemum leucanthemum*). *Weed Technology* 11:176-181.
- Osmund, D. L., D. M. Butler, N. N. Ranells, M. H. Poore, A. Wossink, and J. T. Green. 2007. Grazing practices: a review of the literature. Raleigh, NC, USA: North Carolina Agricultural Research Service, NC State University, Technical Bulletin 325-W.
- Oswood, M. W. and W. E. Barber. 1982. Assessment of fish habitat in streams: goals, constraints, and a new technique. *Fisheries* 7:8-11.
- Platts, W. S. and R. L. Nelson. 1989. Characteristics of riparian plant communities and streambanks with respect to grazing in northeastern Utah. *In: R.E. Gresswell, B.A. Barton, and J.L. Kershner [EDS.]. Proceedings of the Practical Approaches to Riparian Resource Management Educational Workshop; 8-11 May 1989; Billings, MT, USA: US Department of the Interior, Bureau of Land Management, BLM-MT-PT-89-001-4351. p. 73-81.*

Powell, G. W., K. J. Cameron, and R. F. Newman. 2000. Analysis of livestock use of riparian areas: literature review and research needs assessment for British Columbia. Victoria, BC, CAN: BC Ministry of Forestry Research Branch, Work Paper 52/2000.

Schulz, T. T., and W. C. Leininger. 1990. Differences in riparian vegetation structure between grazed areas and exclosures. *Journal of Range Management* 43:295-299.

[USDA] United States Department of Agriculture. 1997. National range and pasture handbook. Washington, DC, USA: US Department of Agriculture, Natural Resources Conservation Service, Grazing Lands