Initial effects of streambank stabilization on a small trout stream
by Walter Virgil McClure

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Fish and Wildlife Management
Montana State University

Abstract:
In a 1.4-km study area of Deep Creek, Montana, during spring 1988, the badly eroded outer (current-bearing) banks of six stream bends were revetted with rock (riprap), six similar banks were revetted with juniper trees, and six such banks were left untreated as controls. Before and after treatment, physical variables of the stream were measured and the trout population was inventoried. Hiding cover for trout changed significantly 8 months after treatment: a mean increase of 195% in bends revetted with trees and a mean decrease of 36% in riprapped and control bends. In that period, no significant changes had developed in amount of pool habitat, in channel width, or in water depth. Stock densities and standing crops of brown and rainbow trout >20 cm long decreased throughout the study area due to drought and irrigation dewatering, but abundance of trout <10 cm long recovered to pre-treatment levels by October 1988 in tree-revetted and control bends. Stock densities of trout decreased significantly in riprapped bends between March and June 1988. There were no significant differences in abundance of trout between the two treatments or the treatment and control bends during March, June, and October 1988. Extreme low flow affected trout populations more than the habitat manipulations.

The main source of streambank erosion observed was mass wasting fracture caused by attached ice shelves during spring thaw. Riprap and tree revetment provided structural integrity and greatly reduced such erosion. Stabilizing streambanks with tree revetments has advantages over riprap because it immediately increases hiding/security cover for trout, traps sediment which serves as soil for natural reestablishment of live vegetation, and eventually decomposes allowing restoration of more natural and functional streambanks.

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A thesis submitted in partial fulfillment
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APPROVAL

of a thesis submitted by

Walter Virgil McClure

This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

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ABSTRACT

In a 1.4-km study area of Deep Creek, Montana, during spring 1988, the badly eroded outer (current-bearing) banks of six stream bends were revetted with rock (riprap), six similar banks were revetted with juniper trees, and six such banks were left untreated as controls. Before and after treatment, physical variables of the stream were measured and the trout population was inventoried. Hiding cover for trout changed significantly 8 months after treatment: a mean increase of 195% in bends revetted with trees and a mean decrease of 36% in riprapped and control bends. In that period, no significant changes had developed in amount of pool habitat, in channel width, or in water depth. Stock densities and standing crops of brown and rainbow trout ≥20 cm long decreased throughout the study area due to drought and irrigation dewatering, but abundance of trout <10 cm long recovered to pre-treatment levels by October 1988 in tree-revetted and control bends. Stock densities of trout decreased significantly in riprapped bends between March and June 1988. There were no significant differences in abundance of trout between the two treatments or the treatment and control bends during March, June, and October 1988. Extreme low flow affected trout populations more than the habitat manipulations. The main source of streambank erosion observed was mass wasting fracture caused by attached ice shelves during spring thaw. Riprap and tree revetment provided structural integrity and greatly reduced such erosion. Stabilizing streambanks with tree revetments has advantages over riprap because it immediately increases hiding/security cover for trout, traps sediment which serves as soil for natural reestablishment of live vegetation, and eventually decomposes allowing restoration of more natural and functional streambanks.

INTRODUCTION

This study was undertaken to evaluate physical and biological effects of two methods of reinforcing stream banks against erosion: revetment with rock (riprap) and with trees. Streambank erosion is a natural process, the rate of which can be influenced by human activities or natural events that change interrelated variables controlling channel shape (Heede 1986; Henderson 1986; White 1973). Where streambank erosion occurs, people often take actions to counter it for protection of property and resource values (Rosgen and Fittante 1986).

Riprap is a common method for stabilizing banks. If properly constructed, riprap not only retards erosion, but also creates overhead hiding and resting niches for trout (White and Brynildson 1967; Binns 1986), provides habitat for benthic invertebrates (Henderson and Shields 1984), and causes deepening of pools (British Columbia Ministry of Environment 1980). Deeper pools benefit trout (Elser 1968). In Huff Creek, Wyoming, trout abundance increased from 36 to 436 trout per mile (1100%) after 3,760 feet of eroding streambanks were stabilized with riprap, check dams and other instream structures (Pistono 1986). In the

Upper Mississippi River, Farbee (1986) found more warmwater fish in areas loosely revetted with stones than in areas revetted with tightly placed smaller stones. Thurow (1987), however, reported lower densities of rainbow trout in riprapped sections than in unaltered sections of the Big Wood River, Idaho.

White and Brynildson (1967) recommended that felled trees be used as trout cover and to stabilize current-bearing stream banks. They described methods they had observed, envisaged, or that had been described by others (R.J. White, pers. commun. 1989). Later, this general method was further developed in the field by various agencies, particularly the U.S.D.A. Forest Service (Pistono 1986).

Tree revetment is now widely used to stabilize streambanks, to provide cover for trout, and to cause silt deposition as sites for willow establishment along banks (Sheeter and Claire 1989). Binns (1986) recommends using green, thickly branched conifers because they provide maximal silt trapping, suitable cover for trout, and attachment surfaces for benthic macroinvertebrates. Pistono (1986) found that tree revetments increased trout habitat quality and trout numbers in Wyoming streams. Sheeter and Claire (in Reeves and Roelofs 1982) reported that whole juniper trees halted bank erosion in Oregon.

The objective of this study was to evaluate changes in physical characteristics of the stream provided by riprap and tree revetments and responses of the trout population to these changes. The hypothesis was that the revetments would provide cover for fish and would narrow and deepen the stream channel, thus improving habitat and leading to greater trout abundance.

DESCRIPTION OF STUDY AREA

Deep Creek, which flows through Broadwater County in central Montana, originates on the north slope of Grassy Mountain in the Big Belt range. It flows westward about 36 km to the Missouri River, 4 km south of the town of Townsend. In this area, average annual precipitation during 1978 to 1988 was 34 cm, most of which occurred between February and June. However, for 1987 and 1988, these amounts were only 19 and 25 cm, respectively. There were irrigation diversions upstream from the study area, which severely reduced the amount of water in the stream each summer.

The study area comprised about 1,400 m of the creek in Section 2, Township 6 North, Range 2 East (Figure 1) on a ranch that was owned by Mr. and Mrs. Ray Goodwin of Helena, Montana, until the winter of 1988-89, when it was bought by the Leslie L. Schipman family. When the study began in 1986, the ranch was run as a grain farm by the Goodwins' daughter and son-in-law, after having been converted from a cattle operation about three years before.

This part of the stream had been chosen in 1984 as a study area because many of the current-bearing (outer or concave) banks of its meander bends were high, steep, and composed of raw soil. The site was also chosen because the riparian area was not grazed by livestock. On both sides of the stream, fences paralleled the approximate mean alignment of the channel. The fences were about 90 m apart and in most places were well outside the riparian

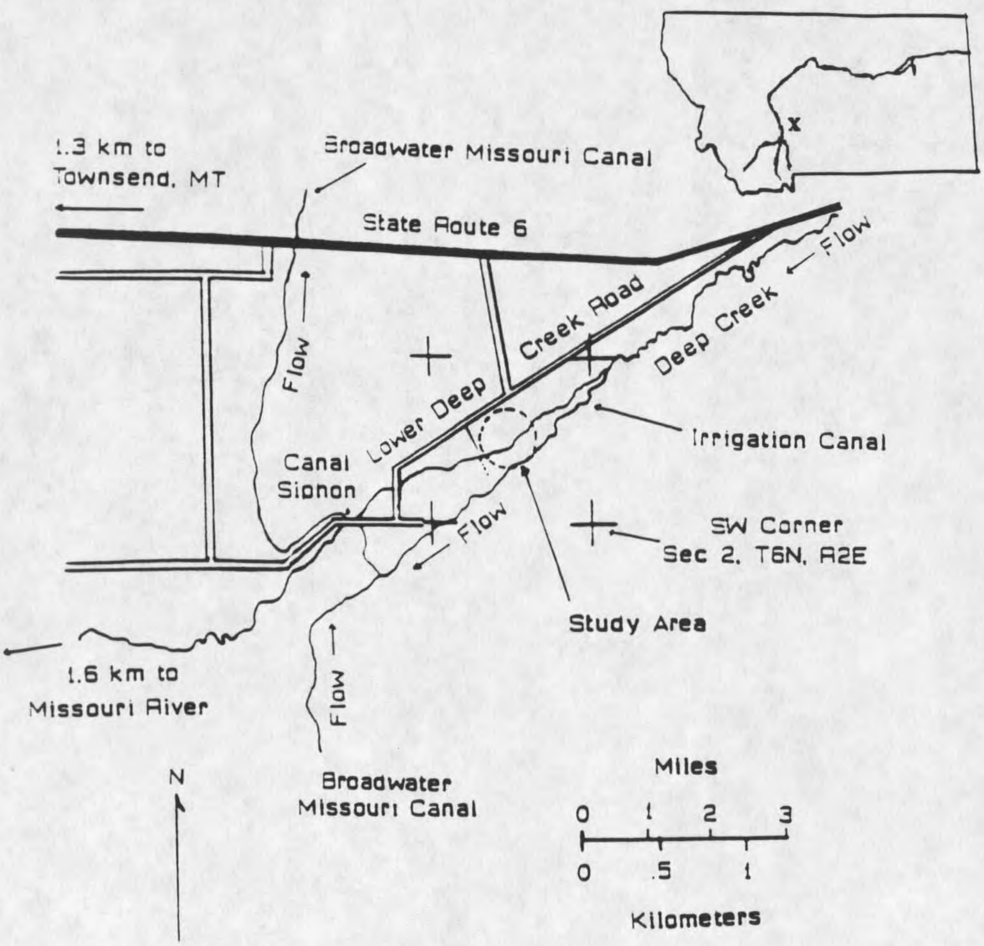

Figure 1. Location of Deep Creek study area relative to local features.

vegetational zone. At one bend, the channel had migrated laterally to within two meters of the fence. Had the stream not become incised (probably due to grazing and other human influence) and had it retained its natural form, the riparian vegetational zone probably would have been wider than the area bounded by the fences. The area between the fences had not been used as pasture since about 1983.

The tops of most of the high, eroded banks were vegetated with orchard grass (Dactylis glomerata) and smooth brome (Bromus inermus). The inside (convex) banks usually were lower, had moister soils, and had thickets of brush upslope from the point bars of gravel or other sediment. Woody vegetation in the study area included willows (Salix sp.), dogwood (Cornus stolonifera), water birch (Betula occidentallis), common snowberry (Symphoricarpos albus) and black cottonwood (Populus trichocarpa).

The stream's water was apparently rich in nutrients. A thick, limey crust and algal growth covered the streambed rocks.

The fish population of Deep Creek included rainbow trout (Oncorhynchus mykiss), brown trout (Salmo trutta), mountain whitefish (Prosopium williamsoni), longnose dace (Rhinichthys cataractae) and sculpin (Cottus sp.).

METHODS

General Approach

The centerline length of the channel was measured and the study area marked off into 100-m reference stations. The reference stations were numbered from 0 at the lower end to 14 at the upper end. Each 100-m "station" segment was identified by the number of the marker at its upper end. Mean wetted width of each station was determined by averaging waterline-to-waterline measurements made at 10-m intervals during streamflow discharge of about 285 L/s.

In August 1987, 18 channel bends that had areas of highly eroded, current-bearing banks were located and assigned numbers. The up- and downstream limits of the erosional or current-bearing zone of each of these bends were marked with stakes and the channel centerline length of each was measured. Six of the bends were selected to be revetted with riprap, six were selected for revetment with cabled trees, and six were assigned as untreated controls (Figure 2). A random method was used for this selection, except that the two bends farthest upstream were designated as controls, so that at least two sites would remain unaffected by sediments that might flow from treatments.

During April and May 1988, riprap (236 m total length) and juniper-tree revetment (211 m total length) were installed on the banks designated for these treatments. The six control bends contained 219 m of current-bearing bank (Table 1). To monitor changes, fish populations and physical characteristics of the 18 channel bends were measured before and after treatment.

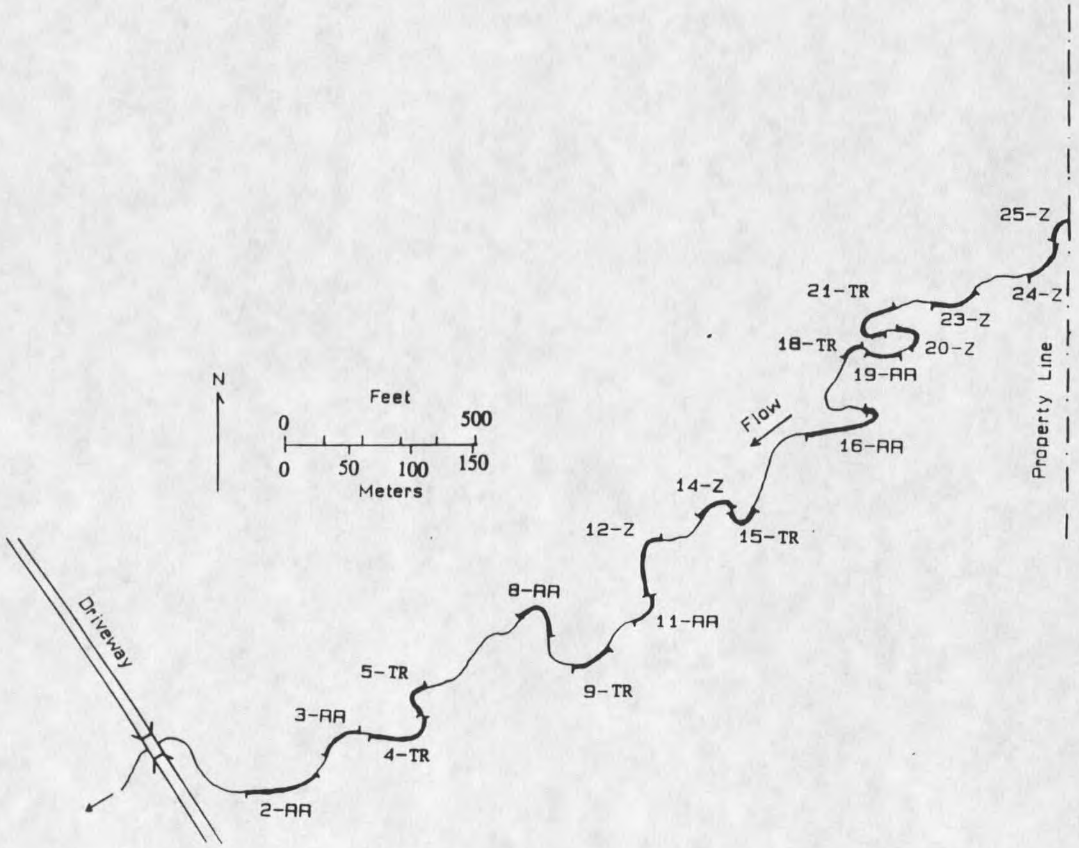

Figure 2. Deep Creek study area, numbers refer to stream bends studied RR = riprap, TR = tree revetment, Z = control.

Table 1. Treatment and length of study bends in the 1.4-km study area of Deep Creek, Montana.

Treatment Bend	Length (m)
Tree Revetment	
4	60
5	32
9	28
15	43
18	14
21	34
Riprap	
2	60
3	29
8	50
11	29
16	46
19	22
Control	
12	68
14	23
20	20
23	58
24	29
25	21

Construction of Revetments

Riprap

In April 1988, the current-bearing banks of bends 2, 3, 8, 11, 16, and 19 were riprapped with angular (blast-quarried) limestone from the Continental Lime Company quarry west of Townsend. The stone was selected in consultation with Dr. David W. Mogk, Montana State University Earth Sciences Department. Dr. Mogk had special expertise in determining suitability of rock for construction purposes, including riprap. The limestone was of a hard, fine-grained structure considered by Dr. Mogk to have low water absorption, hence low susceptibility to freeze-shattering.

The steps in riprap construction were as follows: (1) uneven or overhanging parts of the bank were sloped back to about a 1:1 to 1:1.5 grade with a backhoe; (2) rocks of about 1 m diameter were placed on the stable (armored) stream bed along the toe of the bank; and (3) smaller (ca. 20-80 cm) rocks were arranged blanket-fashion along the length of the bank above this foundation. Finished face slope of the riprap was about 1:1 to 1:2, except that the large rocks at the toe of each structure formed a much steeper (or overhanging) and very irregular face. The riprap blankets were 1 m or more in thickness at the base and tapered to about 0.5 m thickness near the top of the bank (Figures 3 and 4).

Although it is standard practice to key such riprap about one half meter into a "toe trench" that is dug into the streambed, approval not to make such a trench was obtained from the Broadwater Conservation District, which administers stream alteration permits, and from its advisers in the USDA Soil Conservation Service. Instead, the large foundation rocks were laid directly on the stream bed because the bed was already well armored with large stones. The resulting, unkeyed structure was more likely to have overhanging rock elements that would provide cover for trout.

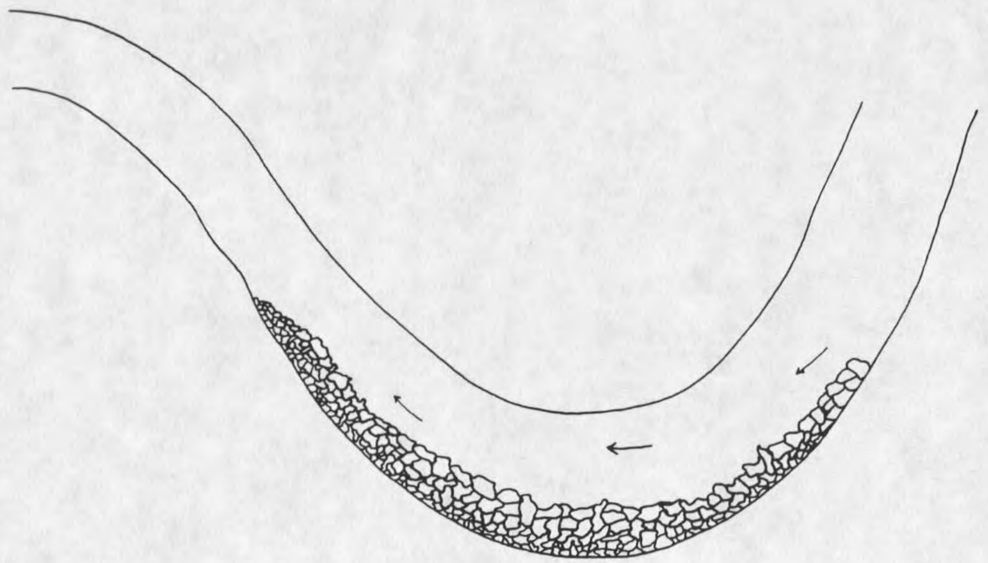

Figure 3. Typical Deep Creek bend after installation of riprap.

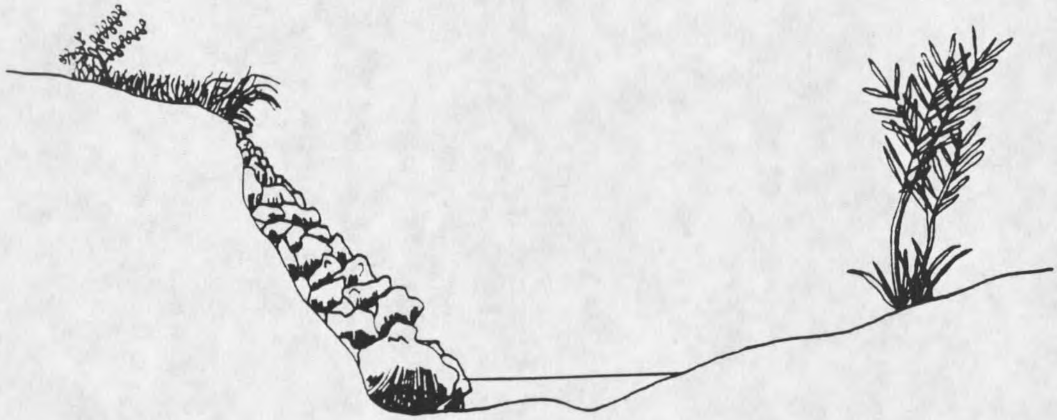

Figure 4. Cross section of riprap revetment. Typical thalweg was 25-30 cm at "normal" low flow (285 L/s).

Tree Revetment

During April and May 1988, bends 4, 5, 9, 15, 18, and 21 were reveted with Rocky Mountain juniper trees (*Juniperus scopulorum*). The trees averaged 5-10 m in length, and most were about 15 to 20 cm diameter at the butt. The trees were laid in an overlapped (1/3 to 1/2 of tree length), thatch-like manner, with the butt ends pointed upstream and somewhat upslope along the bank (Figures 5, 6, 7). Trees were anchored to the streambank and bed by drilling two 1.9 cm holes through each trunk, then driving steel reinforcement rods (rebar) of 1.9 cm

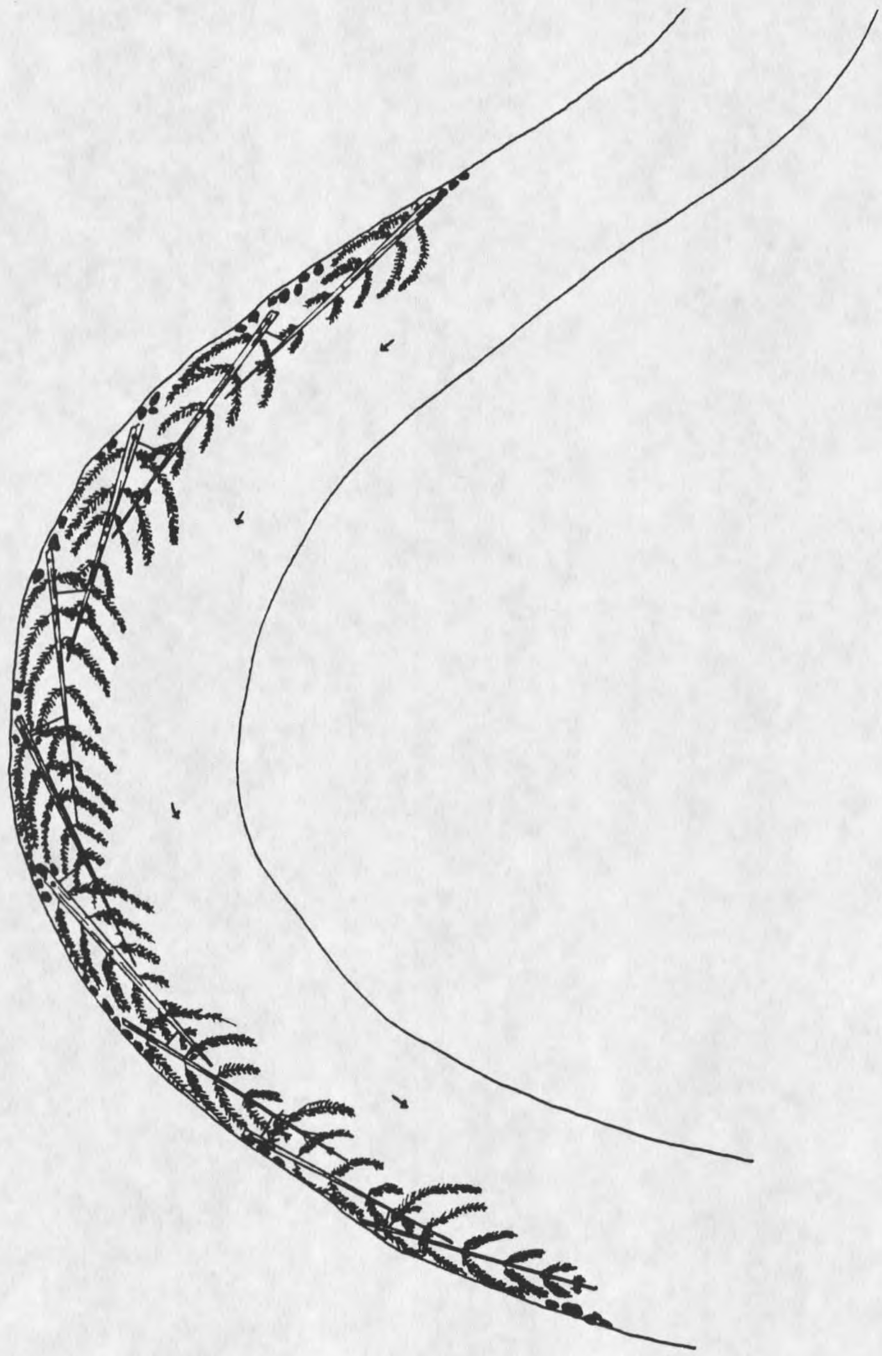

Figure 5. Typical Deep Creek bend after installation of tree revetment.

diameter and about 1.5 m in length through the holes and into the bank with a pneumatic hammer until the amount of bar remaining above the trunk was about 20 cm, which was then bent over (clinched) at about a 90 degree angle (Figures 6 and 7). Some small rock was back- filled between the trees and eroded bank as added reinforcement.

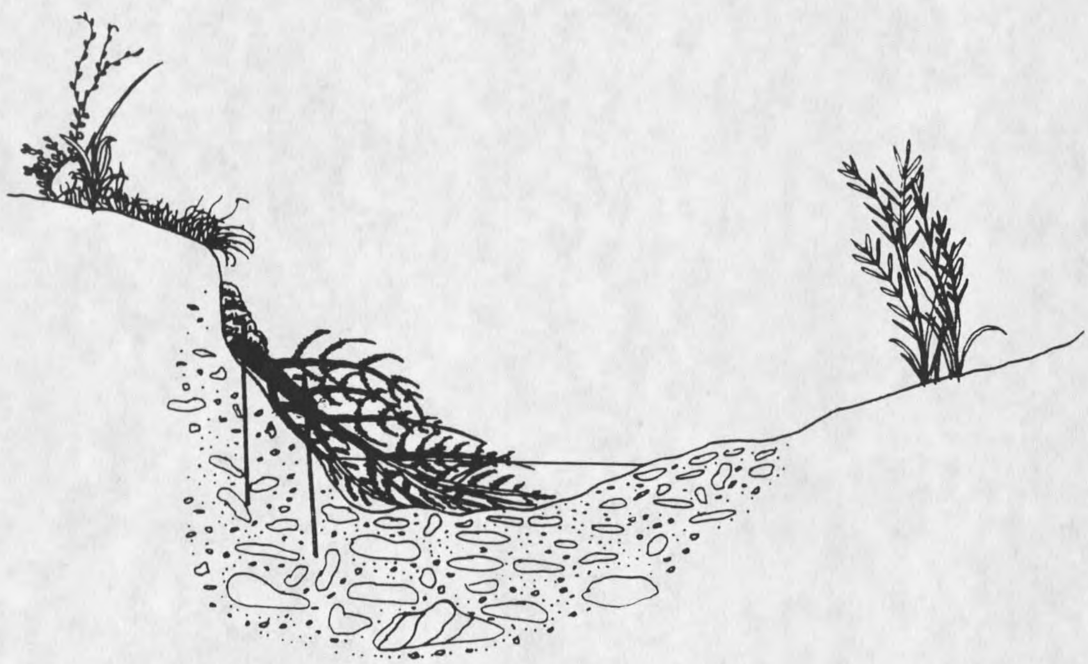

Figure 6. Cross section of tree revetment.

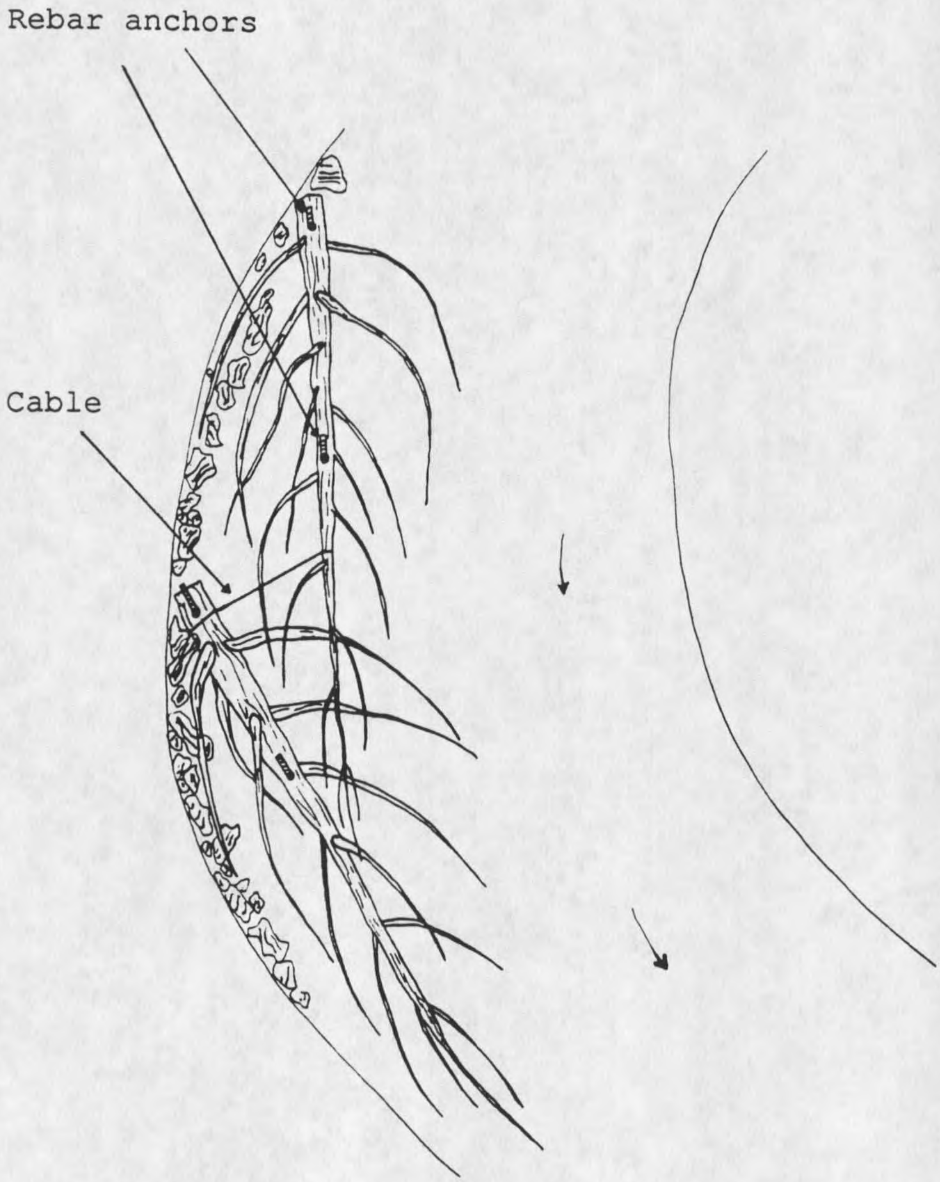

Figure 7. Top view of tree revetment, showing system of rebar anchors, cabling, and rock backfill.

Measurement of Physical Characteristics

Physical characteristics of the study bends were measured along 11 or more cross sections (transverse transects) in each study bend on September 13 to November 8, 1987 and from July 2 to August 5, 1988. Cross section sites were chosen by dividing the centerline length of each bend into 10 equal intervals and placing a transect at each division point. To describe cross-sectional profiles of the channel bed and banks, we measured the horizontal locations and elevations of (1) the edges of permanent vegetation, which defined the "active channel width", (2) water lines (intersection of water surface with banks) which defined the "wetted width", (3) low point (thalweg) of the bed, (4) toe of the current-bearing bank, (5) top of the high bank, (6) crest of the high bank, and (7) bank and channel-bed profile points at 0.5-m intervals from beyond both banks (Figure 8). Elevations were measured with a Lietz model C3E automatic-leveling surveyor's level and stadia rod to the nearest 0.01 foot, then converted to meters. At each point of measurement, the dominant type of streambed material was visually determined as soil, mud, sand, gravel, rubble, rock (boulder), or vegetation. Thus, for most bends, there were 11 transects: one at each end and nine interior transects. The transect lines were marked with wooden stakes on both sides of the channel. A measuring tape was stretched between the stakes to determine locations of the bed and profile points that were described in the

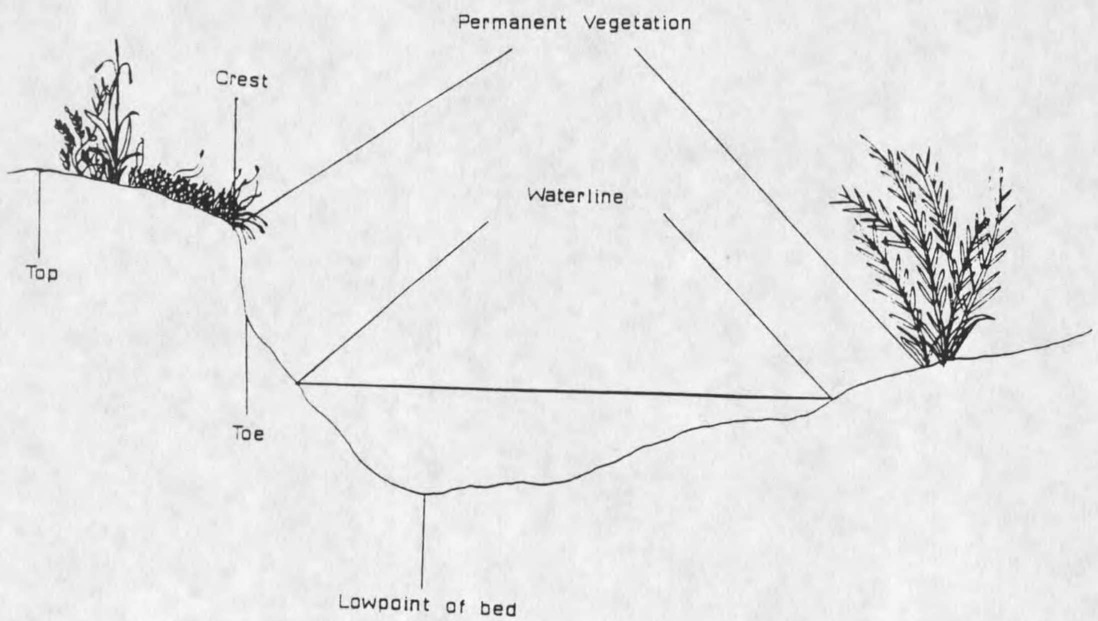

Figure 8. Channel transect features measured in Deep Creek.

measurements. The network of transect end points was surveyed for elevation and horizontal position with an EDM transit under direction of D. A. Tyler, MSU Civil Engineering Department.

Mean water depths and wetted channel widths were calculated at a 285 L/s discharge with the Army Corps of

Engineers HEC-II computer program. The HEC-II program calculates water surface elevations based on channel cross sectional profiles and discharge.

The amount of hiding/security cover available for trout was measured (at a discharge of about 285 L/s) on March 29, 1988 in each study bend immediately before structures were installed and again on November 12, 1988, which was about 8 months after treatment. Hiding/security cover was defined as pools and as any object offering at least a 10-cm overhang, the overhang having water of at least 15 cm depth beneath it and being not higher than 50 cm above the water surface. Pools were defined as those parts of the stream having water depth of at least 40 cm and having slow water velocities in relation to areas immediately up-and downstream. Pool and other cover measurements were made with a 2-m range pole, divided into a 5-cm scale.

For recording streamflow discharge, a porcelain staff gauge was installed at the downstream end of the study area and calibrated by measurement of streamflow discharge at different stages with the Montedoro-Whitney water velocity meter. Staff gauge stage readings were recorded at the start and end of each day during which field work was done on the stream.

Measurement of Trout Populations

Two methods were used to inventory the trout populations. For estimating trout abundance throughout the study area, mark-and-recapture (Petersen-method) population estimates were made in October 1986, June 1988, October 1988, and April 1989. To inventory trout in each of the 18 study bends, multiple removal estimates (Zippin method) were made during March, June, and October 1988. All sampling of fish was by electrofishing with a 220-volt alternator, rectified by a Coffelt model VVP-15 control unit to unpulsed DC, and operated at about 175-200 volts. The electrofishing gear was mounted in a small flat-bottomed boat, pulled upstream by one person. Two other crew members waded upstream ahead of the boat, each with a hand-held positive electrode and a handnet. The negative electrode was attached behind the boat. Captured trout were anesthetized with MS-222 (tricane methanesulfonate), measured to the nearest millimeter (maximum total length), and weighed to the nearest gram.

Mark-recapture Population Estimates

The mark-recapture electrofishing of the entire study area was done by double-run electrofishing. The lower corner of the caudal fin was clipped on the first run, and the fish were released near the downstream end of the section from which they had been caught. To allow the fish to recover from the fatigue of being electroshocked, captured, and handled, an interval of at least two days was maintained between marking and recapture runs.

For estimates of trout populations, the data were stratified according to species and length class, and within each class we applied the Chapman modification of the Petersen formula (Ricker 1975):

$$N = \frac{(M+1)\quad(R+U+1)}{(R+1)} - 1$$

where N is the population estimate, M is the number of fish marked on the first run, R is the number of marked fish recaptured on the second run, and U is the number of unmarked fish captured on the second run. Length classes were chosen so as to maintain similarity of recapture rates (R/M) within class. The estimates for each length class were then reapportioned by centimeter group according to the distribution of M+U among the centimeter groups. M+U is the total of initial captures of fish during the electrofishing. For the mark-recapture estimates, 95% confidence intervals were calculated according to Ricker (1975).

Biomass was calculated by multiplying the estimated number of fish in each centimeter group by mean body weight of fish in that group, as determined graphically from the length-weight relationship of all unmarked fish.

The biomasses of the centimeter groups were summed to obtain population biomass. Linear standing crop (kg/km) and linear stock density (trout/km) were calculated.

Multiple-removal Population Estimates

The Zippin-method population estimates were made by using three- and four-pass removal electrofishing. The upper end of each stream bend was blocked with a net during electrofishing. Fish caught on each pass were measured as previously described, then held in separate nets until the last pass had been completed. The second and subsequent passes were made immediately after the preceding pass had ended. Fish were released near the lower end of each bend after all passes for that bend and the associated fish processing had been finished.

Calculation of population estimates and confidence intervals were made by using the (FPSP-A1) computer program that calculates Zippin population estimates using a removal-depletion maximum-likelihood formula (Platts et al. 1983). Zippin population estimates were calculated by the equation:

$$N = \frac{T}{\hat{Q}}$$

Where N = the population estimate; T = total number of fish captured; and $\hat{Q}$ = estimated proportion of the population that has been captured during all the removal runs. $\hat{Q}$, the population estimate, and confidence intervals were calculated by using the FPSP-A1 computer program described in Platts et al. (1983).

Statistical Analyses

Statistical analyses were performed using programs described in MSUSTAT (Lund 1987) under the direction of M. A. Hamilton, MSU Department of Mathematical Sciences. I used paired-T tests to compare pre- and postconstruction water depths, channel widths, and trout abundance in the study bends. One-way analysis of variance was used to test for differences between treatments in the amount of change in mean widths, mean depths, and cover after construction of revetments. One-way analysis of variance was also used to compare mean stock densities and standing crops of trout between the treated and control bends and to compare differences between treatment changes in stock densities and standing crops before and after construction of revetments.

RESULTS AND DISCUSSION

Streamflow Discharge

Severe drought prevailed during the study. Precipitation in the Townsend, Montana, area was 74% of the long-term average in 1987 and was only 55% of average in 1988 (NOAA 1988). Low natural discharge and diversion of water from Deep Creek for irrigation during the summers of 1987 and 1988 (Figure 9) undoubtedly caused mortality and movement of trout from the study area. In 1988, the study area was completely dewatered in early August, but flow persisted in parts of Deep Creek upstream from the study area (Ray J. White, personal observation).

Changes in Cover and Pools

Tree revetment immediately caused large increases in hiding cover for trout, but cover decreased slightly in riprapped and control bends. As measured in November 1988, about six months after installation, the overhead (non-pool) cover density (square meters of cover per meter of channel) in tree-revetted bends had significantly increased ($p = 0.02$) to 1.24 m^2/m (range 0.59-1.56) from a pre-treatment (March 1988) mean of 0.42 m^2/m (range 0.07-

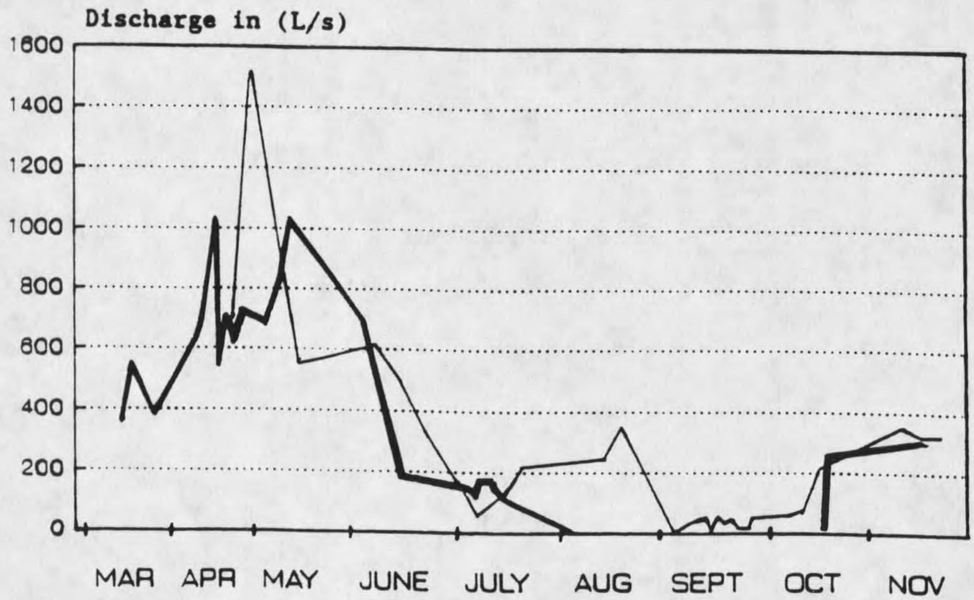

Figure 9. Flow discharge (Liters/second) of Deep Creek, Montana measured at the downstream end of the study area during 1987 = —— and 1988 = ▬▬ .

0.67), an average increase of 0.82 m^2/m or 195% (Appendix Table 11 and Figure 10). Among the six tree-revetted bends, the changes in cover density were all positive and ranged from 62% to 2075% (Appendix Table 11). As expected, the branches and foliage of the juniper trees used in revetment simulated submerged streamside brush and created large amounts of overhead cover.

In contrast, despite efforts to maximize overhead cover when positioning rocks during riprap construction, cover density in riprapped bends fell from a pre-treatment mean of 0.25 m^2/m (range 0.06-0.61) to 0.17 m^2/m (range 0.02-0.47) at six months post-treatment, an average

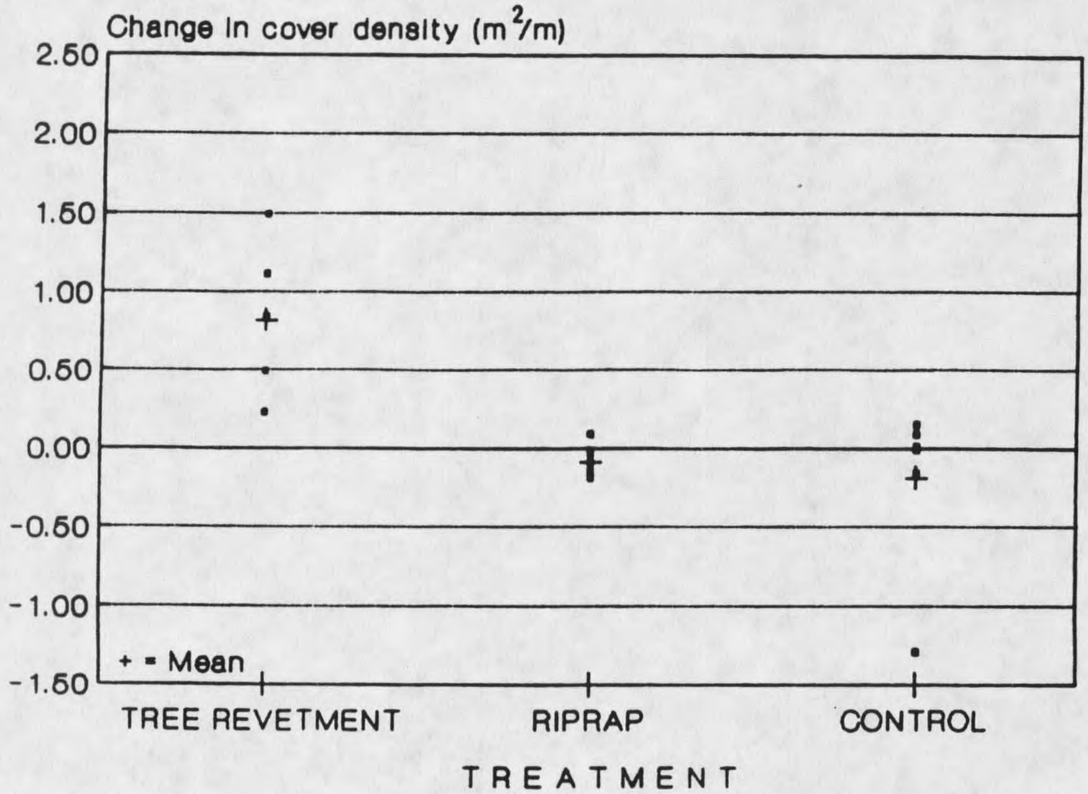

Figure 10. Pre-to-post-treatment changes in overhead (non-pool) cover density (m^2 of cover per m of channel) in study bends of Deep Creek, Montana (measured in March and November 1988) (+ = mean change in overhead cover density).

decrease of 0.09 m^2/m or 36% (Appendix Table 11, Figure 10). The decrease in overhead cover in riprapped bends was not statistically significant ($p = 0.08$). The proportional changes in cover density of riprapped bends ranged from 88% decrease to 72% increase (Appendix Table 11).

In untreated bends, the results resembled those in riprapped bends. Mean overhead cover density did not change significantly ($p = 0.41$) means were 0.53 m^2/m in March 1988 and 0.34 m^2/m in November, an average decrease of 0.19 m^2/m or 36% (Appendix Table 11 and Figure 10); the proportional changes ranged from 68% decrease to 100% increase (Appendix Table 11).

Change in overhead cover density was significantly greater in tree revetted bends when compared to riprapped and control bends ($p < 0.01$). However, the change in overhead cover density between riprapped and control bends was not significantly different ($p = 0.63$) (Table 2 and Appendix Table 11).

Table 2. P-values from ANOVA of between-treatment difference in the pre-to-post-construction changes in overhead cover density in study bends of Deep Creek, Montana (measured in March and November 1988).

Time and Treatment *	P-value
March to November	
TR vs. RR	< 0.01
RR vs. Z	0.63
TR vs. Z	< 0.01

* TR = tree revetment, RR = riprap, Z = control

The density of pools (square meters of pool per meter of channel) in tree-revetted bends, as measured in November 1988, had increased to 0.60 m^2/m (range 0.14 - 1.06) from a pre-treatment (March 1988) mean of 0.43 m^2/m (range 0.00 - 0.91), an average increase of 0.17 m^2/m or 40% (Appendix Table 12 and Figure 11). However, this increase was not statistically significant ($p = 0.11$). Among the six tree-revetted bends, the changes in pool density ranged from -16% to +1500% (Appendix Table 12).

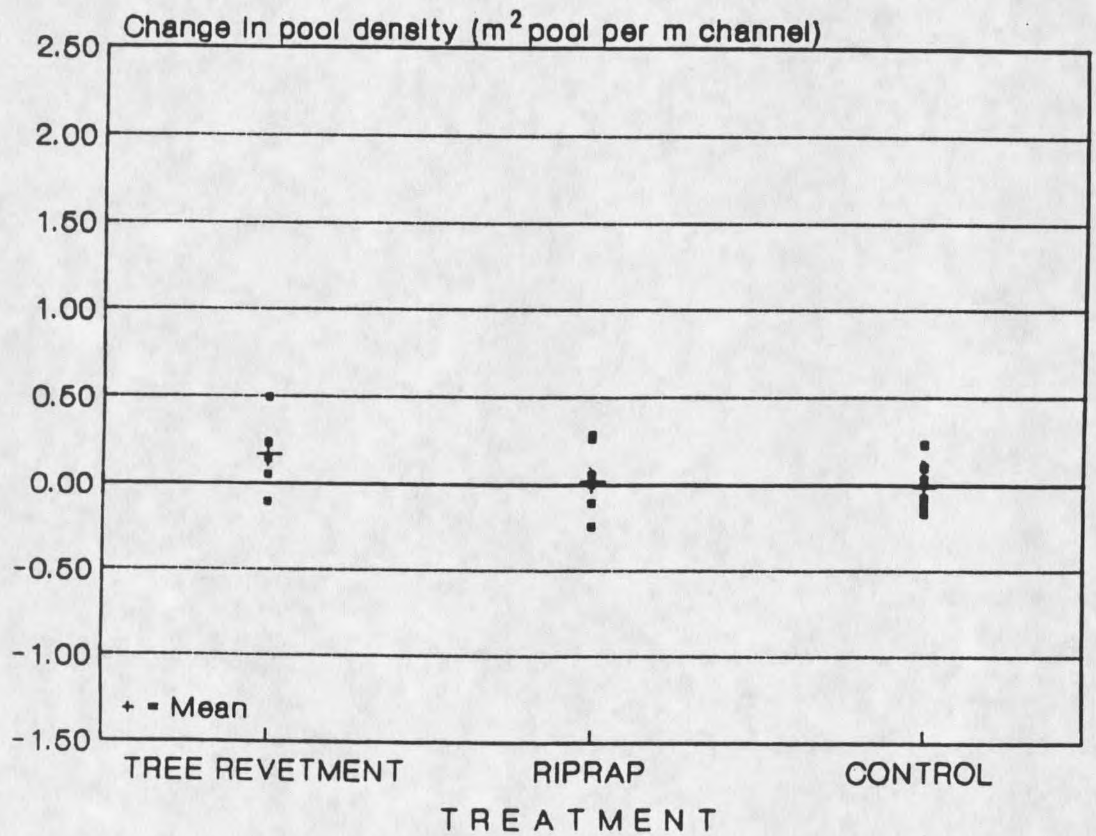

Figure 11. Pre-to-post-treatment changes in pool area per channel length (m^2/m) in treatment and control bends of Deep Creek, Montana (measured in March and November 1988) (+ = mean change in pool density).

In riprapped bends, mean density of pools remained essentially unchanged at 0.21 m^2/m (range 0.00 - 0.65) for the March 1988 pre-treatment measurement and 0.23 m^2/m (range 0.00 - 0.92) for the November post-treatment measurement; mean change was only 10% (Appendix Table 12 and Figure 11). The proportional changes of pool density in riprapped bends ranged from 100% decrease to 185% increase (Appendix Table 12). The change in pool density in riprapped bends was not statistically significant ($p = 0.66$).

The pool density in control bends also stayed about the same (a mean decrease of 0.01 m^2/m and range of -0.17 to +0.23), undergoing an insignificant ($p = 0.96$) 3% mean change between March and November 1988 (Appendix Table 12 and Figure 11). The proportional changes of pool density in control bends ranged from a 50% decrease to 500% increase (Appendix Table 12).

Change in pool density was not significantly different when comparing the treated bends or the treated bends and the control (Table 3 and Appendix Table 12).

When pools were included as cover in tree-revetted bends, the results were similar to changes in overhead cover alone. There was significant increase ($p = 0.01$) from the March estimate of 0.76 m^2/m (range 0.07 - 1.58) to the November estimate of 1.71 m^2/m (range 0.74 - 2.56), an average increase of 0.95 m^2/m or 125% (Appendix Table

13 and Figure 12).

Table 3. P-values from ANOVA of between-treatment difference in the pre-to-post-construction changes in pool density in study bends of Deep Creek, Montana (measured in March and November 1988).

Time and Treatment *	P-value
March to November	
TR vs. RR	0.21
RR vs. Z	0.71
TR vs. Z	0.16

* TR = tree revetment, RR = riprap, Z = control

In riprapped bends, cover density (including pools) did not change significantly ($p = 0.70$). Means decreased only 16% from a pre-treatment mean of 0.51 m^2/m (range 0.06 - 1.10) to 0.39 m^2/m (range 0.02 - 1.13) at six month post-treatment (Appendix Table 13 and Figure 12). The proportional change of cover density (including pools) in riprapped bends ranged from a 85% decrease to a 61% increase (Appendix Table 13).

In control bends, I observed a similar pattern. Cover density (including pools) did not change ($p = 0.41$). Means of total cover densities were 0.93 m^2/m

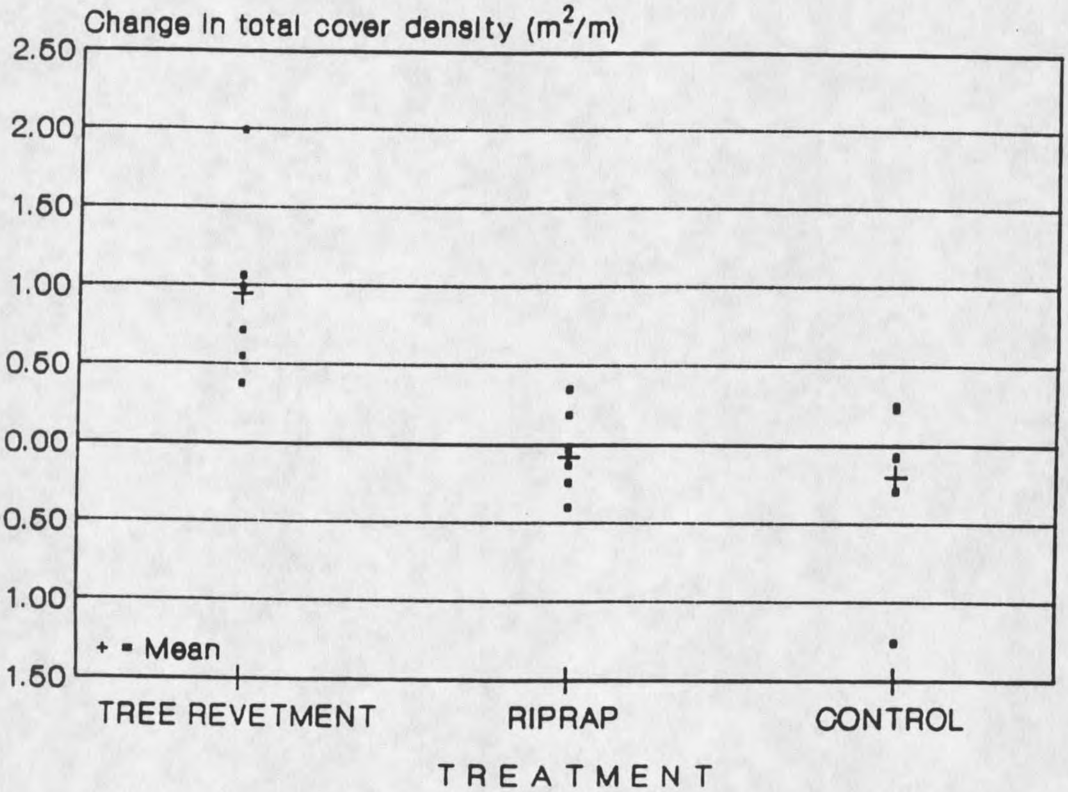

Figure 12. Pre-to-post-treatment changes in total cover (overhead cover and pool area) density (square meter of cover per meter of channel) in treatment and control bends, Deep Creek, Montana (measured in March and November 1988) (+ = mean change in total cover).

(range 0.23 - 1.89) in March 1988 and 0.73 m^2/m (range 0.19 - 1.36) in November 1988, an average decrease of 22% (Appendix Table 13 and Figure 12). The proportional change in control bends ranged from a 67% decrease to a 109% increase (Appendix Table 13).

Change in total cover density were significantly greater in tree revetted bends when compared to riprap bends and control bends ($p < 0.01$). However, the change in total cover density between riprap and control bends was not significantly different ($p = 0.58$) (Table 4 and Appendix Table 13).

Table 4. P-values from ANOVA of between-treatment difference in the pre-to-post-construction changes and total cover density in study bends of Deep Creek, Montana (measured in March and November 1988).

Time and Treatment *	P-value
March to November	
TR vs. RR	< 0.01
RR vs. Z	0.58
TR vs. Z	< 0.01

* TR = tree revetment, RR = riprap, Z = control

Changes in Width and Depth

Calculated at a streamflow discharge of 285 L/s (10 cfs), wetted width of the channel did not change significantly pre-to-post construction in any of the study bend types ($p = 0.59$ for tree revetment, $p = 0.14$

for riprap, and p = 0.40 for control). Also, there were no significant differences in the between-treatment amounts of change (p = 0.09 between tree and riprap, p = 0.08 between riprap and control, and p = 0.96 between tree and control) (Appendix Table 14 and Figure 13).

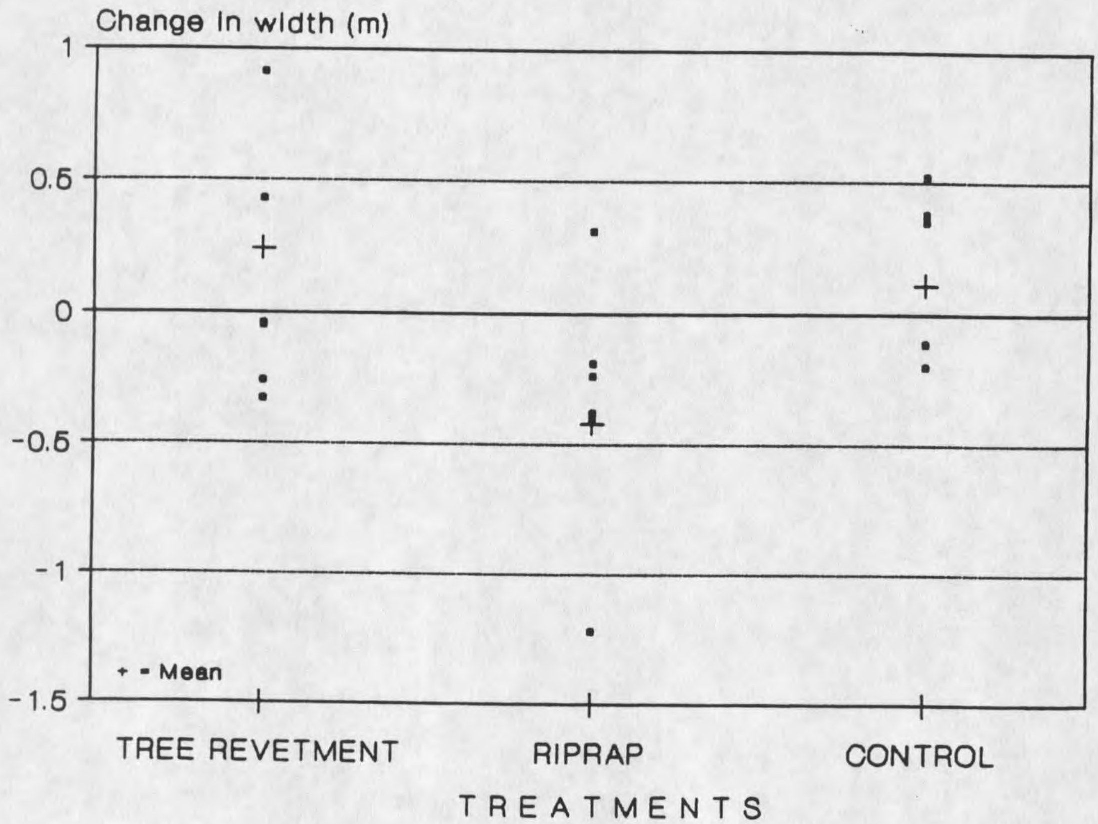

Figure 13. Pre-to-post-construction changes in mean wetted channel widths in revetted and unrevetted study bends at a calculated discharge of 285 L/s, Deep Creek, Montana (+ = mean change in channel width).

No significant difference in mean depth, calculated at 285 L/s, occurred between pre-and-post-construction in either the revetted bends or the controls (p = 0.66 for tree revetment, p = 0.14 for riprap, p = 0.45 for control). Also, there were no significant differences in the amount of change between the treatments (p = 0.77 between tree and riprap, p = 0.21 between riprap and control, p = 0.57 between cable tree and control) (Appendix, Table 14 and Figure 14).

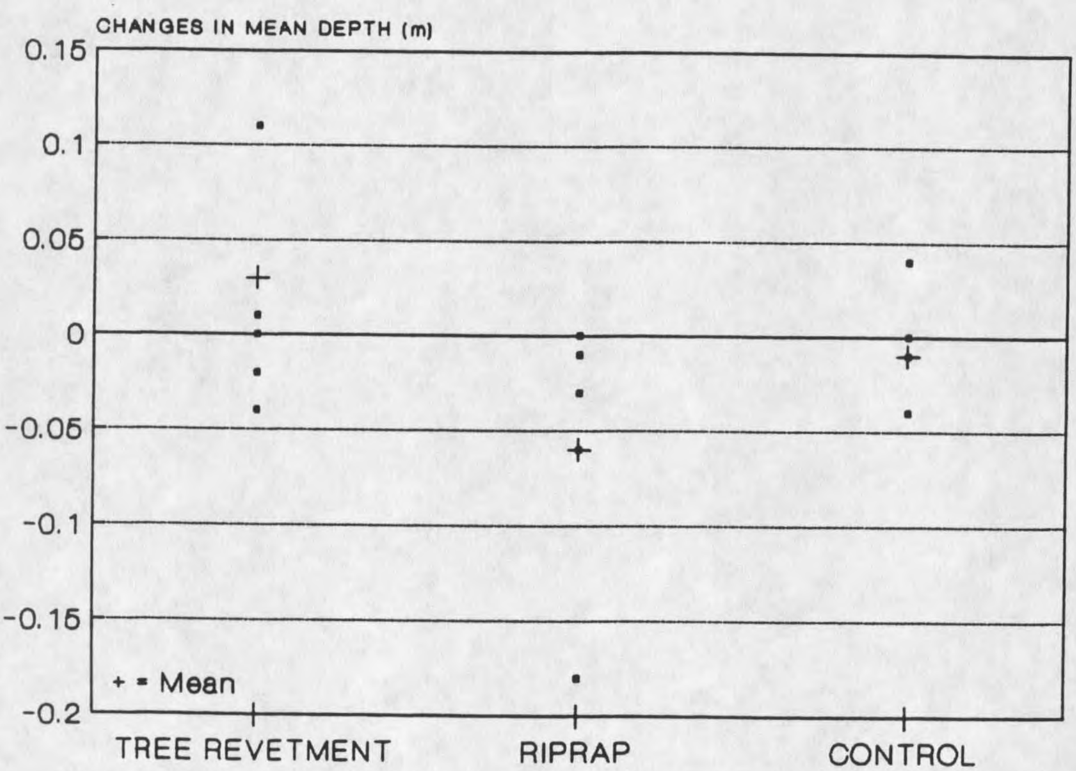

Figure 14. Pre-to-post-construction changes in mean depth in revetted and unrevetted study bends at a calculated streamflow discharge of 285 L/s, Deep Creek, Montana (+ = mean change in mean depth).

Rock revetments should deepen and narrow the channel by retarding lateral scour and promoting down cutting of the bed (British Columbia Ministry of Environment 1980). Tree revetments can also deepen and narrow the stream channel by increasing bed roughness and displacing the lateral erosion energy further downstream. The spring runoff of 1988 was probably abnormally weak and did not provide the erosive power to scour the channel deeper, but this may occur over time.

Trout Abundance

General Trends

During the study period, October 1986 to April 1989, trout abundance decreased in terms of both standing crop (Table 5 and Figure 15) and stock density (Table 6, Figure 16). The decrease was probably due mainly to severe low flow in 1987-88 and complete dewatering of the study area during early August to mid-October 1988 (Figure 9). The October 1988 standing crop of brown trout was about 18% of the October 1986 estimate (Figure 17), and standing crop of rainbow was about 25% of the 1986 estimate (Figure 18).

For both brown and rainbow trout, standing crop and stock density of small fish (< 10 cm) generally increased during the study and abundances of fish larger than 20 cm generally decreased (Tables 5 and 6). Trout less than

Table 5. Standing crop of trout (kilogram per kilometer of channel) in the 1.4-km study area of Deep Creek, Montana.

Size Class (cm)	Species	Standing crop (kg/km)			
		Oct 86	June 88	Oct 88	April 89
<10	brown	0.004	0.071	0.600	0.655
10-19	brown	2.430	3.931	2.160	1.271
≥20	brown	27.060	5.848	2.640	2.524
Total	brown	29.494	9.850	5.400	4.450
<10	rainbow	0.033	0.006	0.330	1.521
10-19	rainbow	3.190	7.156	1.330	1.444
≥20	rainbow	6.520	2.155	0.820	1.800
Total	rainbow	9.743	9.317	2.480	4.765
Total trout		39.237	19.167	7.880	9.215

10 cm in length were age 0 in fall and age I in springtime. Brown trout less than 10 cm in length made up less than 1% of the population in October 1986 and 75% in October 1988 (Table 6 and Figure 19). Young of the year rainbow trout made up 11% of the 1986 population and 68% of the population in October 1988 (Table 6 and Figure 20). Trout population estimates, standing crops, and stock

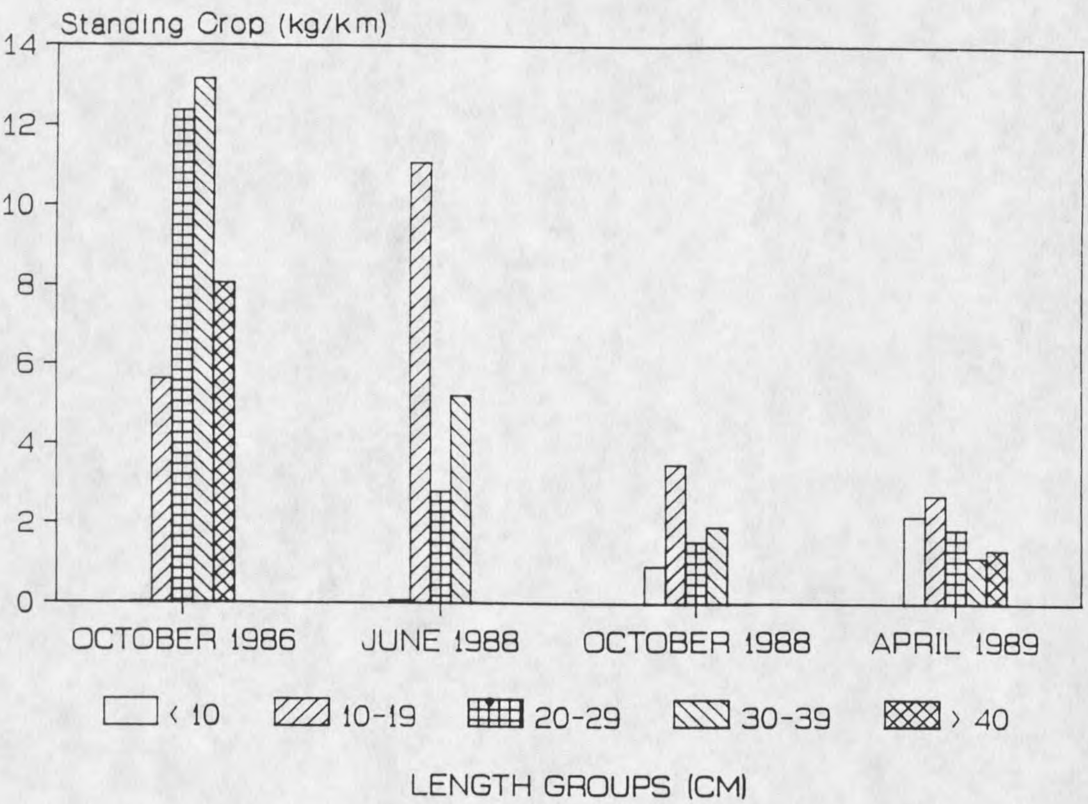

Figure 15. Standing crop (kg/km) of trout (brown and rainbow trout combined) in the 1.4-km study area of Deep Creek, Montana.

densities of the entire study area are in Appendix Tables 15-22.

Low natural discharge and diversion of water from Deep Creek for irrigation during the summers of 1987 and 1988 (Figure 9) undoubtedly caused mortality and movement of trout from the study area.

Small brown and rainbow trout rapidly recolonized the study area when flow resumed. Populations of trout larger than 20 cm had not recovered to 1986 levels by spring 1989 (Tables 5 and 6, Figures 15 and 16). Clothier (1953)

Table 6. Stock density of trout (fish/km) in the 1.4-km study area of Deep Creek, Montana.

Size Class (cm)	Species	Stock density (fish/km)			
		Oct 86	June 88	Oct 88	April 89
<10	brown	1	38	186	139
10-19	brown	44	123	49	85
≥20	brown	101	20	12	20
Total	brown	146	181	247	244
<10	rainbow	13	3	108	269
10-19	rainbow	62	253	44	54
≥20	rainbow	46	10	6	10
Total	rainbow	121	266	158	333
Total trout		267	447	405	577

observed that trout in irrigation ditches of the West Gallatin River, Montana, moved upstream when flows were reduced in the ditches. In Blacktail Creek, Montana, 90%

reduction in stream flow resulted in about a 75% decrease in stock density and upstream movement of brook

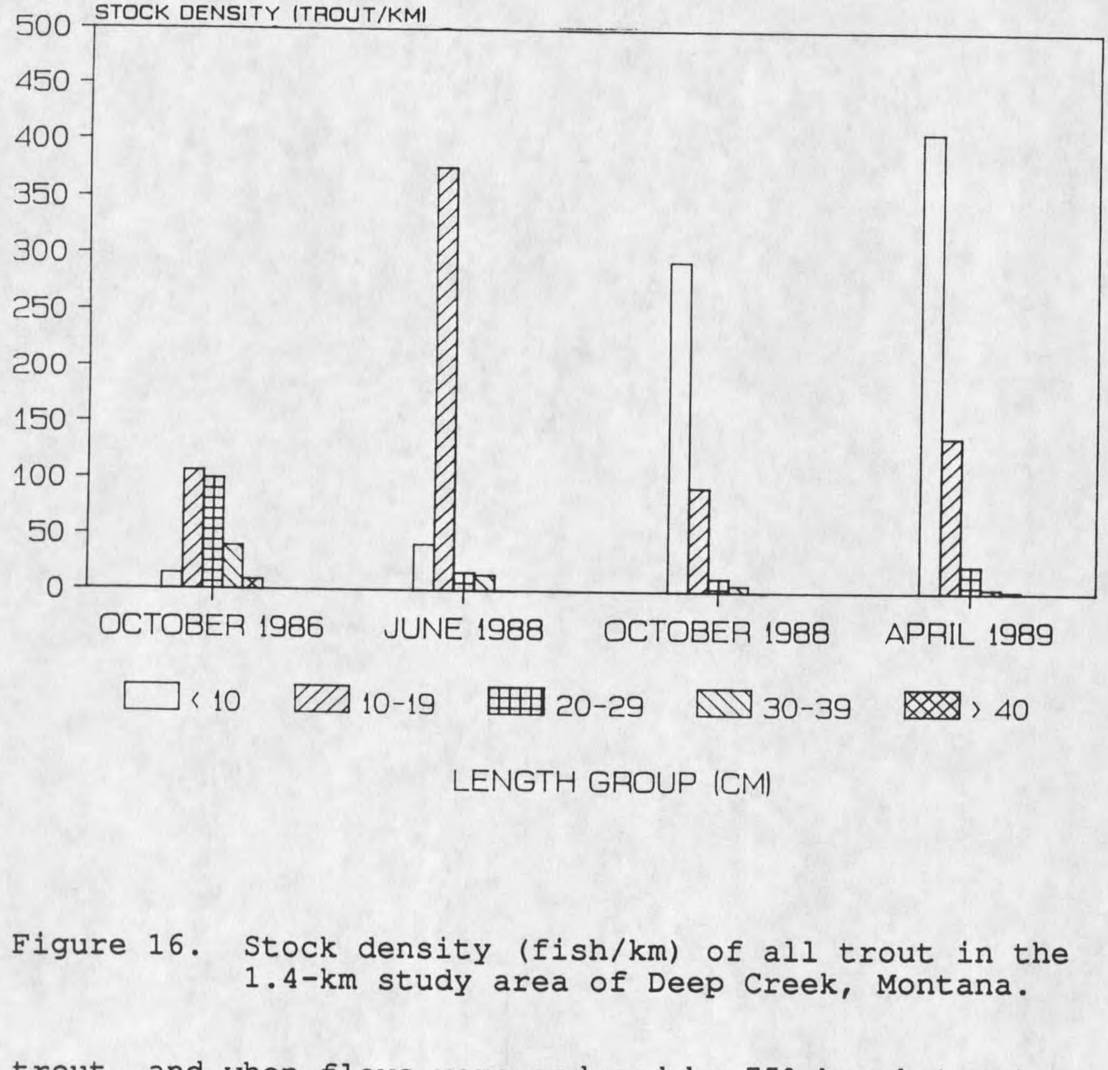

Figure 16. Stock density (fish/km) of all trout in the 1.4-km study area of Deep Creek, Montana.

trout, and when flows were reduced by 75% brook trout densities in runs decreased by 20%, representing a shift to pools (Kraft 1968, 1972). Thurow (1988) observed declines of rainbow trout populations in the Big Wood River, Idaho due to dewatering. During the several weeks when flow stopped in the Deep Creek study area in summer 1988 (early August to mid October), I observed small trout stranded in shallow, isolated pools and away from bankside

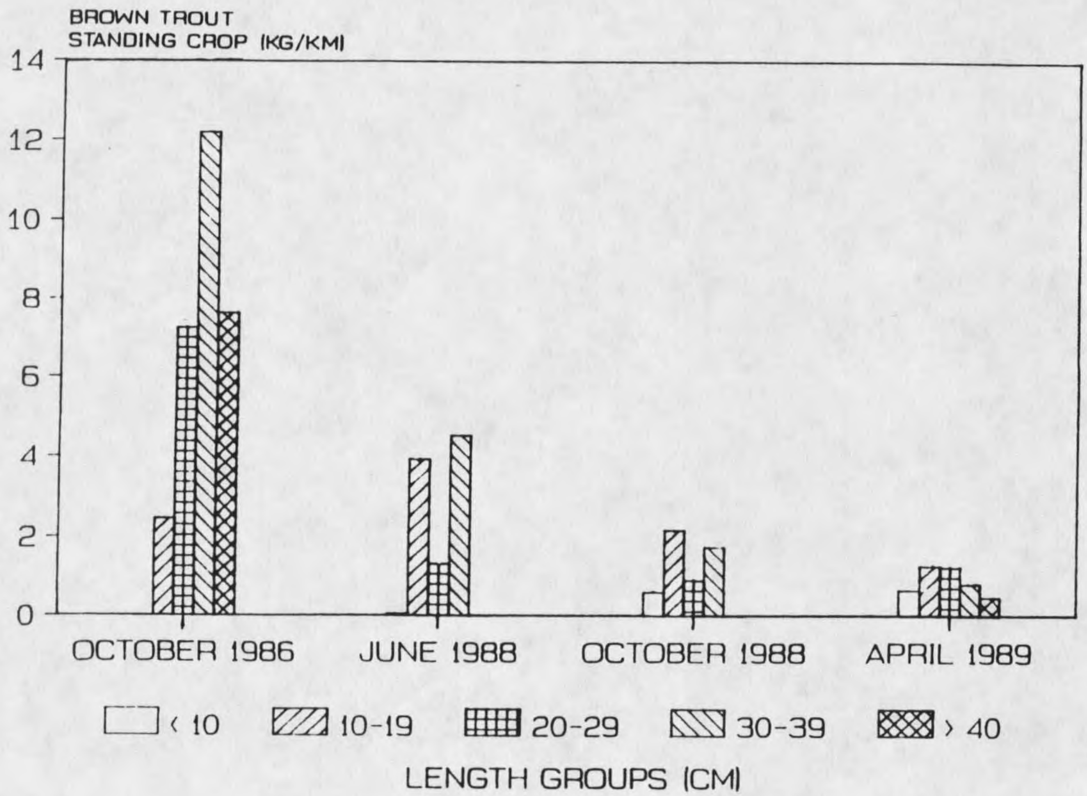

Figure 17. Standing crop (kg/km) of brown trout in the 1.4-km study area of Deep Creek, Montana.

hiding/security cover, which was dewatered. I noticed belted kingfisher (<u>Ceryle alcyon</u>) and great blue heron (<u>Ardea herodias</u>) fishing and inhabiting the stream section. On the day when flow first stopped, Ray J. White (personal communication) saw trout of about 15-30 cm in thermal or oxygen distress in residual pools and a mink dragging an over-30-cm brown trout away from one of the pools.

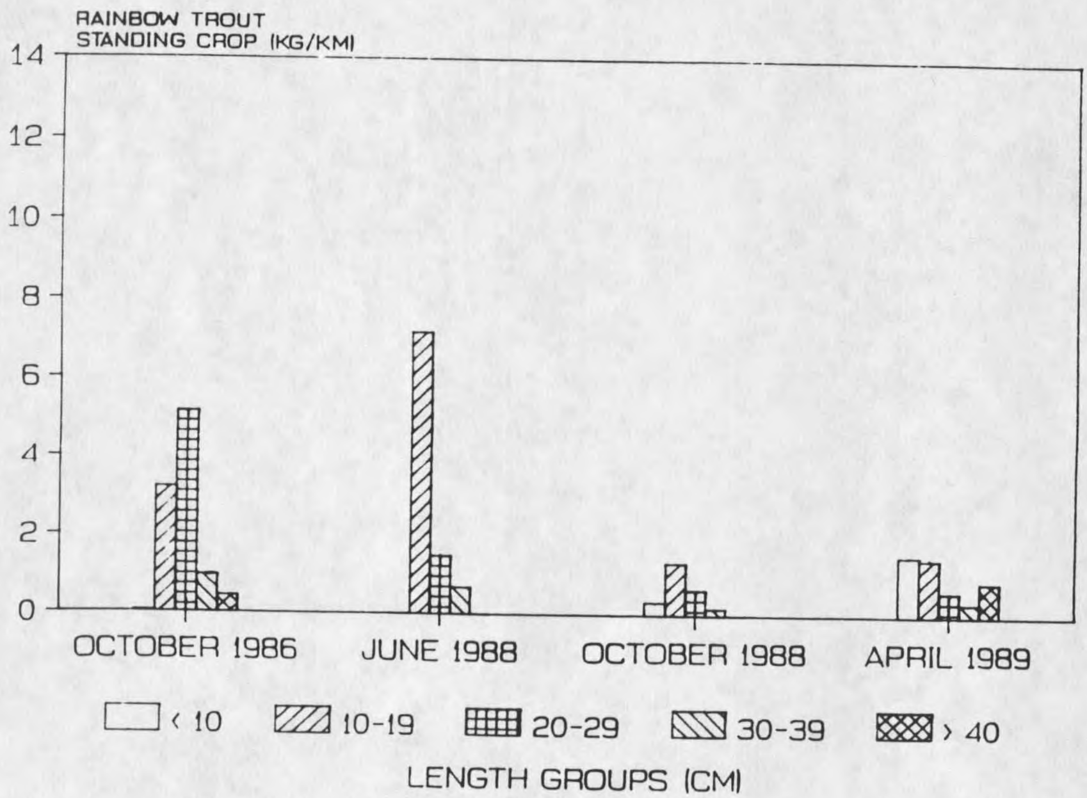

Figure 18. Standing crop (kg/km) of rainbow trout in the 1.4-km study area of Deep Creek, Montana.

Stock densities of brown and rainbow trout greater than 20 cm decreased by about 80% from October 1986 to April 1989 (Figures 19 and 20). Summer low flows, exacerbated by irrigation withdrawals, negatively affected age-II-and-older rainbow trout and age-III-and-older brown trout in the West Gallatin River, Montana (Vincent and Nelson 1978). In the upper Beaverhead River, Montana, age-III-and-older rainbow trout also declined in abundance when subjected to flow reductions, whereas age-II-and-

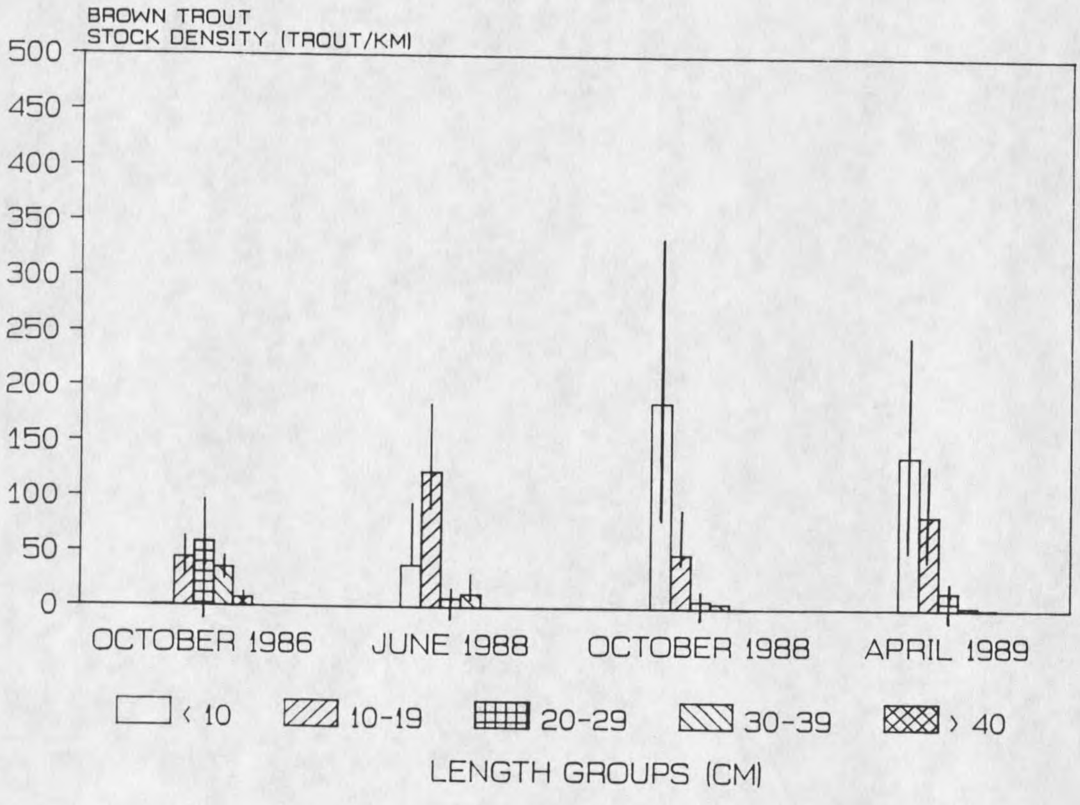

Figure 19. Stock density (fish/km) of brown trout in the 1.4-km study area of Deep Creek, Montana (error bars represent upper value of 95% confidence interval).

younger brown and rainbow trout were less affected (Nelson 1978).

Densities of 10-19 cm trout fluctuated in Deep Creek (Table 6). Large natural variations in abundance of stream-dwelling salmonids are common, and variation in habitat quality and stream flow are among the most important causes (Hall and Knight 1981).

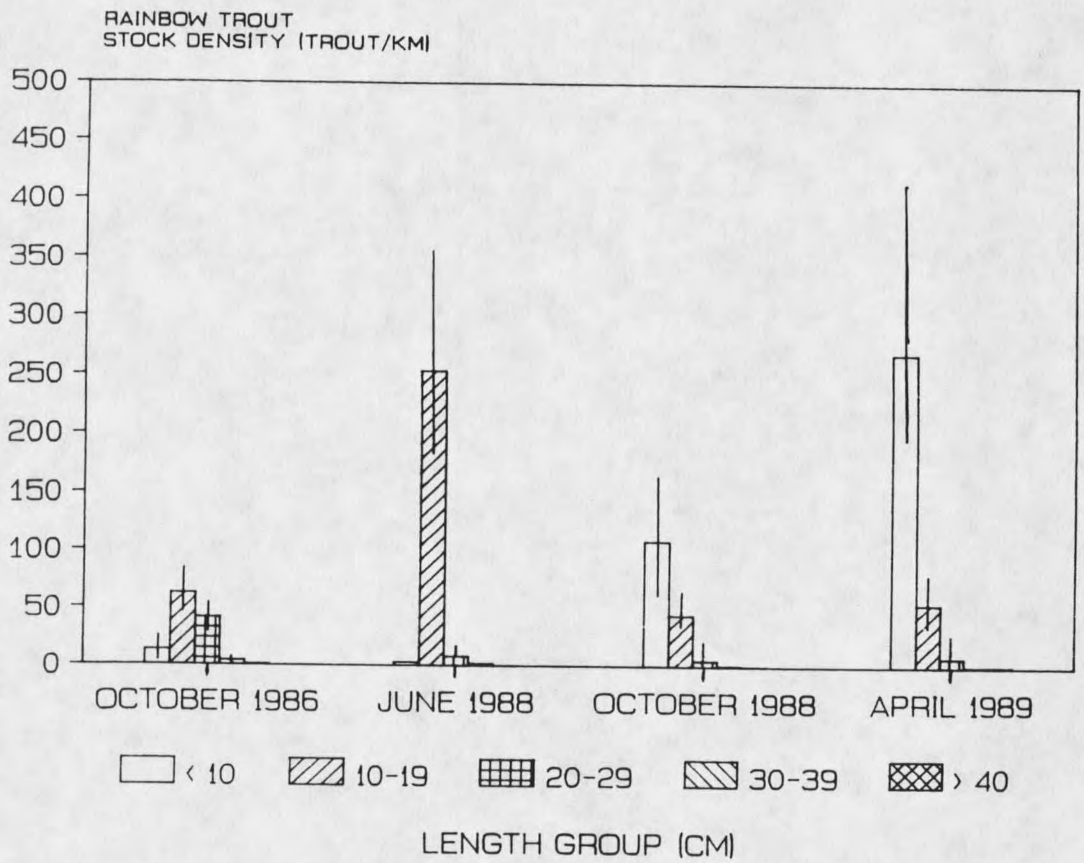

Figure 20. Stock density (fish/km) of rainbow trout in the 1.4-km study area of Deep Creek, Montana (error bars represent upper value of 95% confidence interval).

It is possible that during the fall of 1986 a migratory population of brown trout, ≥20 cm in length, used Deep Creek for spawning. I saw much more spawning activity, redds, paired fish and ripe fish in October of 1986 than in October 1988 in Deep Creek.

1986 than in October 1988 in Deep Creek.

Trout Abundance in Treatment Areas

Immediately after construction, trout abundance decreased on average in each type of treatment bend and in the controls (Table 7, Figures 21 and 22). As measured in June 1988, about three to four weeks post-treatment, mean decrease from March 1988 preconstruction standing crop was 6% in tree-revetted bends, 21% in riprapped bends, and 62% in control bends (Table 7). None of these standing crop decreases was statistically significant, but that for control bends ($p = 0.25$) was closest to being so. The decrease in numerical density in riprapped bends was significant ($p = 0.03$) but for populations having a wide range of body size, numerical density is a much less meaningful measure of abundance than standing crop.

Abundance of trout ≤10 cm in length also decreased on average in each type of treatment bend and control (Table 8, Figure 23 and 24). As measured in June 1988, mean decreases from March 1988 preconstruction standing crop were 83% in tree revetted bends, 97% in riprapped bends, and 88% in control bends (Table 8). The decrease in standing crop was statistically significant in both the riprapped ($p = 0.02$) and control bends ($p = 0.02$). March to June mean decrease in stock density was large (92%) and

Table 7. Mean stock densities and standing crops of all trout in treatment and control bends before and after construction of revetments (standard deviation in parentheses) and change from pre-construction estimates; p-values from paired-T test.

Time and Treatment *	Stock Density (fish/m)	Change from March 1988 (fish/m)	%	P	Standing Crop (g/m)	Change from March 1988 (g/m)	%	P
March 1988								
TR	0.24 (0.19)				4.35 (3.49)			
RR	0.24 (0.10)				6.84 (6.51)			
Z	0.26 (0.16)				6.93 (7.39)			
June 1988								
TR	0.16 (0.12)	-0.08	-33	0.45	4.61 (5.78)	-0.26	-6	0.91
RR	0.15 (0.11)	-0.09	-38	0.03	5.41 (2.59)	-1.43	-21	0.61
Z	0.15 (0.09)	-0.11	-42	0.25	2.62 (1.24)	-4.31	-62	0.25
October 1988								
TR	0.26 (0.20)	+0.02	+8	0.88	3.77 (3.44)	-0.58	-13	0.57
RR	0.13 (0.13)	-0.11	-46	0.23	3.24 (1.99)	-3.60	-53	0.23
Z	0.30 (0.17)	+0.04	+15	0.78	9.27 (10.12)	+2.34	+34	0.50

* TR = tree revetment, RR = riprap, Z = control.

most significant (p = 0.01) in riprapped bends and at least (50%) in tree-revetted bends, but not significantly so (Table 8). In the Big Wood River,

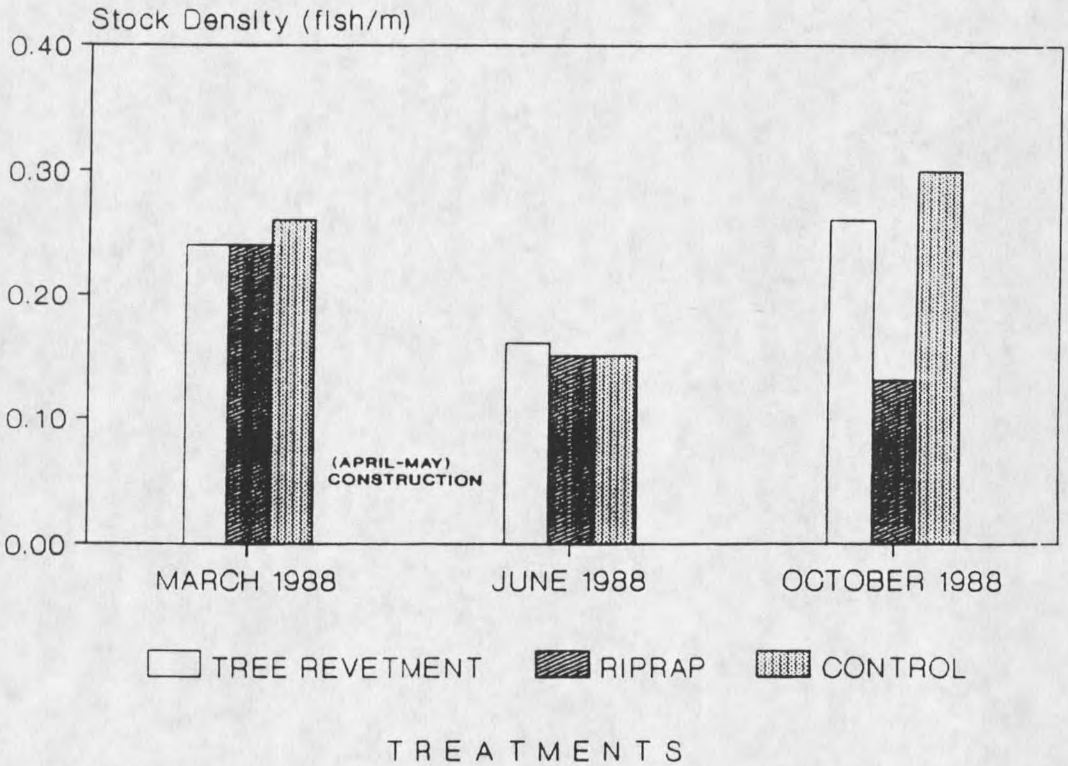

Figure 21. Mean stock density (fish/m) of all trout in treatment and control bends before and after construction in Deep Creek, Montana 1988.

Idaho, stock densities of rainbow trout were eight to ten times higher in natural sections than in riprapped areas (Thurow 1987). In the Ruby River, Montana, stock densities of brown trout in riprapped sections were half those in unaltered sections (Peterson 1974).

Standing crop of trout $\leq$10 cm in length in June 1988, in tree-revetted bends was not significantly different than in control bends (p = 0.61--Table 9). One would have

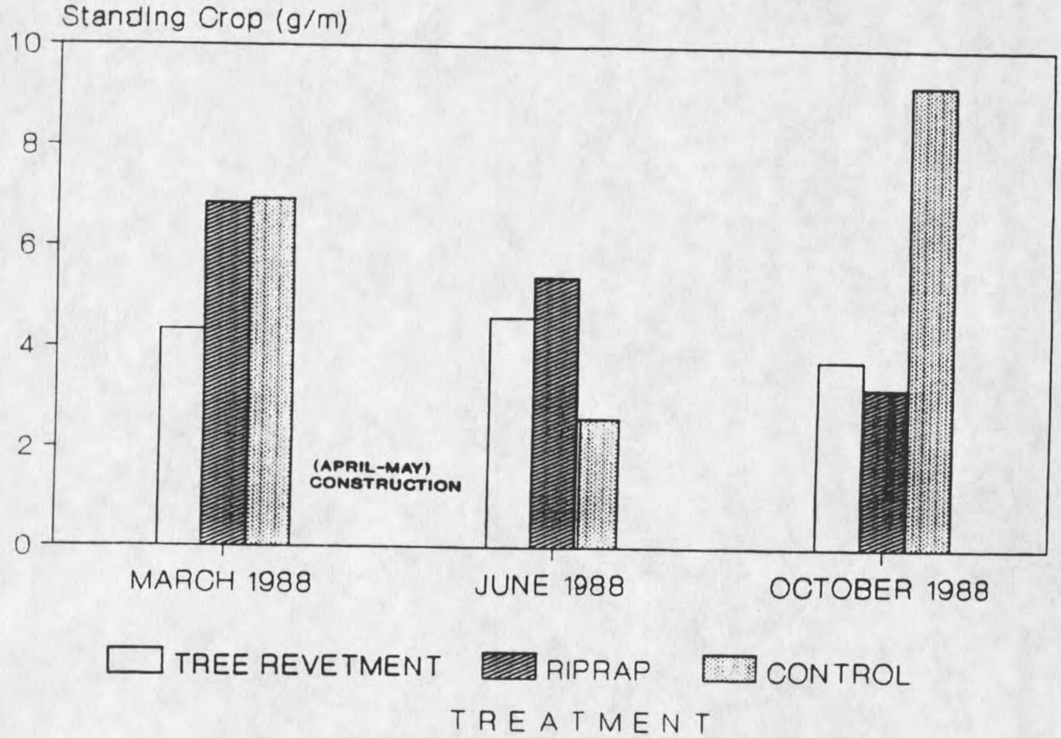

Figure 22. Mean standing crop (g/m) of all trout in treatment and control bends before and after construction in Deep Creek, Montana 1988.

expected small trout to be benefited by the increased overhead cover created by the tree revetment (Appendix Table 11), especially since the cover was composed of small twigs and foliage. In October, about five to six months after construction--and following the dewatering--the recolonized trout population had essentially resumed or slightly exceeded preconstruction levels in tree-revetted and control bends, and may not have recovered in

Table 8. Mean stock densities and standing crops of trout ≤10 cm in length in treatment and control bends before and after construction of revetments (standard deviation in parentheses) and change from preconstruction estimates; p-values from paired-T test.

Time and Treatment *	Stock Density (fish/m)	Change from March 1988 (fish/m)	%	P	Standing Crop (g/m)	Change from March 1988 (g/m)	%	P
March 1988								
TR	0.16 (0.13)				0.83 (0.67)			
RR	0.13 (0.07)				0.72 (0.47)			
Z	0.17 (0.10)				0.87 (0.49)			
June 1988								
TR	0.08 (0.12)	-0.08	-50	0.42	0.14 (0.20)	-0.69	-83	0.07
RR	0.01 (0.01)	-0.12	-92	0.01	0.02 (0.03)	-0.70	-97	0.02
Z	0.05 (0.05)	-0.12	-71	0.69	0.10 (0.10)	-0.77	-88	0.02
October 1988								
TR	0.18 (0.16)	+0.02	+13	0.79	1.21 (1.01)	+0.38	+46	0.56
RR	0.09 (0.12)	-0.04	-31	0.67	0.47 (0.49)	-0.25	-35	0.55
Z	0.19 (0.14)	+0.02	+12	0.81	1.25 (0.93)	+0.38	+44	0.48

* TR = tree revetment, RR = riprap, Z = control.

riprapped bends, although the March-to-October differences in abundance for riprapped bends were not statistically significant (p = 0.23--Table 7 and Figures 21 and 22).

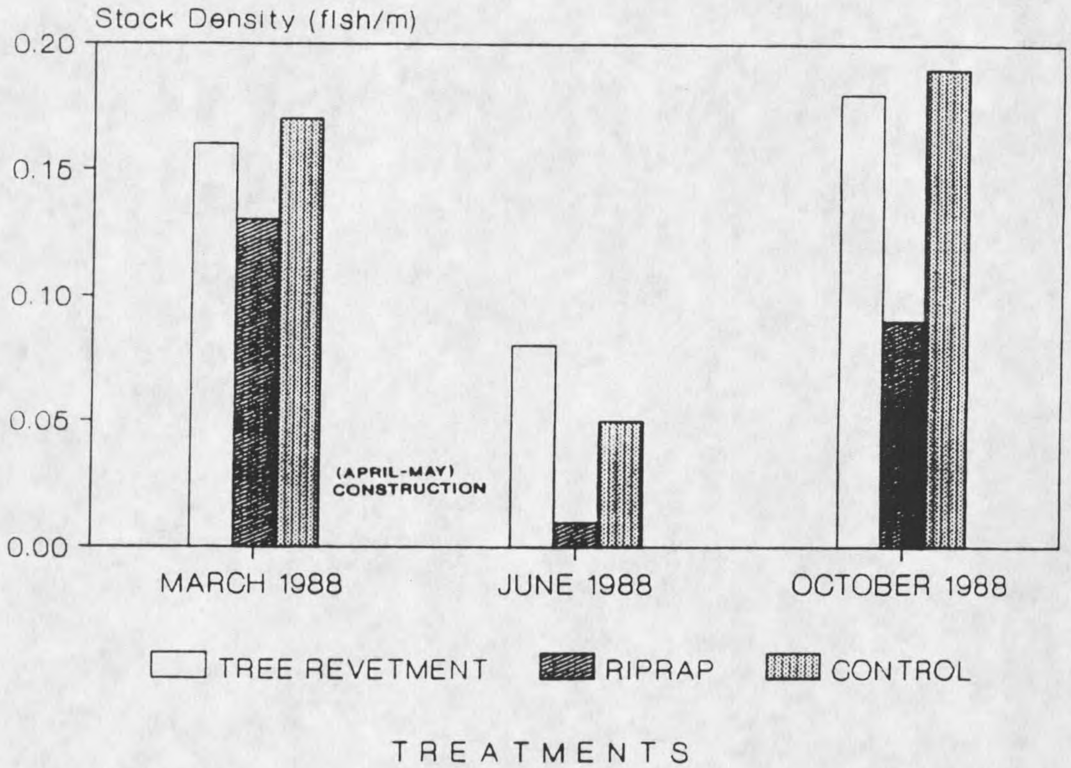

Figure 23. Mean stock density (fish/m) of all trout $\leq$10 cm in length in treatment and control bends before and after construction in Deep Creek, Montana 1988.

There were no significant differences in stock densities or standing crops of trout between the two treatments or the treatments and control bends during March, June, or October 1988 (Table 9). There also were no significant differences between the March to June and March to October treatment changes in stock densities and standing crops (Table 10). This was true for all trout and trout ≤10 cm in length (Figures 25, 26, 27, and 28). Population estimates, standing crops, and stock densities of trout in the study bends are in Appendix Tables 20-30.

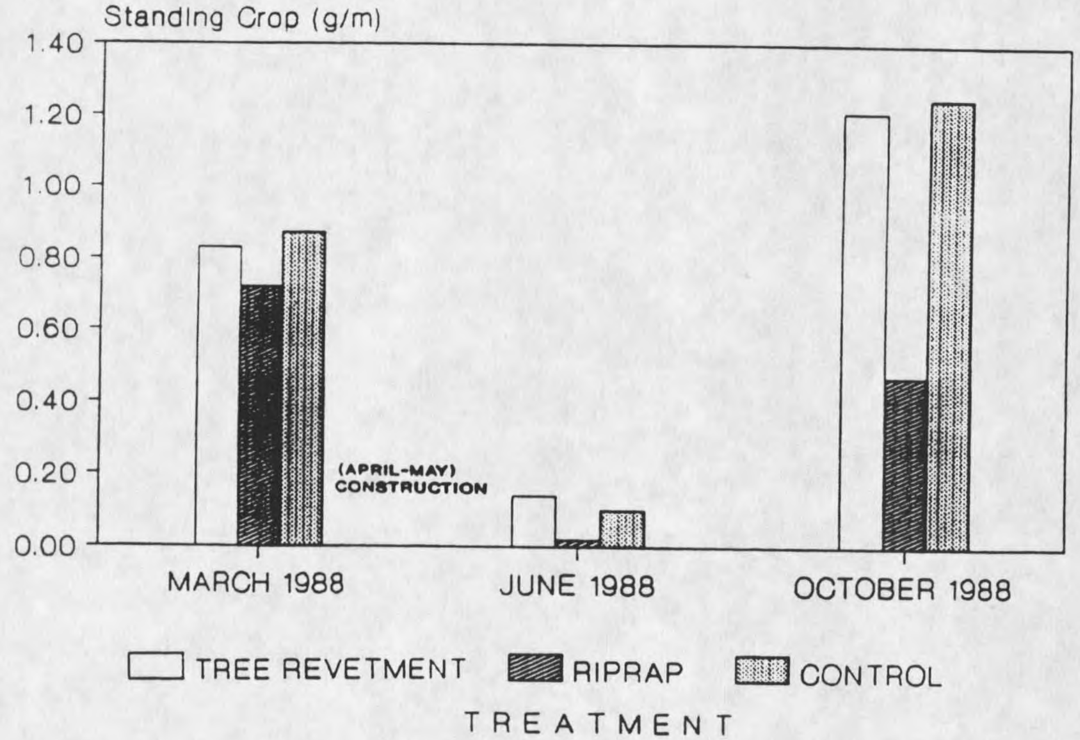

Figure 24. Mean standing crop (g/m) of all trout ≤10 cm in length in treatment and control bends before and after construction in Deep Creek, Montana 1988.

Knudsen and Dilley (1987) suggest the magnitude in the reduction of salmonid densities, as a result of streambank alterations (riprapping), depends on the stream size, size of salmonid, and the severity of the change in habitat. They observed reductions of cutthroat trout

(<u>Oncoryhncus</u> <u>clarki</u>) biomass in small streams and increases in biomass in large streams in Western Washington when banks were riprapped. They concluded that riprap may be more detrimental in small than in large streams.

Table 9. P-values from between-treatment ANOVA of trout abundance, Deep Creek, Montana 1988.

Time and Treatment *	Stock Density trout ≤10 cm	Standing Crop trout ≤10 cm	Stock Density all trout	Standing Crop all trout
March				
TR vs. RR	0.67	0.75	0.99	0.52
RR vs. Z	0.44	0.66	0.84	0.98
TR vs. Z	0.86	0.90	0.82	0.51
June				
TR vs. RR	0.20	0.16	0.88	0.74
RR vs. Z	0.12	0.35	0.92	0.25
TR vs. Z	0.57	0.61	0.81	0.40
October				
TR vs. RR	0.32	0.18	0.89	0.96
RR vs. Z	0.26	0.16	0.15	0.17
TR vs. Z	0.96	0.96	0.19	0.20

* TR = tree revetment, RR = riprap, Z = control

Many trout habitat studies demonstrate the direct relationship between the standing crop or stock density of trout and habitat quality, especially cover (Boussu 1954; DeVore and White 1978; Gunderson 1966; Lewis 1969; Thurow 1990; Wesche et al. 1987; White 1986). Some studies of habitat management projects have shown adverse effects or no increase in the associated salmonid population (Hamilton 1989). Many unsuccessful habitat management

Table 10. P-values from ANOVA between-treatment differences in the pre-to-post-construction changes in trout abundance, Deep Creek, Montana 1988.

Time and Treatment *	Stock Density trout ≤10 cm	Standing Crop trout ≤10 cm	Stock Density all trout	Standing Crop all trout
March to June				
TR vs. RR	0.60	0.98	0.91	0.21
RR vs. Z	0.98	0.83	0.73	0.17
TR vs. Z	0.59	0.81	0.81	0.93
March to October				
TR vs. RR	0.63	0.26	0.66	0.63
RR vs. Z	0.66	0.37	0.46	0.34
TR vs. Z	0.97	0.79	0.24	0.64

* TR = tree revetment, RR = riprap, Z = control

projects may not have been reported at all (Hamilton 1989; Reeves and Roelofs 1982). In the Deep Creek study, I found few positive changes in trout abundance and much negative change, but it is too early to evaluate the ultimate effects of the treatments, and the abnormally low streamflow discharge of 1987-88 probably overrode most other habitat factors.

Lack of instream flow due to drought and irrigation dewatering of Deep Creek was probably the principle reason for decline in standing crop of trout in the entire study area. The significant initial (March-June) decrease in

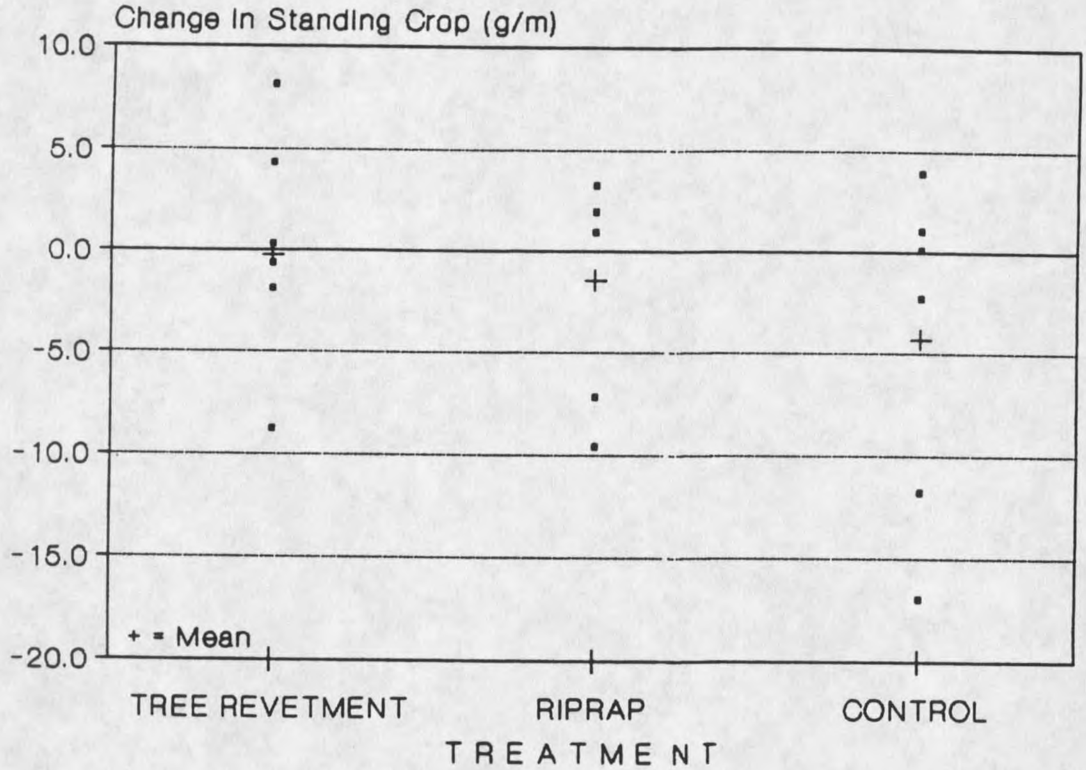

Figure 25. Change in standing crop (g/m) of all trout before and after (March to June) construction of revetments in Deep Creek, Montana 1988.

stock density in the riprapped bends may have been due to the loss of streamside vegetation, or perhaps the disturbance of construction or the change in cover type caused fish to temporarily move out of the riprapped bends. Binns and Eiserman (1979) suggest that a varied stream channel morphology, stable in stream debris, and variety of substrate sizes are necessary for good fish production. When blanket riprap is installed, very little cover diversity is created.

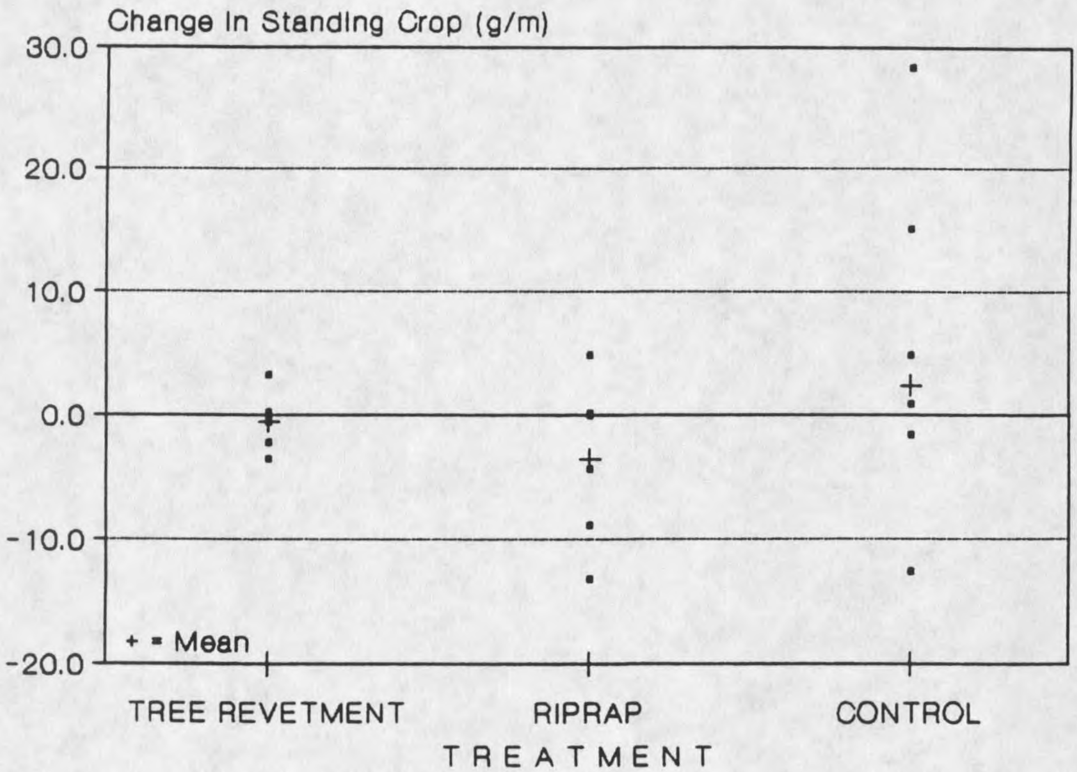

Figure 26. Change in standing crop (g/m) of all trout before and after (March to October) construction of revetments in Deep Creek, Montana 1988.

Further study over a longer period is needed to accurately assess effects of the habitat treatments on this trout population. Everest et al. (1984) suggest a

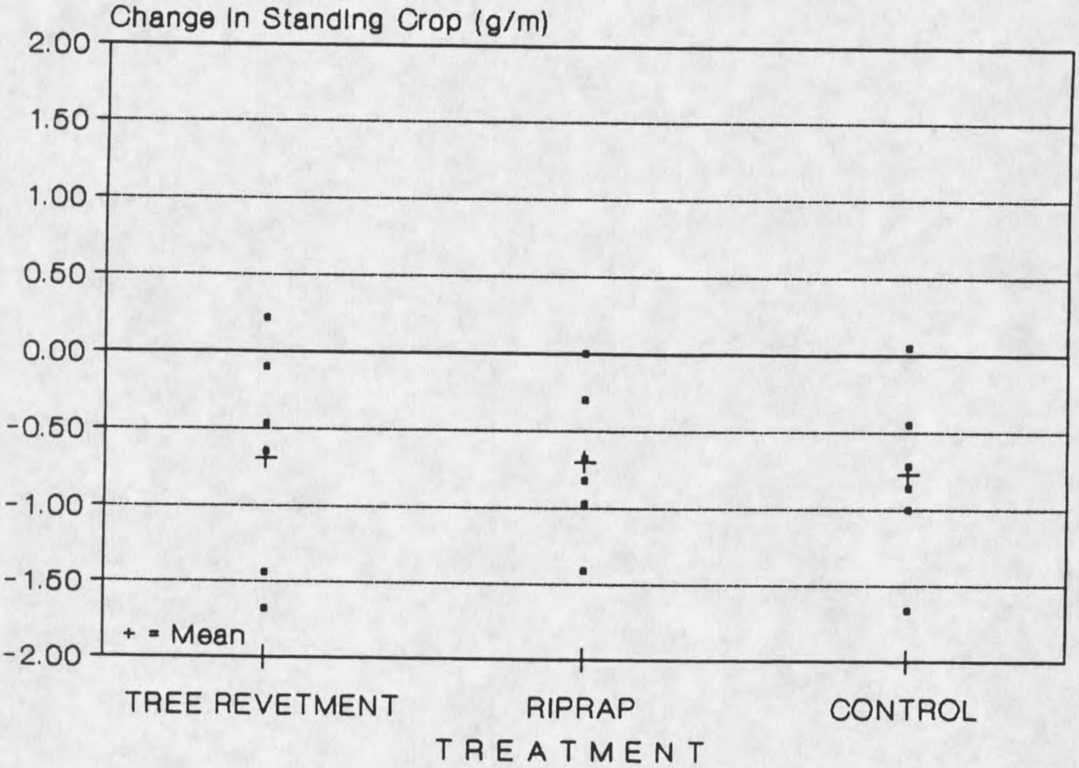

Figure 27. Change in standing crop (g/m) of trout ≤10 cm in length before and after (March to June) construction of revetments in Deep Creek, Montana 1988.

post- construction period of at least three years to effectively evaluate habitat utilization by fish. The natural variability of salmonid populations as described by Hall and Knight (1981) and Platts and Nelson (1988) must be taken into consideration when evaluating a biological response to an instream physical habitat alteration or land management activity.

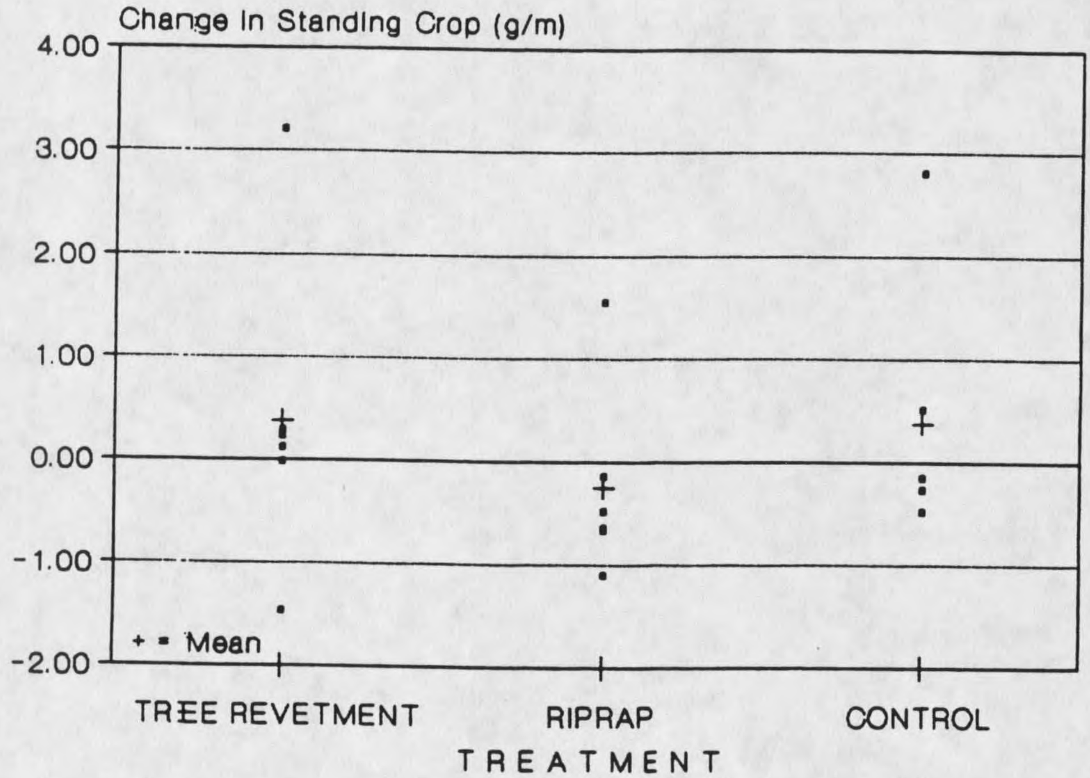

Figure 28. Change in standing crop (g/m) of trout ≤10 cm in length before and after (March to October) construction of revetments in Deep Creek, Montana 1988.

Streambank Erosion and Effects of Revetment

Each winter of the study, thick ice covered the surface of Deep Creek throughout the study area. The ice layer was a meter or more thick in many, if not most, places. Bank erosion by ice was evident during spring thaw in 1988 and 1989. The ice began to melt in early March 1989, very little remained by April 1st. Melting occurred first in the center of the channel, and progressed toward the banks, leaving ice as shelves of 30-60 cm thick, suspended about 1/2 meter above the water surface (Figure 29). In some of the more heavily shaded pools, the ice formed a complete bridge across the stream.

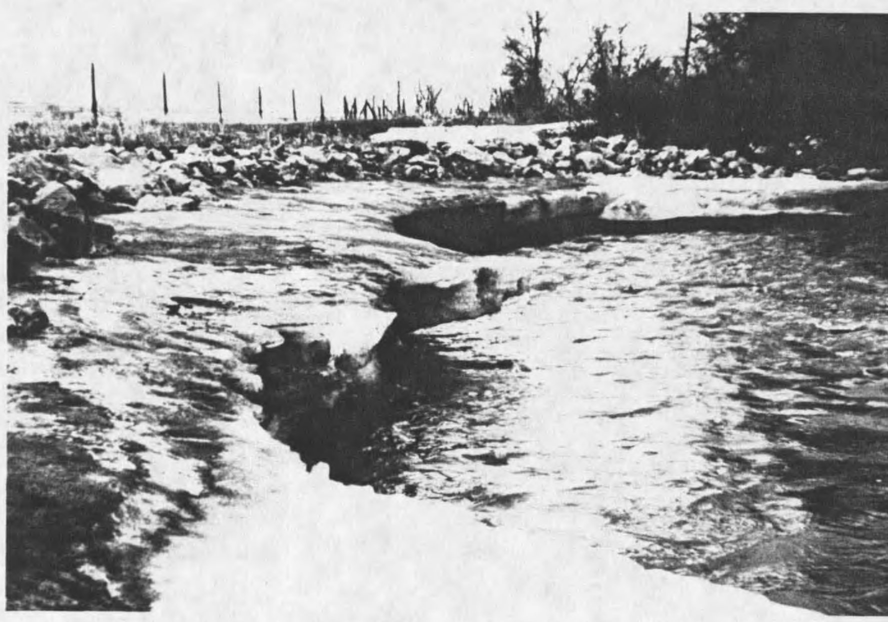

Figure 29. Shelf ice melting on riprap bend of Deep Creek during spring thaw, March 1989.

As the ice shelves collapsed along the non-revetted banks, they often pulled slabs of attached streambank with them, resulting in mass wasting (Figure 30). The line of

Figure 30. Erosion due to ice along outside bend of Deep Creek during spring thaw, March 1989.

bank soil fracture was often about 30 cm from bank edge. The upper surfaces of the high, current-bearing (outer or concave) banks were vegetated primarily with grasses. The large blocks of ice and attached soil fell onto the toe of the bank slope and onto the stream bed. Much of the soil was then washed away by the stream current. Bohn (1989) found streambanks vegetated with grass were better insulated from freeze-thaw cycles and frost heaving than bare soil banks; she concluded that the internal structure of streambanks vegetated with grasses were stronger than those with exposed soil, therefore more resistant to erosion by the stream.

I observed that as the Deep Creek current eroded the fallen slabs of bank soil, stream turbidity increased, and some of the eroded sediment was deposited immediately downstream from the site of bank failure. The increased sediment deposition from bank erosion along outside bends of streams may have several negative effects on the trout population. The increased embeddedness of streambed gravel eliminates space for aquatic macroinvertebrates thus reducing food supply for trout (Binn 1986). Fine sediment also hampers spawning and embryonic survival of salmonids (Chapman and McLeod 1987). Undercut banks that slump into the stream cause loss of overhead cover, and pools become shallower as they fill with sediment (Binns 1986).

Such ice-levered fracturing of current-bearing banks did not occur in bends that had been revetted with riprap or trees. The tree revetments actually supported the ice shelf, allowing it to melt in place (Figure 31). The riprapped bends may also have provided structural integrity to the bank, allowing it to support the ice shelf until it melted or broke off (Figure 29). I did not observe that ice pulled any riprap into the stream.

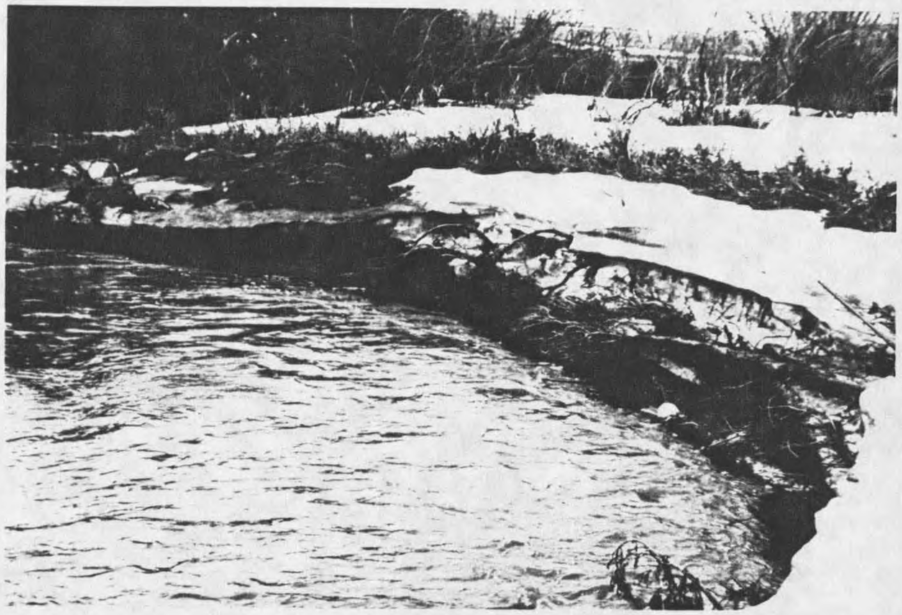

Figure 31. Tree revetment supporting ice shelf in Deep Creek during spring thaw, March 1989.

As the ice shelves broke loose, they formed an ice dam at bend 2 and at the bridge at the lower end of the study area. This caused the stream to completely flood its banks and form temporary side channels in low spots. Such flooding can leave trout stranded away from the main channel (White and Brynildson 1967). By April 1, 1989, very little ice remained.

The space between the tree revetments and the bank is a protected site for sediment deposition and a catch trough for any bank slumping. Willows and other riparian vegetation became established in the soil bed between the

the area behind the revetment and as the juniper trees eventually decompose, the banks revetted with trees should eventually take on a natural appearance. Establishment of streamside vegetation is an important way of stabilizing banks; dense tangles of plants along banks trap organic debris and provide cover for fish (Meehan et al. 1977). The rock riprap bends immediately solve the erosion problem, but do not cause much sediment accumulation for natural regrowth of riparian plants (McBride and Strahan 1983). From standpoints of natural appearance and providing immediate hiding/security cover for trout, I feel the tree revetment is a better way to stabilize streambanks than is riprapping.

SUMMARY

Overhead cover increased significantly in bends revetted with juniper trees, 195% on average, but in riprapped sections and control bends cover decreased by about 36%.

Channel widths and depths did not change significantly within seven months after construction. Also, there were no significant differences in the amount of change between treatments. Post-construction flow was insufficient to scour narrower and deeper channels.

Throughout the study area, abundance of brown and rainbow trout decreased during the study due to increasingly severe drought and irrigation withdrawal from the stream, but standing crops of trout <10 cm long recovered to pre-treatment levels by October 1988 in tree revetted and control bends.

Stock densities of total trout decreased significantly in riprapped bends between March and June 1988. Abundance of trout $\leq$10 cm in length also decreased significantly in riprapped bends. There were no significant differences in abundance of trout between the two treatments or the treatment and control bends during

March, June, and October 1988. Extremely low flow in 1987 and 1988, and a complete dewatering of the study area from early August to mid October 1988 severely reduced the trout population and obscured most effects that the other habitat changes might have had on trout abundance.

The main agent of streambank erosion was fracture and mass wasting due to the lever action of shelf ice. Tree revetment and riprap halted the ice-induced erosion.

Tree revetment has advantages over rock riprap in providing an immediate large increase in hiding/security cover for trout and causing fine sediment to accumulate, which promotes natural revegetation of previously bare soil banks. Tree revetments will decompose eventually and provide a more natural appearing streambank than rock revetments.

Further study is needed to accurately assess the effects of these habitat manipulations on the trout in Deep Creek.

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APPENDIX

Table 11. Changes in overhead cover area and density per length of channel before and after construction, Deep Creek, Montana (measured in March and November 1988).

Treatment Bend # and Length (m)		Cover area (m^2)			Cover density (m^2/m)		Percent Change
		Pre	Post	Change	Pre	Post	Change	
Tree revetment								
4	(60)	40.00	89.81	+49.81	0.67	1.50	+0.83	+124
5	(32)	2.30	50.02	+47.72	0.07	1.56	+1.49	+2075
9	(28)	10.23	16.58	+6.35	0.37	0.59	+0.23	+62
15	(43)	11.94	48.22	+36.28	0.28	1.12	+0.84	+304
18	(14)	1.23	16.70	+15.47	0.09	1.19	+1.11	+1258
21	(34)	22.81	39.63	+16.82	0.67	1.17	+0.49	+74
Mean	(35.2)	14.76	43.49	+28.76	0.42	1.24	+0.82	+195
Riprap								
2	(60)	3.59	1.35	-2.24	0.06	0.02	-0.04	-62
3	(29)	6.32	1.89	-4.43	0.22	0.07	-0.15	-68
8	(50)	16.87	7.47	-9.40	0.34	0.15	-0.19	-56
11	(29)	4.61	2.08	-2.53	0.16	0.07	-0.09	-55
16	(46)	27.93	21.66	-6.27	0.61	0.47	-0.14	-22
19	(22)	2.71	4.67	+1.96	0.12	0.21	+0.09	+72
Mean	(39.3)	10.33	6.52	-3.82	0.25	0.17	-0.09	-36
Control								
12	(68)	37.45	26.38	-11.07	0.55	0.39	-0.16	-29
14	(23)	10.14	12.25	+2.11	0.44	0.53	+0.09	+21
20	(20)	2.38	2.25	-0.13	0.12	0.11	-0.01	-5
23	(58)	12.08	20.95	+8.87	0.21	0.36	+0.15	+71
24	(29)	54.75	17.36	-37.39	1.89	0.60	-1.29	-68
25	(21)	0.12	0.33	+0.21	0.01	0.02	+0.01	+100
Mean	(36.5)	19.49	13.25	-6.24	0.53	0.34	-0.19	-36

Table 12. Changes in pool area and density per length of channel of stream before and after construction, Deep Creek, Montana (measured in March and November 1988).

Treatment Bend # and Length (m)		Pool area (m^2)			Pool density (m^2/m)			
		Pre	Post	Change	Pre	Post	Change	Percent Change
Tree revetment								
4	(60)	50.00	63.61	+13.61	0.83	1.06	+0.23	+28
5	(32)	0.00	15.75	+15.75	0.00	0.49	+0.49	*
9	(28)	0.00	4.16	+4.16	0.00	0.14	+0.14	*
15	(43)	0.48	6.97	+6.49	0.01	0.16	+0.15	+1500
18	(14)	9.60	4.09	-5.15	0.68	0.57	-0.11	-16
21	(34)	31.00	32.62	+1.62	0.91	0.96	+0.05	+5
Mean	(35.2)	15.18	21.20	+6.02	0.43	0.60	+0.17	+40
Riprap								
2	(60)	0.00	0.00	0.00	0.00	0.00	0.00	0
3	(29)	7.37	0.00	-7.37	0.25	0.00	-0.25	-100
8	(50)	0.00	2.71	+2.71	0.00	0.05	+0.05	*
11	(29)	4.40	12.52	+8.12	0.15	0.43	+0.28	+186
16	(46)	22.83	18.11	-4.72	0.50	0.39	-0.11	-22
19	(22)	14.40	20.16	+5.76	0.65	0.92	+0.26	+40
Mean	(39.3)	8.13	8.92	+0.75	0.21	0.23	+0.02	+10
Control								
12	(68)	27.50	18.90	-8.60	0.40	0.27	-0.13	-33
14	(23)	15.00	11.20	-3.80	0.65	0.48	-0.17	-26
20	(20)	3.20	1.62	-1.58	0.16	0.08	-0.08	-50
23	(58)	1.08	6.87	+5.79	0.02	0.12	+0.10	+500
24	(29)	0.00	0.90	+0.90	0.00	0.03	+0.03	*
25	(21)	23.58	28.27	+4.70	1.12	1.35	+0.23	+21
Mean	(36.5)	11.73	11.29	-0.44	0.32	0.31	-0.01	-3

* = % change inappropriate for increase from 0

Table 13. Changes in cover area and density (including pools) per length of channel before and after construction, Deep Creek, Montana (measured in March and November 1988).

Treatment Bend # and Length (m)		Cover area (m^2)			Cover density (m^2/m)			
		Pre	Post	Change	Pre	Post	Change	Percent Change
Tree revetment								
4	(60)	90.00	153.43	+63.43	1.50	2.56	+1.06	+71
5	(32)	2.30	65.78	+63.43	0.07	2.06	+1.99	+2842
9	(28)	10.23	20.74	+10.51	0.37	0.74	+0.38	+103
15	(43)	12.43	55.20	+42.77	0.29	1.28	+0.99	+341
18	(14)	10.83	20.80	+9.97	0.77	1.49	+0.72	+94
21	(34)	53.82	72.26	+18.44	1.58	2.13	+0.55	+35
Mean	(35.2)	29.94	64.70	+34.76	0.76	1.71	+0.95	+125
Riprap								
2	(60)	3.59	1.35	-2.24	0.06	0.02	-0.04	-66
3	(29)	13.69	1.89	-11.80	0.47	0.07	-0.40	-85
8	(50)	16.87	10.18	-6.69	0.34	0.20	-0.13	-38
11	(29)	9.01	14.60	+5.59	0.31	0.50	+0.19	+61
16	(46)	50.77	39.78	-10.99	1.10	0.86	-0.24	-22
19	(22)	17.11	24.83	+7.72	0.78	1.13	+0.35	+45
Mean	(39.3)	18.51	15.44	-3.07	0.51	0.39	-0.08	-16
Control								
12	(68)	64.95	45.29	-19.66	0.96	0.67	-0.29	-30
14	(23)	25.14	23.45	-1.69	1.09	1.02	-0.07	-6
20	(20)	5.57	3.88	-1.69	0.28	0.19	-0.08	-29
23	(58)	13.16	27.82	+14.66	0.23	0.48	+0.25	+109
24	(29)	54.74	18.26	-36.48	1.89	0.63	-1.26	-67
25	(21)	23.70	28.61	+4.92	1.13	1.36	+0.23	+20
Mean	(36.5)	31.21	24.55	-6.66	0.93	0.73	-0.20	-22

Table 14. Pre-to-post-construction changes in mean depths and widths calculated at a streamflow discharge of 285 L/s, Deep Creek, Montana 1988.

Treatment Bend # and Length (m)	Depth (m)				Width (m)			
	Pre	Post	Change	% Change	Pre	Post	Change	% Change
Tree revetment								
4 (60)	0.34	0.45	+0.11	+32	6.57	7.48	+0.91	+14
5 (32)	0.35	0.31	-0.04	-11	3.45	3.12	-0.33	-10
9 (28)	0.19	0.19	0.00	0	5.31	5.27	-0.04	-1
15 (43)	0.26	0.26	0.00	0	4.38	4.33	-0.05	-1
18 (14)	0.27	0.25	-0.02	-7	4.99	4.73	-0.26	-5
21 (34)	0.28	0.29	+0.01	+3	4.71	5.14	+0.43	+9
Mean (35.2)	0.30*	0.32*	+0.03*	+8	5.08*	5.32*	+0.24*	+5
Riprap								
2 (60)	0.25	0.19	-0.06	-24	4.09	3.85	-0.24	-6
3 (29)	0.30	0.27	-0.03	-10	2.86	3.17	+0.31	+11
8 (50)	0.43	0.25	-0.18	-42	4.37	3.15	-1.22	-28
11 (29)	0.27	0.26	-0.01	-4	3.45	3.26	-0.19	-6
16 (46)	0.28	0.28	0.00	0	4.30	3.92	-0.38	-9
19 (22)	0.40	0.39	-0.01	-2	4.34	3.93	-0.41	-9
Mean (39.3)	0.32*	0.26*	-0.06*	-19	3.98*	3.56*	-0.42*	-10
Control								
12 (68)	0.24	0.23	-0.01	-4	3.93	3.82	-0.11	-3
14 (23)	0.33	0.37	+0.04	+12	2.90	3.25	+0.35	+12
20 (20)	0.24	0.23	-0.01	-4	3.41	3.21	-0.20	-6
23 (58)	0.28	0.28	0.00	0	3.59	3.97	+0.38	+11
24 (29)	0.25	0.21	-0.04	-16	3.41	3.21	-0.20	-5
25 (21)	0.24	0.20	-0.04	-17	3.85	4.37	+0.52	+14
Mean (36.5)	0.26*	0.26*	-0.01*	-2	3.61*	3.72*	+0.11*	+3

*Length-weighted

Table 15. Number and biomass of trout in the 1.4-km study area of Deep Creek, Montana October 1986 (95% C.I.).

Size class (cm)	Brown trout No. of fish	Brown trout Biomass (g)	Rainbow trout No. of fish	Rainbow trout Biomass (g)	Total trout No. of fish	Total trout Biomass (g)
< 10	1 (*)	5	18 (5-31)	46	19	51
10-19	62 (39-86)	3399	87 (64-110)	4468	149	7867
20-29	81 (45-117)	10128	58 (46-70)	7194	139	17322
30-39	49 (36-62)	17085	5 (3-7)	1335	54	18420
> 40	11 (5-17)	10677	1 (*)	600 (*)	12	11277
Total	204 (125-282)	41294	169 (118-218)	13643	373	54937

* = estimates too small for confidence interval

Table 16. Number and biomass of trout in the 1.4-km study area of Deep Creek, Montana June 1988 (95% C.I.).

Size class (cm)	Brown trout No. of fish	Brown trout Biomass (g)	Rainbow trout No. of fish	Rainbow trout Biomass (g)	Total trout No. of fish	Total trout Biomass (g)
< 10	53	100	4	8	57	108
	(53-126)		(*)	(*)		
10-19	172	5504	354	10018	526	15522
	(115-229)		(230-478)			
20-29	11	1850	11	2070	22	3920
	(5-23)		(5-23)			
30-39	17	6334	3	947	20	7281
	(12-28)		(*)			
> 40	0	0	0	0	0	0
Total	253	13788	372	13043	625	26831
	(185-406)		(235-501)			

* = estimates too small for confidence interval

Table 17. Number and biomass of trout in the 1.4-km study area of Deep Creek, Montana October 1988 (95% C.I.).

Size class (cm)	Brown trout No. of fish	Brown trout Biomass (g)	Rainbow trout No. of fish	Rainbow trout Biomass (g)	Total trout No. of fish	Total trout Biomass (g)
< 10	260 (78-442)	845	151 (74-228)	462	411	1307
10-19	69 (55-89)	3026	62 (44-80)	1869	131	4895
20-29	10 (8-16)	1261	7 (6-11)	891	17	2152
30-39	7 (5-12)	2433	1 (*)	250	8	2683
> 40	0	0	0	0	0	0
Total	346 (146-559)	7565	221 (124-319)	3472	567	11037

* = estimates too small for confidence interval

Table 18. Number and biomass of trout in the 1.4-km study area of Deep Creek, Montana April 1989 (95% C.I.).

	Brown trout		Rainbow trout		Total trout	
Size class (cm)	No. of fish	Biomass (g)	No. of fish	Biomass (g)	No. of fish	Biomass (g)
< 10	195 (67-323)	917	377 (228-526)	2130	572	3047
10-19	120 (58-182)	1780	75 (53-100)	2022	195	3802
20-29	22 (15-35)	1729	11 (9-16)	849	33	2578
30-39	4 (4-8)	1135	2 (*)	464	6	1599
> 40	1 (*)	665	1 (*)	1208	2 (*)	1873 (*)
Total	342 (144-548)	6226	466 (290-642)	6673	808	12899

* = estimates too small for confidence interval

Table 19. Stock density and standing crop of trout in the 1.4-km study area of Deep Creek, Montana October 1986 (95% C.I.).

Size class (cm)	Brown trout		Rainbow trout		Total trout	
	Fish/km	Kg/km	Fish/km	Kg/km	Fish/km	Kg/km
< 10	1 (*)	0.004	13 (4-22)	0.033	14	0.034
10-19	44 (28-61)	2.430	62 (46-79)	3.190	106	5.620
20-29	58 (32-84)	7.230	41 (33-50)	5.140	99	12.370
30-39	35 (26-44)	12.200	4 (2-5)	0.950	39	13.150
> 40	8 (4-12)	7.630	1 (*)	0.430	9	8.06
Total	146 (90-201)	29.494	121 (85-156)	9.740	267	39.234

* = estimates too small for confidence interval

Table 20. Stock density and standing crop of trout in the 1.4-km study area of Deep Creek, Montana June 1988 (95% C.I.).

Size class (cm)	Brown trout Fish/km	Brown trout Kg/km	Rainbow trout Fish/km	Rainbow trout Kg/km	Total trout Fish/km	Total trout Kg/km
< 10	38 (38-90)	0.071	3 (*)	0.006	41	0.077
10-19	123 (82-164)	3.931	253 (164-341)	7.156	376	11.087
20-29	8 (4-16)	1.321	8 (8-16)	1.479	16	2.800
30-39	12 (9-20)	4.524	2 (*)	0.676	14	5.200
> 40	0	0	0	0	0	0
Total	181 (133-290)	9.847	266 (172-357)	9.31	447	19.164

* = estimates too small for confidence interval

Table 21. Stock density and standing crop of trout in the 1.4-km study area of Deep Creek, Montana October 1988 (95% C.I.).

Size class (cm)	Brown trout		Rainbow trout		Total trout	
	Fish/km	Kg/km	Fish/km	Kg/km	Fish/km	Kg/km
< 10	186 (56-316)	0.600	108 (53-163)	0.330	294	0.930
10-19	49 (39-64)	2.160	44 (31-57)	1.330	93	3.490
20-29	7 (6-11)	0.900	5 (4-8)	0.640	12	1.540
30-39	5 (4-9)	1.740	1 (*)	0.180	6	1.920
> 40	0	0	0	0	0	0
Total	247 (105-400)	5.400	158 (88-228)	2.480	405	7.880

* = estimates too small for confidence interval

Table 22. Stock density and standing crop of trout in the 1.4-km study area of Deep Creek, Montana April 1989 (95% C.I.).

Size class (cm)	Brown trout		Rainbow trout		Total trout	
	Fish/km	Kg/km	Fish/km	Kg/km	Fish/km	Kg/km
< 10	139 (48-230)	0.655	269 (163-376)	1.521	408	2.176
10-19	85 (41-130)	1.271	54 (38-71)	1.444	139	2.715
20-29	16 (11-25)	1.235	8 (6-11)	0.606	24	1.841
30-39	3 (3-6)	0.811	1 (*)	0.331	4	1.142
> 40	1	0.475	1	0.863	2	1.338
Total	244 (103-391)	4.447	333 (207-458)	4.765	577	9.212

* = estimates too small for confidence interval

Table 23. Number and biomass of trout in study bends before revetment construction in Deep Creek, Montana March 1988.

Treatment Bend	Brown trout No. of fish	Brown trout Biomass (g)	Rainbow trout No. of fish	Rainbow trout Biomass (g)	Total trout No. of fish	Total trout Biomass (g)
Tree revetment						
4	11	75	16	109	27	184
5	0	0	4	257	4	257
9	1	5	1	13	2	18
15	13	48	9	169	22	217
18	0	0	0	0	0	0
21	4	267	5	50	9	317
Riprap						
2	5	45	9	77	14	122
3	6	13	2	489	8	502
8	2	15	4	33	6	48
11	10	13	2	215	12	138
16	8	16	2	61	10	77
19	3	11	1	304	4	315
Control						
12	9	38	6	86	15	124
14	7	293	3	131	10	424
20	3	23	0	0	3	23
23	6	610	6	317	12	927
24	10	32	5	84	15	116
25	0	0	1	5	1	5

Table 24. 95% confidence intervals for Zippin population estimate of trout in Deep Creek, Montana March 1988.

Treatment Bend	Brown trout No. of fish	Rainbow trout No. of fish
Tree revetment		
4	(11-12)	(16-17)
5	*	(4-5)
9	*	*
15	(13-15)	(9-10)
18	*	*
21	(4-5)	(5-6)
Riprap		
2	(5-6)	(9-10)
3	(6-7)	(2-2)
8	(2-2)	(4-6)
11	(10-12)	*
16	(8-9)	(2-2)
19	*	*
Control		
12	(9-11)	(6-6)
14	(7-8)	(3-3)
20	*	*
23	(6-6)	(6-6)
24	(10-12)	(5-5)
25	*	*

* = estimates too small for confidence interval

Table 25. Number and biomass of trout in study bends after revetment construction in Deep Creek, Montana June 1988.

Treatment Bend	Brown trout No. of fish	Brown trout Biomass (g)	Rainbow trout No. of fish	Rainbow trout Biomass (g)	Total trout No. of fish	Total trout Biomass (g)
Tree revetment						
4	7	285	5	161	12	446
5	7	432	3	86	10	518
9	0	0	0	0	0	0
15	3	136	0	0	3	136
18	1	4	0	0	1	4
21	9	19	2	162	11	181
Riprap						
2	2	160	2	158	4	318
3	0	0	3	295	3	295
8	2	65	1	30	3	95
11	6	105	5	89	11	194
16	3	72	3	95	6	167
19	2	64	2	40	4	104
Control						
12	4	100	1	31	5	131
14	0	0	1	34	1	34
20	0	0	1	44	1	44
23	5	26	5	219	10	245
24	5	30	1	20	6	50
25	3	6	3	81	6	87

Table 26. 95% confidence intervals for Zippin population estimate of trout in Deep Creek, Montana June 1988.

Treatment Bend	Brown trout No. of fish	Rainbow trout No. of fish
Tree revetment		
4	(7-8)	(5-6)
5	(7-8)	*
9	*	*
15	(3-3)	*
18	*	*
21	(9-10)	(2-2)
Riprap		
2	(2-2)	*
3	*	(3-3)
8	(2-2)	*
11	(6-7)	(5-6)
16	(3-4)	(3-3)
19	*	*
Control		
12	*	*
14	*	*
20	*	*
23	(5-5)	(5-5)
24	*	*
25	*	*

* = estimates too small for confidence interval

Table 27. Number and biomass of trout in study bends after construction, Deep Creek, Montana October 1988.

Treatment Bend	Brown trout No. of fish	Brown trout Biomass (g)	Rainbow trout No. of fish	Rainbow trout Biomass (g)	Total trout No. of fish	Total trout Biomass (g)
Tree revetment						
4	2	12	2	35	4	47
5	3	148	3	116	6	264
9	1	9	0	0	1	9
15	3	19	7	42	10	61
18	5	36	2	9	7	45
21	9	277	4	18	13	295
Riprap						
2	2	11	2	108	4	119
3	2	40	1	78	3	118
8	3	81	2	207	5	288
11	1	8	1	3	2	11
16	1	8	2	76	3	84
19	5	72	4	48	9	120
Control						
12	10	197	2	31	12	228
14	3	43	2	12	5	55
20	2	40	0	0	2	40
23	5	49	9	148	14	197
24	2	14	6	55	8	69
25	7	469	6	132	13	601

Table 28. 95% confidence intervals for Zippin population estimate of trout in Deep Creek, Montana October 1988.

Treatment Bend	Brown trout No. of fish	Rainbow trout No. of fish
Tree revetment		
4	*	(2-3)
5	*	*
9	*	*
15	(3-4)	(7-9)
18	(5-5)	*
21	(9-11)	(4-6)
Riprap		
2	*	*
3	*	*
8	(3-4)	(2-3)
11	*	*
16	(1-2)	*
19	(5-7)	(4-5)
Control		
12	(10-11)	*
14	(3-4)	*
20	(2-3)	*
23	(5-6)	(9-9)
24	*	(6-7)
25	*	(6-7)

* = estimates too small for confidence interval

Table 29. Stock density and standing crop of trout in study bends. Means and standard deviations (S.D.) Deep Creek, Montana March 1988.

Treatment Bend # and Length (m)		Brown trout		Rainbow trout		Total trout	
		Fish/m	g/m	Fish/m	g/m	Fish/m	g/m
Tree revetment							
4	(60)	0.18	1.25	0.27	1.82	0.45	3.07
5	(32)	0.00	0.00	0.13	8.03	0.13	8.03
9	(28)	0.04	0.17	0.04	0.46	0.08	0.63
15	(43)	0.30	1.12	0.21	3.93	0.51	5.05
18	(14)	0.00	0.00	0.00	0.00	0.00	0.00
21	(34)	0.11	7.85	0.15	1.47	0.26	9.32
Mean	(35.2)	0.11	1.73	0.13	2.62	0.24	4.35
S.D.	(14.1)	0.11	2.78	0.09	2.72	0.19	3.49
Riprap							
2	(60)	0.08	0.75	0.15	1.28	0.23	2.03
3	(29)	0.21	0.44	0.07	16.86	0.28	17.31
8	(50)	0.04	0.30	0.08	0.66	0.12	0.96
11	(29)	0.34	0.45	0.07	4.31	0.41	4.76
16	(46)	0.17	0.35	0.04	1.33	0.21	1.68
19	(22)	0.14	0.48	0.05	13.82	0.19	14.32
Mean	(39.3)	0.16	0.46	0.08	6.38	0.24	6.84
S.D.	(13.5)	0.10	0.14	0.04	6.50	0.10	6.51
Control							
12	(68)	0.13	0.55	0.09	1.26	0.22	1.81
14	(23)	0.30	12.74	0.13	5.70	0.43	18.43
20	(20)	0.15	1.15	0.00	0.00	0.15	1.15
23	(58)	0.10	10.52	0.10	5.47	0.20	15.98
24	(29)	0.34	1.10	0.17	2.90	0.51	4.00
25	(21)	0.00	0.00	0.05	0.23	0.05	0.23
Mean	(36.5)	0.17	4.34	0.09	2.59	0.26	6.93
S.D.	(19.2)	0.12	5.21	0.05	2.31	0.16	7.39

Table 30. Stock density and standing crop of trout in study bends. Means and standard deviations (S.D.) Deep Creek, Montana June 1988.

Treatment Bend # and Length (m)	Brown trout		Rainbow trout		Total trout	
	Fish/m	g/m	Fish/m	g/m	Fish/m	g/m
Tree revetment						
4 (60)	0.12	4.75	0.08	2.68	0.20	7.43
5 (32)	0.22	13.50	0.09	2.69	0.31	16.19
9 (28)	0.00	0.00	0.00	0.00	0.00	0.00
15 (43)	0.07	3.16	0.00	0.00	0.07	3.16
18 (14)	0.07	0.29	0.00	0.00	0.07	0.29
21 (34)	0.26	0.56	0.06	4.76	0.32	0.56
Mean (35.2)	0.12	3.71	0.04	1.69	0.16	4.61
S.D. (14.1)	0.09	4.70	0.04	1.82	0.12	5.78
Riprap						
2 (60)	0.03	2.67	0.03	2.63	0.06	5.30
3 (29)	0.00	0.00	0.10	10.17	0.10	10.17
8 (50)	0.04	1.30	0.02	0.60	0.06	1.90
11 (29)	0.21	3.62	0.17	3.07	0.38	6.69
16 (46)	0.06	1.57	0.07	2.07	0.13	3.64
19 (22)	0.09	2.91	0.09	1.82	0.18	4.73
Mean (39.3)	0.07	2.01	0.08	3.39	0.15	5.41
S.D. (13.5)	0.07	1.20	0.05	3.13	0.11	2.59
Control						
12 (68)	0.06	1.47	0.06	0.46	0.12	1.93
14 (23)	0.00	0.00	0.04	1.48	0.04	1.48
20 (20)	0.00	0.00	0.05	2.20	0.05	2.20
23 (58)	0.09	0.45	0.09	3.78	0.18	4.23
24 (29)	0.17	1.03	0.03	0.69	0.20	1.72
25 (21)	0.14	0.29	0.14	3.86	0.28	4.15
Mean (36.5)	0.08	0.54	0.07	2.08	0.15	2.62
S.D. (19.2)	0.06	0.54	0.04	1.35	0.09	1.24

Table 31. Stock density and standing crop of trout in study bends. Means and standard deviations (S.D.) Deep Creek, Montana October 1988.

Treatment Bend # and Length (m)		Brown trout		Rainbow trout		Total trout	
		Fish/m	g/m	Fish/m	g/m	Fish/m	g/m
Tree revetment							
4	(60)	0.03	0.20	0.03	0.58	0.06	0.78
5	(32)	0.09	4.63	0.09	3.63	0.18	8.26
9	(28)	0.04	0.32	0.00	0.00	0.04	0.32
15	(43)	0.07	0.44	0.16	0.98	0.23	1.42
18	(14)	0.36	2.57	0.14	0.14	0.50	3.21
21	(34)	0.43	8.15	0.12	0.53	0.55	8.68
Mean	(35.2)	0.17	2.72	0.09	0.98	0.26	3.77
S.D.	(14.1)	0.16	3.18	0.06	1.23	0.20	3.44
Riprap							
2	(60)	0.03	0.18	0.03	1.80	0.06	1.98
3	(29)	0.07	1.38	0.03	2.69	0.10	4.07
8	(50)	0.06	1.62	0.04	4.14	0.10	5.76
11	(29)	0.03	0.27	0.03	0.10	0.06	0.37
16	(46)	0.02	0.17	0.04	1.65	0.06	1.82
19	(22)	0.23	3.27	0.18	2.18	0.41	5.45
Mean	(39.3)	0.07	1.15	0.06	2.09	0.13	3.24
S.D.	(13.5)	0.07	1.11	0.05	1.21	0.13	1.99
Control							
12	(68)	0.15	16.42	0.03	0.46	0.18	16.88
14	(23)	0.13	1.87	0.09	0.52	0.22	2.39
20	(20)	0.10	2.00	0.00	0.00	0.10	2.00
23	(58)	0.22	0.84	0.16	2.55	0.38	3.39
24	(29)	0.07	0.48	0.21	1.90	0.28	2.38
25	(21)	0.33	22.33	0.28	6.29	0.61	28.62
Mean	(36.5)	0.16	7.32	0.13	1.95	0.30	9.27
S.D.	(19.2)	0.09	8.70	0.10	2.13	0.17	10.12

Table 32. Number and biomass of trout ≤10 cm in length in study bends before and after construction of revetments, Deep Creek, Montana 1988.

Treatment Bend	March		June		October	
	No. of fish	Biomass (g)	No. of fish	Biomass (g)	No. of fish	Biomass (g)
Tree revetment						
4	20	105	2	4	3	17
5	3	15	0	0	2	19
9	1	5	0	0	1	9
15	14	62	0	0	10	61
18	0	0	2	4	7	45
21	5	41	11	19	8	49
Riprap						
2	10	49	0	0	2	11
3	4	28	0	0	1	9
8	5	15	0	0	1	8
11	6	43	1	2	2	11
16	7	33	1	2	2	11
19	0	0	0	0	8	34
Control						
12	11	51	1	2	7	41
14	5	23	0	0	2	12
20	2	9	0	0	1	6
23	8	58	4	8	11	88
24	10	52	2	4	7	44
25	1	5	3	6	10	64

Table 33. Stock density and standing crop of trout ≤10 cm in length in study bends. Means and standard deviations (S.D.) Deep Creek, Montana 1988.

Treatment Bend # and Length (m)	March Stock Density fish/m	March Standing Crop g/m	June Stock Density fish/m	June Standing Crop g/m	October Stock Density fish/m	October Standing Crop g/m
Tree revetment						
4 (60)	0.33	1.75	0.03	0.07	0.05	0.28
5 (32)	0.09	0.47	0.00	0.00	0.06	0.59
9 (28)	0.04	0.10	0.00	0.00	0.04	0.32
15 (43)	0.33	1.44	0.00	0.00	0.23	1.42
18 (14)	0.00	0.00	0.14	0.22	0.50	3.21
21 (34)	0.15	1.21	0.32	0.56	0.24	1.44
Mean (35.2)	0.16	0.83	0.08	0.14	0.18	1.21
S.D. (14.1)	0.13	0.67	0.12	0.20	0.16	1.01
Riprap						
2 (60)	0.17	0.82	0.00	0.00	0.03	0.18
3 (29)	0.14	0.97	0.00	0.00	0.03	0.31
8 (50)	0.10	0.30	0.00	0.00	0.02	0.16
11 (29)	0.21	1.48	0.03	0.07	0.07	0.38
16 (46)	0.15	0.72	0.02	0.04	0.04	0.24
19 (22)	0.00	0.00	0.00	0.00	0.36	1.55
Mean (39.3)	0.13	0.72	0.01	0.02	0.09	0.47
S.D. (13.5)	0.07	0.47	0.01	0.03	0.12	0.49
Control						
12 (68)	0.16	0.75	0.01	0.03	0.10	0.60
14 (23)	0.22	1.00	0.00	0.00	0.09	0.52
20 (20)	0.10	0.45	0.00	0.00	0.05	0.30
23 (58)	0.14	1.00	0.07	0.14	0.19	1.52
24 (29)	0.35	1.79	0.07	0.13	0.24	1.52
25 (21)	0.05	0.24	0.14	0.29	0.48	3.05
Mean (36.5)	0.17	0.87	0.05	0.10	0.19	1.25
S.D. (19.2)	0.10	0.49	0.05	0.10	0.14	0.93