North American Journal of Fisheries Management

ISSN: 0275-5947 (Print) 1548-8675 (Online) Journal homepage: http://www.tandfonline.com/loi/ujfm20

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To cite this article: Thomas J. Myers & Sherman Swanson (1995) Impact of Deferred Rotation Grazing on Stream Characteristics in Central Nevada: A Case Study, North American Journal of Fisheries Management, 15:2, 428-439, DOI: 10.1577/1548-8675(1995)015<0428:IODRGO>2.3.CO;2

To link to this article: http://dx.doi.org/10.1577/1548-8675(1995)015<0428:IODRGO>2.3.CO;2

North American Journal of Fisheries Management 15:428–439, 1995

Impact of Deferred Rotation Grazing on Stream Characteristics in Central Nevada: A Case Study

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Abstract.—Three central Nevada streams were selected to study the watershed-scale effects on stream morphology and bank stability of deferred rotation cattle grazing, complete rest from grazing, and the presence of road crossings. The streams had gravel substrates, and their entrenchments, width : depth ratios, sinuosities and gradients were moderate. Based on statistical analysis of 1980 stream survey results, geologic basin features, and the occurrence of similar flooding, we concluded that the three streams had similar conditions at the start of the grazing treatment. Since 1980, deferred rotation grazing allowed much improvement of aquatic and riparian habitats but the improvement was limited by the presence of roads, which apparently added sediment to the streams. Complete rest from grazing without the presence of roads allowed the most improvement. Of the variables measured in the 1980 survey, streambank soil stability, type and amount of vegetation cover, and quality of pools improved most in all three streams. The best values for channel and water width : depth ratios, channel entrenchment, bank angle, bank undercut, and bank depth were measured on the stream managed with complete rest. Deferred rotation grazing in the absence of roads produced the second best values. The ratio of channel width to base flow water width was significantly higher on bare ground transects. Shrub and tree cover increased significantly more on the rested than on the grazed watersheds. These results should help managers select aquatic habitat and stream morphology objectives for grazing management.

The first scientific documentation that livestock grazing could be detrimental to streams and rivers occurred early in this century (Duce 1918; Bryan 1925; Leopold 1946). Currently, land managers accept the view that grazing may degrade aquatic and riparian habitat (Platts 1991) and that careful management of grazing in the riparian zone is necessary to halt degradation and improve stream conditions (Platts and Meehan 1983; Armour et al. 1991). Such livestock grazing management includes various fencing, rotation, and deferment schemes (Platts 1991; Kovalchik and Elmore 1992).

Numerous studies have shown that stream form, in-channel aquatic habitat, and riparian vegetation have been improved by fencing or livestock exclosures (e.g., Gunderson 1968; Claire and Storch 1983; Duff 1983; Platts et al. 1983; Platts and Nelson 1985b; Clifton 1989). Kaufman and Krueger (1984) and Platts (1991) reviewed the literature on livestock exclosures. However, complete exclosure of livestock from riparian habitats is often economically or politically infeasible (Platts and Wagstaff 1984) and may be ineffective if improvements do not occur across the watershed (Kondolf 1993).

Much less research has been done on other forms of intensive management. Platts and Nelson (1985a) concluded that, although rest rotation grazing systems, in which a period of rest from grazing is rotated among pastures, could improve degraded streams running through a pasture complex, these systems could degrade previously ungrazed streams. They also found that 1 year of rest allowed vegetation growth that subsequently attracted heavy grazing. However, based mostly on personal observations, Platts (1991) concluded that strategies of rest rotation and deferred rotation (delay in the start of seasonal grazing in a different pasture each year) had fair to good stream rehabilitation potential.

Most published studies of exclosures and grazing systems have focused intensively on small riparian research pastures. There has been little research at the watershed scale, the most common scale of land management. Because of ecologic and hydrologic linkages along a stream (Vannote et al. 1980), the effects of grazing management may depend on the geology of the watershed and the cumulative impact of all management activities (Williamson et al. 1992; Kondolf 1993). For example, the impact of downstream grazing may depend, in part, on the flux of sediment from upstream produced by a mining operation or a road. Also, similar grazing intensities may cause substantially more erosion on certain soil types.

Very little research on grazing system effects on aquatic habitat has addressed specific stream type (Platts 1991). Chapman and Knudsen (1980) and Myers and Swanson (1991), using studies based

TABLE 1.—Comparison of geomorphic and ecologic characteristics among the three study streams. There are no significant differences among any of the values, which are reported as averages.

Characteristic	Washington Creek	San Juan Creek	Marysville Creek
Aspect	Northwest	Northwest	Northwest
Area (km^2)	21.1	25.8	18.9
Upper basin geology	Quartzite	Quartzite	Quartzite
Study reach geology	Granite	Granite	Granite
Valley width (m)	82	84	86
Gradient (%)	3.8	3.0	2.5
Median substrate particle diameter (D_{50} mm)	22	28	10
Sinuosity	1.3	1.3	1.3
Stream type[a]	B4	B4	B4
Riparian zone width (m)	12	14	10
Beaver presence	None	Inactive dams	None
Grazing management	Deferred rotation	Deferred rotation[b]	Rest

[a] According to Rosgen (1994).
[b] There are also seven road crossings on this stream.

on less intense measurements over a wide geographic area, concluded that streams of various similar types that had less grazing damage to riparian vegetation also had better aquatic habitat and bank stability. However, these studies suffered from a lack of knowledge of the type of management that led to the grazing damage.

Salmonid populations vary with the quality of the aquatic habitat. Various measures of pools (Kozel et al. 1989; Heggenes et al. 1991; Modde et al. 1991; Larscheid and Hubert 1992), cover (Kozel and Hubert 1989; Kozel et al. 1989; Larscheid and Hubert 1992), substrates (Lanka et al. 1987; Kozel et al. 1989), bank stability (Binns and Eiserman 1979), riparian vegetation (Wesche et al. 1987b), and stream channel cross sections (Lanka et al. 1987; Kozel et al. 1989; Larscheid and Hubert 1992) have been shown to vary significantly with fish populations. This paper analyzes on a watershed scale the effects of deferred rotation cattle grazing and roads on stream morphology and aquatic habitat of gravel-bottom streams (type B4 of Rosgen 1994) in the Great Basin of Nevada.

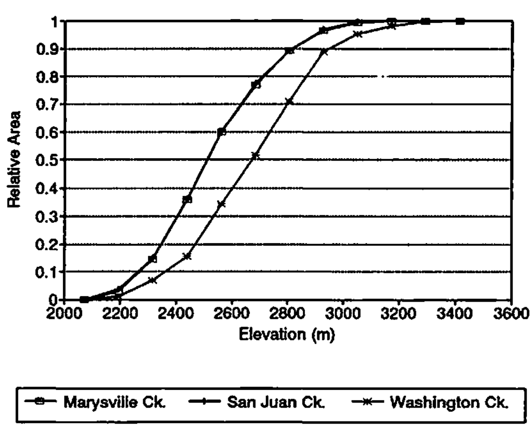

FIGURE 1.—Hypsometric curves for Marysville, San Juan, and Washington creeks. The curves for Marysville and San Juan creeks virtually coincide.

Study Area

We chose three Toiyabe National Forest streams that flowed within a 30-km radius in the Toiyabe Mountains of central Nevada because of their similarity in basin size, valley width, orientation, geology, and riparian vegetation and because of the differences in their management histories (Table 1). Similar basin conditions are important because channel shape and condition may be related to land type (Modde et al. 1991; Nelson et al. 1992). The 2-km-long, third-order study reaches were downstream from all perennial tributaries but were within the foothills, upstream from diversions and effluent losses. We assumed that similar natural starting conditions and basin properties would allow any changes in aquatic habitat that resulted from differing grazing management to be measured.

In 1980, survey crews led by the Nevada Department of Wildlife (NDW) performed aquatic habitat stream surveys on our study streams (Myers and Swanson 1991, 1992). These surveys provided the baseline data for this study. Conditions of the study reaches represent the cumulative effects of upstream and onsite watershed management and geomorphic controls.

Hypsometric curves (Figure 1) show that area–elevation relations are virtually identical for Marysville and San Juan creeks. Washington Creek is about 100 m higher at its downstream end and 200 m higher at the upstream end. Hypsometric curves represent a probability distribution for runoff from a basin (Rodriquez-Iturbe and Valdes 1979). From them can be derived the time required for runoff represented by a unit hydrograph of given duration (Rodriquez-Iturbe and Valdes 1979) or an instantaneous unit hydrograph (Rodriquez-Iturbe et al. 1982) to drain from a watershed. Thus, runoff from the three basins should be temporally similar.

There were no flow gauges on these watersheds. However, based on two gauges within 20 km, the area experienced snowmelt floods with return intervals of between 50 and 150 years in 1983 and 1984. Spot measurements of base flow in July 1992 showed that flow ranged from 0.015 to 0.028 m^3/s.

Hydraulic geometry relationships of channel width with annual flow rate (or other suitable flow variable) are similar for similar streams (Leopold and Maddock 1953). With basin area as a surrogate for flow (Richards 1982), we found no significant differences ($P = 0.15$) among the streams in the relation of $\log_{10}$ (active channel width) to $\log_{10}$ (basin area). We also found no significant correlation between the stream morphologic variables described below and either the basin area or the valley width (at 12.2 m above the stream).

Based on 1980 observations (NDW, unpublished data), the ecological conditions on each stream were very similar. The dominant riparian vegetation most commonly was a mixture of sagebrush *Artemesia* spp. and quaking aspen *Populus tremuloides*. Willows *Salix* spp. were also present (but not dominant) on Washington Creek. Less common were pinyon pine *Pinus monophylla*, woods rose *Rosa woodsii*, water birch *Betula occidentalis*, snowberry *Symphoricarpos oreophilus*, chokecherry *Prunus virginiana*, and mountain spray *Holodiscus dumosus*. In 1992, the dominant vegetation on all streams was willow, with intermittent quaking aspen. This similarity is important because riparian vegetation adds organic matter to the stream, stabilizes the banks, and provides the coarse woody debris responsible for habitat unit formation (Myers and Swanson 1994).

Watershed Management

The watersheds of Washington and San Juan creeks are different pastures of the Washington C&H allotment of the Austin District of the Toiyabe National Forest. It has been grazed under a deferred rotation strategy since 1986. The allotment management plan allows 430 cow–calf pairs to be released into alternating pastures in mid-June and rotated to the other pasture in early August. Grazing continues to the end of September. Total animal unit months are less than 720. In 1991, there were 300 cow–calf pairs, and in 1992, the year of this study, there were 330 cow–calf pairs. Monitoring in 1992 indicated that utilization in key riparian areas was 59% on San Juan Creek and 69% on Washington Creek, with little shrub usage. The cattle were released late (June 20) into San Juan Creek and were moved on August 29. Observations of livestock bank damage indicated there was very little difference in active bank damage between San Juan and Washington creeks. The San Juan Creek and Washington Creek pastures of the allotment contain 24 and 21 km of riparian habitat, respectively.

The presence of roads is the major difference in the management conditions of Washington and these two San Juan creeks. An improved dirt road crosses San Juan Creek seven times, whereas a four-wheel drive track crosses Washington Creek once, at least 1 km below the study reach. The U.S. Forest Service estimates that two vehicles a week use the road on San Juan Creek between May and November (D. Flanagan, Toiyabe National Forest, personal communication). However, while collecting data in 1992, we observed about five vehicles a day.

Marysville Creek had been rested from grazing since 1986. One road crosses the creek about 2 km below the study reach.

The variation in grazing management among watersheds allowed comparison between 7-year periods of deferred rotation grazing with and without the presence roads and road-based recreation, and between deferred rotation and complete rest from grazing.

Methods

For study we chose stream reaches about 2 km long on the downstream ends of the three watersheds. These reaches reflected the effects of grazing treatments that occurred throughout the entire upstream watershed. Although these reaches were generally quite homogeneous, they contained sections bisected by roads or bedrock, sections heavily trampled by campers, and short sections totally inaccessible to cattle because of thick vegetation.

Along each reach, we chose the general locations of four sampling units so they would be representative of the stream reach and avoid the heterogeneities just described. After we chose the general location, we located the first transect randomly. The sampling units consisted of 26 transects spaced at 3-m intervals. The total length of

TABLE 2.—Response variables monitored to determine changes in Washington, San Juan, and Marysville creeks.

Variable	Measurement and unit
Aquatic habitat variables	
Pool percent	Percent of reach surface area in pools
Pool quality	Percentage of pool area that is in quality pools
Real pool percent	Percentage of reach surface area in quality pools; pool percent × pool quality
Gravel–cobble percent	Percentage of base flow substrate that is gravel or cobble (2–256 mm)
Embeddedness	Percentage of gravel and larger substrate in the base flow channel that is surrounded by finer material (sand or silt)
Bank stability	Percentage of banks that are stable
Cover	Percentage of optimum vegetation on banks; optimum is defined as full shrub coverage, and trees, grass or forbs, and bare ground are 75, 50, and 25%, respectively, as desirable as shrubs
HCI	Habitat condition index, which embraces pool percent, pool quality, gravel–cobble percent, bank stability, and cover
Stream morphologic variables	
Water width : depth	Ratio of wetted width to average depth
Channel width : depth	Ratio of channel width to average channel depth
Entrenchment	Ratio of floodable area width, the width at twice the active channel maximum depth, to the channel width
WIDRAT	Ratio of active channel width to water width
Bank angle	Angle the bank makes with the horizontal at the water level; less than 90° indicates an undercut
Bank undercut	Distance from the maximum overhang within the active channel to the furthest point under the bank
Bank depth	Base flow water depth at the point the water touches the bank

sampling units was equal to about 15% of the study reach. This exceeded the intensity of sampling recommended by Overton et al. (1993) for determining differences between two B4 streams produced by management. Because the active channel width is near 2.5 m, the actual length sampled equals about 120 channel widths. Sampling by NDW crews in 1980 was similar but less intensive. In each reach, they chose four sampling units, each consisting of five transects spaced at 14.9-m intervals.

We optimized the response variables compared among streams by using those that explained most of the variations in trout populations in the studies cited above. These included various measures of pools, cover, substrate, bank stability, riparian vegetation, and stream channel cross sections. Table 2 describes all variables used in this study. All sampling in each year occurred during base flow periods to ensure the consistency that would allow comparison between years.

A pool is a stream habitat feature that has a gradient less than the average stream gradient and mostly subcritical flow (Grant et al. 1990). The NDW surveyors defined a pool as a feature with surface velocity less than 0.3 m/s. A high-quality pool is deeper than the average stream depth and longer or wider than the average stream width, and it has cover on at least one quarter of its perimeter. We refer to high-quality pools as "real" pools to distinquish them from low-quality pools, which include shallow areas of the transect with low water velocity called edgewater (McCain et al. 1990).

We measured the length of the base flow channel covered by material of the following sizes: silt–clay, less than 0.062 mm; sand, 0.062–2 mm; gravel, 2–64 mm; cobble, 64–264 mm; boulder, larger than 264 mm. We estimated embeddedness by measuring the percent of substrate below the transect that was embedded. We also performed pebble counts on all stations with the method used by Wolman (1954).

A bank that showed no evidence of recent erosion, deposition from the upper banks, or a predominance of small, easily removed soil was considered stable. The stability may have been a result of dense, well-rooted vegetative cover or a cobble mantle. We converted the percentage of a bank that was judged stable into four categorical ratings for association analysis: greater than 75% stable, 50–75% stable, 25–50% stable, and less than 25% stable. We applied these categories to individual transects and to the entire sampling unit.

We rated vegetation on each end of each transect categorically for shrubs, trees, grass or forbs, and bare ground. Coverage with shrubs at both ends of all transects was taken to be the optimum condition (100%); trees were rated 75% of optimum, grass or forbs 50%, and bare ground 25%. This cover variable was used only to calculate habitat condition indices.

We summarized aquatic habitat variables with a habitat condition index (HCI), modeled after composite variables used by different management agencies (e.g., USFS 1985; Myers and Swanson 1991).

$$\text{HCI} = (\text{PROPT} + \text{PQUAL} + \text{SUBS} + \text{COVER} + \text{STAB})/5.$$

Here, PROPT is a measure of how close the pool percent is to the perceived optimum of 50% (USFS 1985):

$$PROPT = 100 - \frac{|50 - PR|}{50} \times 100;$$

PR is pool percent, PQUAL is the percent of total pool area that is of high quality, SUBS is the percent of stream bottom with gravel or cobble, STAB is percent stable banks, and COVER is the percent of optimum bank vegetation.

We rated ungulate damage categorically as 75–100% unaffected, 50–75% unaffected, 25–50% unaffected, or less than 25% unaffected. Affected areas had trampled banks or grazed vegetation. The total percent damaged over the entire sampling unit was the average of the mid-range values over the transects. For categorical analysis, we also used simple ratings of no damage or some damage.

We designed the variable WIDRAT to measure relative changes between the base flow and active channels. The ratio of channel width to water width represents the width within the channel that is above the base flow water level. This can reflect the ratio of the average annual flood to the base flow (Leopold and Maddock 1953; Osterkamp and Hupp 1984).

Statistical methods.—We compared normally distributed response variables among streams (treatments) with one-way analysis of variance (ANOVA) and between years (1980 and 1992) with two-sample *t*-tests with unequal variances (Neter et al. 1985). We compared nonnormal variables, such as bank angle, undercut, and depth, among streams, vegetation types, and bank soil stabilities with Kruskal–Wallis nonparametric ANOVA (Sokal and Rohlf 1981). A low mean rank for bank angle indicates high quality. A high mean rank for undercut and depth indicates high quality. We used chi-square tests (Fienberg 1980) to test the hypothesis of independence among categorical variables such as vegetation type or stream. We rejected the null hypotheses at the 5% significance level and concluded that differential changes occurred among the streams if there were differences in 1992 but not in 1980.

Results

Ungulate Damage

Overall in 1980, there was ungulate damage on 48% of the banks and no significant variation among the streams. In 1992, the damage decreased to only 6% of the banks. There were significant (P = 0.000) differences among streams in 1992; Marysville Creek had no damage, but Washington and San Juan creeks had damage on 15% and 8% of their banks, respectively.

Aquatic Habitat Variables

None of the aquatic habitat variables varied significantly among the streams in 1980; however, pool quality, gravel–cobble percent, and bank stability improved significantly between 1980 and 1992 (Table 3). Pool percent and bank stability varied significantly among streams in 1992. Pools decreased on Marysville Creek, which had the most stable banks. San Juan Creek, which had the least stable banks, had the highest pool percent (also the closest to the optimum of 50%) because of the large number of log-formed and shallow, silt-formed pools (Myers and Swanson 1994). However, variation in real pool percent was less significant because many of the pools on San Juan Creek were edgewater. The HCI improved significantly from 1980 to 1922 but did not vary significantly among streams in either year.

Embeddedness was significantly higher on San Juan Creek than on the other two streams (Table 3). Substrate distributions in 1980 and pebble counts in 1992 (Figure 2) showed that Marysville Creek tended to have the smallest substrate—about 8% in the silt size-range. However, there was no significant difference among individual size fractions. The combination of small substrate with low embeddedness illustrates that Marysville Creek had a stable bed that has little sediment settling in the gravels. Apparently, the sediment load did not exceed the transport capacity of Marysville or Washington creeks, possibly, because it entered during high and rising flows. The high embeddedness on San Juan Creek, which has larger substrate and no silt, suggests that fine sediment reached the stream from the uplands, upper banks, or roads during flows that were insufficient to transport it past gravels in the study reach.

Vegetation type in 1992 varied among streams (Table 4) for several reasons. First, San Juan Creek had a much higher amount of bare ground than expected and Marysville Creek a much lower amount. Second, Washington Creek had more than twice as many transects with trees as expected, and Marysville Creek had trees on only one transect. Third, Marysville Creek had more transects with shrubs than expected, and San Juan Creek had fewer than expected. Only complete-reach values for cover were available for 1980 and they varied from 60% on Marysville Creek to 71% on San Juan Creek. As described above, observations of species type were similar among streams in 1980, with the exception that willows were present, although not abundant, on Washington Creek.

TABLE 3.—Mean values and coefficients of variation (CV = 100·SD/mean) for aquatic habitat variables by stream and year. Values were analyzed among streams with a one-way analysis of variance; when the F-value was significant, stream data were subjected to multiple-comparison tests, and means along a row without a letter in common are significantly different ($P \leq 0.05$). A standard t-test with 11 df or a Mann-Whitney U-test was used to compare overall values between years. The HCI is habitat condition index. PR is pool percent. PRREAL is real pool percent. PQUAL is pool quality. SUBS is substrate. STAB is bank stability, and EMB is embeddedness. Variables are described in Table 2.

		Among streams		Marysville Creek		San Juan Creek		Washington Creek		Overall		Overall, between years	
Variable	Year	F	P	Mean	CV	Mean	CV	Mean	CV	Mean	CV	t or U	P
HCI	1980	1.1	0.38	42	20	48	11	39	27	43	20	−8.9	0.00[a]
	1992	1.3	0.32	75	5	69	8	70	8	71	7		
PR	1980	4.9	0.07	29	44	40	17	29	19	33	27	1.3	0.19[a]
	1992	9.2	0.01	18 z	17	38 y	20	25 zy	34	27	25		
PRREAL	1980	1.0	0.41	18	76	30	23	20	86	23	58	0.25	0.80[a]
	1992	3.6	0.07	14	21	29	29	19	52	21	39		
PQUAL	1980	0.43	0.81	25	119	21	121	13	200	20	138	2.7	0.01[b]
	1992	0.45	0.65	62	42	45	65	52	20	53	26		
SUBS	1980	1.7	0.23	77	18	87	8	74	10	80	13	−2.1	0.05[b]
	1992	0.49	0.63	92	7	86	12	87	15	88	12		
STAB	1980	0.01	0.99	50	59	48	40	48	55	48	52	−4.8	0.00[a]
	1992	17.0	0.00	97 z	2	76 y	8	85 y	8	86	6		
EMB	1992	8.8	0.01	8 z	22	18 y	28	10 z	37				

[a] Analyzed by t-test with unequal variance.
[b] Analyzed by Mann-Whitney U-test.

In 1980, bank stability did not vary by stream or the amount of ungulate damage, presumably because of the widespread ungulate damage. In 1992, bank stability varied significantly with vegetation type (Table 5), which suggests a possible explanation for the 1992 variation in bank stability among streams. However, most of the significance was a result of the preponderance of transects with bare ground that rated poor or fair for bank stability and the small number of bare transects with excellent stability.

Stream Morphological Variables

All measured stream morphological variables varied significantly among streams in 1992 (Table 6). Estimates of 1980 water width : depth ratios did not vary among streams. Between 1980 and 1992, there was little change of the water width : depth ratio on Marysville Creek, but the ratios on both San Juan and Washington creeks increased substantially. Width : depth ratios were similarly large for San Juan and Washington creeks, which suggested a higher bed-load fraction of the sediment load (Schumm 1977). The ratio WIDRAT was highest for San Juan Creek, which suggested a higher ratio of high flows to base flows. The mean entrenchment ratio was significantly lower (entrenchment was greater) for San Juan Creek than for the other two streams.

Although bank angle, bank undercut, and bank depth varied significantly with vegetation type, bank stability, and ungulate damage, their variation was greatest among streams (Table 7). Unless caused by recent bank erosion, lower bank angles and greater undercuts and bank depths are desirable. The mean rank for Marysville Creek was best for all three variables. Although it appeared that the poorest bank stability rating was associated with the best bank shape, this was misleading because of the very low number of poor stability observations (24 of 596 possible observations). Many were bank undercuts caused by fresh erosion on bare ground (bank angle was less than 70° on 38% of observations in which bank stability was rated poor).

Bank undercut varied significantly among vegetation types and bank angle nearly did, but bank depth decidedly did not (Table 7). Trees (including quaking aspen on these streams) impart good qualities to banks; only two transects with trees had poor stability. The lack of variation of bank depth with vegetation type, given that tree-lined banks had the lowest angles and deepest undercuts, suggests that undercuts of such banks occur above the water surface.

Marysville Creek had the best bank structure of the three streams (Figure 3). Almost 65% of the Marysville transects had bank angles less than

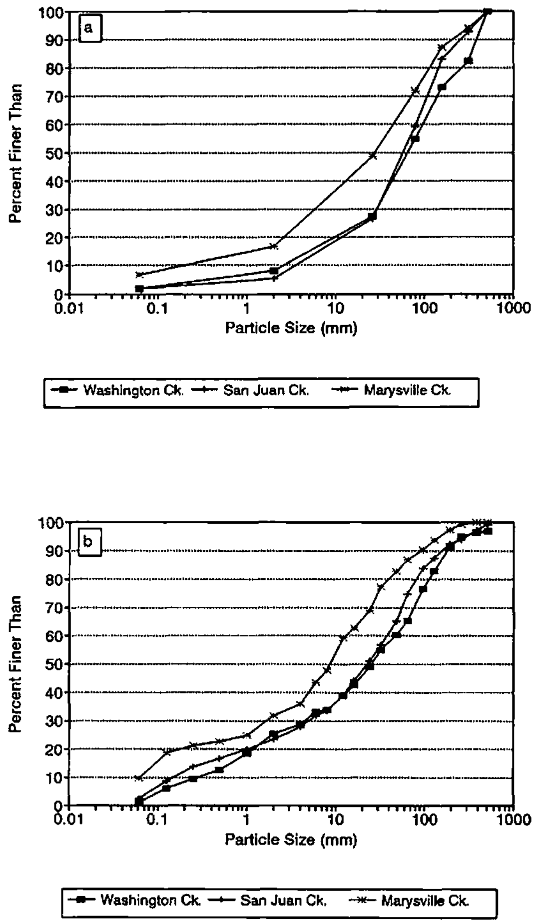

FIGURE 2.—Substrates in 1980 (a) and pebble count in 1992 (b) for Washington, San Juan, and Marysville creeks.

140°, compared with only 40% and 25% for Washington and San Juan creeks, respectively (Figure 3a). For angles less than 90°, percentages were 40%, 18%, and 16% for the three streams. The constantly increasing curve for Marysville Creek indicates that it had a variety of bank angles, whereas the other two streams had few angles between 40 and 100°. More than twice as many undercut banks existed on Marysville Creek, although it had less than half as many deep undercuts (Figure 3b). Less than half of the transects on Marysville had no bank water depth; more than 80% of the transects on both of the other streams had no bank water depth (Figure 3c). Overall, banks on Marysville Creek provided better salmonid cover (Wesche et al. 1987a).

TABLE 4.—Contingency table of vegetation type and stream in 1992. Expected values (number of transect ends) assumed independence between vegetation and stream ($\chi^2 = 77.8$, df = 6, $P < 0.001$).

Category or statistic	Stream: Marysville Creek	San Juan Creek	Washington Creek
Bare ground			
Observed	2	44	11
Expected	19.1	19.5	18.4
Cell χ^2	15.3	30.7	3.0
Herbs or forbs			
Observed	132	113	110
Expected	119.1	121.5	114.3
Cell χ^2	1.4	0.6	0.2
Trees			
Observed	1	5	18
Expected	8.1	8.2	7.7
Cell χ^2	6.2	1.3	13.6
Shrubs			
Observed	63	40	51
Expected	51.7	52.7	49.6
Cell χ^2	2.5	3.1	0.0

Discussion

The variables measured in 1992 indicated that Marysville Creek was in the best condition and that San Juan Creek was in the poorest condition. Excepting vegetation type, most variables indicated that Washington Creek was more similar to

TABLE 5.—Contingency table of bank stability and vegetation type rating on each transect along Washington, San Juan, and Marysville creeks, 1992. Expected values assume independence between stability and vegetation type ($\chi^2 = 281.4$, df = 9, $p < 0.001$).

Category	Vegetation type: Bare	Herbs or forbs	Trees	Shrubs
Poor bank stability (<25% stable)				
Observed	22	1	1	0
Expected	2.3	14.4	1.0	6.3
Cell χ^2	167.1	12.5	0.0	6.3
Fair bank stability (25–50% stable)				
Observed	24	27	4	13
Expected	6.6	40.9	2.8	17.8
Cell χ^2	46.2	4.7	0.6	1.3
Good bank stability (50–75% stable)				
Observed	6	79	10	28
Expected	11.9	74.0	5.0	32.1
Cell χ^2	2.9	0.3	5.0	0.5
Excellent bank stability (>75% stable)				
Observed	5	248	9	113
Expected	36.2	225.6	15.2	97.9
Cell χ^2	26.9	2.2	2.6	2.3

TABLE 6.—*One-way analysis of variance of stream morphologic variables*; CHWD is *channel width* : *depth ratio*, WATWD is water width : depth ratio, ENTR is entrenchment ratio, and WIDRAT is channel width : water width. Variables are defined in Table 2. The coefficient of variation (CV) equals 100·SD/mean. For among-stream comparisons with significant *F*-values, means along a line without a letter in common are significantly different (multiple-comparison tests, $P \leq 0.05$).

		Among streams		Marysville Creek		San Juan Creek		Washington Creek	
Variable	Year	*F*	*P*	Mean	CV	Mean	CV	Mean	CV
CHWD	1992	'4.85	0.009	10.4 z	51	13.2 y	49	12.1 zy	58
WATWD	1980	0.25	0.785	21	27	23	18	24	18
	1992	11.2	0.000	21.8 z	46	31.8 y	62	30.9 y	56
ENTR	1992	22.4	0.000	1.74 z	140	1.13 y	45	1.65 z	65
WIDRAT	1992	3.62	0.027	1.62 z	31	1.91 y	48	1.74 z	46

San Juan Creek than to Marysville Creek. Conditions at the start of the grazing treatments (1980) were very similar. This suggests that more improvement occurred with 7 years of complete rest than with deferred rotation grazing.

The streams that experienced deferred rotation grazing, Washington and San Juan creeks, improved substantially between 1980 and 1992. Bank stability increased 28 and 37% along the streams with and without roads, respectively. Gravel–cobble substrate increased 13% in the stream without roads but not at all in the stream with roads. Embeddedness was twice as high in the stream with roads as in the stream without roads. Pool percent changed very little in the grazed streams, but high-quality pools increased by 25 and 40% on the streams with and without roads, respectively. However, bank stability on the rested stream, Marysville Creek, increased 40%, desirable stream bottom increased 15% and high-quality pools increased by over 40%. Comparison of the recovery between deferred rotation and complete rest suggests that additional improvement is possible on the grazed streams.

The HCI also improved significantly with time in all streams, but there was no difference among streams even with differential change of bank stability. Pool percent actually decreased with time on Marysville Creek because of a decrease in edgewater area (Myers and Swanson 1994), thereby counteracting the improved bank stability. There was generally poor correlation among aquatic habitat variables (Table 8). The negative correlations between pool variables and gravel–cobble percent in 1992 suggest that pools decreased with increased cobble and gravel (Figure 4). This probably resulted from particle sorting whereby large pools contain more small substrate than small pools (Milne 1982). The low correlations between the cobble–gravel percent and percent quality pool

TABLE 7.—Comparison of stream morphologic variables among streams (1—Marysville; 2—San Juan; 3—Washington), vegetation types (1—bare ground; 2—grass and forbs; 3—trees; 4—shrubs), bank stabilities, (1—poor; 2—fair; 3—good; 4—excellent), and ungulate damages (1—some damage; 2—no damage). Kruskal–Wallis one-way analyses of variance (*H* statistic) were used for three or four categories and Mann-Whitney *U*-tests were used for two categories. Complete lack of variation would result in all mean ranks approaching 294.

				Mean rank for factor level:			
Variable	Factor	*H* or *U*	*P*	1	2	3	4
Bank angle	Stream	49.	0.00	221	330	309	
	Vegetation	7.6	0.06	287	298	219	268
	Stability	28.	0.00	212	288	353	269
	Damage	3.6	0.00	279	379		
Bank undercut	Stream	16.	0.00	318	275	282	
	Vegetation	8.5	0.04	319	288	338	282
	Stability	13.	0.01	353	273	273	298
	Damage	1.9	0.06	295	243		
Bank depth	Stream	79.	0.00	363	255	257	
	Vegetation	1.8	0.61	311	292	293	283
	Stability	26.	0.00	353	263	246	308
	Damage	3.4	0.00	298	203		

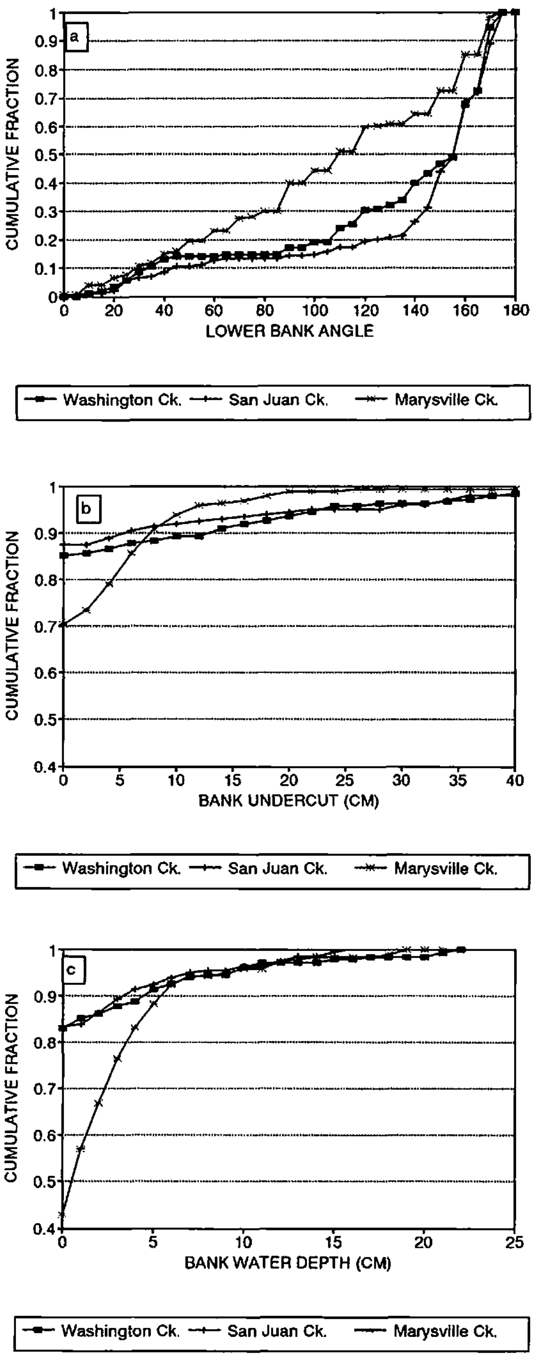

FIGURE 3.—Cumulative frequency distributions of lower bank angle (a), bank undercut (b), and bank water depth (c) for Washington, San Juan, and Marysville creeks.

TABLE 8.—Correlation matrix of aquatic habitat variables: PR is pool percent, PRREAL is the real pool percent, PQUAL is percent quality pools, STAB is percent stability, SUBS is substrate, and COVER is percent of optimum vegetation. An asterisk means that the definitions of compared variables are too similar for a correlation to be meaningful. See Table 2 for description of variables.

Variable	PR	PRREAL	PQUAL	STAB	SUBS
		1980 variables			
PRREAL	*				
PQUAL	0.57	*			
STAB	−0.53	−0.52	−0.25		
SUBS	0.04	0.01	0.02	0.67	
		1992 variables			
PRREAL	*				
PQUAL	−0.15	*			
STAB	−0.67	−0.48	0.30		
SUBS	−0.72	−0.83	−0.07	0.14	
COVER	−0.18	−0.24	−0.36	0.39	0.11

suggests there is no variation in particle sorting with respect to pool cover. The overall lack of sensitivity of the habitat condition index and the inverse relation between several of its constituent variables suggest that the overall index does not adequately summarize changes that may occur along streams.

The large difference in morphology among the streams also indicated that better conditions developed on Marysville Creek with rest from grazing. Bank recovery apparently occurs more slowly with deferred rotation grazing than with complete rest. Marysville Creek had more shrubs (mostly woods rose and willow) in 1992, whereas none were observed in 1980. This suggests that livestock under deferred rotation consume some shrubs. Kovalchik and Elmore (1991) also determined that deferred grazing under commonly used grazing intensities is often incompatible with willow regrowth. Changes in vegetation type with time, the positive association of both bank stability and stream with vegetation type, and the positive relationship of bank shape variables with vegetation type all suggest that better bank shape corresponds with the increase in shrubs on Marysville Creek. Platts and Nelson (1985a) suggested that vegetative growth during the period of rest in rest rotation grazing was not accompanied by improvements in deteriorated channels. Similar processes may have operated here because improved vegetation cover and bank stability apparently had not caused better bank or channel shape on the streams with continuing grazing. Shrubs on Marysville Creek may have caused the more desirable stream morphologic conditions.

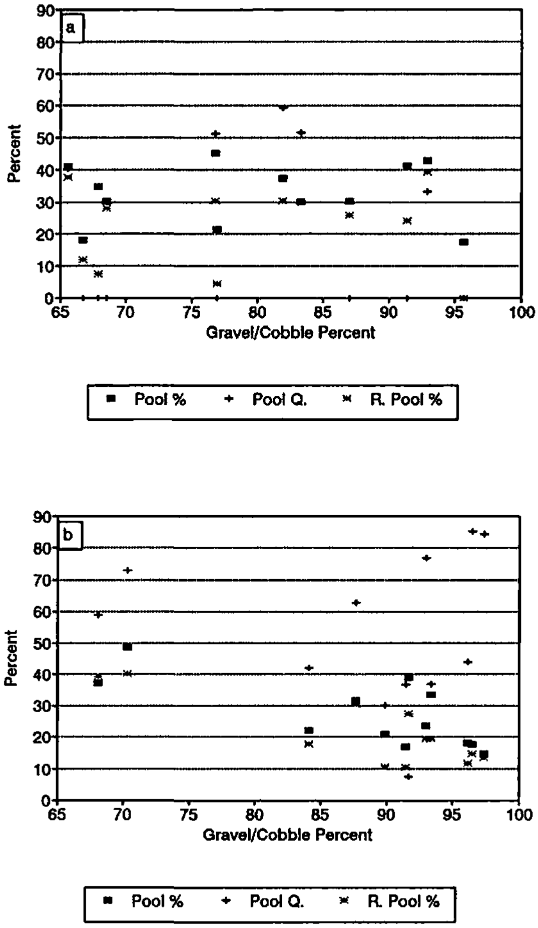

FIGURE 4.—Relationships of pool variables and substrate (gravel and cobbles, 2–264 mm) over all three streams for 1980 (a) and 1992 (b). Pool Q = pool quality; R. Pool = real pool.

The major difference between San Juan and Washington creeks is the presence of road crossings on San Juan Creek. The seven road crossings are probably the source of large amounts of sediment that are added to the stream, as indicated by the high embeddedness. Roads increase runoff (Harden 1992) and flow velocity, thereby increasing erosion and transport capacity (Branson et al. 1981; Reid and Dunne 1984). Embeddedness occurs when the concentration or size of suspended sediment exceeds that which can be transported in the stream after bed-load movement has ceased. The low entrenchment ratio, high active channel : base flow ratio and high width : depth ratios on San Juan Creek suggest that most flow will remain in or over the channel and that transport capacity is high during high flows but low during low flows (Schumm 1968). The increased sediment loading must be substantial or poorly timed to exceed the increased transport capacity. Others (e.g., Satterlund 1972; Branson et al. 1981; Chamberlin et al. 1991) noted increased sediment loading caused by roads, although most referred to logging practices or provided no references. Recently, Brown (1994) completed research that quantified increased sedimentation caused by off-road vehicle use. This research did not concentrate on measuring the impact of roads on streams, but the results complement previous research on the detrimental effects of roads on rangeland streams.

In summary, our research showed that deferred rotation grazing allowed improvement of aquatic habitat conditions from very poor initial conditions on type B4 streams in the foothills of the Toiyabe Range in Nevada, but that 7 years of rest from grazing allowed greater improvement. Pool habitat recovery lagged substantially behind improvements in bank stability and cover. Roads may also have a major effect on habitat conditions and the rate of recovery. Myers and Swanson (1991, 1992) have shown that stream type explains variations of many aquatic and bank stability variables. Therefore, land managers could use these results to consider management changes on similar streams in other areas. Depending on management priorities and objectives, exclosure or deferred rotation grazing could be appropriate for improving aquatic and riparian habitat.

Acknowledgments

Research was funded by a Federal Aid in Sport Fish Restoration grant from the Nevada Division of Wildlife and funds from the Nevada Agricultural Experiment Stations Project 5293. Special thanks are due to Dale Flanagan, Tim Bond, G. Fred Gifford, and Leroy McClelland for information, assistance, or review.

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