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STREAMBANK AND VEGETATION RESPONSE TO SIMULATED CATTLE GRAZING

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Abstract: Simulated grazing techniques were used to investigate livestock impacts on structural and vegetation characteristics of streambanks in central Idaho, USA. The treatments, continued over two years, consisted of no grazing, simulated moderate early summer grazing, simulated moderate mid-summer grazing, and simulated heavy season-long grazing. The moderate treatments depressed the streambank surface about 3 cm, while the heavy season-long treatment resulted in an 11.5-cm depression. There were no differences between the no-grazing and moderate-grazing treatments for change in stream width, bank angle, bank retreat, or root biomass. The heavy season-long treatment, however, produced significant changes in these variables. The amount of foliage biomass (i.e., kg ha^{-1}) removed by treatment was similar between the two years of study for the moderate treatments. The foliage removed from the heavy season-long treatment plots greatly decreased in the second year as plant growth decreased. Ten months after the last treatment application, the average spring foliage growth was 20–43% lower on the moderate treatment plots and 51–87% lower on the heavy season-long treatment plots than on the untreated control plots.

Key Words: riparian, mountain meadow, root biomass, stream channel, streambank deformation, simulated grazing

INTRODUCTION

Riparian ecosystems are normally the most ecologically productive and diverse of all terrestrial habitats (Gregory et al. 1991, Naiman et al. 1993). In the United States, riparian zones have been greatly reduced in area by human activity (Swift 1984). In addition, the functional characteristics of the remaining areas are often reduced through chronic impacts in or near the riparian zone. Such impacts include stream impoundments, irrigation diversion, channel modification, logging, pollution, recreation, and grazing (Swift 1984, Knopf et al. 1988, Busch and Scott 1995).

Concern about the impacts of livestock, particularly cattle, grazing in riparian zones is widespread across the public lands of the western United States. Livestock grazing has reportedly damaged about 80% of the streams and riparian ecosystems in the arid regions of western United States (Belsky et al. 1999). Approximately 30 water quality, stream channel morphology, hydrology, riparian soil, and instream vegetation characteristics are negatively affected by improper livestock use (Belsky et al. 1999). Many reductions in riparian native biodiversity have been associated with the presence of livestock grazing (Saab et al. 1995, Fitch and Adams 1998, Belsky et al. 1999).

Riparian zones are major components of aquatic vertebrate food resources and habitats (Platts 1983, Gregory et al. 1991, Murphy and Meehan 1991). Both research and anecdotal evidence suggest that heavy cattle grazing negatively impacts fish habitats by removing the cover of overhanging banks and vegetation and by causing deposition of fine sediments on spawning gravels and in pools (Meehan and Platts 1978, Armour et al. 1991). The benefits of a vigorous herbaceous plant community, and therefore of greater root length density and root mass, include greater resistance to particle erosion and greater resistance to streambank compression and shear. This is particularly true in alluvial meadow streambanks (Kleinfelder et al. 1992, Dunaway et al. 1994). Greater stem and foliage length also provide protection to the substrate surface under conditions of inundated flow (Clary et al. 1996, Skinner 1998).

Grazing animals primarily affect foraging areas by defoliating plants, trampling soil and plants, and excreting wastes that may nourish plants (Heitschmidt 1990, Matches 1992). Defoliation of plants can greatly affect production of both foliage and roots resulting in decreased plant vigor, biomass, and species diversity (Jameson 1963, Kauffman and Krueger 1984, Briske 1991). A major effect of soil compaction by hoof ac-

Table 1. Some comparative characteristics of the three study sites at the initiation of the study. Means and standard errors (in parentheses) are presented.

Characteristic	Stanley Creek	Park Creek	Thatcher Creek
Wetted stream width (m)	1.59 (0.04)	1.51 (0.06)	1.37 (0.03)
Bank angle (°)	60.06 (3.78)	109.53 (5.50)	107.81 (5.26)
Soil strength (kg/cm²)	1.18 (0.10)	1.05 (0.12)	1.03 (0.10)
Soil moisture (%)			
Early summer (late June)	39.34 (1.07)	168.41 (14.62)	44.28 (3.20)
Mid-summer (late July)	35.25 (2.25)	183.81 (11.92)	44.18 (3.69)
Early fall (late August)	36.50 (3.42)	139.12 (31.74)	39.50 (4.60)
Graminoid heights (cm)	25.06 (1.26)	27.69 (1.20)	29.56 (1.16)
Forb heights (cm)	8.97 (0.67)	9.41 (0.57)	10.78 (0.87)
Root biomass (g/core)	4.41 (0.32)	5.18 (0.23)	4.33 (0.37)

tion is reduced macropore space, which reduces infiltration, percolation, root growth, and overall plant production (Lull 1959, Bryant et al. 1972). The response of plant growth to nutrient return via excreta of grazing animals may be less than assumed. Much or perhaps nearly all of the nitrogen in urine and feces can be lost to volatilization or leaching (Watson and Lapins 1969, Floate 1970, Woodmansee 1978). Ball et al. (1979) found that only 22% of nitrogen from animal wastes may be recovered in plant tissue. As stocking rates increase, herbage growth decreases because the benefits of increased nitrogen transfer are outweighed by the negative effects of trampling and increased intensity of defoliation (Curll and Wilkins 1982, 1983). All three primary grazing effects (defoliation, trampling, and nutrient return) have been shown to affect plant growth in riparian meadows significantly (Clary 1995).

Studies of simulated livestock grazing have some advantages over studies using actual livestock; they cost less, require much less space, and provide an opportunity to examine the various individual effects of grazing (Clary 1995). There has been some question whether defoliation by clipping duplicates the effects of grazing in upland situations where grazing may be patchy (Stroud et al. 1985, Wallace 1990); however, in meadow situations, cattle tend to graze to a relatively uniform stubble height (Bartolome 1984). The simulation of trampling combined with defoliation should result in a plant response closely paralleling the response to actual livestock grazing (Bryant et al. 1972), particularly when the effect of nutrient return is added.

Although there are many anecdotal accounts and observations of cattle breaking down streambanks (Adams and Fitch 1995, Martin and Schumaker 1998), there is little quantification of the impacts necessary to damage streambanks. Few references provide actual documentation of the amount of livestock use required to change stream channel and streambank morphology to a measurable degree (Trimble and Mendel 1995, Jolley et al. 1997). In the present study, the hypothesis was that physical and biological changes would occur when streambanks were subjected to simulated typical total animal impacts of cattle. A goal was to provide information that would assist in the development of grazing strategies designed to stay within the annual tolerance of a site for plant and streambank/channel impacts.

STUDY AREA AND METHODS

This study was conducted on three streams north of Stanley, Idaho, USA in central Idaho's Sawtooth Valley. Stanley Creek and Park Creek are in the Sawtooth National Forest, while Thatcher Creek is in the Challis National Forest. The distance of these streams from the town of Stanley and the elevation at the study sites are as follows: Stanley Creek, 5.9 km and 1972 m; Park Creek, 8.8 km and 1976 m; and Thatcher Creek, 25.0 km and 2006 m. These streams meander through mountain meadows, average 1 to 2 m in width (Table 1), and are slightly entrenched with well-vegetated streambanks. Rosgen stream classifications at the study sites are Stanley Creek, C4; Park Creek, E4, and Thatcher Creek, E4 (Rosgen 1996). Average annual precipitation at Stanley (1912 m elevation) is approximately 389 mm. Average annual temperature is 2° C, while the average temperature during June, when the root biomass and the final foliage sampling were conducted, is 11° C (Idaho Climatic Services, personal communication).

The Stanley Creek and Thatcher Creek soils are classified as loamy, cryic Fluventic Ustochrepts, and the Park Creek soil is classified as a loamy, cryic Fluventic Haplaquoll. The A horizon of Stanley Creek is dark yellowish brown, Park Creek is black, and Thatcher Creek is brown. Thatcher Creek had the most rock fragments (25%), while Stanley Creek and Park Creek had the most clay (5%). All three study sites have buried soil horizons at 18 to 33 cm below the surface (D. Gilman, personal communication). Streamside vegetation at the study sites was dominated by water sedge (*Carex aquatilis* Wahl.), beaked sedge (*C. utriculata* Boott, formerly *C. rostrata* Stokes), and Baltic rush (*Juncus balticus* Willd.). Several of the more abundant forbs were white clover (*Trifolium repens* L.), American alpine speedwell (*Veronica wormskjoldii* Roem.& Schult.), monkey-flower (*Mimulus* spp.), and common willow-weed (*Epilobium glandulosum* Lehm.). Adjacent moist meadow sites were typically dominanted by the graminoids Jones sedge (*C. jonesii* Bailey), small-winged sedge (*C. microptera* Mack.), field woodrush (*Luzula campestris* (L.) DC), and Kentucky bluegrass (*Poa pratensis* L.). Typical forbs included aster (*Aster* spp.), yarrow (*Achillea millefolium* L.), rosy pussy-toes (*Antennaria microphylla* Rydb.), and common dandelion (*Taraxacum officinale* Weber). Several other characteristics of the study sites are presented in Table 1.

Livestock use of the Sawtooth Valley began with sheep grazing by 1879. Up to 200,000 sheep grazed during summers in the Sawtooth Valley. Cattle grazing began about 1899, but little attention was given to grazing management until the 1970s. Heavy use of riparian meadows apparently occurred during most of this period (Clary 1999). The sites in this investigation had been protected from grazing for 5 to 10 years before initiation of the study.

The treatments applied were intended to simulate no grazing, moderate early summer grazing, moderate mid-summer grazing, and heavy season-long grazing. Eight main plots were randomly established per stream–two replicates per treatment. Each main plot had four 1-m^2 subplots arranged in two rows perpendicular to the streambank. Each row contained one subplot centered approximately 1.75 m from the streambank edge (meadow plot) and one subplot overlapping the streambank (streambank plot). A half meter buffer zone was established around the subplots for protection and access.

Grazing simulation treatments were patterned after those in Clary (1995), with suggestions and refinements contributed by Al Medina (Rocky Mountain Research Station, Flagstaff, AZ) and Pat Momont (Caldwell Research and Extension Center, Caldwell, ID). The moderate seasonal treatments were designed to represent the total impact that cattle would have while grazing the foliage to a 10-cm height, an often-used riparian grazing guideline (see Clary 1995 Table 5), or in the case of this study, it represented a grazing intensity of about 1 AUM (animal unit month) ha^{-1}. The heavy season-long treatment was designed to represent the total impact of cattle grazing to a 1-cm height at three times during the grazing season (the authors have witnessed riparian areas subjected to severe regrazing with residual forage lengths of 1 cm or less). The trampling impact and nutrient return for the heavy season-long treatment would represent about 7.5 AUM ha^{-1} of ''use'' as animals would be expected to spend substantial time on site attempting to regraze the short stubble heights of a streamside area.

The moderate treatments were applied to the appropriate subplots once in either late June (early summer) or late July (mid-summer) in 1996 and 1997. Vegetation was defoliated by clipping to a height of 10 cm. Cattle trampling was simulated by 50 random impacts by a hoof imitator (14-kg steel weight with impact surface area of 100 cm^2 dropped from 75 cm) per subplot (Clary 1995, Al Medina, Rocky Mountain Research Station, personal communication). The number of impacts was based upon the estimated animal days of use on the site that would be required to consume the defoliated vegetation and the likely number of hoof prints per animal day (Scholl 1989). Animal waste was represented by 0.8 g of urea in 0.25 liter of water (simulated urine) and fresh manure that was applied at a rate of 66 g m^{-2} per subplot. The amounts were based upon local forage production and consumption estimates and on excretion values from Tiedemann et al. (1986) and Pat Moment, Caldwell Research and Extension Center, Caldwell, ID, personal communication. The heavy season-long treatment was applied in late June, late July, and again in late August in 1996 and 1997. Vegetation was defoliated to 1 cm in height, 120 random hoof-imitator impacts were applied, urine was represented by 2.0 g urea in 0.25 liter of water, and fresh manure was applied at a rate of 165 g m^{-2} per subplot. Treatments were initiated in the spring of 1996 and ended in the fall of 1997. Final measurements were taken in the spring of 1998.

Changes in soil surface and bank profile were determined by a bankometer patterned after a rill meter (McCool et al. 1981). A 1.3-cm conduit pipe, 3 m long with 0.6-cm holes drilled on 2.5-cm centers, was anchored to rebar stakes. Forty stainless steel rods, 0.6-cm in diameter, were positioned through the drilled holes in the conduit pipe and lowered to the soil surface (Figure 1). The length remaining above the conduit was recorded for each rod position. Two bankometer positions on each of the 96 subplots accommodated 7,680 rod locations.

Determination of treatment effect on streambank elevation was a function of the average change in readings over time. Bankometer readings were made each spring and fall. Bank angle from water's edge to top of bank (Platts et al. 1987), wetted stream width, and average existing stream depth (average of 4 measures across the stream) were determined after spring snow melt flow had subsided at the beginning and at the end

Figure 1. Bankometer positioned on a study plot in central Idaho.

of the study. Bank retreat at water's edge during the treatment period was recorded at the end of the study. With the exception of the bankometer measurements, the variables discussed above had a sample size of 96 for each measurement period.

Soil strength was measured by a pocket penetrometer. The penetrometer method has been correlated with unconfined strengths and zones of compaction among similar soil types (Bradford 1986). Twelve samples were taken at each main plot, for a total of 288 measurements each spring and fall of the study. Moisture in the top 15 cm of soil was sampled gravimetrically by four 2.5-cm cores per main plot for a total of 96 per treatment each spring and each additional treatment application. Dry weight was determined by heating samples at 100° C for 24 hours.

Root sampling was conducted by extracting 4.5-cm-diameter, 15-cm-deep soil cores. Twelve samples were taken at each main plot, for a total of 288 cores, both at the beginning of the study in the spring of 1996 (in buffer areas) and at the end of the study in the spring of 1998 (in treated plots). Gross root biomass was determined by washing the samples over a 1.6-mm screen, drying at 100° C for 24 hours, and weighing. The organic matter was burned off using denatured alcohol as an accelerant. The ash was gently blown away, and the residual mineral particles originally attached to the roots were weighed and subtracted from the initial gross dry weight to obtain the net root dry biomass (modification of Lim and Jackson 1982).

Plant data were collected from the central 0.25 m^2 of the 96 1-m^2 treatment subplots. Plant heights, separated by graminoids and forbs, were recorded at the beginning and end of the study. Above-ground current year's growth of graminoids and forbs was determined by harvesting plants to ground level in the spring of 1998. Foliage removed during treatment and during the final harvest was bagged, dried at 100° C for 24 hours, and weighed.

A mixed-model analysis of variance was used to analyze data with one date of measurement or to analyze the change in variables between the beginning and end of study. A protected Fisher's LSD multiple range test was used to differentiate treatments. A mixed-model analysis of variance with AR(1) error structure (Littell et al. 1996) was used for the repeated

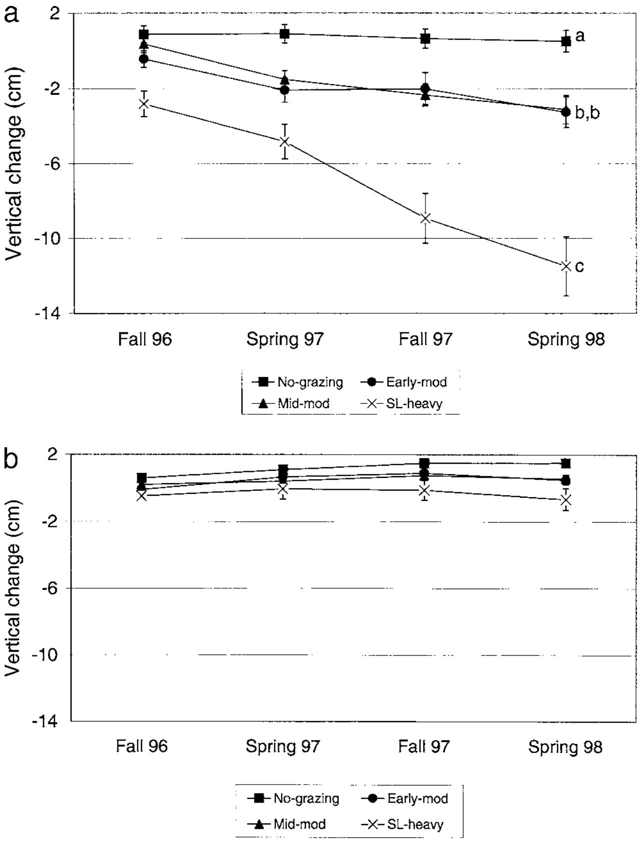

Figure 2. Mean depression of soil surface related to time and four simulated grazing treatments: a. streambank, b. meadow. Treatments with different letters have significantly different population means at the $P < 0.05$ level.

measures analysis of bankometer data. Effects of soil moisture content were examined through correlation with response variables. Probability values of 0.05 or less were considered significant in all tests.

RESULTS

Streambank surface elevations were significantly affected by the treatments ($F_{3,6} = 33.05$, $P < 0.01$). The streambank plots receiving simulated grazing treatments had a cumulative reduction in average surface elevation as the surface structure became progressively more deformed and broken (Figure 2a). The two moderate intensity treatments had about 3 cm of average surface depression, while the heavy season-long treatment had about 11.5 cm of average surface depression as the edge of the bank became severely deformed. In contrast, the meadow plots experienced relatively little change from the simulated grazing ($F_{3,6} = 2.68$, $P = 0.14$) (Figure 2b). Bank retreat, or the retreat of the streambank face at water's edge, was also affected by treatment ($F_{3,6} = 10.02$, $P = 0.01$). The no-grazing and moderate-grazing treatments were comparable, averaging about 3.5 cm of bank retreat at the water's edge, but the heavy season-long treatment resulted in substantially greater bank retreat of about 12 cm over the study period (Table 2). Stream discharge on the study areas was less in 1998 than in 1996. This generally resulted in reduced wetted stream width. The wetted stream width at the plot locations, however, responded differentially with treatment ($F_{3,6} = 19.44$, $P < 0.01$). The no-grazing and moderate-grazing treat-

Table 2. Changes in streambank characteristics and standard errors (in parentheses) in response to simulated grazing in central Idaho.

Simulation treatment	Bank retreat (cm)	Stream width (m)	Bank angle (°)	Penetrometer (kg/cm^2)
No grazing	1.96 (0.39)a[1]	−0.22 (0.05)a	−7.71 (4.62)a	0.13 (0.11)a
Stanley Creek	2.00 (0.91)	−0.33 (0.06)	−3.75 (7.25)	0.22 (0.19)
Park Creek	1.75 (0.70)	−0.30 (0.07)	−6.87 (9.57)	0.08 (0.21)
Thatcher Creek	2.12 (0.44)	−0.04 (0.09)	−12.50 (7.76)	0.10 (0.20)
Early summer moderate	5.54 (1.17)a	−0.28 (0.05)a	8.75 (5.77)ab	0.24 (0.16)a
Stanley Creek	1.75 (0.94)	−0.33 (0.07)	12.87 (9.78)	0.86 (0.22)
Park Creek	11.00 (2.40)	−0.37 (0.07)	12.75 (9.27)	−0.60 (0.22)
Thatcher Creek	3.87 (0.35)	−0.15 (0.11)	0.62 (11.51)	0.48 (0.10)
Mid-summer moderate	2.96 (0.53)a	−0.24 (0.05)a	−10.68 (9.50)a	0.37 (0.14)a
Stanley Creek	1.50 (0.63)	−0.22 (0.06)	9.62 (8.87)	0.77 (0.24)
Park Creek	4.87 (0.52)	−0.35 (0.10)	−9.31 (20.36)	−0.20 (0.13)
Thatcher Creek	2.50 (1.10)	−0.17 (0.06)	−32.34 (16.44)	0.55 (0.22)
Season-long heavy	12.38 (1.14)b	0.01 (0.06)b	34.42 (7.69)b	0.08 (0.07)a
Stanley Creek	9.87 (1.08)	−0.06 (0.03)	71.37 (9.52)	0.36 (0.12)
Park Creek	18.12 (1.75)	−0.07 (0.14)	6.87 (8.18)	−0.24 (0.12)
Thatcher Creek	9.12 (1.19)	0.15 (0.08)	25.00 (10.43)	0.13 (0.06)

[1] Values followed by different letters within a column are significantly different at the $P < 0.05$ level.

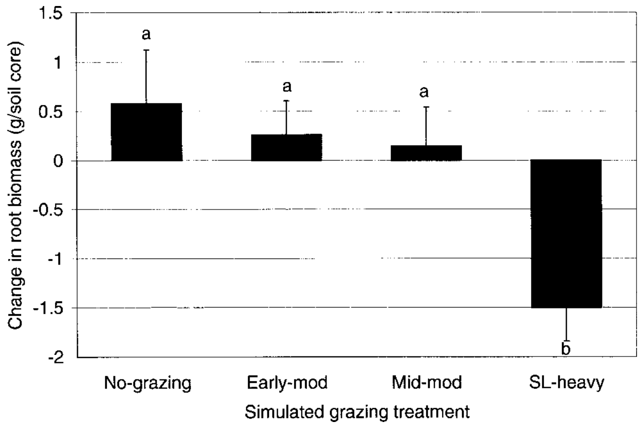

Figure 3. Change in root biomass in response to four simulated grazing treatments. Treatments with different letters are significantly different at the $P < 0.05$ level.

ments had about 0.25 m narrower stream wetted-widths. The heavy season-long treatment differed significantly from the other treatments and resulted in no reduction in stream wetted width even in the face of the reduced flow (Table 2). The bank retreat increase with this treatment (described above) apparently countered the effects of the lower flow, resulting in a measured wetted stream width similar to that at the initiation of the study. Bank angle also experienced a significant change related to treatment ($F_{3,6} = 4.90$, $P = 0.04$). All treatments but season-long heavy had statistically similar changes in bank angle that averaged -3 degrees. Season-long heavy had an increase in bank angle of 34 degrees, producing a substantial flattening of the bank face (Table 2).

Penetrometer readings, although showing a short-term increase from the heavy season-long treatment ($F_{3,6} = 3.65$, $P = 0.02$), did not appear to retain the change over winter. There were no differences in soil penetrability among treatments when comparing spring 1998 readings to that of spring 1996 ($F_{3,6} = 0.57$, $P = 0.65$) (Table 2). Root biomass changed little during the study for the no-grazing and the moderate-grazing treatments, whereas the heavy season-long treatment produced a 32.5% decrease following the 2 treatment years ($F_{3,6} = 5.20$, $P = 0.04$) (Table 1, Figure 3).

Significant correlations ($r = 0.44$–0.62, $P = 0.01$–0.03) occurred between bank retreat and streambank moisture on treated plots but not on controls ($r = 0.17$, $P = 0.41$). No soil moisture correlations were found with changes in elevation of the soil surface ($r = 0.04$, $P = 0.74$), stream width ($r = 0.26$, $P = 0.20$), or bank angle ($r = 0.29$, $P = 0.17$).

The height of graminoid plants at the vegetative/boot phenological stage was greater in 1998 than in 1996 for the no-grazing treatment, showed little change for the moderate treatments, but decreased by an average of 43% for the heavy season-long treatment (Streambank $F_{3,6} = 10.35$, $P = 0.01$; Meadow $F_{3,6} = 11.52$, $P = 0.01$) (Tables 1 and 3). A similar but non-significant trend of decrease in height growth with increasing treatment stress occurred for the forb species (Streambank $F_{3,6} = 1.94$, $P = 0.22$; Meadow $F_{3,6} = 1.97$, $P = 0.22$).

Total foliage removed as part of the treatments differed substantially. The values varied from 0 (no grazing) to 107.2 g m^{-2} (heavy season-long) (Figures 4a and b). There were significant interactions between treatment and year (Streambank $F_{3,88} = 17.18$, $P < 0.01$; Meadow $F_{3,88} = 11.43$, $P < 0.01$). The amount of foliage removed in the second year of the season-long treatment was reduced by as much as 73% compared to the first year. This occurred because of the decrease in plant growth in response to the severe treatment.

Total above-ground biomass produced in the spring of 1998 differed significantly among treatments (Streambank $F_{3,6} = 12.41$, $P = 0.01$; Meadow $F_{3,6} = 5.13$, $P = 0.04$). The strongest effect occurred in the streambank location. The moderate-grazing treatments yielded biomass values of about 57% of the no-grazing plots, and the heavy season-long treated plots yielded only about 13% of the no-grazing plots (Table 4). Equivalent values for the meadow plot locations were 80% and 49% of the no-grazing treatment.

DISCUSSION

Excessive grazing along streams removes protective vegetation and tramples banks into sloping profiles. The sloping of a streambank, which is normally steep, vertical, or undercut, represents a fundamental change in channel morphology that is detrimental to most native biota (Bohn 1986). Such channel morphology is strongly influenced by the stabilization contributed via riparian vegetation (Fitch and Adams 1998). Herbaceous roots and rhizomes provide much of the compressive strength and soil stability for streambanks in meadow situations (Kleinfelder et al. 1992, Dunaway et al. 1994). Streambanks on our sites were well-vegetated with a variety of plant species. The most prominent plants near the water's edge were water sedge, beaked sedge, and Baltic rush, species known to be strongly-rooted (Manning et al. 1989, Platts and Nelson 1989, Kleinfelder et al. 1992, USDA Forest Service 1992, Dunaway et al. 1994). Thus, our study sites should not have been particularly susceptible to streambank damage. Our season-long, heavy simulated grazing treatment, however, did result in a significant increase in streambank surface depression, bank retreat, and bank angle within a two-year period.

Table 3. Change in average vegetation heights and standard errors (in parentheses) between beginning of study June 1996 and end of study June 1998 in central Idaho.

Simulation treatment	Graminoid		Forb	
	Streambank	Meadow	Streambank	Meadow
No grazing	6.92 (1.40)b[1]	7.75 (2.63)b	2.66 (1.66)a	2.83 (1.55)a
Early-summer moderate	0.17 (1.68)b	4.58 (1.86)b	−1.25 (0.95)a	−2.67 (1.21)a
Mid-summer moderate	−1.58 (1.40)b	3.67 (1.96)b	−1.50 (1.28)a	−1.92 (1.16)a
Season-long heavy	−12.42 (2.16)a	−8.92 (2.31)a	−3.42 (1.49)a	−3.17 (1.15)a

[1] Values followed by different letters within a column are significantly different at the $P < 0.05$ level.

Another factor affecting the vulnerability of streambanks to trampling damage is soil moisture content. Montana researchers found a substantial correlation between changes in stream-channel area and streambank soil moisture, and little correlation between channel area and observed cattle presence in the riparian area (Marlow and Pogacnik 1985, Marlow et al. 1987). They suggested that a primary guideline for grazing riparian areas would be to limit livestock use to the seasonal periods of dry (<10% moisture) streambanks.

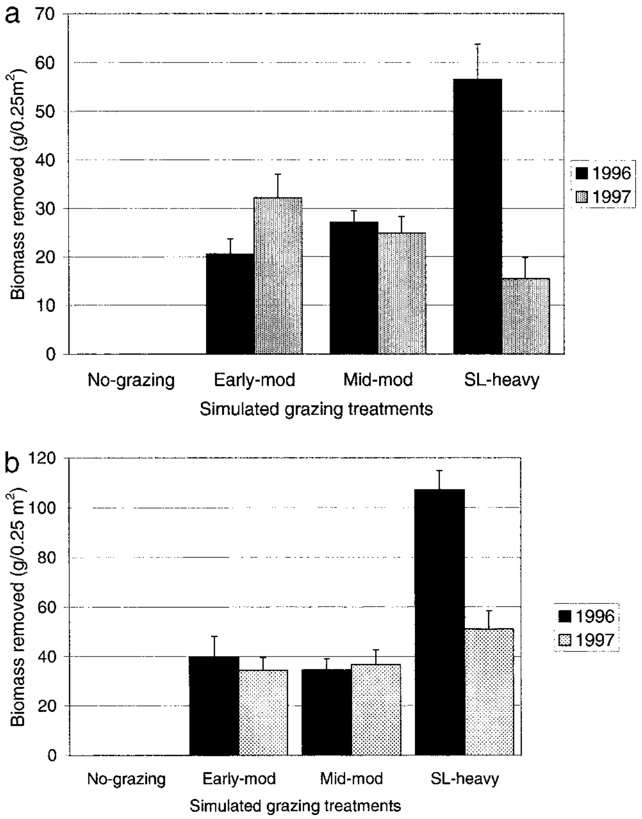

Figure 4. Foliage biomass removed under four simulated grazing treatments for two consecutive years for: a. streambank and b. meadow. Note severe reduction in harvested foliage under the heavy season-long treatment suggesting large reduction in biomass growth in the second year of the study (also see Table 4). Interactions between treatment and year were significant ($P < 0.01$).

Conversely, we found relatively limited correlation between variations in streambank soil moisture and streambank damage in the present study. Perhaps one reason was that the banks of the study streams remained well above the 10% moisture threshold for bank toughness suggested by Marlow and Pogacnik (1985). Average early fall streambank moisture was 36% at Stanley Creek, 39% at Thatcher Creek, and over 100% at Park Creek.

Livestock grazing in many locations has been shown to increase soil compaction, decrease soil infiltration, increase runoff of surface water, and increase soil erosion (Alderfer and Robinson 1949, Warren et al. 1986, Usman 1994, Trimble and Mendel 1995). Grazing season impacts on surface soils can be substantially reversed due to the action of freeze-thaw and wet-dry cycles (Tollner et al. 1990, Weigel et al. 1990). Our data and those of Wheeler (1998) from moist riparian areas suggest a similar result because the growing season treatment differences in soil characteristics were lost over winter.

Benefits to plant composition of using rotational or other specialized grazing systems are cited for many conditions (Holechek et al. 1989, Heitschmidt and Taylor 1991). However, the actual grazing system used seems to have little effect on the total trampling impact (Abdel-Magid et al. 1987, Guthery and Bingham 1996, Holechek et al. 2000). The specific grazing system used (i.e., timing and frequency of grazing) probably would not have great importance in our study area because the streambanks did not dry to the level that could potentially allow seasonal protection from trampling damage. The primary way to control streambank deformation on our sites is apparently to concentrate on controlling the total animal use of streambank areas rather than manipulation of the type of grazing system. Control of livestock activity on streambanks is often easier to accomplish in the spring when livestock prefer the floodplain and upland sites compared to the wetter streamside areas (Siekert et al. 1985, Clary and Booth 1993, Del Curto et al. 2000).

There has been little quantification of the amount of livestock use required to change stream channel and

Table 4. Above-ground current year's growth (g 0.25 m^{-2}) and standard errors (in parentheses), spring 1998 in central Idaho.

Simulation treatment	Graminoid		Forb		Total	
	Streambank	Meadow	Streambank	Meadow	Streambank	Meadow
No grazing	71.83 (6.95)c[1]	80.08 (13.84)a	9.42 (2.23)a	20.92 (5.08)b	81.25 (7.42)c	101.00 (11.89)b
Early summer moderate	42.67 (5.56)b	78.83 (10.03)a	3.91 (1.34)a	7.50 (1.79)a	46.58 (6.23)b	86.33 (9.81)b
Mid-summer moderate	43.25 (4.40)b	69.12 (13.31)a	3.12 (0.44)a	6.62 (1.58)a	46.37 (4.13)b	75.75 (13.08)ab
Season-long heavy	6.45 (2.67)a	45.83 (5.64)a	4.25 (2.71)a	3.66 (1.32)a	10.70 (3.18)a	49.50 (5.17)a

[1] Values followed by different letters within a column are significantly different at the $P < 0.05$ level.

streambank morphology (Trimble and Mendel 1995, Jolley et al. 1997). Treatment levels that have comparatively little effect on meadow plots can literally crush the streambanks at the water's edge. The potential loss of livestock forage supplies and, perhaps more importantly in these narrow streamside zones, fish and wildlife habitat and general channel stability is significant. Although the most severe treatment reduced 1998 above-ground plant biomass production by 87% at the streambank location, the retention of substantial plant growth and the comparatively little change in streambank characteristics under moderate levels of simulated grazing are encouraging. This suggests that careful grazing management can result in harvest of riparian forage without severe environmental impacts. Other studies involving actual grazing tests support this contention (Clary 1999).

Earlier simulation efforts resulted in plant responses similar to that expected from anecdotal accounts and observations (Clary 1995). The sloping of the streambanks and the reduction in plant vigor in the present study also suggest that the simulation of season-long heavy grazing produced an expected result. Data concerning the actual density of hoof prints that occur under differing environmental and management situations are very limited, however. More information on hoof print density and hoof impact is needed to ensure accurate simulation of total grazing impacts.

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