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Effect of Fertilizer Applications and Grazing Exclusion on Species Composition and Biomass in Wet Meadow Restoration in Eastern Washington

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Erratum added 7/23/02

Erratum

This erratum updates the address of the senior author, John Beebe. The correct address in Massachusetts is indicated below.

Authors

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Abstract

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Fertilizer applications and grazing exclusion were used as restoration strategies in degraded wet meadows in eastern Washington to grow biomass in the root systems where it could not be grazed. We used a split-block design to test vegetation responses to six fertilizer rates, eight fertilizer types, and three grazing treatments after three growing seasons. Little change in plant composition was detected, but weed biomass was reduced by 50 percent in cattle plus elk grazing. Although forb shoot biomass did not increase, grass shoot biomass doubled but was influenced by grazing treatments. Root biomass doubled under fertilizer applications. A 10-percent decline in soil bulk density suggested a reduction in soil compaction. These responses were attributed to the increased root biomass. Optimum fertilization rates of 100 kg/ha were recommended along with carefully administered grazing schedules for meadow community restoration.

Keywords: Meadow restoration, grazing treatments, soil bulk density, root biomass, weed reduction, plant composition.

Summary

Many meadows on the east slopes of the Cascade Range in Washington are being overused. This is thought to be causing shifts in plant communities to early-succession stages or infestations of introduced species (weeds). We used treatment combinations of grazing exclusion and fertilizer applications of varying rates and mixtures to document changes in plant communities, to evaluate shoot and root biomass, and to examine effects on soil properties in four east-slope meadow areas near Yakima, Washington.

There were no clear changes in plant community composition associated with any treatment combinations for the period of the study. Grazing treatments appeared to affect as much as a 55-percent decline in nonnative plant species. Grass shoot biomass increased by 400 kg/ha in no-grazing treatment. For forb biomass, there were no clear patterns of fertilizer or grazing effects. Root biomass doubled to an average of 90 $\mu g/cm^2$ with fertilizer treatments after three seasons. Soil compaction increased by 19 percent in cattle grazing treatments but decreased by 8 percent where only elk grazed. Water well depths increased, but this could not clearly be attributed to effects of the treatment.

For the meadows in this study, we conclude that no particular mix or rate of fertilizer contributed to plant community changes or to shoot biomass accumulations. Root biomass, however, clearly improved overall treatment types and levels. We saw some evidence that nonnative (weed) to native plant ratios can be reduced by limited grazing activity. When livestock grazing was restricted, soil compaction was reduced slightly. We believe that selected application of fertilizer and limited grazing prescriptions can contribute to an improvement of meadowlike conditions in similar east-slope meadow areas.

Introduction

Meadows and associated riparian areas provide a stable boundary between aquatic and terrestrial ecosystems. Terrestrial meadow species and processes can be degraded through excessive grazing pressure that alters plant composition, reduces plant vigor and productivity, reduces surface litter, lowers soil fertility, and creates less favorable soil water regimes (Kauffman and Krueger 1984, Roath and Krueger 1982, Schulz and Leininger 1990, Skovlin 1984).

Damage to riparian zones by cattle grazing on public lands has been identified as the critical conflict between wildlife and livestock (Clary 1995), and grazing is suggested as the single greatest threat to trout and wildlife habitat in the Western United States (Platts 1981). Increased forage demand by expanding elk herds in conjunction with continued livestock grazing seems to be degrading riparian and meadow vegetation and soil resources. Preliminary investigations indicate that many meadows on the east slopes of the Cascade Range in Washington are being overused, which is causing shifts in plant communities to early-succession stages or introduced species.

Bayoumi and Smith (1976) and Basile (1970) have suggested fertilization of big game ranges to provide increased or more nutritious forage for wildlife and livestock (Wikeem et al. 1993). Increased forage production for wildlife and livestock may be a side benefit from this research, but our main focus is the restoration of the plant, soil, and water components of the meadow ecosystem. The use of fertilizers is basic to the trend from extensive to intensive forage management, and there is a high probability of significant plant response on moist meadow sites (Vallentine 1977). Work by Kie and Myler (1987) suggests that phosphorous fertilization could benefit meadow restoration in the Sierra Nevada of California, but only one level of one type of fertilizer was tested.

Grazing animals remove protective plant material and compact surface soil layers, thereby reducing infiltration rates and soil water status (Branson et al. 1981). Schulz and Leininger (1990) found two times the litter cover and one-quarter the amount of bare ground inside exclosures on grazed meadows. Bulk densities of forest and rangeland soils on heavily grazed areas are about 1.2 times that of ungrazed areas (Lull 1959, Read 1957). Clary (1992) found the surface of compacted riparian soils rapidly decreased in bulk density with the removal of grazing animals.

The purpose of this study was to assess plant biomass and soil characteristics to treatments of reduced grazing pressure and fertilizer applications on degraded meadows in eastern Washington. Specific objectives were to (1) document changes in plant community composition, species richness, species evenness in response to ungrazed, cattle and elk-grazed, and elk-only grazed areas and response to fertilizer application; (2) assess shoot and root biomass response to fertilizer type and rates and by grazing level; (3) determine if soil compaction was reduced, and (4) evaluate soil-water status in grazing treatments and among fertilizer applications.

Methods

Site

The study sites are four separate riparian moist meadows in the Rimrock Lake basin of the Naches Ranger District of the Wenatchee National Forest on the east slopes of the Cascade Range in the state of Washington (table 1, fig. 1.) The sites are representative of a general population of such meadows in this region.

Table 1—Selected site characteristics for Naches meadows sites

Site	Latitude	Longitude	Elevation	Slope	Aspect	P[a]	T[b]	Plant assoc.[c]	Soil order	Dom. veg.[d]
			m							
Fish	46.41.27	120.05.31	1027	Flat	S	800	27	Abgr/Psme	Inceptisol	*Poa*/*Chicorum*
Horse	46.38.22	121.06.15	875	<5%	N	800	27	Abgr/Psme	Inceptisol	*Poa*/*Trifolium*
Jump	46.38.48	121.03.07	1094	Flat	W	800	27	Abgr/Psme	Inceptisol	*Poa*/*Carex*
Min	46.34.24	121.07.30	1088	<15%	W	800	27	Abgr/Psme	Inceptisol	*Poa*/*Achillea*

[a] Annual precipitation.
[b] Maximum July temperature (°C).
[c] Plant association.
[d] Dominant vegetation.
Source: Franklin and Dyrness 1988.

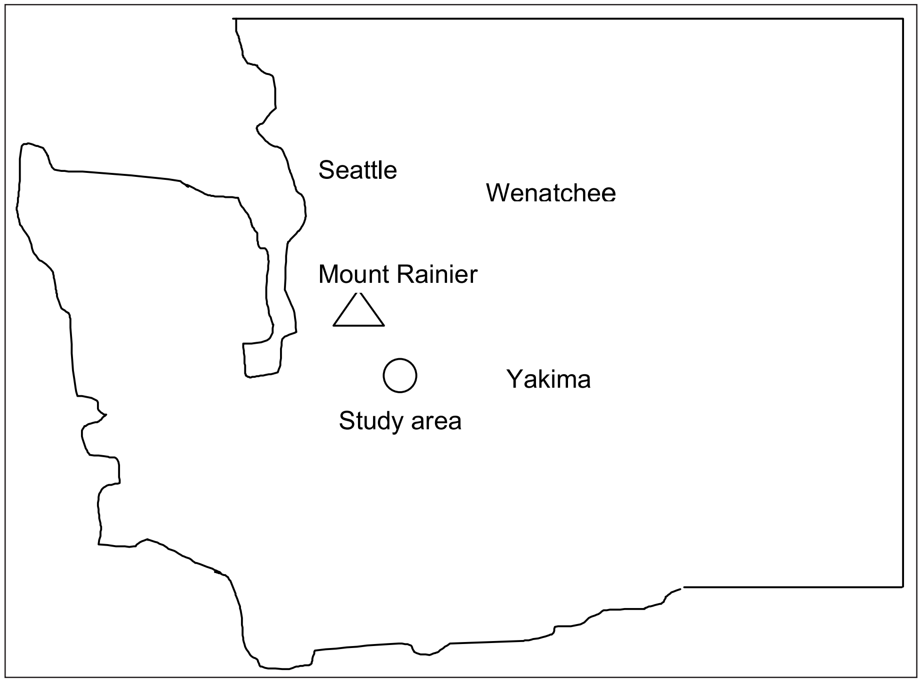

Figure 1—Washington State with study area shown by circle between Mount Rainier and Yakima.

Experimental Design

This study had two main treatments: grazing and trampling, and fertilizer applications. A split-block experimental design was used with grazing and trampling as the main plot treatments and fertilizer as subplot treatments on four sites considered to be replicates. There were three types of grazing and trampling (none, elk, and elk + cattle) provided by fenced exclosures and four fertilizer mixtures of nitrogen (N), phosphorous (P), potassium (K), and sulfur (S), which are abbreviated as NPKS, NPS, PKS, and NKS. Each fertilizer was applied in an increasing amount from 0 to 250 kg/ha per plot. Individual element plots were fertilized at 125 kg/ha to define the effects of individual nutrients (N, P, K, S) on species composition, root growth, and soil compaction. In all treatments, fertilizer applications were made in autumn during the first 3 years of the study. Soil compaction was estimated from bulk density samples taken at 1- to 10-cm and 10- to 20-cm depths in each treatment plot at the start of the study and at the end of the third season. Water sampling wells were 3.38 cm PVC pipe buried to 1-m depths. Water depths were measured biweekly from snowmelt until soil dried to field capacity in spring in the initial season and the final field season.

Plot Layout

Meadows selected were uniform in species composition and physiognomy within and among sites. One main plot at each meadow was fenced to exclude elk and cattle, another main plot was fenced to exclude cattle only, and another left unfenced, permitting both elk and cattle grazing. Main plots were 30 by 30 m divided into four 5- by 18-m center plots, and four individual element plots (5 by 6 m) with 2-m external buffer strips between plots and exclosure boundaries. The 5-m widths of both center and individual element plots were divided into a 1-m-wide central area and two 2-m-wide internal buffer areas on each lateral side. Central plots were fertilized with NPKS, NPS, PKS, or NKS. Individual element plots were fertilized with N, P, K, or S.

Vascular Plant Measurement

Vascular plant species cover was measured by the first vertical intercept of a 10-pin intercept frame in the central 18- by 1-m area of center plots and in the central 6- by 1-m area of the individual element plots (Warren-Wilson 1963). Vegetation taxonomy follows Hitchcock and Cronquist (1973) and Soil Conservation Service (1983). Clipped shoot samples and root biomass samples were taken from the internal buffer strips within each central and individual element fertilizer plots (Ahmed et al. 1983, Society of Range Management 1986). Root biomass was determined from soil core segments (3.38-cm diameter by 5-cm lengths for a total of 91.4 cm core sample length) that were washed and dried at 105 °C for 48 hours, ashed (at 250 °C), and weighed for root biomass, ash free (Society of Range Management 1986).

Data Analysis

Vegetation composition was analyzed for species richness and diversity by using the computer software PC-ORD (McCune and Mefford 1997). Vegetative similarity values were computed for both fertilizer plots and the grazing treatments by the Sorenson method (Magurran 1988). The influence of exotic plant species (weeds) by grazing and fertilizer treatments was determined by calculating weed to native vegetation ratios. Importance values were calculated for species listed after three seasons by summing relative cover, relative frequency, and relative biomass and converting to percentage (Brower et al. 1990, p. 85). Shoot and root biomass was compared in a split-block analysis of variance with seven fertilizer levels and three grazing treatments for shoots and three fertilizer levels for root biomass (SAS System 1994, Wilkinson and Hill 1992). The Student's t-test was used to compare means of categorical values in weed ratio comparisons, comparison of bulk densities in compaction measures, and in well water depths among main treatments.

Results

Changes in Species Composition

Values for species richness, evenness, and diversity are shown in table 2 for the main treatments, grazing, and the subplots treatments of fertilizer application. There was no clear change in species composition or in their abundance after three growing seasons. Species evenness ranged from 0.647 to 0.898 and showed no obvious change after the third season. Diversity value differences among the fertilizer applications ranged from -23 to +6.6 after the third season, showing no clear pattern. The greatest change was a reduction in diversity of 14 and 23 percent in the fertilizer mixtures PKS and P only. A similar reduction in diversity was observed in the 100 kg/ha fertilizer plot. Vascular plant diversity declined in each of the main grazing treatments with a drop of 11 percent for the cattle plus elk grazing, a reduction of 3.7 percent in elk-only grazing, and a decline of 5.7 percent in no-grazing treatment (table 2).

In the 1992 season, seven grasses and 24 forbs made up the species list in the sample plots. Kentucky bluegrass (*Poa pratensis* L., an introduced grass species) dominated; with nearly triple the importance of the next species, Chicory weed (*Chicorium intybus* L.) and common tarweed (*Madia gracilis* (J.E. Smith) Keck) (see table 3). After the 1994 season, there were eight grasses and 21 forbs in the plots at this sampling. Five grasses accounted for 43 percent of the vegetative importance on the meadow plots. Kentucky bluegrass was again dominant with three times the importance of each of the next four species. There was shifting in the species composition with 12 species increasing and 10 decreasing in importance rank. By the third season, five new species had appeared and seven had disappeared from the plots (table 3).

Table 2—Species richness (S), evenness (E), and diversity (H') for vascular plant species at Naches meadows restoration sites after three seasons of treatment, 1992 and 1994[a]

	1992			1994			
	S	E	H'	S	E	H'	Difference in H'
							Percent
Fertilizer rate (kg/ha):							
0	18	0.782	2.262	19	0.767	2.258	-.1
50	15	.735	1.991	16	.728	2.018	+1.3
100	20	.751	2.249	16	.697	1.933	-14
150	19	.738	2.173	17	.775	2.195	+1.0
200	19	.737	2.17	15	.751	2.033	-6.3
250	19	.739	2.176	17	.73	2.068	-4.9
Fertilizer type:[b]							
NPKS	16	.728	2.018	20	.719	2.153	+6.6
NPS	17	.764	2.163	20	.759	2.274	+5.1
PKS	22	.685	2.118	16	.686	1.902	-10
NKS	18	.759	2.194	20	.703	2.106	-4.0
N	10	.902	2.076	10	.829	1.908	-8.1
P	13	.898	2.302	9	.805	1.768	-23
K	11	.874	2.095	10	.853	1.964	-6.2
S	11	.837	2.008	10	.819	1.886	-6.0
Grazing scheme:							
Cattle + elk	18	.742	2.144	19	.647	1.904	-11
Elk	18	.761	2.199	20	.706	2.116	-3.7
None	27	.672	2.213	18	.722	2.086	-5.7

[a] Values shown are for 6 fertilizer rates, 8 fertilizer types, and 3 grazing treatments.
[b] Fertilizer types are NPKS = nitrogen, phosphorous, potassium, sulfur; applied in the amount of 125 kg/ha for each mixture.

Table 3—Species list for Naches meadows plots with relative importance values and ranks for first and third sampling season

Rank	1992 season Scientific name	1992 season Common name	Relative importance	1994 season Scientific name	1994 season Common name	Relative importance
			Percent			*Percent*
1	*Poa pratensis*[a]	Kentucky bluegrass	15.22	*Poa pratensis*[a]	Kentucky bluegrass	18.69
2	*Cichorium intybus*[a]	Chicory weed	6.36	*Hordeum brachyantherum*	Fox barley grass	6.57
3	*Madia gracilis*	Common tarweed	6.22	*Agropyron spicatum*	Bluebunch grass	6.39
4	*Hordeum brachyantherum*	Fox barley grass	5.88	*Phleum pratense*[a]	Common timothy grass	6.29
5	*Phleum pratense*[a]	Common timothy	5.72	*Carex geyeri*	Sedge grass	5.10
6	*Carex geyeri*	Sedge grass	5.26	*Madia gracilis*	Common tarweed	5.01
7	*Achillea millefolium*	Yarrow	4.79	*Achillea millefolium*	Yarrow	4.79
8	*Juncus balticus*	Rush	4.14	*Cichorium intybus*[a]	Chicory weed	4.63
9	*Tragopogon dubius*[a]	Salsify	3.61	*Potentilla gracilis*	Cinquefoil	3.93
10	*Bromus mollis*[a]	Brome grass	3.20	*Taraxacum officinale*[a]	Dandelion	3.15
11	*Potentilla gracilis*	Cinquefoil	3.02	*Bromus mollis*[a]	Brome grass	2.93
12	*Lotus denticulatus*[a]	Trefoil	2.90	*Lomatium nudicale*	Biscuitroot	2.88
13	*Agropyron spicatum*	Bluebunch grass	2.69	*Tragopogon dubius*[a]	Salsify	2.56
14	*Chrysanthemum leucanthemum*	Ox daisy	2.41	*Rosa gymnocarpa*	Wild rose	2.54
15	*Eriophyllum lanatum*	Sunflower	2.19	*Aster campestris*	Meadow aster	2.40
16	*Aster campestris*	Meadow aster	2.17	*Trifolium repens*[a]	White clover	2.16
17	*Allium acuminatum*	Onion	2.17	*Eriophyllum lanatum*	Sunflower	2.10
18	*Festuca occidentalis*	Fescue grass	1.98	*Chrysanthemum leucanthemum*	Ox daisy	1.95
19	*Senecio integerrimus*	Groundsel	1.98	*Lotus denticulatus*[a]	Trefoil	1.95
20	*Lomatium nudicale*	Parsley	1.97	*Microster gracilis*	Falsephlox	1.81
21	*Trifolium repens*[a]	White clover	1.97	*Festuca occidentalis*	Fescue grass	1.58
22	*Taraxacum officinale*[a]	Dandelion	1.87	*Epilobium minutum*	Willoweed	1.58
23	*Lathyrus pauciflorus*	Peavine	1.73	*Agrostis alba*[a]	Redtop grass	1.49
24	*Microsteris gracilis*	Falsephlox	1.59	*Symphoricarpos albus*	Snowberry	1.49
25	*Fragaria vesca*	Strawberry	1.50	*Equisetum arvense*	Horsetail	1.46
26	*Collomia linearis*	Collomia	1.47	*Vicia sativa*[a]	Vetch	1.46
27	*Rumex acetosella*[a]	Sorrel	1.44	*Fragaria vesca*	Strawberry	1.23
28	*Epilobium minutum*	Willoweed	1.36	*Collomia linearis*	Collomia	1.06
29	*Equisetum arvense*	Horsetail	1.14	*Perideridia gardneri*	Yampa	.84
30	*Sisyrinchum douglasii*	Grass widows	1.06			
31	*Anaphalis margaritaceae*	Everlasting	1.03			

[a] Invader species.

Similarity in vegetative composition for the fertilizer plots ranged from 0.612 to 0.897 between sampling years (table 4). Composition similarities among fertilizer treatments ranged from 0.670 to 0.780. There was a 22- to 32-percent decrease in between-year similarity for fertilizer treatments with a P component in the fertilizer mixtures. Among the grazing treatments, vegetation similarity was reduced by about 30 percent after the third season, particularly where there was no grazing. Between-year similarity was comparable for cattle plus elk and elk-only grazing but was much lower in the no-grazing treatment (table 5). Between-treatment similarity values were comparable for each sample period but much lower in the third than first sampling season.

Introduced Plant Species

Introduced (weed) species included chicory, trefoil (*Lotus denticulatus* (Drew) Greene), dandelion (*Taraxacum* dubius Hall.), bromegrass (*Bromus mollis* L.), bentgrass (*Agrositis alba* L.), timothy grass (*Phleum pratensis* L.), white clover (*Trifolium repens* L.), vetch (*Vicia sativa* L.) and the plot dominant Kentucky bluegrass. Introduced-species composition remained consistent between 1992 and 1994 with 9 species documented in the first season and 10 in the third with little shifting in importance value ranks. Three introduced species increased in importance and three declined, with one, sorrel (*Rumex acetosella* L.), not observed in the third season and two appearing new, bentgrass and vetch. Chicory, the most dominant of the weed species in the first season, however, declined in importance by about a third after the third season.

In the grazing treatments, weed species seem to decline by the third season when compared to native species on a biomass ratio basis. Figure 2 shows cattle plus elk grazing influenced a decline in the weed-to-native species ratio by about 55 percent. Weeds in elk-only grazing appear to have declined by about 40 percent, but in the no-grazing treatments, the weed-to-native species ratio increased 40 percent by the third season.

Shoot and Root Biomass

By 1994, the application of six fertilizer rates of 0 to 250 kg/ha did not significantly affect biomass for either forbs or grass shoots ($p = 0.779$ for forbs, $p = 0.271$ for grass, see table 6). Forb biomass was not much greater than that for zero fertilizer rates (fig. 3). Whereas grass biomass values were higher than in the zero rate, there were three cases of values that were less for no-fertilizer applications. Shoot biomass values for fertilizer rates show nearly the same pattern when shown for fertilizer types. No particular fertilizer mixture shows greater shoot biomass accumulation than another.

Grazing treatments appeared to have the greatest effect on shoot biomass accumulation by 1994, but the gains were largely for grass shoots ($p = 0.000$ for grass and $p = 0.062$ for forbs). The increases were nearly four times the initial 1992 measures, ranging from 505 to 760 kg/ha grass biomass in no-grazing treatments. Grazing treatment did not seem to have an effect on forb biomass by 1994.

There was a clear pattern of increased grass shoot biomass with reduced grazing pressure at the four sites. Grazing by both cattle plus elk permitted grass biomass accumulation in a range of 100 to 300 kg/ha. Elk-only grazing allowed biomass accumulations up to about 400 kg/ha. The greatest overall shoot biomass accumulations were in no-grazing treatments for grasses, which nearly doubled from 422 to 820 kg/ha. This pattern is similar for both fertilizer rates and fertilizer types (figs. 3 and 4).

Table 4—Vegetation similarity values for fertilizer type plots for and between two sample years, 1992 and 1994[a]

	NPKS[b]		NPS		PKS		NKS	
Type	1992	1994	1992	1994	1992	1994	1992	1994
NPKS	0.643[c]							
NPS	.767	.780	0.829					
PKS	.670	.696	.697	.711	0.612			
NKS	.717	.767	.765	.766	.735	.687	.897	

[a] Zero is most dissimilar, 1 is most similar.
[b] Fertilizer types are NPKS = nitrogen, phosphorous, potassium, sulfur; applied in the amount of 125 kg/ha for each mixture.
[c] Depicts similarity value between years for a fertilizer type.

Table 5—Vegetation similarity values for grazing treatments for and between two sample years[a]

	Cattle + elk[b]		Elk only		No grazing	
Treatment	1992	1994	1992	1994	1992	1994
Cattle + elk	0.751[c]					
Elk only	.627	.438	.734			
No grazing	.629	.420	.667	.559	.533	

[a] Zero is most dissimilar, 1 is most similar.
[b] Grazing method.
[c] Depicts similarity value between years for a fertilizer type.

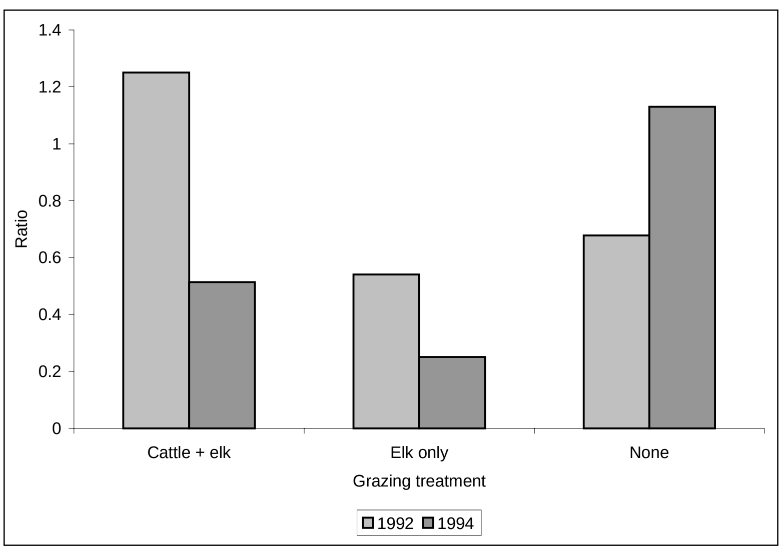

Figure 2—Ratio of weed-to-native species biomass in three grazing treatments for 1992 and 1994. *Poa* not included.

Table 6—Analysis of variance table for grass and forb shoot biomass in fertilizer rate and type treatment plots for 1994

Source	Sum of square	Df	Mean square	F-ratio	P-value
Grass shoots:					
Fertilizer rates	0.504	6	0.084	1.272	0.271
Grazing exclusion	15.278	2	7.639	115.369	.000
Exclusion × rates	.770	12	.064	.972	.476
Error	16.628	252	.066		
Fertilizer types	.846	7	.121	1.204	.301
Grazing exclusion	8.706	2	4.353	43.372	.000
Exclusion × types	7.329	14	.166	1.658	.065
Error	24.086	240	.100		
Forb shoots:					
Fertilizer rates	1.178	6	.196	1.074	.379
Grazing exclusion	1.031	2	.515	2.819	.062
Exclusion × rates	2.748	12	.0228	1.249	.250
Error	46.063	252	.183		
Fertilizer types	1.362	7	.195	.871	.536
Grazing exclusion	.615	2	.307	1.376	.225
Exclusion × types	3.037	14	.217	.971	.484
Error	53.623	240	.0223		

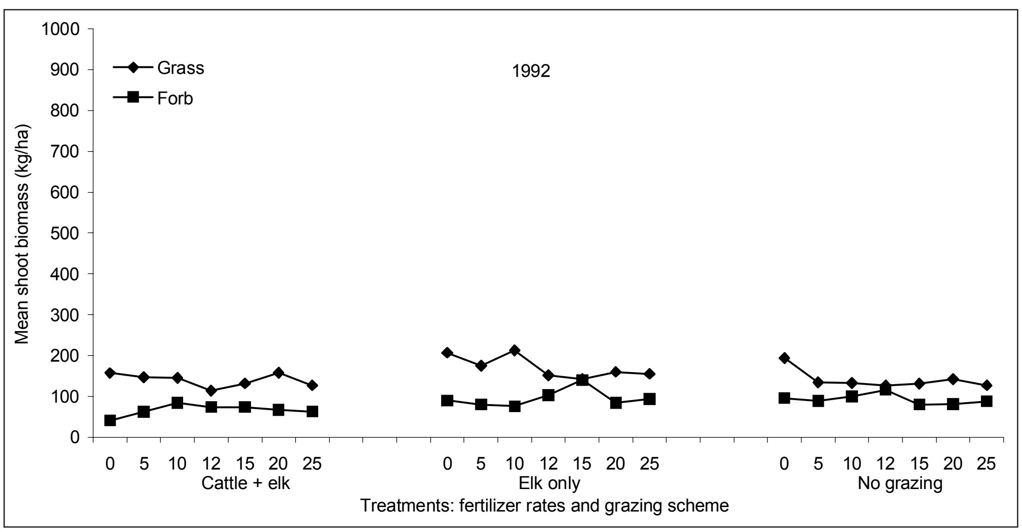

Figure 3—1992 mean shoot biomass for forbs and grasses in Naches meadows by fertilizer rates and grazing treatments. Grazing treatments are C = cattle + elk, E = elk only, N = no grazing. Fertilizer rates are 0 = no fertilizer, 5 = 50 kg/ha, 10 = 100 kg/ha, 12 = 125 kg/ha, 15 = 150 kg/ha, 20 = 200 kg/ha, 25 = 250 kg/ha.

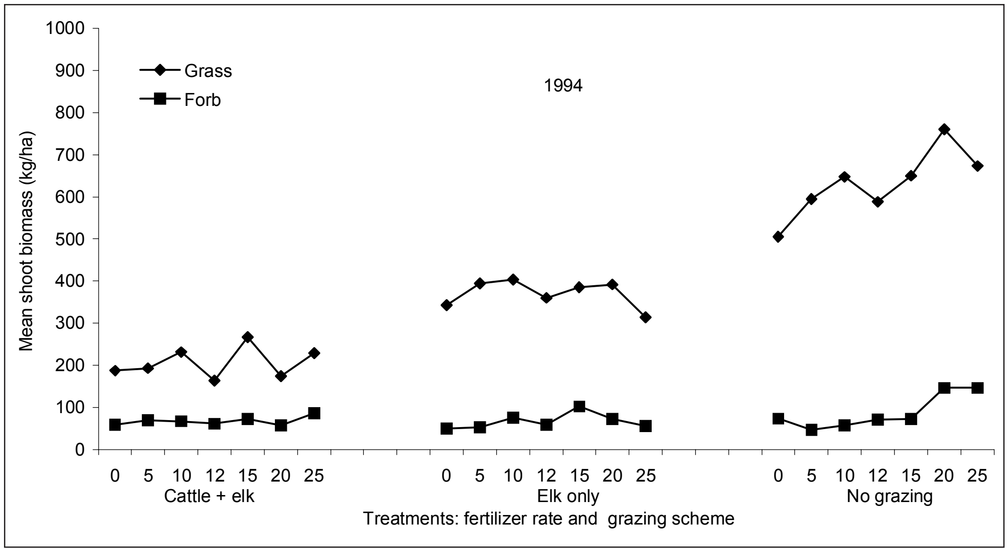

Figure 4—1994 mean shoot biomass for forbs and grasses in Naches meadows by fertilizer rates, and grazing treatments. Grazing treatments are C = cattle + elk, E = elk only, N = no grazing. Fertilizer rates are 0 = no fertilizer, 5 = 50 kg/ha, 10 = 100 kg/ha, 12 = 125 kg/ha, 15 = 150 kg/ha, 20 = 200 kg/ha, 25 = 250 kg/ha.

Root biomass was drastically influenced by fertilizer treatments after the third season. In each type and rate of fertilizer used, there was at least a doubling in root biomass after three seasons and two fertilizer applications. First season biomass values were less than 40 mg for both fertilizer types and rates (fig. 5). By the third season, mean root biomass values ranged from 90 to 163 mg for four fertilizer rates. There were no significant differences in root biomass values either among the fertilizer rates and types or between the grazing treatments. The biomass values seem to peak at 100 and 125 kg/ha fertilizer rates and then decline at 200 kg/ha.

Soil Compaction

Soil compaction was affected by grazing treatments. After three seasons, there was a significant increase in soil compaction in cattle plus elk grazing by 19 percent to 1.64 g/cm^3 ($p < 0.01$). In the elk-only grazing treatment, however, soil compaction declined by 6 percent to 1.58 g/cm^3 ($p < 0.05$). For the no-grazing treatment, soil compaction declined by 8 percent to 1.62 g/cm^3 ($p < 0.10$) (fig. 6). There were no significant differences in t-test comparisons soil bulk density among fertilizer rates or types ($P = 0.351$). In three-fourths of the fertilizer mixture plots, however, bulk density was less in the third season by 7.1 percent at the 7-cm depth. A computation of the ratio of soil bulk density at 7- and 15-cm depths shows that in 1992, bulk density at each depth was comparable at 1.0048 but that in 1994, the same ratio was 0.9007. This suggests an overall decrease in soil bulk density by about 10 percent; not a large amount but perhaps the beginning of a recovery.

Well Water Depths

There was an increase in well water depths by the third sampling season. In the grazing treatments, cattle plus elk showed an increase of water depth of 27 percent, elk-only grazing had an increase of 12 percent, and no-grazing treatment wells showed an increase of 17 percent (fig. 7). No information is available for wells in fertilizer subplots.

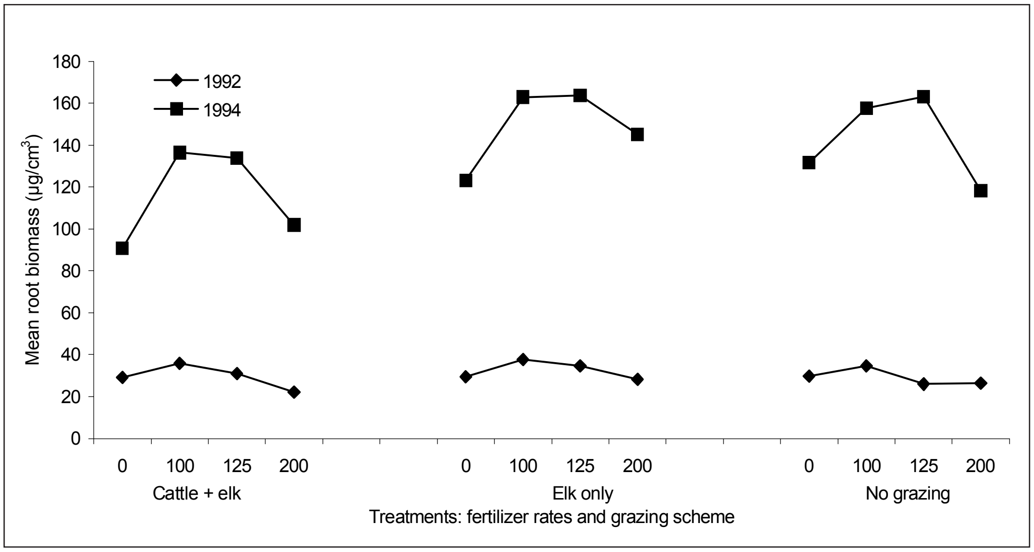

Figure 5—Mean root biomass (micrograms per cubic centimeter [µg/cm^3]) for Naches meadows by fertilizer rates and grazing treatment for 1992 and 1994. Grazing treatments are C = cattle + Elk, E = elk only, N = no grazing. Fertilizer rates are 0 = no fertilizer, 5 = 50 kg/ha, 10 = 100 kg/ha, 12 = 125 kg/ha, 15 = 150 kg/ha, 20 = 200 kg/ha, 25 = 250 kg/ha.

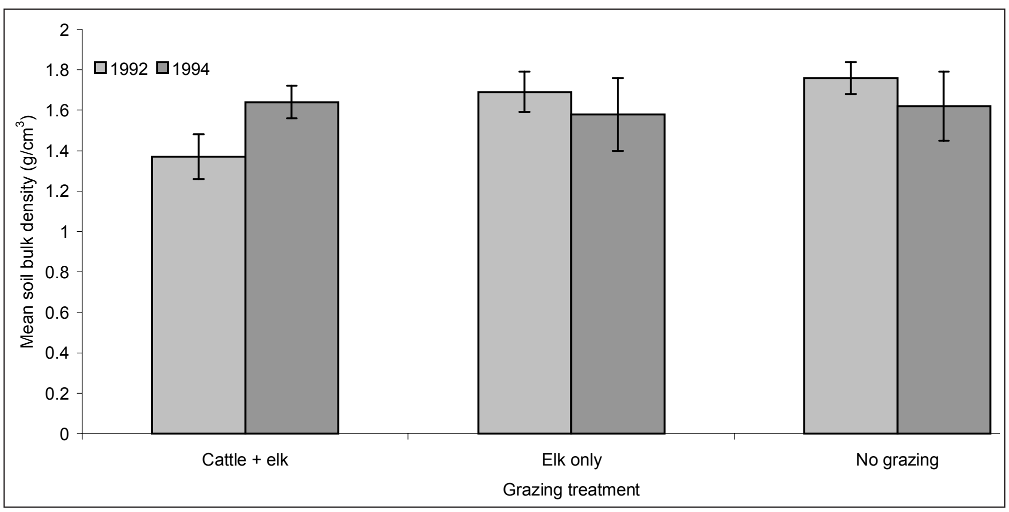

Figure 6—Mean soil bulk density for Naches wet meadows in three grazing treatments with fertilizer applications. N = 240. Bars are 95 percent confidence intervals.

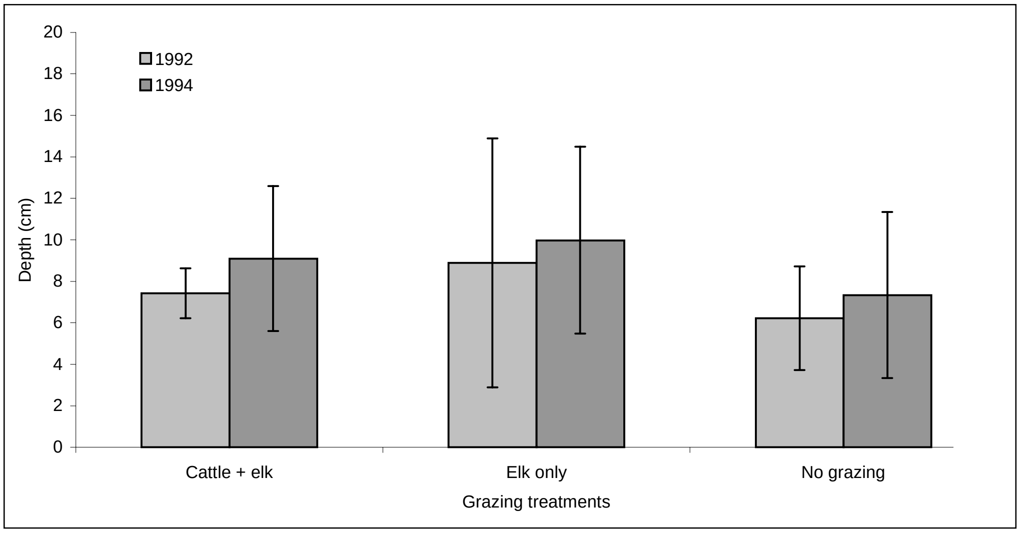

Figure 7—Depths of test wells on Naches meadows following two applications of fertilizer in three grazing treatments for 2 years. Values are means. N = 48 wells. Bars are 95 percent confidence intervals.

Discussion

The fertilizer amendments and grazing-exclusion methods in range and meadow restoration have met with varying success in many applications (Agladze 1974, Dormaar et al. 1989, Kie and Myler 1987, Skovlin 1984). We believe that there is evidence here of progress toward rehabilitation in these wet meadows during the study period. The current stability of vascular plant composition is probably due to the dominance of Kentucky bluegrass in all plots and sites. Others (Green and Kauffman 1995, Skovlin 1984) also have reported this. The overall decline in species diversity in grazing exclosures is consistent with results by Green and Kauffman (1995) and Leege et al. (1981). But in this study, the cattle plus elk grazing treatment showed the greatest decline in species diversity. We think this may have been an effect of the fertilizer treatment applications. There was considerable shifting in the relative importance ranks of forbs and less dominant grasses among the fertilizer treatments. This suggests considerable dynamism or activity among these species for space and resources on these sites. Fertilizers favor the competitive strategy over the residual or tolerance strategy for vascular plant groups; i.e., fertilizer benefits those species adapted to rapidly capturing resources and put on biomass (Grime 1979, Tilman 1984). An increase in grass biomass, particularly under the grazing treatments, was evidence of their ability to efficiently sequester the available new resources. Berendse (1985) reported on this phenomenon of competition between plant populations with different nutrient requirements.

The apparent reduction in biomass of introduced species that we report should be carefully considered in that it largely occurred among the grazing treatment where both cattle and elk were permitted to forage. We included among the listed invasive species Kentucky bluegrass, fox barleygrass (*Hordeum brachantherum* L.), and common timothy grass. These are preferred forage in this meadowtype community and so consequently would be reduced. Nonetheless, there were reductions in importance value ranks on introduced species during this period, and the potential for grazing ungulates to reduce invasive plant species should be an investigative problem. The proportion of exotic introduced species in the duration of this study ranged from 29 to 34 percent. This is within the range reported by Green and Kauffman (1995) for moist meadows over a 10-year period of 27 to 41 percent. Their data from northeastern Oregon also reflect a 14-percent decline in introduced species proportions owing to grazing during their study.

We believe that the doubling of root biomass was the clearest indication that fertilizer treatments were successful techniques in this meadow restoration. There also were increases in shoot biomass, but these seem most affected by grazing treatments. With a fertilizer treatment, therefore, we can increase biomass that directly improves soil conditions and retains community vegetation composition. Although no particular fertilizer mixture type appeared to affect root biomass significantly, there is a consistent decline in root biomass when fertilizer rates are at 200 kg/ha. This suggests a possible toxicity effect worthy of further investigation in this setting. In contrast, we would hesitate to conclude that an optimum root biomass accumulation occurred at 100 kg/ha with only four fertilizer rates tested here (0, 100, 125, and 200 kg/ha). We speculate that root biomass increase has affected soil compaction (bulk density) and increased in water well depths, which are important factors in the restoration of meadows. Grazing exclusion partly explains reductions in soil compaction and has been reported on by others (Clary 1992, Dormaar et al. 1989). In this study, we believe the fertilizer treatments affected the bulk density through the growth of the root biomass. The increase in well water depth cannot be positively attributed to the treatments; however, if the trend continues, the meadow will return to a more mesic state.

Conclusion

Meadow restoration strategies of fertilizer additions and grazing exclusion were used in degraded meadows of eastern Washington. Plant diversity and composition showed little change by the third sampling season, but there was evidence of reduction in the importance values of invader weeds in these communities. Fertilizer treatments doubled root biomass, whereas grazing has little effect. Grass shoot biomass increased with reduced grazing treatments as well as fertilizer applications. Forb shoot biomass showed little change after three seasons. Root biomass improvements appeared to influence improved soil compaction except in the cattle plus elk grazing regime. Improved water well depths suggest these treatment combinations can be successfully used in the restoration of wet meadow sites. Limited cattle and wildlife grazing may be sustainable if meadow features and hydrologic characteristics are restored over time.

Equivalents

When you know:	Multiply by	To find:
Centimeters (cm)	2.540	Inches
Meters (m)	3.281	Feet
Kilograms (kg)	2.205	Pounds
Grams (g)	0.035	Ounces
Micrograms (µg)	0.001	Milligram
Cubic centimeters (cm^3)	16.39	Cubic inches
Hectares (ha)	2.471	Acres
Celsius (C)	1.8	Fahrenheit
Milligram (mg)	0.001	Gram

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