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Vegetation and soil responses to grazing simulation on riparian meadows

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Abstract

Riparian areas have not responded consistently to grazing systems, suggesting that more knowledge is needed to explain how different areas respond to specific stresses. Several studies were conducted to determine herbaceous plant response to simulated grazing on riparian areas. One low-elevation redtop (*Agrostis stolonifera* L.) site in Oregon and 2 high-elevation sedge (*Carex* spp. L.) sites in Idaho were studied for 3 years. Several combinations of defoliation, compaction, nutrient return, and season of use were examined. The redtop community responded to spring, fall, or spring-fall defoliations by maintaining or increasing the following year's aboveground biomass production. The sedge communities maintained or decreased the following years's biomass production after spring, mid summer, or late summer defoliations. An increase in forbs occurred in 1 sedge community following spring defoliations to 1- or 5-cm residual stubble heights. The most consistent plant response among areas was reduction in height growth and biomass production following compaction treatments. When both defoliation and compaction are considered, it appears that spring, fall, or spring and fall grazing to a 5-cm stubble height on the redtop site would not decrease riparian herbage production. In contrast, when defoliation, compaction, and nutrient return effects are considered in the mountain meadow sedge-dominated communities, grazing once annually during the growing season to a 5-cm stubble height in the spring, or to a 10-cm stubble height in late summer, or at a utilization rate exceeding 30% of the total annual biomass production can reduce herbage production significantly. Results suggest that many of the land management agency riparian guidelines would maintain biomass productivity in these sedge-dominated communities.

Key Words: ***Agrostis stolonifera, Carex* spp., *Alopecurus pratensis*, defoliation, compaction, nutrient return**

Riparian areas have reacted erratically to the application of many traditional upland grazing systems (Skovlin 1984, Platts 1991). The lack of consistent results is largely a reflection of the differences in plant species, environmental conditions, and livestock concentrations found in riparian areas. Improved information is needed concerning the response of riparian forage plants to grazing animals if riparian grazing systems are to experience consistent success (Platts and Raleigh 1984).

Grazing animals primarily affect foraging areas by defoliating plants, trampling soil and plants, and excreting wastes that may nourish plants (Heitschmidt 1990, Matches 1992). Reviews by Heitschmidt (1990) and Matches (1992) have pointed out that in mesic grazing lands, plant communities may produce more herbage as a result of some degree of defoliation, while plant communities in arid situations may produce less herbage as a result of almost any amount of defoliation. A major effect of soil compaction by hoof action is reduced macropore space, that 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 is often assumed. Nearly all of the N in urine and feces can be lost to volatilization or leaching (Watson and Lapins 1969, Floate 1970, Woodmansee 1978). The amount recovered in plant tissue may be only 22% (Ball et al. 1979). Perhaps the most complete study of combined defoliation, trampling, and excreta effects was conducted on a perennial ryegrass-white clover (*Lolium perenne* L.-*Trifolium repens* L.) pasture grazed by sheep (Curll and Wilkins 1983). Overall, as stocking rates increased, herbage growth was decreased, since the benefits of increased N transfer were outweighed by the negative effects of trampling and increased intensity of defoliation (Curll and Wilkins 1982, 1983).

Studies of simulated livestock grazing have advantages over studies using livestock; they cost less and require less space, and they provide the opportunity to examine the various individual effects of grazing. 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, there should be less concern in meadow situations where 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 livestock grazing (Bryant et al. 1972), particularly when nutrient return is added. This paper reports 3 different, but related, simulation studies. The objective of these studies was to simulate and evaluate livestock grazing on herbaceous riparian

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meadows including the effects of defoliation, compaction, nutrient return, and season of treatment.

Study Areas

Heavy to very heavy grazing use had occurred for many years previous to fencing of the study areas. Each area had several years of recovery before the treatment sequences were initiated.

Willow Creek Area

This area is located about 16 km north-northwest of Brogan, Ore., along Willow Creek in section 19, T14N, R42E. Elevation of the study area is 927 m. The flow of Willow Creek is controlled by Malheur Reservoir about 6 km upstream; therefore, the area rarely experiences flooding in the spring. The valley is V-shaped with a narrow riparian area. Most of the study quadrats were within 3 m of the streambank. At the time the area was fenced in 1987, the closely grazed vegetation appeared to be predominantly Kentucky bluegrass (*Poa pratensis* L.). Redtop (*Agrostis stolonifera* L.) became the predominant species within 2 years after fencing. The vegetation on the surrounding uplands is typical of the sagebrush (*Artemesia* spp. L.) ecosystem (Garrison et al. 1977).

Soils are formed in mixed alluvial sediments derived from basalt and volcanic ash on benches and terraces. The surface 15 cm of soil is a sandy loam to loamy sand with 10% cobble and gravel. At 15 to 28 cm a cobbly sandy loam to very gravelly loam horizon occurs with 22 to 52% cobble and gravel. Below 51 cm is very gravelly coarse sand overlaying streambed cobble and gravel (Jack R. Wenderoth, Vale District, BLM, Vale, Ore., personal communication 1992).

Annual precipitation at the nearby community of Brogan was 30.4 cm, 18.0 cm, and 18.2 cm for water years 1989, 1990, and 1991, respectively. Mean annual precipitation at Brogan for the period 1987-1993 was 23.4 cm. The nearest reporting weather station, Vale, approximately 48 km south and about 120 m lower in elevation than Brogan, has a long-term average annual precipitation of 24.5 cm. Growing season at Vale averages 139 days, frost to frost.

Valley Creek Area

This area is located about 6 km northwest of Stanley, Ida., along Valley Creek near the border of sections 24, T11N, R12E and 19, T11N, R13E. The elevation is 1,950 m. The area was fenced in 1986 and is representative of the mountain meadows ecosystem containing wet to intermittently wet sites in the forest zone of the mountain West (Garrison et al. 1977). This reach of Valley Creek flows through an open valley. Typical plants at the study site were water sedge (*Carex aquatilis* Wahl.), slenderbeak sedge (*C. athrostachya* Olney), smallwing sedge (*C. microptera* Mack.), meadow foxtail (*Alopecurus pratensis* L.), and thickstem aster (*Aster integrifolius* Nutt.).

Soils are formed in alluvial sediments derived primarily from granite. The upper 11 cm has a loam texture with very high organic matter. From 11 to 27 cm is a silty loam, and from 27 to 58 cm is a very gravelly loamy sand with 45% gravel. Below 58 cm are stones and small boulders in free water (David R. Gilman, Sawtooth National Forest, Twin Falls, Ida., personal communication 1992).

Annual precipitation at the nearby community of Stanley was 31.4, 39.3, 32.6, and 28.7 cm for water years 1989 through 1992, respectively. The long-term average annual precipitation is 42.7 cm. Growing season at Stanley averages 12 days, frost to frost.

Stanley Creek Area

This area is located about 6 km northwest of Stanley along Stanley Creek in portions of section 29, T11N, R13E. The elevation is 1,950 m. The area was fenced in 1987. At the site of the experimental area, Stanley Creek flows through a broad, flat valley characterized by mountain meadows. Typical plants at the study area included water sedge, slenderbeak sedge, shortbeak sedge (*Carex simulata* Mack.), and Wolf's willow (*Salix wolfii* Bebb).

Soils are formed in alluvium and lacustrine sediments derived from granite. They have moderately rapid permeability. The upper 38 cm is typically a gravelly loam with 25% cobbles. Immediately below is a gravelly sandy clay loam with 30% cobbles (David R. Gilman, Sawtooth National Forest, Twin Falls, Ida., personal communication 1991).

Annual precipitation and temperature regimes are similar to nearby Valley Creek.

Methods

Willow Creek Area

Forty-eight 1-m² quadrats were established along Willow Creek in a completely randomized block design in the fall of 1988. The objective at Willow Creek was to study the effects of defoliation height (DH), soil compaction (C), and season of treatment (S) on herbaceous riparian vegetation height growth and biomass production, and on soil strength and compression. Seasons of defoliation and compaction treatments were spring (May), fall (September), and spring and fall. Phenological stages for the predominant species, redtop, were "vegetative" in May and "seed mature" in September. Treatments were applied from the fall of 1988 through the spring of 1991. All combinations of defoliation, compaction, and season were represented in the study. Each treatment combination had 2 replications. Plots assigned to either spring or fall treatments were defoliated and/or compacted once each year; those assigned to spring-fall treatments were subjected to defoliation and/or compaction twice each year. The mechanical defoliation treatments consisted of no defoliation (i.e., control), and defoliation to 10-cm, 5-cm, and 1-cm stubble heights. The compaction treatments consisted of compaction and no compaction. The soil was compacted by dropping a 14 kg steel impactor from a height of about 75 cm. The impact surface area was 100 cm². This procedure appeared to duplicate the impression depth of the hoof print of a mature cow. Each compacted quadrat was completely covered by impacts since typical stocking rates of 2+ aum/ha should result in an average trampling of 1 "m²/m²" (Scholl 1989). Observations of typical heavily grazed riparian areas show the entire area covered with hoof impacts. An area is normally covered several times over with hoof impacts in very heavily grazed areas. On upland sites it has been shown that cattle tend to step between grass plants with a tussock growth form (Balph and Malechek 1985). Results of Balph et al. (1989) show that as bunchgrass tussocks become shorter, cattle are more likely to step on them. On heavily grazed riparian areas with their characteristic sod-forming vegetation composition, the plants appear to be subjected to direct trampling that would not only compact the soil, but may also subject plant crowns to compression injury.

Standing crop of current green biomass was estimated by a disk meter (Karl and Nicholson 1987) in the fall of 1989 and 1990. The meter readings were calibrated to local vegetation conditions annually by selecting temporary plots with a range of biomass and determining the relationship between vegetation dry weight and disk meter reading. Twelve to 15 samples were utilized to calibrate the disk meter for each situation annually. A complete harvest of all dry matter, both current growth and litter, from the center 1/4 of the plots was conducted in the fall of 1991. All biomass measurements, therefore, occurred 12 months after fall treatments and 4 months after spring treatments. Average graminoid and forb heights were measured at the time of final harvest.

Soil strength was determined with a pocket penetrometer in the fall of 1989 and 1991. This method has been correlated with unconfined compressive strength of soil, and it is useful in comparing relative strengths and zones of compaction among similar soil types (Bradford 1986). Soil strength was measured in 2 opposing corners of the quadrats and averaged. The corners were selected to best represent mineral soil, that is, soil surface not covered by heavy litter or duff, or rock. Measurements of soil surface elevation was made from a reference device placed over 2 heavy stakes located on opposing corners of each quadrat. Three measurements from the reference bar over the 0.25-m² harvest area were taken before and after each treatment episode.

Valley and Stanley Creek Areas

Two sets of 32, 1-m² quadrats were established along Valley Creek in completely randomized block designs during the fall of 1989. The study continued through 1992. The objective was to investigate the effects of defoliation, soil compaction, nutrient return (NR), and season of treatment on herbaceous riparian vegetation. The treatments of defoliation and soil compaction were similar to those described for Willow Creek. Manure and urea solution were added to designated plots to approximate the nutrient return by grazing animals. Fifty-five g of dry current year's manure and 1 g of urea in 1 L of water were applied to the designated quadrats. The amounts applied were based on local production and consumption estimates, and on generalized values from Tiedemann et al. (1986).

All treatments were applied to 1 set of quadrats in spring (June) and to the other set in late summer (late August-early September). The phenological stages of the predominant sedges were "partially headed" in June and "seed mature" in late August-early September. Each plot received one treatment or treatment combination annually. Measures of treatment response were similar to those for Willow Creek apart from: 1) biomass production was expressed as seasonal standing crop except that final harvest in 1992 allowed percentage removed in 1992 to be calculated on total annual biomass production, and 2) measurements of soil surface level were not taken. All combinations of defoliation, compaction, and nutrient return were represented within seasons. Each treatment combination had 2 replications per season.

Twelve 0.25-m² quadrats were established along Stanley Creek in a completely randomized block design in the summer of 1989. The objective was to study the effects of defoliation during the first week of August on herbaceous riparian vegetation. Phenological stage of predominant sedges was "seed mature." The treatments were no defoliation, and defoliation to 10-cm, 5-cm, and 1-cm stubble heights. Each plot was subjected to a single defoliation annually. Each treatment had 3 replications. Average plant height was measured annually at the time of treatment. The dry weight of vegetation removed by each defoliation was determined. Complete harvest of the center 1/4 of each plot was completed in October 1991 to determine the defoliation effects on biomass production.

A summary of the treatment and measurement schedule for the 3 study areas is found in Table 1.

Analysis

Statistical analysis was by analysis of variance utilizing a General Linear Model. Significant differences among 3 or more means were identified by the use of a protected Fisher's LSD. All differences reported were signicant at $P < 0.10$.

Table 1. Annual treatment and measurement schedule for 3 years of study.

	Dates of activity		
	Annual treatment	Annual measurement	Final measurement
Willow Creek	Spring	Fall	Fall
	Fall	Fall	Fall
	Spring-Fall	Fall	Fall
Valley Creek	Spring	Spring	Late summer
	Late summer	Late summer	Late summer
Stanley Creek	Mid summer	Mid summer	Fall

Results

Willow Creek Area

Height Response

Compaction (C) reduced graminoid height growth by an average of 10.3% (Table 2), however, an interaction between compaction and season ($P = 0.004$) suggested graminoid height growth was reduced more from spring or spring and fall compaction than by fall compaction. The average reduction in graminoid height growth following spring or spring and fall treatments only was 19.8% (39.4 vs. 48.8 cm). No main effect of defoliation height (DH) or season (S) was apparent. Forb heights for defoliation treatments averaged only 51.4% of the control treatment heights (Table 2).

Biomass Response

Annual biomass production was related to DH, C, and year (Y) (P = 0.048, 0.003, <0.001, respectively). The 5-cm defoliation treatment produced more annual biomass than the control or the 1-cm defoliation treatment; the 10-cm defoliation treatment produced more biomass than the control (Fig. 1). None of the defoliation treatments decreased production, even though foliage removal was up to 90% of the total annual growth (Fig. 1, Table 2). Compaction reduced production by an average of 13.8% (122.2 vs. 141.7 g/0.25 m²), but a strong interaction with season occurred ($P = 0.009$) wherein the primary compaction effect occurred in the spring. Spring and spring-fall compaction treatments reduced annual biomass production an average of 22.2% (114.7 vs. 147.4 g/0.25 m²). Average annual production of all treatments declined through the study period (175.3 down to 98.9 g/0.25 m²) as drought conditions became more severe and streamflow releases from the upstream reservoir decreased. Total standing crop biomass (including litter) at final harvest was significantly related only to DH ($P = 0.076$). The primary cause of the differences in total biomass was the variation in dead biomass (previous years' foliage and litter) ($P < 0.001$). The 1-cm and 5-

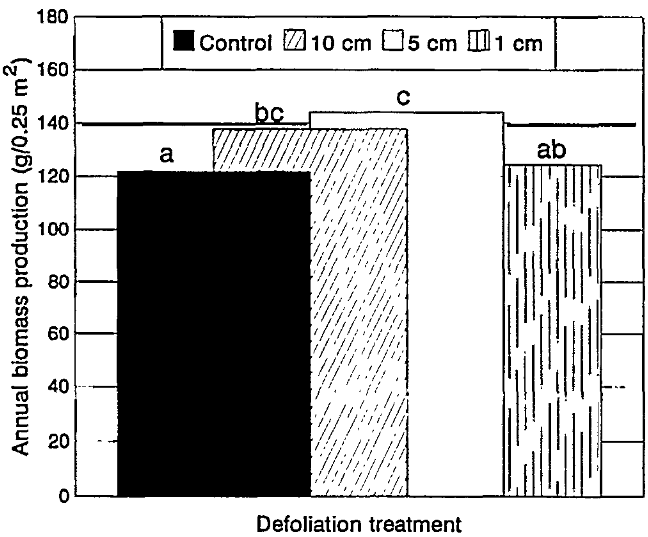

Fig. 1 Effect of defoliation to different stubble heights on annual biomass production at Willow Creek. Treatments with different letters are different at $P < 0.10$.

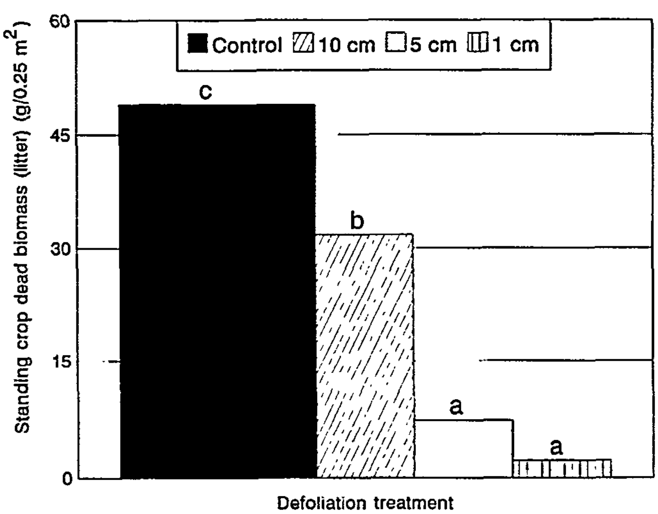

Fig. 2. Effect of defoliation to different stubble heights on the standing crop of dead biomass (litter) at Willow Creek. Treatments with different letters are different at $P < 0.10$.

cm treatments had little dead foliage and litter present (Fig. 2).

Botanical Composition

Redtop dominated all treatments throughout the study. The forb components included slender bird's-foot trefoil (*Lotus tenuis* Wadst. & Kit. ex Willd.), thistle (*Cirsium* spp. Mill.), meadow goldenrod (*Solidago canadensis* L.), and field horsetail (*Equisetum arvense* L.). Little relationship was apparent between treatment and individual forb species, except that slender bird's-foot trefoil appeared only on quadrats defoliated during the spring or during spring and fall. The mean proportion of forbs in the total biomass composition was 18.8%. No significant differences were found among treatments.

Soil Response

Compaction increased soil compressive strength by an average of 59.2% (Table 2). An interaction of C x S occurred ($P = 0.074$), reflecting a greater effect of the spring and fall compaction treatment as compared to the individual spring or fall treatments. The greatest soil strength was measured in the final year of treatment (Table 2). The compaction treatment also changed the elevation of the soil surface ($P = 0.001$). The control quadrats were appar-

Table 2. Various 1991 measures on the Willow Creek quadrats.

Treatment	Heights		Graminoid biomass Removed by defoliation			Soil
comparisons	Graminoids	Forbs	Spring	Fall	Sp/fall	strength
	-------cm-------			-----------%----------		-kg/cm²-
Defoliation						
Control	45.4	60.9b[1]	--	--	--	2.01
10 cm	43.8	31.9a	15.1	46.7a	33.7a	1.93
5 cm	45.8	28.3a	22.6	62.4b	68.2b	1.98
1 cm	42.1	33.8a	23.4	73.5b	90.8c	2.22
P[2]	NS	0.002	NS	0.039	<0.003	NS
Compaction						
No	46.7	43.3	21.5	62.5	60.5	1.57
Yes	41.9	34.1	19.2	59.2	67.9	2.50
P	0.027[3]	NS	NS	NS	NS	<0.001
Season						
Spring	42.2	40.9	20.4	--	--	2.00
Fall	44.7	38.1	--	60.9	--	1.90
Spring and fall	45.9	37.1	--	--	64.2	2.20
P	NS[3]	NS	--	--	--	NS
Year						
1991	--	--	--	--	--	2.46
1989	--	--	--	--	--	1.61
P	--	--	--	--	--	<0.001

[1] Means within treatments followed by different letters are different at $P < 0.10$.
[2] Probability of random differences within the treatment comparisons.
[3] Interaction occurred between compaction and season. Primary reduction of graminoid height growth occurred following spring or spring-fall treatments.

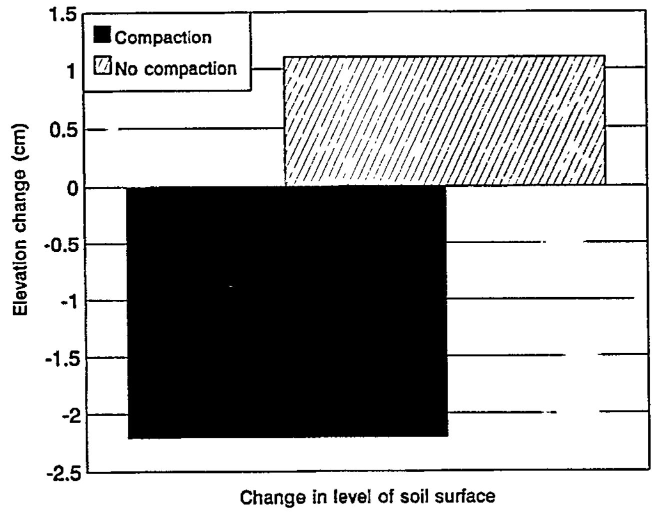

Fig. 3. Effect of compaction from 1988 to 1991 on soil surface elevation at Willow Creek.

ently still recovering from previous grazing impacts; the soil surface level rose more than 1 cm during the 3 years of study (Fig. 3). In contrast, soil surface of the compacted quadrats was lowered more than 2 cm.

Valley Creek Area

Height Response.

Graminoid height growth was reduced by both defoliation and compaction (Table 3). Perhaps the most important finding was the interaction among late summer DH and C treatments (P = 0.016); and by a similar, but nonsignificant, trend among spring treatments. Severe defoliation or compaction reduced height growth to a similar level, but the application of both treatments simultaneously did not increase the total effect. The effects were, therefore, not additive.

Biomass Response

Defoliation and C affected the following year's biomass (Table 3). An interaction of DH x C occurred for spring treatments (P = 0.064), and a similar nonsignificant trend occurred for late summer treatments. In these cases severe defoliation or compaction reduced biomass production to a similar level within seasons, however, the combination of both treatments did not reduce biomass production further–a strong nonadditive effect. Defoliation treatments that removed greater than 30% of the annual biomass production reduced the following year's biomass production below that of the control (Table 3). Compaction reduced the following year's standing crop biomass an average of 7.1 (spring) to 11.3% (late summer). Nutrient return in late summer increased the following year's biomass by 9.9%, but NR on spring plots showed no response (Table 3). A possible reason is that nutrients from the spring application can be used during the remainder of the growing season, after plant measurements are made; therefore, they would be less available for the following spring's growth. Nutrients from the late summer application would be potentially more available for the following growing season.

Graminoid biomass regrowth that occurred between the 1992 spring treatment and the final harvest in late summer 1992 was directly related only to the compaction treatment. Compaction reduced regrowth from 17.6 to 7.2 g/0.25 m2 (P < 0.001). No significant differences occurred in the amount of forb regrowth.

Botanical Composition

All of the quadrats were dominated by graminoids throughout the study. Twenty-nine spring treatment quadrats were dominated by sedges and 3 by meadow foxtail. Twenty-five late summer

Table 3. Various measures on the Valley Creek quadrats.

Treatment	Graminoid height		Standing crop live biomass		Graininoid biomass harvested 1992		Soil strength	
Comparisons	Spring	Lt sum	Spring	Lt sum	Spring	Lt sum	Spring	Lt sum
	-----cm-----		--g/0.25 m²--		-------%-------		---kg/cm²---	
Defoliation								
Control	20.6d[1]	27.9b	44.8b	74.2c	--	--	1.42	1.88
10 cm	18.9c	22.8a	42.8ab	66.4b	19.2a	32.7a	1.57	1.94
5 cm	16.8b	22.1a	41.3a	62.0ab	39.0b	55.3b	1.44	1.80
1 cm	14.0a	21.8a	40.1a	60.5a	54.1c	74.7c	1.56	2.15
P[2]	<0.001	0.001[3]	0.032[3]	<0.001	<0.001	<0.001	NS	NS
Compaction								
No	19.3	25.8	43.8	69.7	37.7	47.0	1.46	1.77
Yes	15.8	22.0	40.7	61.8	37.2	34.4	1.53	2.11
P	<0.001	0.001[3]	0.009[3]	0.001	NS	<0.001	NS	0.004
Nutrient return								
No	17.8	23.5	42.5	62.7	36.2	40.8	1.53	1.86
Yes	17.3	24.3	42.0	68.9	38.7	40.6	1.46	2.02
P	NS	NS	NS	0.010	NS	NS	NS	NS
Year								
92	18.1	22.2	44.6b	62.9a	--	--	1.95c	2.32b
91	17.0	25.6	34.1a	65.3ab	--	--	1.44b	1.79a
90	--	--	48.1c	69.1b	--	--	1.10a	1.72a
	NS	0.002	<0.001	0.094	--	--	<0.001	<0.001

[1] Means within treatments followed by different letters are different at P < 0.10.
[2] Probability of random differences within the treatment comparisons.
[3] Interaction occurred between defoliation height and compaction. The individual effects did not appear to be additive.

treatment quadrats were dominated by sedges, 6 by meadow foxtail, and 1 by Kentucky bluegrass. The second most abundant species, spring or late summer treatments, was usually meadow foxtail or Kentucky bluegrass. The third most abundant plant was often a forb—typically thickstem aster. The proportion of forbs in the total biomass composition averaged 17%, and was significantly related only to to the spring DH treatment ($P = 0.076$). The proportion of forbs in the 5-cm and 1-cm DH treatments was about 10% higher than the control.

Soil Strength

Soil compressive strength or resistance to penetration was significantly related only to Y (year) and to late summer C; although spring C produced a similar trend (Table 3). The highest values of soil strength were associated the driest year of the study.

Stanley Creek Area

Height Response

Midsummer height growth was affected by the 2 previous years of defoliation that removed 29-75% of the annual biomass production ($P < 0.001$) (Fig. 4). Graminoid height growth for the control and the 10-cm stubble height treatment were similar. In contrast, the 5-cm and the 1-cm stubble height treatments had reduced height growth. Plants subjected to the most severe defoliation (1-cm stubble height) had a height growth reduction of 42% in 1991 compared to 1989.

Biomass Response

Biomass was less responsive to the defoliation treatments than was height. After 3 treatment cycles only the 1-cm stubble height treatment had significantly reduced total annual production of herbage (Table 4). The reduced vigor in the 1-cm treatment resulted in no more foliage harvested than in the 5-cm treatment. This suggests no forage harvest benefit from continued severe grazing. As would be expected, the residual fall herbage was vastly different among treatments because of the limited regrowth on the defoliated quadrats (Table 4).

Discussion

The results of the different phases of this investigation demonstrate, in part, why riparian grazing approaches often seem to have inconsistent results. Different riparian areas respond differently. A growth response to grazing, as suggested by Tierney (1992) and reported by Bryant (1985), appears to have occurred in the redtop community on a site with a long growing-season, but not in the sedge-dominated communities in high mountain meadows sites where the growing season is short.

Table 4. Various 1991 measures on the Stanley Creek summer defoliated quadrats.

Treatment comparisons	Total biomass production	Biomass harvested	Fall biomass residual
	g/0.25 m²		
Defoliation			
Control	32.0b[1]	0.0a	32.0c
10 cm	28.2b	8.2b	20.0b
5 cm	29.5b	14.9c	14.6b
1 cm	18.2a	13.7c	4.5a
P[2]	0.094	<0.001	0.001

[1] Means within treatments followed by different letters are different at $P < 0.10$.
[2] Probability of random differences within the treatment comparisons.

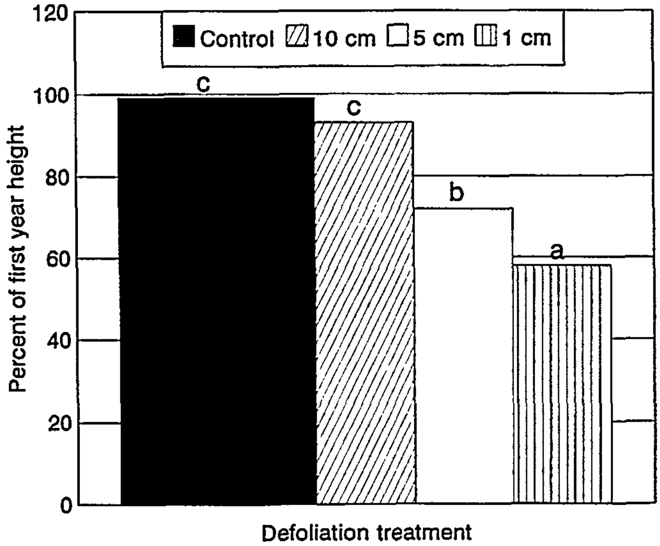

Fig. 4. Response to stubble height defoliation by graminoid plant height growth in 1991 at Stanley Creek. Treatments with different letters are different at $P < 0.10$.

It is not clear why the sites responded differently to defoliation since the average proportion of foliage removed was similar. The positive response to defoliation by the redtop plant community may have been a combination of tolerance to grazing (Raven 1986), reduction in litter buildup (Volland 1978, Branson 1985, Oesterheld and McNaughton 1991), longer growing season, or the lack of defoliation during the "boot" stage (Miller et al. 1990). In some cases redtop has been shown to decline in the absence of grazing, although this was apparently a result of increased competition from other plant species (Pehrsson 1988). Maschinski and Whitham (1989) concluded that compensatory plant response to defoliation varied with competition, nutrient levels, and timing of herbivory. Although Belsky (1987) seriously questioned the expression of overcompensation, or growth response to defoliation, she concluded that moderately grazed wetlands were the most likely situation for this to occur, assuming compaction was not severe.

Little information is available on the response to grazing by sedge species on high-elevation sites. Most of these species are assumed to be relatively resistant to grazing because of their rhizomatous growth habit (Hansen et al. 1988) although results have varied. Nebraska sedge (*Carex nebrascensis* Dewey) reduced spring height growth, but not shoot densities, following the previous summer's 64% utilization rate (Ratliff and Westfall 1987). One year after shorthair sedge (*Carex exserta* Mackenzie), shorthair reedgrass (*Calamagrostis breweri* Thurb.), and rock sedge (*Carex scopulorum* T.H. Holm) were defoliated, total root nonstructural carbohydrates were reduced by 20 to 40% (Debenedetti 1980). In contrast, grazing removal of 15 to 25% (June) and 41 to 44% (Sept.) of beaked sedge (*Carex rostrata* ex With.) shoot height for 2 years resulted in increased shoot density and no effect on shoot productivity (Allen and Marlow 1994). In the present study there appeared to be decreased height growth and biomass production by the sedge-dominated community in response to some of the 10-cm treatments, most of the 5-cm treatments, and all of the 1-cm defoliation treatments. This occurred even though the litter buildup on the mountain meadows was similar to that on Willow Creek. There was no indication that treatment in spring or mid summer was more detrimental than late summer treatment, at least when defoliating to stubble-height criteria. Although plants are often potentially more susceptible to defoliation in the spring particularly at the "boot" phenological stage (McLean and Wikeen 1985, Miller et al. 1990), a stubble-height removal results in a lower percent defoliation in the spring when plants have not reached full stature, than in the fall when plants are fully grown.

A relatively consistent effect among the sites was the reduction of plant growth by compaction. The reduction of height growth and biomass production at Willow Creek and Valley Creek averaged 12-13% when the quadrats were compacted annually. Bryant et al. (1972) found an 8 to 50+% reduction in Kentucky bluegrass yields after trampling treatments by mature cattle. The approximation of animal nutrient return on Stanley Creek suggested an increase in biomass production of about 10% in response to the late summer treatment. This was substantially less than that measured by Curll and Wilkins (1983) under intensive sheep grazing of a grass-clover sward.

An increase in the proportion of forbs in the composition only occurred on 1 sedge-dominated site. This followed spring defoliation treatments to 1- or 5-cm residual stubble heights. Additional changes may have appeared if the study had been longer, as 3 years is a short period for successional change. In wet meadows most changes in species composition apparently occur from grazing-induced changes in meadow hydrology and lowering of the water table rather than from defoliation or compaction (Bartolome 1984).

In recent years land management agencies have established a variety of forage utilization standards or guidelines for riparian areas. These typically include residual stubble height or utilization by weight criteria (Table 5). Grazing simulation studies described here suggest that all of the listed agency guidelines would be adequate to maintain the vigor of herbaceous riparian communities dominated by plants, such as redtop, adapted to disturbance. Our results infer that redtop will maintain vigor under defoliation to a 5-cm stubble height and the associated trampling compaction. In contrast, our results from mountain meadow communities indicate that defoliation to a 5-cm stubble height with the associated trampling damage and nutrient return will often reduce future sedge biomass production and may allow a greater proportion of forbs in the plant community composition. It appeared that a 10-cm or greater stubble height may be required to insure full biomass production in these high-elevation, sedge-dominated communities. If utilization guidelines are used, those

Table 5. Several land management agency riparian grazing utilization standards and guidelines.

Criteria	Where applied	Information source
Residual stubble height of herbaceous forage		
10 to 20 cm	Streams important to threatened and endangered fish species	BLM, Idaho, Erv Cowley, personal communication, 1994
10 to 15 cm	Carex communities in mountain riparian areas	USFS Region 2, Rangeland Ecosystem Inventory and Management Guide, 1994
10 to 15 cm	Highly sensitive riparian areas in unsatisfactory condition	USFS, Upper Ruby Final EIS, Beaverhead NF, Montana, 1992
5 to 8 cm	Relatively stable riparian areas in satisfactory condition	ditto
10 to 15 cm	Seasonlong riparian grazing	USFS, Region 4, Desk Guide, 1993; and Clary and Webster (1989)
10 cm	Rotation riparian grazing	USFS, Region 4, Desk Guide, 1993
Percentage utilization by weight of herbaceous forage		
30%	Riparian areas not meeting Sawtooth FLRMP[1] standards	USFS, Stanley Basin Final EIS, Sawtooth NF, Idaho, 1993
40 to 50%	Riparian areas meeting Sawtooth FLRMP standards	ditto
25%	Primary chinook salmon production areas	USFS, Bear Valley and Elk Creek, Biological Opinion, Boise NF, Idaho, 1993
45 to 60%	Rotation grazing systems	USFS, Land Resource and Management Plan, Boise NF, 1990
30 to 55%	Seasonlong grazing	USFS, Region 4, Desk Guide, 1993
50 to 65%	Rotation grazing	ditto

[1]Forest Land Resource Management Plans

rates that do not exceed 30% of the annual biomass production will likely maintain production the following year. Therefore, the majority of land management agencies' riparian (streamside) residual stubble height grazing recommendations in Table 5 appear to be adequate for maintenance of biomass production in our mountain meadow sedge-dominated communities. Some of the percentage utilization criteria, however, may be too liberal to maintain full productivity on high elevation sites, based on our Valley Creek data. The specific recommendations listed here, however, do not address the issues of streambank stability and channel maintenance.

Literature Cited

Allen, D.R., and C.B. Marlow. 1994. Shoot population dynamics of beaked sedge following cattle grazing. J. Range Manage. 47:64-69.

Balph, D.F., M.H. Balph, and J.C. Malechek. 1989. Cues cattle use to avoid stepping on crested wheatgrass tussocks. J. Range Manage. 42:376-377.

Balph, D.F., and J.C. Malechek. 1985. Cattle trampling of crested wheatgrass under short-duration grazing. J. Range Manage. 38:226-227.

Ball, R., D.R. Keeney, P.W. Theobald, and P. Nes. 1979. Nitrogen balance in urine-affected areas of a New Zealand pasture. Agron. J. 71:309-314.

Bartolome, J.W. 1984. Impacts of grazing intensity and grazing systems on vegetation composition and production, p. 917-925. *In:* Developing strategies for rangeland management. Westview Press, Boulder, Colo.

Belsky, A.J. 1987. The effects of grazing: confounding of ecosystem, community, and organism scales. Amer. Nat. 129:777-783.

Bradford, J.M. 1986. Penetrability, p. 463-478. *In:* A. Klute (ed.), Methods of soil analysis, part 1. Mongr. 9. Amer. Soc. Agron., Madison, Wisc.

Branson, F.A. 1985. Vegetation changes on western rangelands. Range Monogr. 2. Soc. for Range Manage., Denver, Colo.

Bryant, H.T., R.E. Blaser, and J.R. Peterson. 1972. Effect of trampling by cattle on bluegrass yield and soil compaction of a Meadowville loam. Agron. J. 64:331-334.

Bryant, L.D. 1985. Livestock management in the riparian ecosystem, p.285-289. *In:* R.R. Johnson, C.D. Ziebell, D.R. Patton, P.F. Ffolliott, R.H. Hamre (tech. coords.), Riparian ecosystems and their management: Reconciling conflicting uses: First North American Riparian Conference. USDA, Forest Serv., Gen. Tech. Rep. RM-120.

Clary, W.P., and B.F. Webster. 1989. Managing grazing of riparian areas in the Intermountain Region. USDA Forest Serv. Gen. Tech. Rep. INT-263. Intermountain Res. Sta., Ogden, Ut.

Currl (Curll), M.L., and R.J. Wilkins. 1982. Effects of treading and the return of excreta on a perennial ryegrass-white clover sward defoliated by continuously grazing sheep, p. 456-458. *In:* J.A. Smith and V.W. Hays (eds.), Proceedings 14th International Grasslands Congress. Westview Press, Boulder, Colo.

Curll, M.L., and R.J. Wilkins. 1983. The comparative effects of defoliation, treading and excreta on a *Lolium perenne-Trifolium repens* pasture grazed by sheep. J. Agr. Sci. Camb. 100:451-460.

Debenedetti, S.H. 1980. Response of subalpine meadow communities of the southern Sierra Nevada, California, to four clipping regimes. *In:* 33d annual meeting abstracts and position statements. Society for Range Management. p. 29.

Floate, M.J.S. 1970. Decomposition of organic materials from hill soils and pastures: II. Comparative studies on the mineralization of carbon, nitrogen and phosphorus from plant materials and sheep faeces. Soil Biol. Biochem. 2:173-185.

Garrison, G.A., A.J. Bjugstad, D.A. Duncan, M.E. Lewis, and D.R. Smith. 1977. Vegetation and environmental features of forest and range ecosystems. USDA, Agr. Handb. 475.

Hansen, P.L., S.W. Chadde, and R.D. Pfister. 1988. Riparian dominance types of Montana. Misc. Publ. 49. Montana For. and Conserv. Exper. Sta., Missoula, Mont.

Heitschmidt, R.K. 1990. The role of livestock and other herbivores in improving rangeland vegetation. Rangelands 12:112-115.

Karl, M.G., and R.A. Nicholson. 1987. Evaluation of the forage-disk method in mixed-grass rangelands of Kansas. J. Range Manage. 40:467-471.

Lull, H.W. 1959. Soil compaction on forest and range lands. USDA, Forest Serv, Misc. Publ. 768.

Maschinski, J., and T.G. Whitham. 1989. The continuum of plant responses to herbivory: the influence of plant association, nutrient availability, and timing. Amer. Nat. 134:1-19.

Matches, A.G. 1992. Plant response to grazing: a review. J. Prod. Agr. 5:1-7.

McLean, A., and S. Wikeen. 1985. Rough fescue response to season and intensity of defoliation. J. Range Manage. 38:100-103.

Miller, R.F., M.R. Haferkamp, and R.F. Angell. 1990. Clipping date effects on soil water and regrowth in crested wheatgrass. J. Range Manage. 43:253-257.

Oesterheld, M., and S.J. McNaughton. 1991. Effect of stress and time for recovery on the amount of compensatory growth after grazing. Oecologia 85:305-313.

Pehrsson, O. 1988. Effects of grazing and inundation on pasture quality and seed production in a salt marsh. Vegetatio 74:113-124.

Platts, W.S. 1991. Livestock grazing, p. 389-423. *In:* W.R. Meehan (ed.), Influences of forest and rangeland management on salmonid fishes and their habitats. Amer. Fish. Soc. Spec. Pub. 19. Bethesda, Md.

Platts, W.S., and R.F. Raleigh. 1984. Impacts of grazing on wetlands and riparian habitat, p. 1105-1117. *In:* Developing strategies for rangeland management. Westview Press, Boulder, Colo.

Ratliff, R.D., and S.E. Westfall. 1987. Dry-year grazing and Nebraska sedge (*Carex nebraskensis*). Great Basin Nat. 47:422-426.

Raven, P.J. 1986. Vegetation changes within the flood relief stage of two-stage channels excavated along a small rural clay river. J. Appl. Ecol. 23:1001-1011.

Scholl, D.G. 1989. Soil compaction from cattle trampling on a semiarid watershed in northwest New Mexico. New Mexico J. Sci. 29:105-112.

Skovlin, J.M. 1984. Impacts of grazing on wetlands and riparian habitat: a review of our knowledge, p. 1001-1103. *In:* Developing strategies for rangeland management. Westview Press, Boulder, Colo.

Stroud, D.O., R.H. Hart, M.J. Samuel, and J.D. Rodgers. 1985. Western wheatgrass responses to simulated grazing. J. Range Manage. 38:103-108.

Tiedemann, A.R., H.R. Sanderson, and N.J. Cimon. 1986. Future site productivity considerations of short-duration, high-intensity grazing, p. 137-144, *In:* J.A. Tiedeman (ed.), Short duration grazing. Proceedings of the short duration grazing and current issues in grazing management shortcourse. Coop. Ext. Serv., Wash. State Univ., Pullman.

Tierney, R.W. 1992. Transpiration and water use in a montane riparian ecosystem. Ph.D. Diss. Colo. State Univ.

Volland, L.A. 1978. Trends in standing crop and species composition of a rested Kentucky bluegrass meadow over an 11-year period, p. 526-529. *In:* D.N. Hyder (ed.), Proceedings of the First International Rangeland Congress. Soc. Range Manage., Denver.

Wallace, L.L. 1990. Comparative photosynthetic responses of big bluestem to clipping versus grazing. J. Range Manage. 43:58-61.

Watson, E.R., and P. Lapins. 1969. Losses of nitrogen from urine on soils from south-western Australia. Aust. J. Exp. Agr. and Anim. Husb. 9:85-91.

Woodmansee, R.G. 1978. Additions and losses of nitrogen in grassland ecosystems. BioScience 28:448-453.