AN ABSTRACT OF THE THESIS OF

Barbara L. Fontaine for the degree of Master of Science in Fisheries presented on July 30, 1987.

Title: An Evaluation of the Effectiveness of Instream Structures for Steelhead Trout Rearing Habitat in the Steamboat Creek Basin.

Redacted for Privacy

Abstract Approved

James D. Hall

Several types of instream structures were evaluated for their potential to provide rearing habitat and to increase reach carrying capacity for steelhead trout (*Salmo gairdneri*). Evaluation was conducted in each season over the course of 1 year.

Blast pools created in bedrock glides increased the carrying capacity of stream reaches during late summer. Three types of boulder and log structures in gravel-cobble glides did not significantly increase the late summer standing crop of juvenile steelhead. During summer, juvenile steelhead selected the habitat provided by the four types of structures over the untreated glide habitats. The instream structures were used by steelhead for feeding stations, resting areas, and hiding cover. Structures located near the thalweg held substantially more summering steelhead than structures in off-thalweg positions, regardless of structure design.

In winter, seven structure designs were evaluated. The structures that were placed in zones of slow water (deep pools, margin

backwater pools, and dam pools) provided the most effective winter habitat for juvenile steelhead. The structures with the largest concentrations of boulders and rubble generally held the highest winter densities.

During the spring and fall months, habitat utilization was less predictable. Spring and fall were times of transition in which the utilization of habitat structures was probably influenced by changing water temperatures and hydraulic conditions.

Prior to initiating habitat modification programs, habitat managers should conduct an on-site examination of the rearing strategy and seasonal habitat needs of the target species. A pre-work evaluation should be designed to gain an understanding of the most likely environmental factors that limit production. Without such preliminary information, and without a follow-up evaluation, managers cannot recognize their mistakes, innovate appropriate new techniques or determine if funds have been wisely spent.

An Evaluation of the Effectiveness of Instream Structures for Steelhead Trout Rearing Habitat in the Steamboat Creek Basin

by

Barbara L. Fontaine

A THESIS

submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of
Master of Science

Completed July 30, 1987

Commencement June 1988

APPROVED:

Redacted for Privacy

Professor of Fisheries in charge of major

Redacted for Privacy

Head of Department of Fisheries and Wildlife

Redacted for Privacy

Dean of Graduate School

Date thesis is presented July 30, 1987

Typed by Rochelle Belloir for Barbara L. Fontaine

ACKNOWLEDGMENTS

I would like to thank my graduate committee, Drs. Fred Everest and Bob Beschta who freely offered sound direction and insightful advice. My major Professor, Dr. Jim Hall, provided vital assistance at every turn. Dr. Hall's wise perspective was invaluable during the development of the study plan, in the field, and in editing this thesis.

I would also like to acknowledge my husband, Don Morrison, for the moral and financial support during the five quarters of classes, and the Forest Service for support of the field project. Three Forest Service employees, Jerry Harryman, David Harris, and Tom Merritt played instrumental roles in the development of this thesis. Jerry, my work supervisor, worked long and hard to meet the extra work load while I was away at school. David worked undauntingly as a field assistant to see this project through. Also, the art work was done by David. Tom's tenacious efforts at anchoring the habitat structures allowed this study to continue, inspite of the February 1986 floods. My husband Don and friends Reg Cullen and Patricia Lee enthustically volunteered their weekends to help me in the field.

I thank my Mom and Dad for all the moral support they consistently gave to me over the course of this project and over the years. And finally, I would like to dedicate this thesis to the memory of Jamie. Her friendship and enduring positive attitude was a pleasure for the 15 years that she was my dog.

TABLE OF CONTENTS

LIST OF FIGURES

Figure

An Evaluation

of the Effectiveness of

Instream Structures for Steelhead Trout Rearing Habitat

in the Steamboat Creek Basin

INTRODUCTION

Stream habitat degradation and declining populations of wild salmonids have prompted private, state, and federal stream improvement programs. Recently, funding for rehabilitation and enhancement of streams supporting anadromous fish has increased dramatically. This upward trend in spending has not been matched with efforts to evaluate the effectiveness of the "improvements" (Hall and Baker 1982, Reeves and Roelofs 1982, Hall 1984, Bisson 1987). As a result, habitat manipulation is far ahead of our understanding of the critical habitat requirements of juvenile salmonids and the effects of stream "improvements" on rearing salmonids. Without critical evaluation, we cannot recognize our mistakes, innovate appropriate new techniques, or determine if funds have been wisely spent.

The few studies that have been conducted to measure the effects of instream structures on the summer standing crop of anadromous salmonids have reported varied results. Four types of instream structures constructed in Idaho streams did not markedly increase the production of juvenile salmonids during the summer (Petrosky and

Holubetz 1986). Similarly in British Columbia, Ptolemy (1980) found no significant increase in the summer abundance of coho (Oncorhynchus kisutch) fry in reaches where three types of boulder and rootwad structures had been constructed. In Fish Creek Oregon, creation of dam pools and edge alcoves did not significantly alter the summer standing crop of 1+ steelhead (Everest et al. 1985, 1986). On the other hand, Ward and Slaney (1981) reported a significant increase in the summer standing crop of steelhead parr (age 1+) and coho fry (age 0+) in reaches of the Keogh River, British Columbia where five different types of log and boulder structures were built. The placement of boulder clusters in Red Cap Creek California resulted in a two-fold increase in summer densities of 1+ steelhead 2 yr after placement, while densities in untreated control reaches increased by only 15% in the same period (Overton et al. 1981). Similarly, summer population estimates of steelhead parr increased by 100% 2 yr after placement of boulder structures in a reach of Hurdygurdy Creek California, while densities in control reaches declined (Moreau 1984). Comparable results were reported in a coastal Oregon stream (House and Boehne 1985). Reaches manipulated with boulder groupings had a 61% increase in 1+ steelhead after 2 yr, while 1+ densities in the control section increased 15%. Bjornn (1971) added piles of large rubble to two reaches of Big Springs Creek in Idaho. During August, 1 yr after manipluation, 100% more steelhead used the treated reaches than the comparable untreated reaches.

Fewer studies have evaluated the effectiveness of artificial habitat structures during the winter. In the Big Springs Creek rubble piles, Bjornn found 50% more overwintering steelhead than in the control reaches. In Fish Creek, Everest et al. (1985, 1986) observed the highest densities of wintering juvenile steelhead at boulder berm structures and in boulder riprap. They reported that juvenile steelhead were highly concentrated in these favored habitats. In the Keogh River, reaches treated with boulders held twice the number of overwintering steelhead than did similar untreated reaches (Ward and Slaney 1981).

The purpose of my study was to determine if some commonly used types of instream structures could be applied to increase the carrying capacity of juvenile steelhead within study reaches in both summer and winter. In addition, the use of structures by juvenile steelhead was studied to gain an understanding of how instream structures provide habitat during all seasons.

STUDY SITE

The study took place within the Steamboat Creek watershed. Steamboat Creek drains 375 km^2 on the west slope of the Oregon Cascades. It flows into the North Umpqua River 63 km northwest of Roseburg (Figure 1). The area's climate and volcanic geology created steep, mountainous topography. Precipitation averages 140 cm per year at the month of Steamboat Creek. The majority of the precipitation occurs between November and April, while the summers are usually warm and dry. Flashy winter runoff and low summer base flow are characteristic of the study streams. Maximum discharge of Steamboat Creek during this 2-yr study was 620 m^3/sec in February 1986, while the average minimum summer discharge was 1.0 m^3/sec (Steamboat Creek gaging station, near the mouth).

Stream study sites (Figure 1) were established on upper Steamboat Creek, a fifth order stream; on Cedar Creek, a third order stream; and on Little Rock and Horseheaven creeks, which are both fourth order streams. The elevation of the study sites range from 595 to 825 m. Stream gradients within study reaches range from 0.5% to 2%. Maximum summer water temperatures observed in upper Steamboat Creek reached 23°C, while maximum temperatures in the study tributaries ranged from 17°C (Horseheaven Creek) to 20°C (Cedar Creek). Winter water temperatures were observed as low as 1°C.

The stream sections under consideration have been affected by a range of land management activities. Timber harvest in the vicinity

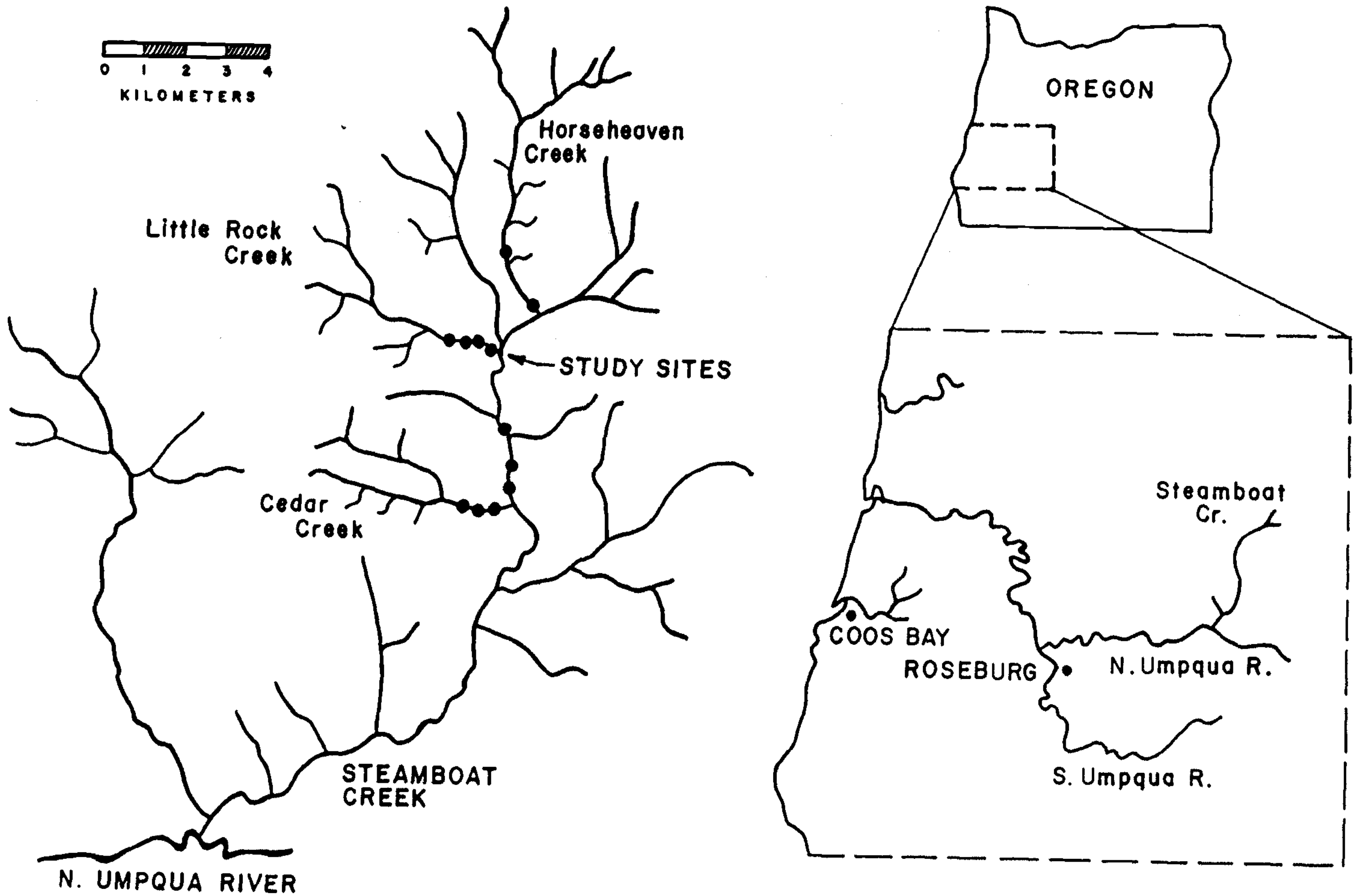


Figure 1. Location of study area in Western Oregon.

began in the early 1960's. Approximately 25% of the Steamboat drainage has been logged. The remaining unlogged forest is primarily old growth Douglas-fir. Roads parallel all four streams and a patchwork of clearcuts exists along portions of each stream. Recent clearcuts have streamside buffer zones of variable width (9 - 30 m), but all riparian conifers were usually harvested in older clearcuts. Most of the natural instream woody debris had been previously removed from the study reaches. About 10 - 15 yr ago, mass wasting of soil from landslides originating in clearcuts entered Little Rock Creek and Cedar Creek within portions of study sections. However, fine sediment loads are currently not excessive in these streams.

Resident rainbow trout (*Salmo gairdneri*), cutthroat trout (*S. clarki*), and summer and winter-run steelhead trout were present within the stream sections under study. Of these species, steelhead are by far the most abundant. Other fishes observed in these waters were: the redside shiner (*Richardsonius balteatus*), Pacific lamprey (*Lampetra tridentata*), dace (*Rhinichthys* spp.), sculpin (*Cottus* spp.), and sucker (*Catostomus* spp.). The entire Steamboat Creek drainage has been closed to fishing and mining since 1932.

METHODS

Seven types of instream structures (Figure 2) were built during the summer months of 1985 and 1986. The structures were designed to enhance rearing habitat for steelhead trout by adding summer rearing space and cover, and by adding winter cover. The habitat structures were anchored into place using 1.2 cm (1/2 in.) galvanized steel cable and polyester resin (Fontaine and Merritt, in progress). The cable was secured by glueing it into 1.4 cm (9/16 in.) diameter holes that were drilled into the boulders with a roto-hammer rock drill.

The effectiveness of four structure types (boulder clusters, boulder-log clusters, angle logs, and blast pools) was evaluated during the summer and autumn months 1 yr after construction. The above structure types and three additional designs (single boulders, boulder pairs, and interstitial blasting), installed in August 1986, were evaluated during the winter and spring months in 1986-1987.

Evaluation of the Physical Habitat

Twelve streambed contour transects were installed to measure changes in channel bed topography. The transects were established adjacent to selected structures within five of the gravel-cobble reaches. The profiles were measured shortly after construction in September 1985 and then again 1 yr later. Nylon cord was strung across the channel between two nails. The nails were driven into streamside trees, marked, and left in place for later measurement.

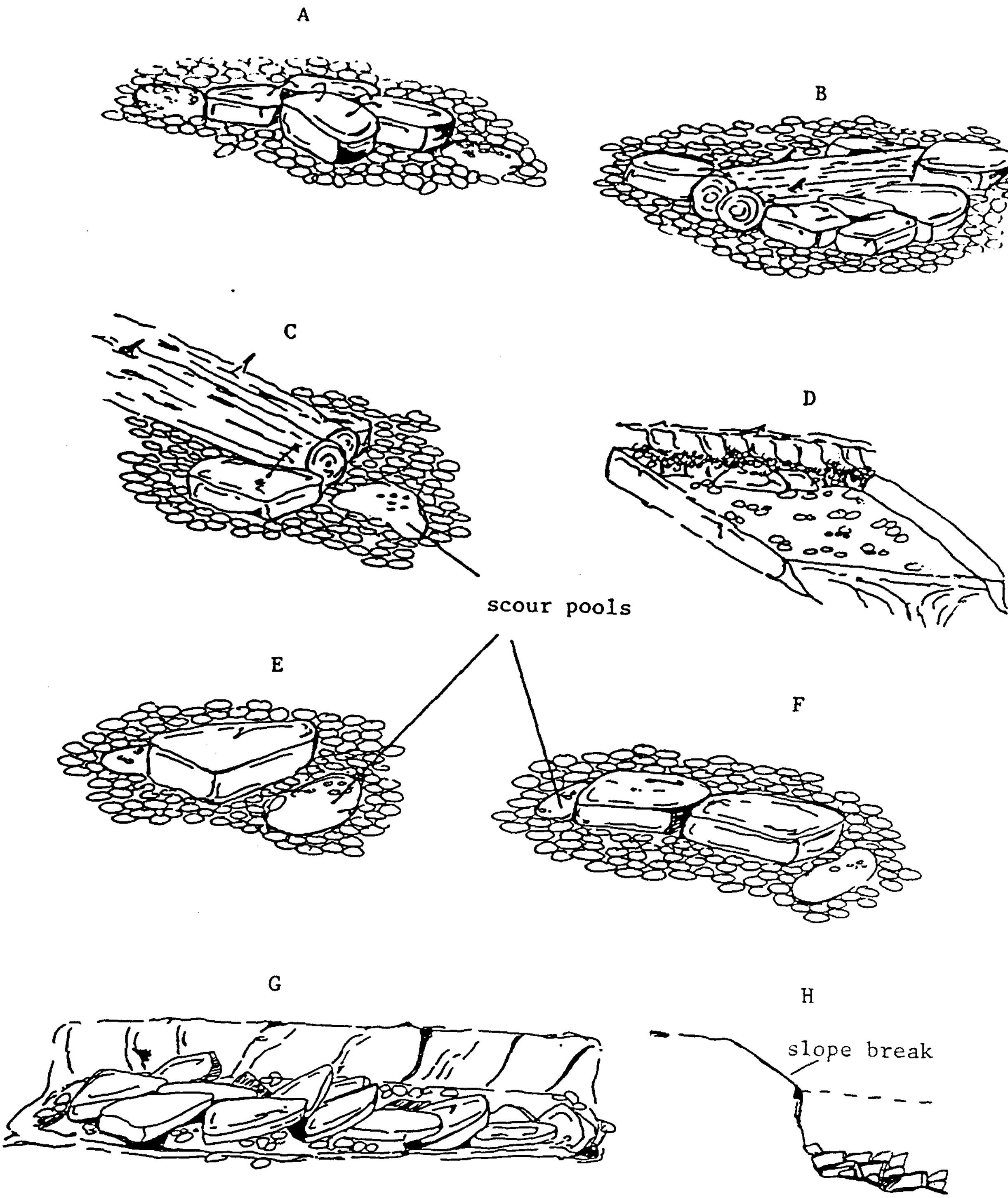


Figure 2. The seven types of structures that were evaluated. Boulder clusters (A), boulder-log clusters (B), Angle logs (C), and blast pools (D) were evaluated during the summer and autumn months. The above structure types and three additional designs-- single boulders, boulder pairs, and interstitial blasting (E,F, and G) were evaluated during the winter and spring months. Interstitial blasting (G) was accomplished by blasting bedrock into large boulder-sized chunks that remained essentially in place. This created many interstitial spaces for cover. Blast pool placed below a slope break (H).

The cord was cinched tight to eliminate sag. The distance was then measured from the cord down to the stream bottom (to the nearest 10 cm) at 0.5-m intervals along each transect. The surface area and depth of each scour pool were measured, and general trends of scour and deposition were noted.

Summer and Autumn Evaluation

Summer evaluation focused on the period of low streamflow in August. We made the assumption that the streams were fully seeded because there was an abundance of emergant fry during the springs of 1985 and 1986. Next, we assumed that rearing space during summer low flow was limiting the summer carrying capacity. Chapman (1962) reported that under conditions of full seeding, intraspecific competition forces juvenile salmonids to occupy all suitable habitats. When the amount of habitat decreases during late summer, subordinate individuals are forced to emigrate and the carrying capacity is lowered. Therefore, steelhead densities within study reaches during low flow conditions were thought to be an appropriate measure of treatment success.

Autumn evaluation began when juvenile steelhead started to redistribute in mid September. The autumn evaluation period extended into the time when falling water temperatures caused fish to seek winter cover in late October.

The four structure types that were evaluated during the summer and autumn periods were built in glides (Bisson et al. 1982, Appendix

1) that lacked large woody debris, natural boulders, pools, alcoves, or other forms of habitat diversity. Boulder clusters, boulder-log clusters, and angle logs were built within glides of gravel and cobble substrate (4-26 cm, Wentworth Scale). Blast pools were created within bedrock glides.

In the gravel-cobble reaches, each of the three treatments was applied following a randomized block experimental design (Kirk 1977). Each treatment (structure type) was randomly assigned to one of four, 30-m-long, homogeneous reaches within a block (Figure 3). One reach within each block was left untreated as a control. There were three blocks totaling 12 reaches on Steamboat Creek and two blocks totaling eight reaches on Horseheaven Creek. Four 20-m-long bedrock study reaches were established on Little Rock Creek; two were treated with blast pools and two were left untreated as controls.

In the gravel-cobble reaches, pre-treatment and post-treatment juvenile (age 0+ and 1+) densities were estimated by divers. Pre-treatment dives took place in early July 1985, prior to low flow conditions. Post-treatment dives spanned the summer and autumn periods in 1986. Snorkle counts were conducted by one to four divers between the hours of 1000 and 1500. To facilitate the process, each gravel-cobble reach was divided longitudinally into two or more census corridors. The number of longitudinal corridors used depended on the width of the stream and the amount of area a diver could thoroughly cover in one pass. The corridors were delineated with plastic survey flagging laid out along the stream bottom. The flagging served as a reference for a diver swimming up through a corridor. Only those fish

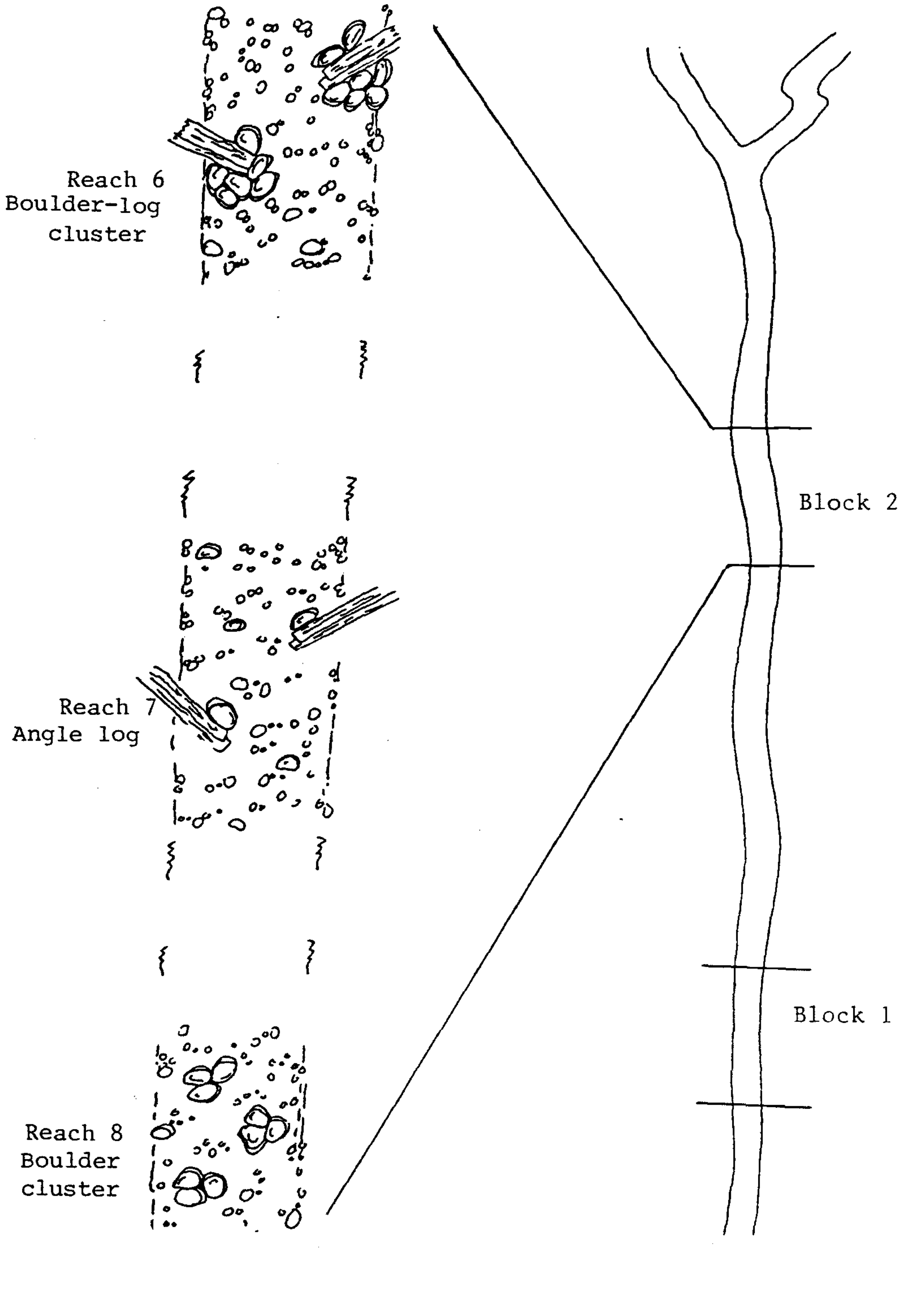


Figure 3. On gravel-cobble glides, three treatments were applied following a randomized block experimental design. Each structure type was randomly assigned to one of four homogeneous reaches within a block. One reach within each block was left untreated as a control (not shown).

holding a station (Edmundson et al. 1968) within a diver's section were counted. This was done to avoid double counting fish that moved on ahead of the diver. The divers moved in unison up their respective corridors. Plexiglas slates were carried by each diver to record fish numbers and distribution. Dive lights were used to help see fish in cover or dimly lit locations.

Census corridors were laid out and reach measurements were made several days prior to snorkeling. Depth was measured at 1-m intervals along four cross-sectional transects, spaced 10 m apart. Reach width was measured at each cross-section.

Unfortunately, divers failed to properly distinguish between age 0+ and 1+ steelhead during pre-treatment sampling in 1985; many 0+ were counted as 1+. As a consequence, the 1985 pre-treatment fry and parr counts were summed into total juvenile densities for each reach and used as a covariate in an analysis of covariance (Anderson et al. 1980). The covariate established a comparative baseline for control and treated reaches. The 1986 post-treatment densities during summer low flow in control reaches were compared with densities in treated reaches during the same period. The summed juvenile counts from 1985 were not compared with the post-treatments counts of total juveniles because censusing occured during different months. Also the 1985 crop of 0+ steelhead was substantially greater than that in 1986 (Appendix 2).

Scale samples were collected and examined during the summer of 1986 to verify the distinction between the two age classes (Appendix 3). It was not possible to separate 0+ cutthroat trout or resident rainbow trout from 0+ steelhead, so all 0+ salmonids were reported as steelhead in this study.

The bedrock study reaches on Little Rock Creek were censused with a modified direct observation technique. Blast pools were individually censused by divers. However, most of the untreated bedrock area was too shallow (<20 cm) to snorkle. We censused these shallow zones by scanning the area with binoculars, while standing on elevated bank locations. Counts obtained by remote viewing were better than counts obtained while walking or crawling through the reach, because an observer directly overhead caused fish to scatter. Remote enumeration was only effective under the existing conditions of clear, shallow water and smooth surface flows over a bedrock background. Census corridors were not used in the bedrock study reaches, but surface area and volume estimates were obtained with the methods previously described. Pre-treatment counts were not obtained in the bedrock study reaches.

During low streamflow 1 yr after construction, 14 of the treated study reaches were classified into discrete habitat units following the system of Bisson et al. (1982) (Appendix 1). The area of each habitat unit was measured. It was then noted whether or not the habitat unit was the product of a habitat structure. The proportion of each habitat type within each reach was determined by summing the area of the specific habitat types and dividing by total reach area. During post-treatment censusing, fish were enumerated within each discrete habitat type.

Habitat utilization was calculated according to the equation of Bisson et al.(1982):

$U=(D_h-D_r)/D_r$

Where:

U = Habitat utilization coefficient

D_h = Density (fish/m^2) in the habitat type of interest.

D_r = Density (fish/m^2) within the entire stream reach.

This method of quantifying habitat utilization expresses the fraction of the reach population found within a particular habitat type to the relative abundance of that habitat type available in the reach. The values of U range from -1 for unoccupied habitats to plus infinity for highly preferred habitats. A utilization coefficient of zero indicates that fish density within the particular habitat type was the same as the density over the entire study reach. Habitat utilization by age group (0+, 1+) was determined by taking the mean of the coefficients of all like habitat units in the treated reaches.

Detailed underwater observations of habitat use by steelhead parr were made on nine of the gravel-cobble experimental reaches during a 5-day sampling period in August 1986. Every 1+ steelhead encountered within these treated study reaches was catalogued according to habitat type occupied and behaviors observed. Behaviors were classified as either feeding or resting. A fish was classified as feeding if it pursued prey at least once during the observation period (observation time averaged about 5 min per fish). A fish was classified as resting if it did not pursue prey and was not actively swimming in the current. Hiding behavior was documented when a fish escaped into cover. Hiding was provoked when one of two underwater observers lobbed a rock into the immediate vicinity of the fish. The type of escape cover used and the distance traveled to cover were noted. Physical parameters of the sites utilized by parr were measured. These were water depth, average focal point velocity, distance to thalweg, and distance to nearest habitat structure.

Winter and Spring Evaluation

The use of instream structures by juvenile steelhead during the winter was evaluated between November 1986 and March 1987. This evaluation period was identified by water temperatures less than 7°C. Under these conditions, steelhead occupied the interstices of stream substrate, out of the main water column. Winter sampling was done during mild flow conditions using a variable voltage generator-powered, backpack electroshocker (Coffelt BP-6). Electroshocking successfully drew juvenile steelhead out of their winter holding sites and sampling mortality was negligible. We did not determine the degree of sampling efficiency, but suspected that some of the larger, more complex structures were not as thoroughly sampled as smaller, single element structures.

Snorkeling was used occasionally to observe overwintering behavior and attempt to pinpoint overwintering locations. To locate wintering steelhead in temperate streams, divers have had to excavate them out of the substrate (Edmundson et al. 1968, Everest and Chapman

1972, Everest et al. 1985 and 1986). Consequently, snorkeling was not an effective method of sampling large, immovable stream structures.

We electrofished within the immediate area of individual structures and at selected, untreated sites. The untreated sites were adjacent to structures having similar flow conditions and bottom substrate. Eighty-seven structures, representing seven designs, and 25 untreated sites were sampled in three streams. Each site was sampled on at least two different days. Most untreated sites were sampled only once. Many fish that were drawn out of the substrate were not stunned enough to be caught. However, if a fish was seen, it was usually possible to tell if it was a salmonid and whether it was age 0+ or 1+. Stunned fish were netted and held in a bucket until they recovered. Fish were then released back to the site where they were caught and the sampling area was measured. Upon release, fish swam quickly back into cover. I chose to use the largest fish count from each site to calculate site-specific density. We shifted back to snorkle sampling in the spring when fish left their winter hiding locations.

RESULTS AND DISCUSSION

Changes in the Physical Habitat

In February 1986, 5 months after the stream structures were installed, two 5-yr flood events occurred within a 24-h period. The structures on upper Steamboat Creek experienced flows of approximately 215 m^3/sec. The angle logs on Steamboat Creek were not properly anchored. As a result, they moved during high flows and they became ineffective as habitat structures. Consequently, the angle log treatment on Steamboat Creek was dropped from the analysis. All the other study structures on Steamboat and the three study tributaries remained intact.

Lateral scour pools (Appendix 1) formed adjacent to many of the boulder clusters, boulder-log clusters, single boulders, and boulder pairs within gravel-cobble reaches. Scour was most prevalent around structures that were placed within or near the thalweg. Lateral scour pools usually occurred on one or both sides of boulder structures. Angle logs usually formed scour pools at the tip (Figure 2, Appendix 4). Scour pools also formed under angle logs that were installed with the bank end elevated. The average surface area of lateral scour pools was 4.4 m^2 and the average depth of scour was 0.35 m.

Structures placed near stream margins did not form scour pools unless the thalweg passed in the immediate vicinity. Thirty percent of the structures located on stream margins were partially buried by deposits of bedload. A zone of deposition consistently occurred in the downstream wake of all structures regardless of structure location within the channel.

Blast pools that were placed below natural slope breaks (Figure 2) were hydraulically scoured of their blasted rubble by winter flows. In relatively flat reaches, blast pools were not scoured during winter flows. Blast pools that were placed too close to other structures (e.g. in the downstream wake of a boulder cluster or angle log) were filled in with bedload.

Summer Evaluation

During summer low-flow conditions, steelhead densities in the treated, gravel-cobble reaches of Steamboat and Horseheaven creeks were not significantly different from untreated, control reaches ($P > 0.20$, Analysis of covariance). However, the mean denisities of juvenile steelhead in treated reaches were in most cases slightly higher than those in control reaches (Figure 4). During the same period, treated bedrock reaches on Little Rock Creek had five times more 0+ and seven times more 1+ steelhead than comparable bedrock control reaches. The results on Little Rock Creek were statistically significant ($P < 0.01$, Mann-Whitney U Test, Daniel, 1978), suggesting that the late summer carrying capacity of bedrock reaches was increased by the addition of blast pools.

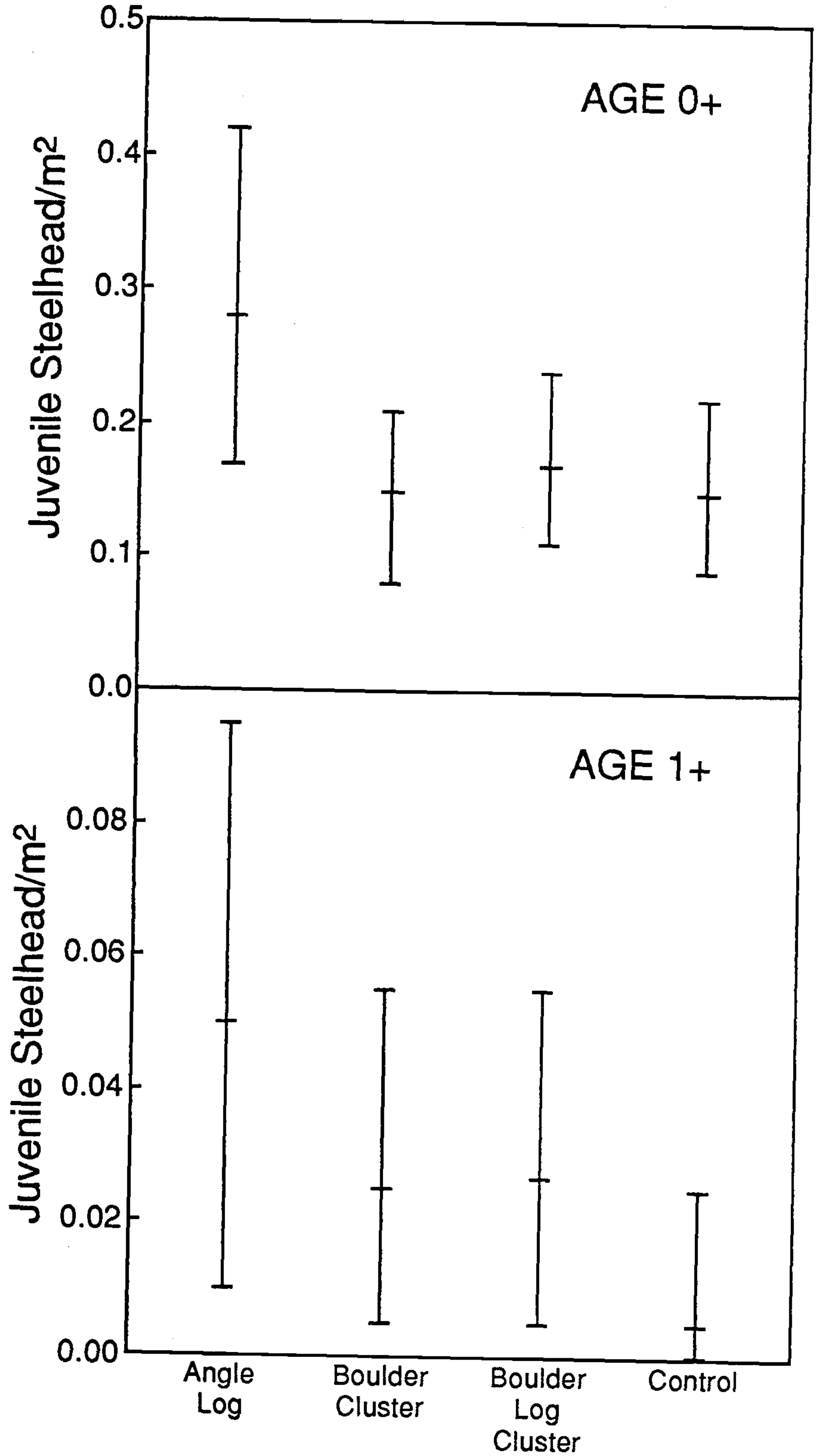


Figure 4. Mean and 95% confidence interval estimates of 0+ and 1+ steelhead densities in the gravel-cobble study reaches of Steamboat and Horseheaven creeks during August 1986. The interval estimates were calculated using the least significant difference values.

Though the response of the fish population to habitat manipulation was variable, juvenile steelhead showed a strong preference for the microhabitats created by all types of instream structures in all three streams. In the 12 treated reaches of Horseheaven and Steamboat creeks, steelhead selected the cover of instream structures and the scour pools adjacent to structures over the glide habitats (Table 1). The blast pools in Little Rock Creek were also highly preferred. In the spring, emergent fry were not strongly associated with structures for cover and feeding stations (see p. 43). However, by late summer fry generally developed a closer association with the habitat structures. These behavioral changes reflect what was observed as a gradual trend of increased use of structures by 0+ steelhead over the course of the summer and fall.

Habitat utilization coefficients (U) showed that 1+ steelhead had a stronger preference for the treated habitats than did underyearlings (Table 1). Parr used the preferred habitats (blast pools, scour pools, natural pools, and structure cover) more exclusively, and avoided glides more completely than 0+ steelhead. We observed that the use of preferred habitats by 0+ steelhead was strongly influenced by the agonistic behavior of 1+ steelhead occupying the sites. During late summer, underyearlings usually occupied the downstream ends of scour pools and blast pools, while 1+ fish held and defended the heads of pools. Territorial behavior within the intersticies of structures was more difficult to interpret. Extended observation periods on some structures revealed that the fish holding within the structures tended to tolerate higher

Table 1. Mean habitat utilization coefficients (U) representing juvenile steelhead (age 0 and 1+) preference of five different microhabitat types within 14 treated reaches. Data were collected during summer low flow 1986.

		Structure cover		Structure scour pools		Natural trench & plunge pools		Glides		Blast pools	
		0+	1+	0+	1+	0+	1+	0+	1+	0+	1+
Horse-heaven Creek 6 reaches	Utilization coefficient (U)	0.7	2.8	2.4	14.7	14.1	14.9	0.0	-0.1		
	Total fish	23	9	70	24	22	8	197	7		
	No. of habitat units	13		13		3		6			
	Habitat surface area (m^2)	44		67		11		823			
Steam-boat Creek 6 reaches	Utilization coefficient (U)	4.0	11.4	8.3	36.5	15.9	7.3	-0.9	-0.9		
	Total fish	21	16	33	15	4	0	98	2		
	No. of habitat units	17		12		1		6			
	Habitat surface area (m^2)	132		65		5		3,082			
Little Rock Creek 2 reaches	Utilization coefficient (U)							-0.8	-1.0	1.7	2.3
	Total fish							16	0	133	15
	No. of habitat units							2		6	
	Habitat surface area (m^2)							254		106	

densities of conspecifies than were tolerated by the steelhead holding stations out in the main current.

Some of the preferred habitat units were used more than others. For instance, on reach 1 of Horseheaven Creek, one scour pool had a habitat specific density of 2.86 parr/m^2 and a parr utilization coefficient of +56.2, while another scour pool, only 3 m away held 0.36 parr/m^2 with a utilization value of +6.2 (Appendix 5). A similar pattern of differential utilization was seen in underyearlings.

The differential use of the habitat structures and associated microhabitats during late summer was apparently a result of structure location rather than design. Structures located in or near the thalweg held significantly more 0+ and 1+ steelhead than structures located off the thalweg and near stream margins ($P < 0.01$ for both 0+ and 1+, Mann-Whitney U test, Figure 5). By late summer, structures along stream margins were seldom used by juvenile steelhead during daylight hours. In many study reaches, only one or two structures, located in the direct path of the thalweg, appeared to be effective.

Night observations of steelhead distribution in three treated reaches of Horseheaven Creek were inconclusive. None of the 1+ fish that normally occupied these reaches was found. Age 0+ steelhead were settled on the substrate, generally out in the open, wherever flows were slow (stream margins and backwater areas below structures). Use of the interstitial spaces and the cover of instream structures during the night was not apparent, though viewing conditions were difficult.

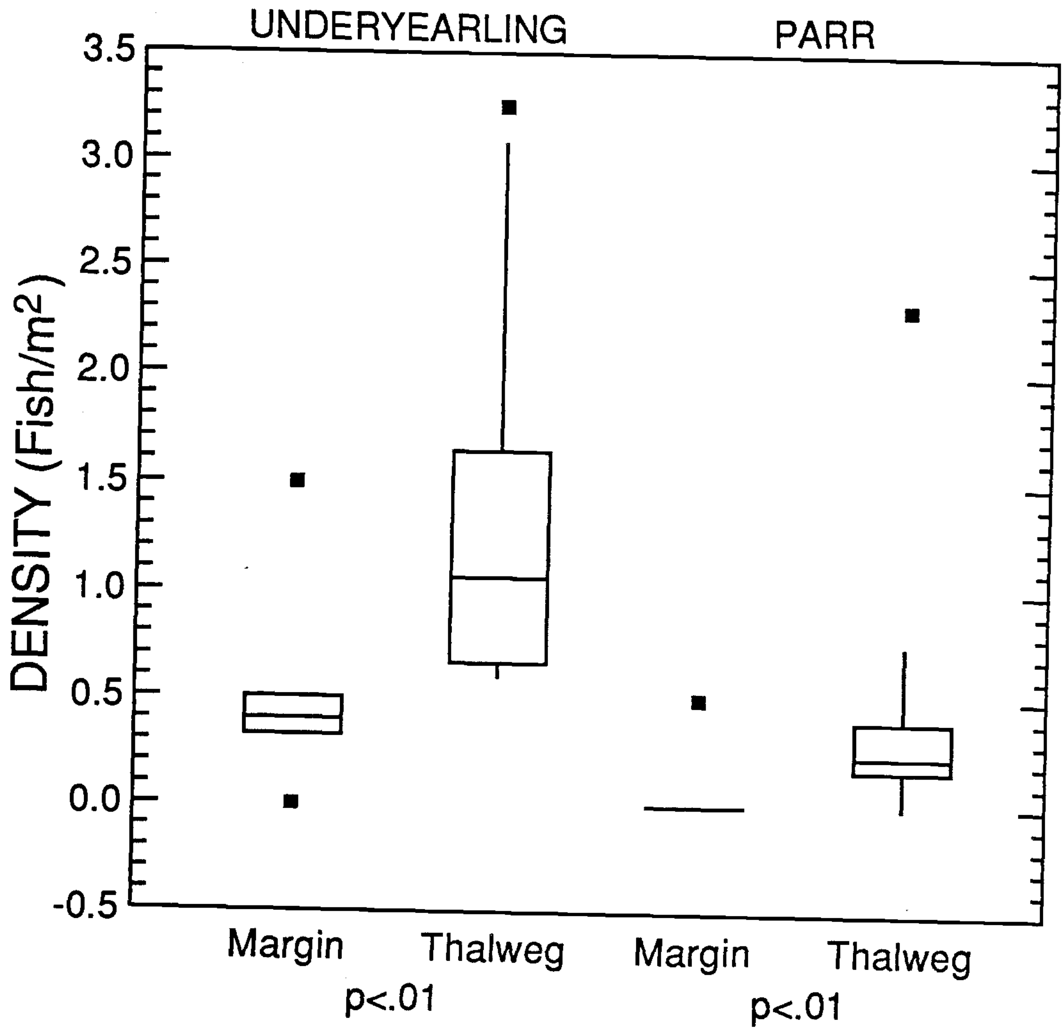


Figure 5. Box and whisker plots of juvenile steelhead densities associated with seven structures located near stream margins and 15 structures located near the thalweg. Density estimates were made during summer low flow, August 1986. The box covers the interquartile range - the middle 50% of the density values between the upper and lower densities. The central line is the median value. The "whiskers" extend out to those values that are within 1.5 times the interquartile range. Any densities beyond the whiskers are plotted as separate points. For parr in margin structures, the box is represented by a single line at zero because all interquartile values are zero.

Night sampling occurred only once in August, so these findings are preliminary.

Other investigators, finding no significant increase in anadromous fish production after the addition of instream structures, suggested reasons for the lack of positive results. Ptolemy (1980) and Everest et al. (1986) concluded that the amount of stream area actually altered by the structures was insufficient to significantly affect summer standing crops or smolt yield. In an Idaho study, Petrosky and Holubetz (1986) concluded that the potential benefits of instream structures could not be realized due to a lack of full seeding in the study streams.

When reach populations have increased following the installation of instream structures, the changes have been attributed to the habitat structures (Bjornn 1971, Ward and Slaney 1981, Overton et al. 1981, Moreau, 1984, House and Boehne, 1985). Habitat management with instream structures has generally been accepted as a means of increasing the carrying capacity of streams. Under conditions of full seeding, intraspecific competition for food and space forces juvenile salmonids to fill all suitable habitats (Chapman, 1962). Therefore, the addition of appropriate living space in streams lacking this element would provide new space for individuals that would otherwise be forced to emigrate (Reeves and Roelofs, 1982). Theoretically, the end result of adding rearing habitat would be an increase in smolt production.

This presumption should hold if, in fact, rearing space is a critical factor limiting production. However, Everest and Sedell

(1984) and Bisson (1987) warned against initiating stream modification projects without thorough consideration of the spectrum of factors that potentially limits production in the basin where the work is to be done.

I believe that the lack of a significant population response in the treated reaches of Steamboat and Horseheaven creeks was due in part to factors other than ineffective structure design. For one, the fraction of each reach actually influenced by the habitat structures was very low (Appendix 5). More structures per reach may have resulted in a significant effect, especially on Horseheaven Creek.

On Steamboat Creek, other factors affected reach carrying capacity. Food availability may have limited the summer standing crop on four study reaches of Steamboat Creek because water velocities were visibly much slower than in other study reaches. Aquatic insect drift has been shown to be low or non-existent in slow currents (Chapman and Bjornn, 1969). Everest and Chapman (1972) and Slaney and Northcote (1974) found that steelhead fry emigrated from study channels when prey abundance was lowered. These factors suggest that low amounts of food may have been responsible for low fish densities within study reaches on Steamboat Creek. In addition, high water temperatures and competition with redside shiners undoubtedly had an effect on the population of juvenile steelhead in Steamboat Creek. During a three week period in August, water temperatures in Steamboat Creek study areas sustained average daily maximums of 19^{o}C (Appendix 6). In laboratory stream channels, juvenile steelhead tended to abandon their territories and emigrate when water temperatures were high (19-22^{o}C)

(Reeves et al. 1987). A further reduction in abundance of juvenile steelhead occurred when redside shiners were introduced into these warm water laboratory channels. On Steamboat Creek we noted large numbers of redside shiners in several of the treated reaches. As water temperatures increased over the course of the summer, fewer steelhead were found in Steamboat Creek, and shiners generally monopolized the structures. As many as 30 shiners were found within one boulder cluster.

It is impossible to increase the summer carrying capacity of a reach by increasing the quality of the rearing space when factors other than rearing space are limiting production. In Steamboat Creek, water temperature, interspecific competition, and food availability all appeared to influence the summer standing crop of juvenile steelhead. Under these circumstances, a test of the effects of habitat structures in Steamboat Creek turned out to be inconclusive.

On Little Rock Creek, rearing space was limiting the carrying capacity of bedrock study reaches. Prior to the addition of blast pools, these reaches were too shallow to hold 1+ steelhead, and they offered a bare minimum of rearing space for 0+ fish. The habitat-specific densities within blast pools (Appendix 1) show that these structures were responsible for the increase in the late summer standing crop within these reaches.

Detailed underwater observations revealed that parr maintained territories in close proximity to habitat structures, especially if the structure was located near the thalweg. Eighty-eight percent of all steelhead parr encountered within nine treated glides occupied locations either within the confines of structures or within 2 m of a structure (Figure 6). Sixty-three percent of the parr occupied sites within 2 m of the summer thalweg (Figure 6).

The scour pools associated with habitat structures functioned as feeding locations for steelhead parr within the treated glides. Sixty percent of all the parr encountered in the reaches were feeding. Of these, 63% maintained focal points within the scour pools of habitat structures, 21% fed in natural scour or plunge pools, and 16% fed in glide habitats. Several scour pools extended underneath one or two boulders of a structure. This type of scour pool usually developed when a structure was in the main path of the thalweg. In such pools, fish held feeding focal-points under the boulders.

The intersticies of boulder clusters and boulder-log clusters functioned as resting habitat for steelhead parr during the day. Forty percent of all the parr encountered in the reaches were classified as resting. Of these, 90% rested in the shaded interstitial chambers of boulder clusters and boulder-log clusters, where the current velocity was negligible. Native cobbles provided resting locations for the remaining 10% of resting parr. Angle logs did not provide resting opportunities, apparently due to lack of both interstitial areas and appropriate low velocity zones. Resting fish were mainly inactive and aggressive encounters were relatively few.

Boulder clusters and boulder-log clusters also provided escape cover for parr. When disturbed, 52% escaped into natural cover locations and 48% escaped into habitat structures. The natural escape locations were usually the largest nearby cobble, as native boulders

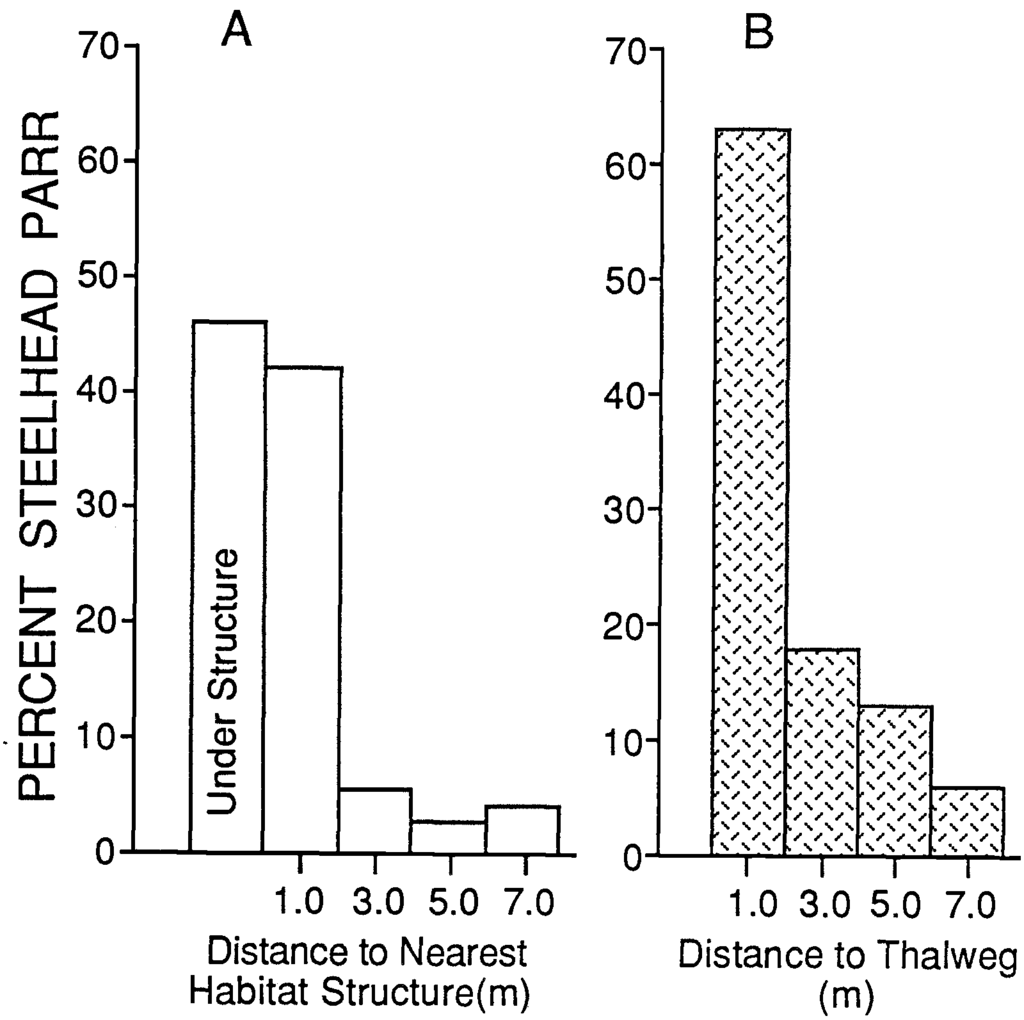


Figure 6. The percentage of 1+ steelhead holding stations at various distances from habitat structures (A) and the thalweg (B) during summer low flow in Steamboat and Horseheaven creeks, 1986.

were not present in the study glides. Many fish were reluctant to leave their focal points. In some cases it was necessary to throw several rocks in order to provoke a hiding response. Fish quickly ventured out of hiding and usually resumed feeding at the same focal point. When provoked again, parr usually returned to the same location for cover.

The disproportionately high use of mid-channel structures is consistent with other studies that examined juvenile steelhead habitat utilization during the summer. As steelhead fry grow, they progressively use faster, deeper water typical of mid-channel locations (Hartman, 1965; Everest and Chapman, 1972). Furthermore, swifter currents carry more drifting food organisms (Chapman and Bjornn, 1969; Everest and Chapman, 1972).

In my study, structures in off-thalweg locations often failed to develop scour pools. In fact, some structures on the margin caused streambed aggradation. As a result, the water surrounding these structures during summer was very shallow. Some structures on stream margins became dewatered during August, and they provided no summer rearing habitat. In contrast, mid-channel structures offered a myriad of microhabitat elements. The scour pools associated with mid-channel boulder clusters and boulder-log clusters offered fast and relatively deep water. Immediately adjacent to the scour pools, boulder clusters and boulder-log clusters provided a velocity rest zone, hiding cover, and shade. Smith and Li (1982) suggested that by maintaining a focal point in the quiet water zone of an obstruction (boulder), young juvenile steelhead were able to conserve energy yet feed in the adjacent swift water. Also, Dolloff (1983) postulated that instream boulders and debris offered fish the opportunity to visually isolate themselves from one another. Visual isolation may allow fish to tolerate higher densities of conspecifics.

In Waddell Creek, California, Shapovalov and Taft (1954) reported that activity levels of juvenile steelhead slowed and feeding was greatly diminished during late summer when stream temperatures were high. This is consistent with our findings of a substantial fraction (40%) of "resting" parr within the confines of instream structures. In Steamboat Creek, temperatures were taken at the parr resting stations under boulder clusters and boulder-log clusters. In some instances, temperatures at the resting stations were 0.3 to 0.6°C cooler than stream bottom temperatures adjacent to structures. Cooler groundwater flow may have been made available within the depths of these scour pools.

If rearing space is limiting the summer carrying capacity of juvenile steelhead, then the creation of lateral scour pools, plunge pools, or blast pools (all with cover) would all be appropriate habitat manipulation techniques to apply in shallow reaches. Boulder clusters could be used to create lateral scour pools in gravel-cobble riffles and glides. Boulder clusters are effective scour elements that also provide cover. Furthermore, boulder clusters are easy to install, and they do not require extensive anchoring, as do angle logs and boulder-log clusters. Blast pools should be created below a natural slope break or in high velocity reaches so that their depth will be maintained by hydraulic scouring with winter flows.

Plunge pools are scoured on the downstream side of log weirs that are placed over gravel substrate. On bedrock, a plunge pool can be created by first blasting a pool and then placing a log weir directly upstream.

During mid to late summer, both age classes of steelhead seek areas of swift current velocity for feeding. Summer rearing pools for steelhead should be created near mid-channel, within riffles and glides, where the summer thalweg velocities are approximately 0.15 to 0.40 m/sec (Reiser and Bjornn, 1979).

Preliminary results suggest that among pools, the deeper ones are more effective for the summer rearing of steelhead. Blast pools should be at least 1.5m deep. Plunge pools are usually deeper than lateral scour pools because water falling over an obstruction has more potential energy than water that is diverted around an obstruction. The current velocity within dam pools (upstream of weirs) is generally too slow to attract steelhead during the summer. However, dam pools serve an important role during other seasons.

Autumn Evaluation

The autumn evaluation period was defined by pronounced changes in both weather and steelhead behavior. In 1986, the first fall freshets began after a series of storms in mid September; streamflow remained elevated thereafter. Also in September, water temperatures dropped from consistently warm summer levels. During the first 10 days of that month, the average maximum temperature in Cedar Creek was

13.8°C. During the rest of the month, daily maximums averaged 9.4°C. October water temperatures remained relatively stable with highs averaging 8.3°C.

With the onset of autumn conditions in September, juvenile steelhead began a pattern of movement and redistribution. In glides, 0+ densities declined gradually over a 4-week period, but 1+ steelhead left the glides abruptly during the second week of September (Figure 7). There was also a sudden decline in abundance of 1+ in natural pools and blast pools (Figure 8). Conversely, there was an autumn increase in the numbers of 0+ steelhead in some of the natural and created pools (Figure 8). Underyearling densities appeared to increase only within the deeper pools that were located near the center of the channel (Figure 8). Shallow blast pools did not attract 0+ steelhead in the fall (Figures 7 and 8). During autumn occupancy of deep pools, underyearling steelhead fed voraciously at activity levels substantially higher than summer. Though densities were high within the pools, aggressive encounters were less frequent than observed in the summer.

The 0+ steelhead that remained in glides during October became more closely associated with the cover provided by instream structures. Underyearlings were observed holding within boulder clusters that had been previously dominated by 1+ fish. At this time 1+ fish were no longer seen in glides.

During the third week in September, very few 1+ steelhead were seen during diving surveys of extensive areas of Steamboat Creek and the study tributaries. We assumed that a substantial portion of the

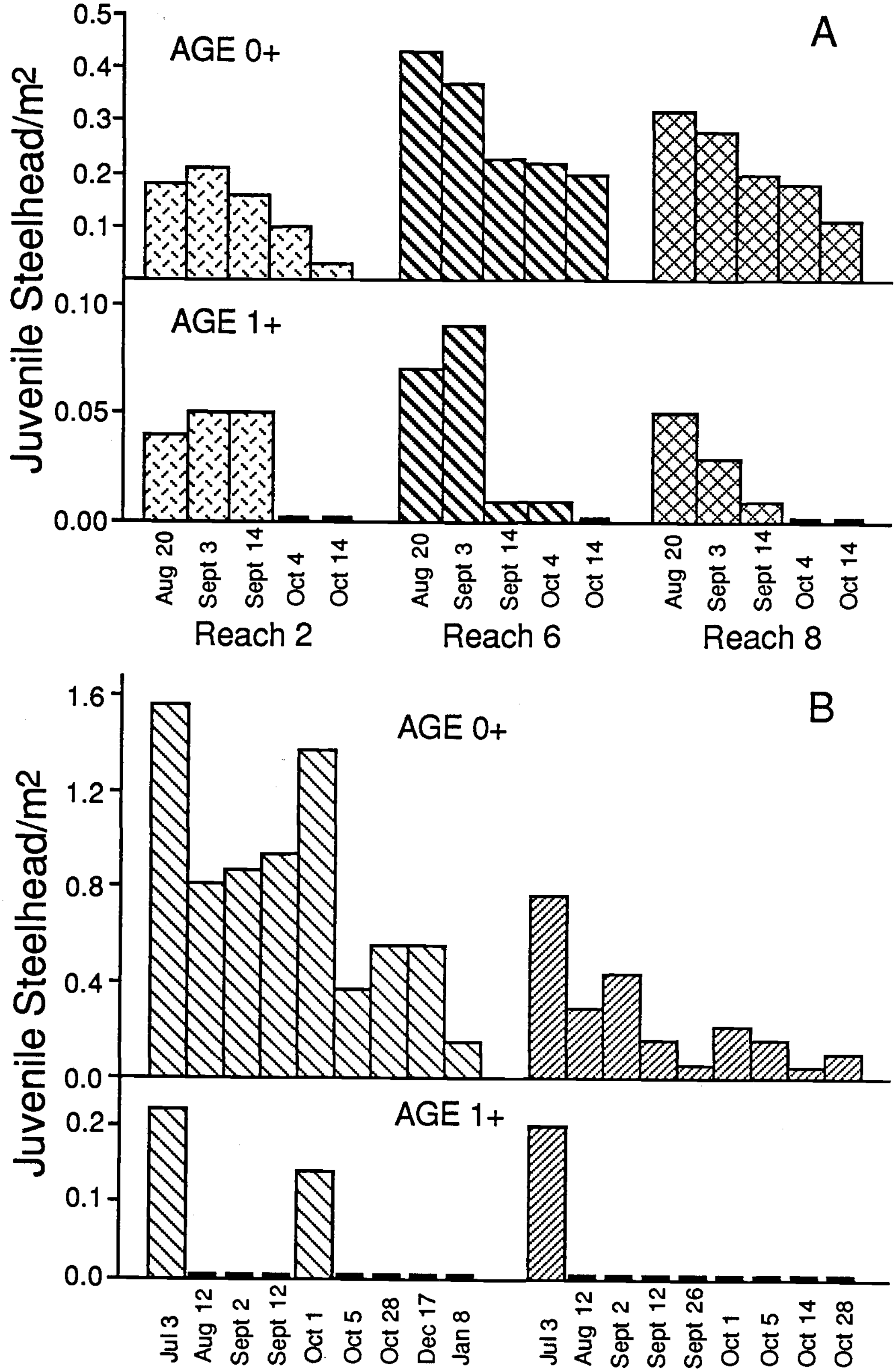


Figure 7. Seasonal trend of juvenile steelhead densities in (A) three enhanced glides in Horseheaven Creek and (B) two blast pools located along the channel margin of Little Rock Creek, 1986-87.

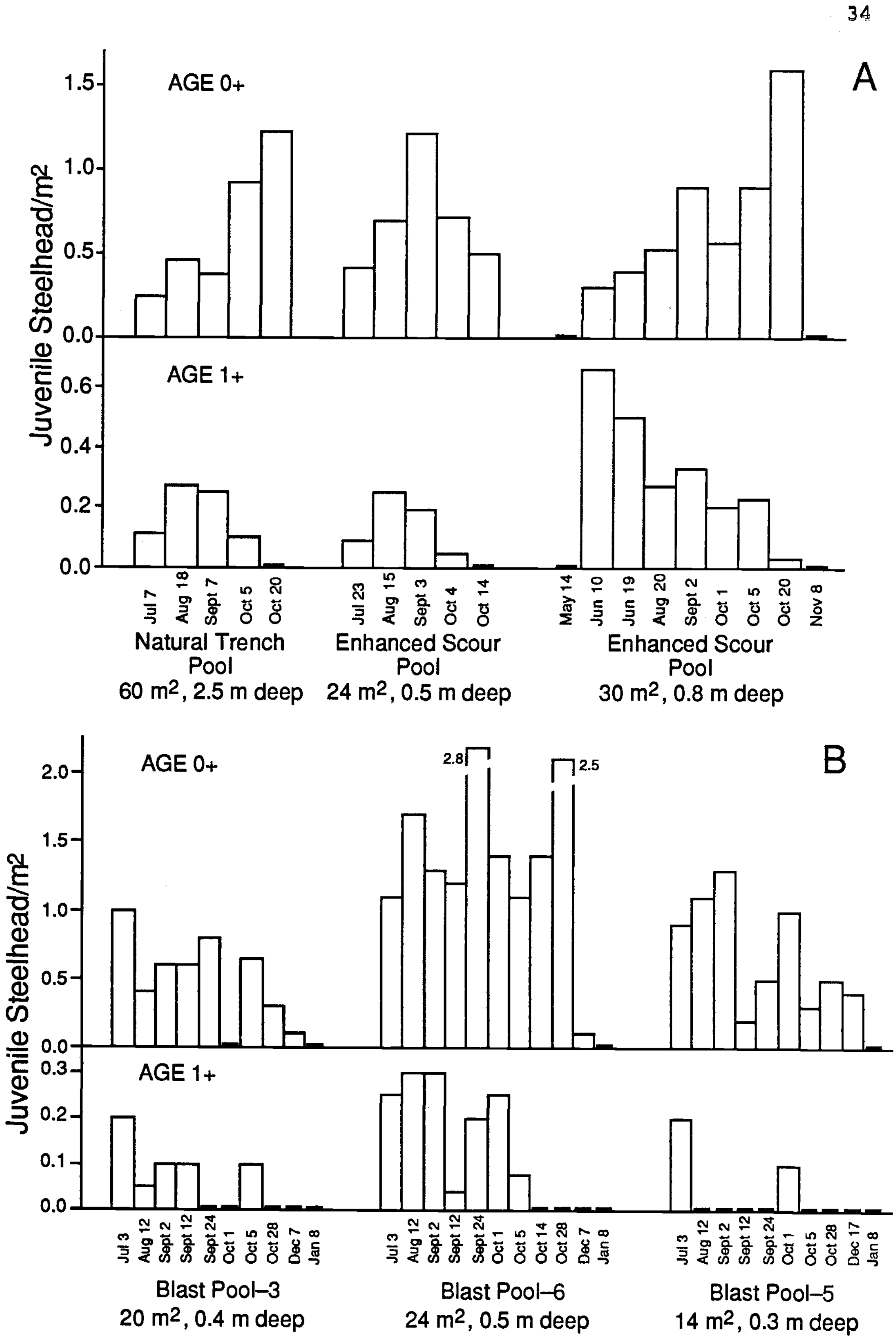


Figure 8. Seasonal trend of juvenile steelhead densities in (A) three mid-channel pools in Little Rock and Horseheaven creeks, and (B) three blast pools located mid-channel in Little Rock Creek, 1986-87.

1+ had either migrated or entered into winter hiding. The daily minimum water temperatures at this time averaged 10°C. Yearling steelhead in laboratory streams generally did not begin winter hiding until temperatures dropped below 9°C (Everest et al. 1986).

The possibility of an autumn exodus of 1+ steelhead from tributaries of Steamboat Creek is consistent with trends described elsewhere. Some authors suggested that 1+ steelhead presmolts migrated at the end of their second summer, probably overwintered in mainstem rivers (Tredger 1980, Loch et al. 1985, Leider et al. 1986). Everest et al. (1986) also documented an autumn decline of 1+ steelhead in Fish Creek. But a Humphrey trap at the mouth of that basin revealed no out-migration of parr. Instead, they observed small groups of 1+ attempting to migrate upstream. It was suggested that these fish moved upstream in search of winter cover. Others have documented a fall influx of juvenile salmonids into tributaries from mainstem rivers (Everest 1973, Bustard and Narver 1975, Cederholm and Scarlett 1982). Cederholm and Scarlett (1982) suggested that fall presmolts, after leaving their natal streams and traveling down to the mainstem, entered lower elevation tributaries to spend the winter.

Based on a series of controlled-stream trough experiments, Bjornn (1971) discounted food availability, population density, and streamflow as mechanisms causing the fall redistribution of 1+ steelhead. He concluded that declining water temperatures triggered a winter hiding response, and that fish migrated downstream when they were unable to find suitable winter cover. He suggested that if enough winter cover were available, fish would not leave. Based on

Bjornn's hypothesis, we can speculate that either the habitat structures were not adequate enough to entice 1+ steelhead to remain in the study tributaries for their second winter or that our winter sampling method failed to find 1+ steelhead. However, it may also be possible that 1+ fish from Steamboat Creek migrated in autumn regardless of cover availability -- perhaps in response to inherited traits.

Steelhead originating in Steamboat Creek may have an autumn-winter strategy like that described by Cederholm and Scarlett (1982). By chance, a substantial number of 1+ steelhead were found in December in Kelly Creek, a third-order tributary of Rock Creek--32 km downstream of Steamboat Creek. Winter sampling was conducted with a spinning rod during freshet conditions and extreme turbidity. Almost every cast made in two pools produced a 1+ steelhead. Kelly Creek is mainly on private timber land. Conifers have been logged from riparian zones. Large woody debris was missing from the stream channel, and only two pools existed within the 2.5 km section examined.

Although 1+ steelhead likely moved out of the study sites, many underyearlings remained and redistributed. Everest et al. (1986) also reported a gradual decline of 0+ steelhead in glides of Fish and Wash creeks during fall. However, they did not observe an increase of 0+ in pools--but rather a decline. In Idaho, Sheppard and Johnson (1985) and Johnson and Kucera (1986) reported autumn movement of 0+ steelhead to sites of larger substrate. This is consistent with our October observations of closer 0+ alignment to instream structures in glides.

However, these authors in Idaho, and Bustard and Narver (1975) in British Columbia, did not see an autumn movement of 0+ steelhead into pools.

The autumn use of pools by underyearlings may be more prevalent in years of mild autumn weather or in warmer geographic regions. The shift to pools occurred at a time when water temperatures were cool, but stable. Fall is also typically a time when invertebrate drift is relatively abundant (Chapman and Bjornn 1969). At elevated prey levels and cooler water temperatures, aggressive behavior and territory size both decrease, allowing more fish to occupy a given microhabitat (Hartman 1965, Slaney and Northcote 1974). It is likley that this fall feeding period is an important time of rapid growth and "fattening" prior to the long winter hiding period experienced by the underyearlings.

Deep pools were found to be the best locations for fall residence. In deep pools, fish could swim down, out of the turbulence of fall freshets. However, deep pools were very rare in the study streams. A possible management technique would be the creation of deep pools. This could be accomplished by the installation of weirs designed to cause downstream plunge pools. The creation of deep blast pools in appropriate bedrock locations would also be an option. The addition of boulders and large woody debris to both natural and created pools would vastly increase the opportunity to escape fast currents during freshets.

Winter Evaluation

During the winter sampling period (December 4, 1986 to March 10, 1987) no juvenile steelhead were observed up in the water column. During this period, water temperatures ranged from 0.3°C to 6.8°C, and the daily mean water temperature remained below 6.4°C (Boulder Creek gaging station). Freshets during the 1986-1987 winter were mild. Only one storm event in November reached the stage of a 2-yr return interval.

The ratio of age 0+ to age 1+ steelhead changed substantially from the summer average of 10:1. During winter sampling the ratio increased to 18:1. The disproportionately low number of 1+ found in the winter supported the previously stated hypothesis of parr out-migration. However, we do not know if parr migrated upstream or down. Populations of juveniles in several sampled habitats remained relatively constant over the winter (Figure 9).

Of the seven structure types sampled during the winter, five held significantly more 0+ steelhead (Mann-Whitney U-test,) than comparable untreated sites (Figure 10). Boulder clusters in pools and boulder-log clusters in riffles held significantly higher densities of 1+ steelhead than comparable control areas (Figure 11). Generally, the habitat structures that were placed in quiet hydraulic zones (deep natural pools, backwater pools, and dam pools) were the most effective structures for both 0+ and 1+ steelhead during the winter (Figures 10 and 11). Also, the structures with the largest concentration of boulders and greatest number of crevices held the highest fish

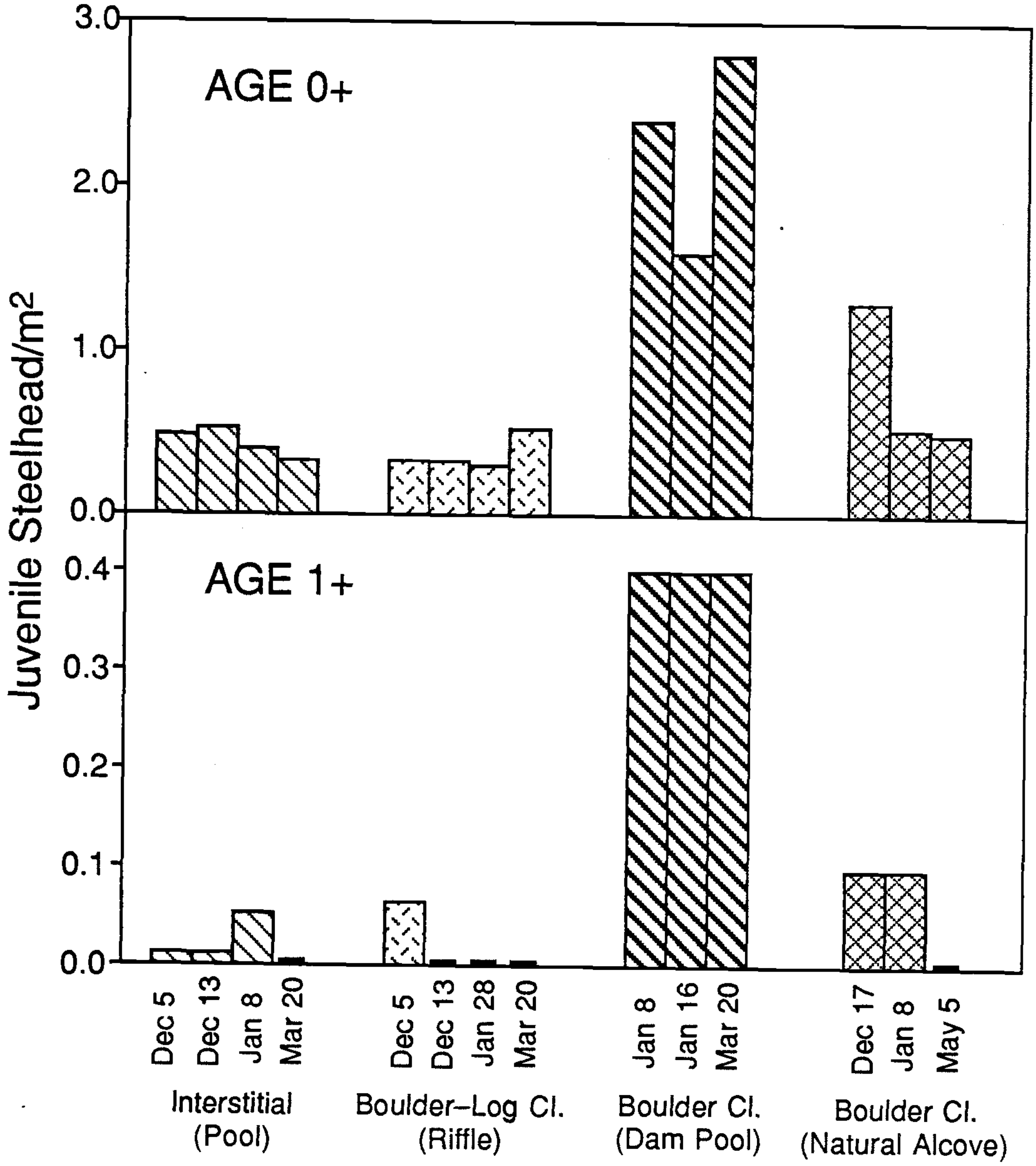


Figure 9. Trend of juvenile steelhead densities found within four individual stream structures at various times during winter, 1986-87. These structures were chosen for extended sampling because they were thought to be representative of certain structure design and location.

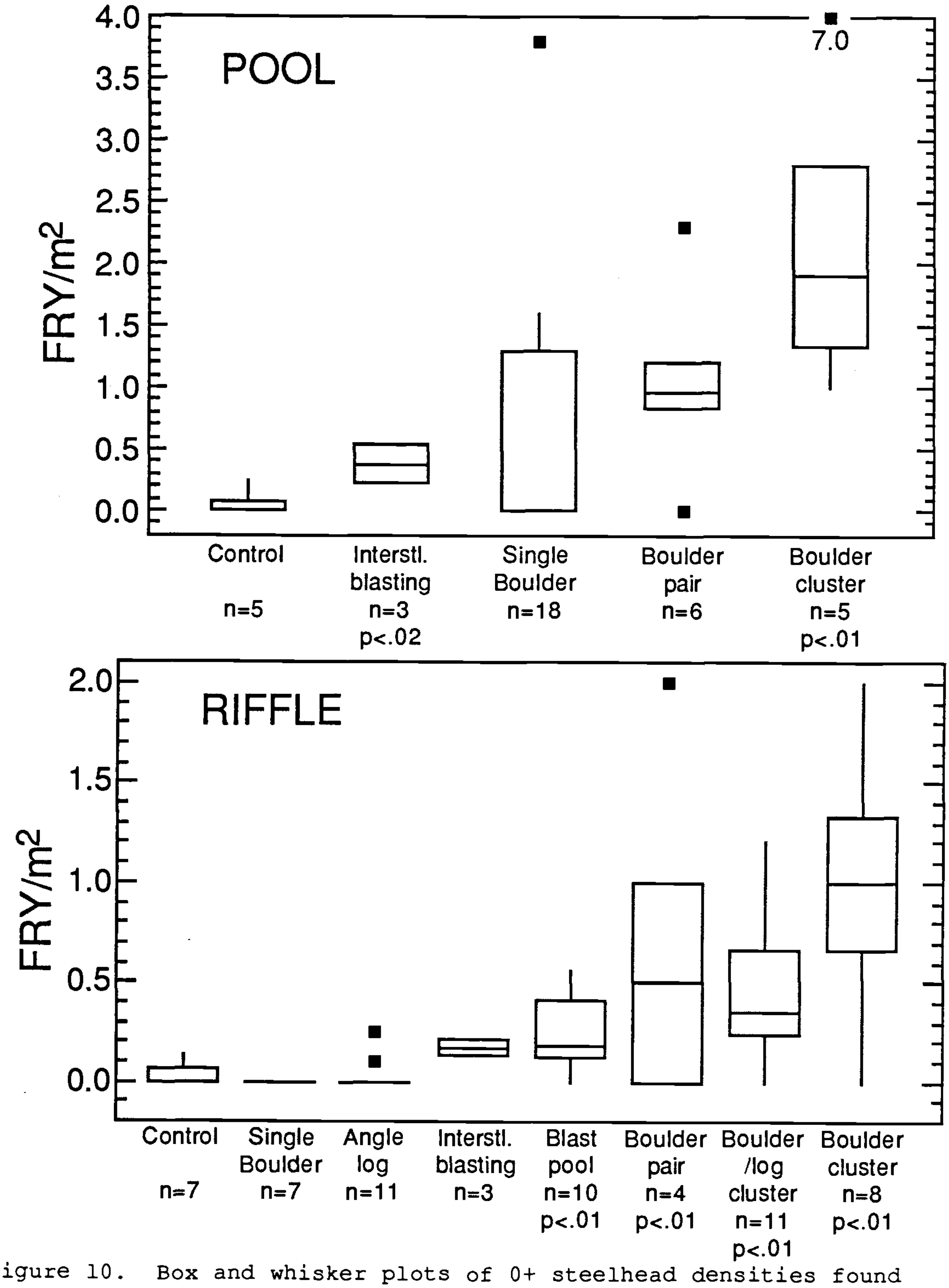


Figure 10. Box and whisker plots of 0+ steelhead densities found within various types of structures (placed in pools and riffles) during winter 1986-87. The median values are zero for those boxes without central lines. Those figures depicted by single lines represent samples in which all interquartile values are zero. P values are listed for those structure types that held significantly more 0+ steelhead than control sites. N values represent the number of structures sampled in each category.

densities per square meter of habitat. The least effective winter structures (angle logs, single boulders, boulder pairs) provided little or no interstitial space for refuge from winter water velocities.

Others have also found that juvenile steelhead mainly wintered in pools characterized by low current velocity and abundant cover such as boulders, rubble, cobble, or woody debris, (Bustard and Narver 1975, Ward and Slaney 1981, Bisson and Nielsen 1983, Everest et al. 1985, 1986, Heifetz et al. 1986). Bisson and Nielsen (1983) noted that utilization of winter cover was primarily dictated by hydraulic conditions. They reported that riffles and glides were avoided in the winter, but avoidance was lessened by the presence of cover.

For wintering steelhead, the addition of boulders and large cobble to quiet water zones is probably the most desirable habitat management technique. On tributaries of Steamboat Creek, quiet water zones are rare during winter. We have concentrated boulder placement in natural backwater pools and deep mid-channel trench pools where we expect the structures to be most effective. Dam pools created by the installation of log weirs also provide additional pools for boulder, rubble and rootwad placement. However, placement of winter cover in dam pools should be done after new bedload recruitment to avoid burial. Boulder-log clusters placed along the stream margin within riffles created quiet water zones like those found in natural backwater pools. The logs for these structures were placed in an upstream position to divert the current away from downstream boulders (Figure 2).

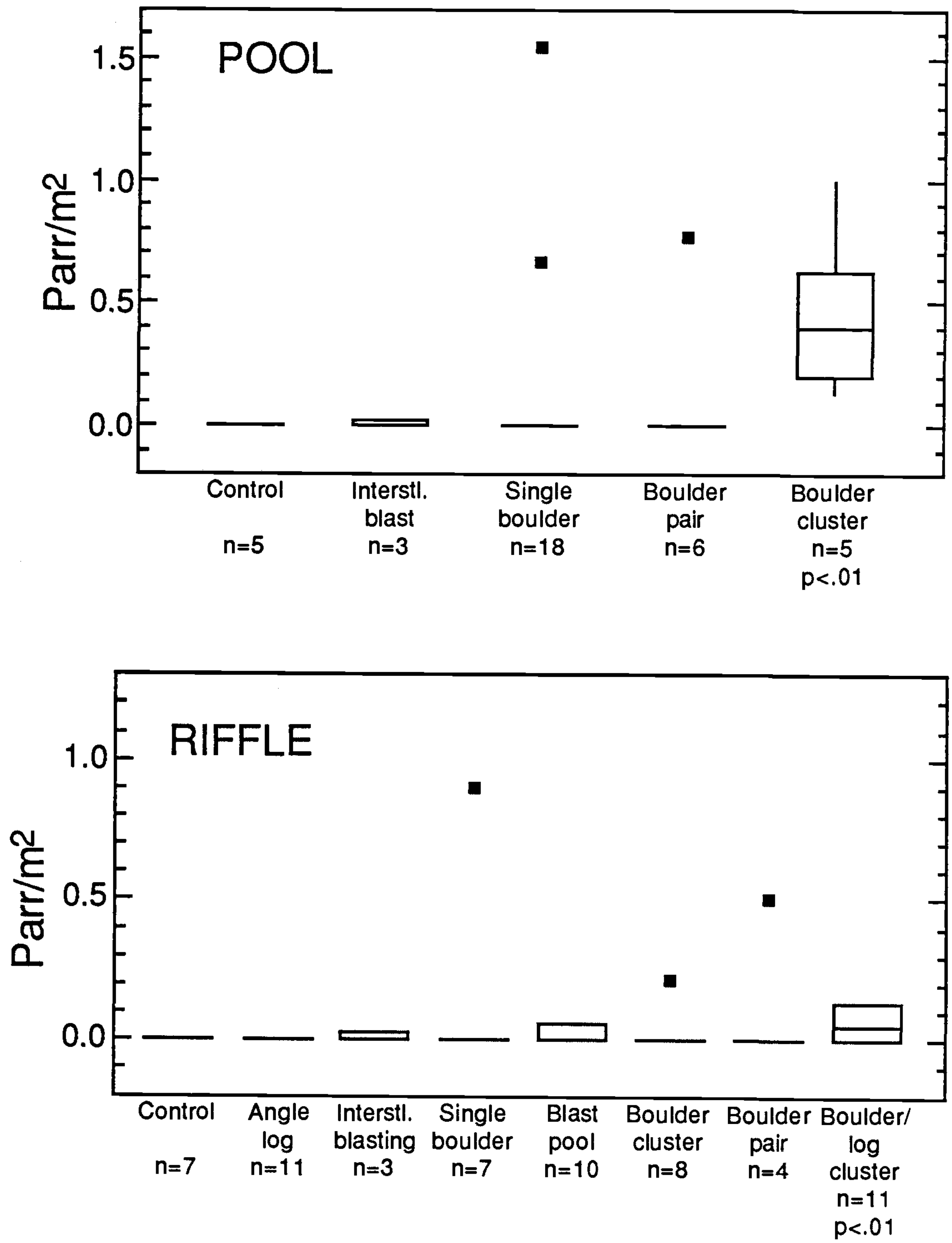


Figure 11. Box and whisker plots of 1+ steelhead densities found within various types of structures (placed in pools and riffles) during winter 1986-87. P values are listed for those structure types that held significantly more 1+ steelhead than control sites. N values represent the number of structures sampled in each catagory.

The use of logs for winter cover has not shown to be as effective as boulders for wintering steelhead. Logs are difficult to anchor and keep stable during winter storm events (Fontaine and Merritt in progress). Rootwads (with intact root masses) anchored together with boulders have shown promise. The large amount of interstitial space provided by rootwads appeared to be effective for winter hiding habitat. Unfortunately, the small number of rootwads available for evaluation did not provide a sufficient sample size to warrant firm conclusions.

Sring evaluation

Fry

Fry began to emerge from the gravel in early May in both 1986 and 1987. At this time, young fry congregated close to stream margins, where they took advantage of the low velocity zones and backwater areas created by instream structures. Dam pools, created upstream of log weirs, were also a favored habitat of young fry. Emergent fry did not hold stations directly under or within stream structures as did parr. The casual use of structures by young fry appeared to be more of a response to the hydraulic conditions created by the structures rather than the cover they offered. However, what appeared to be a casual association with instream structures may be critical during some years. Everest et al. (1986) established that high spring flows negatively affected the survival of emergent fry. They suggested that quiet water zones were a key habitat element for young fry.

Shortly after emergence, young fry swam about in an apparently random manner, searching for and seizing many drifting particles. Many items that were found unsuitable were rejected (conifer needles were a common example). Trial and error feeding behavior of young steelhead fry was also described by Shapovalov and Taft (1954). Sheppard and Johnson (1985) noted that steelhead fry were not associated with cover. Hoar et al. (1957) reported that the fry of certain salmon species were more attracted to bright, open areas than zones of shade and instream cover. Drifting invertebrates are more readily seen by fish in open, well-lit areas (Wilzbach et al. 1986). If feeding is a learned behavior, there are obvious survival advantages to fry that forage in open areas with good visibility rather than seek cover in stream structures.

Parr and Smolts

In Little Rock Creek, most parr and smolts maintained winter hiding behavior through the spring months. In this stream, many steelhead parr were first observed up in the water column and actively feeding on March 9, 1987. However, four subsequent dives on Little Rock Creek (April 1, April 28, May 5, and May 20), revealed no sign of parr in the water column. After snorkeling on May 20, electroshocking was used to confirm that fish were still down in the substrate. There were no obvious temperature or streamflow trends that explained the early surfacing (March 9), or the subsequent persistence of winter hiding on Little Rock Creek (Figure 12). In Carnation Creek British Columbia, Bustard and Narver (1975) found that most steelhead were active when water temperatures were above $7^{\circ}C$. However, they also observed that steelhead parr could be up and actively feeding at $6^{\circ}C$, or virtually all hiding at $7^{\circ}C$.

Spring re-entry into the water column by steelhead parr differed among the study streams. While some parr had surfaced on March 9 in Little Rock Creek, none were seen in the water column that day on Horseheaven Creek. On May 5, after diving five sites on Little Rock Creek and seeing no steelhead active, divers examined four locations on Cedar Creek. There, a large number of steelhead parr were up and actively feeding.

Spot sampling of water temperatures while snorkeling showed that Cedar Creek was slightly warmer (about $0.5^{\circ}C$) than Little Rock and Horseheaven creeks. Continuous temperature records were not available during winter on these streams, but temperature differences appeared minor. On Boulder Creek, a gaged tributary to the North Umpqua, water temperatures during the spring of 1987 fluctuated around the winter threshold level of 5-$7^{\circ}C$ (Hartman 1965, Chapman and Bjornn 1969, Everest and Chapman 1972), (Figure 12).

Extended winter hiding behavior during the spring, when water temperatures rise above reported threshold levels, may have a survival advantage. Gardiner and Geddes (1980) reported that by the end of winter, juvenile Atlantic salmon were in a nutritionally depleted state. They speculated that frequent behavioral changes of fish, from

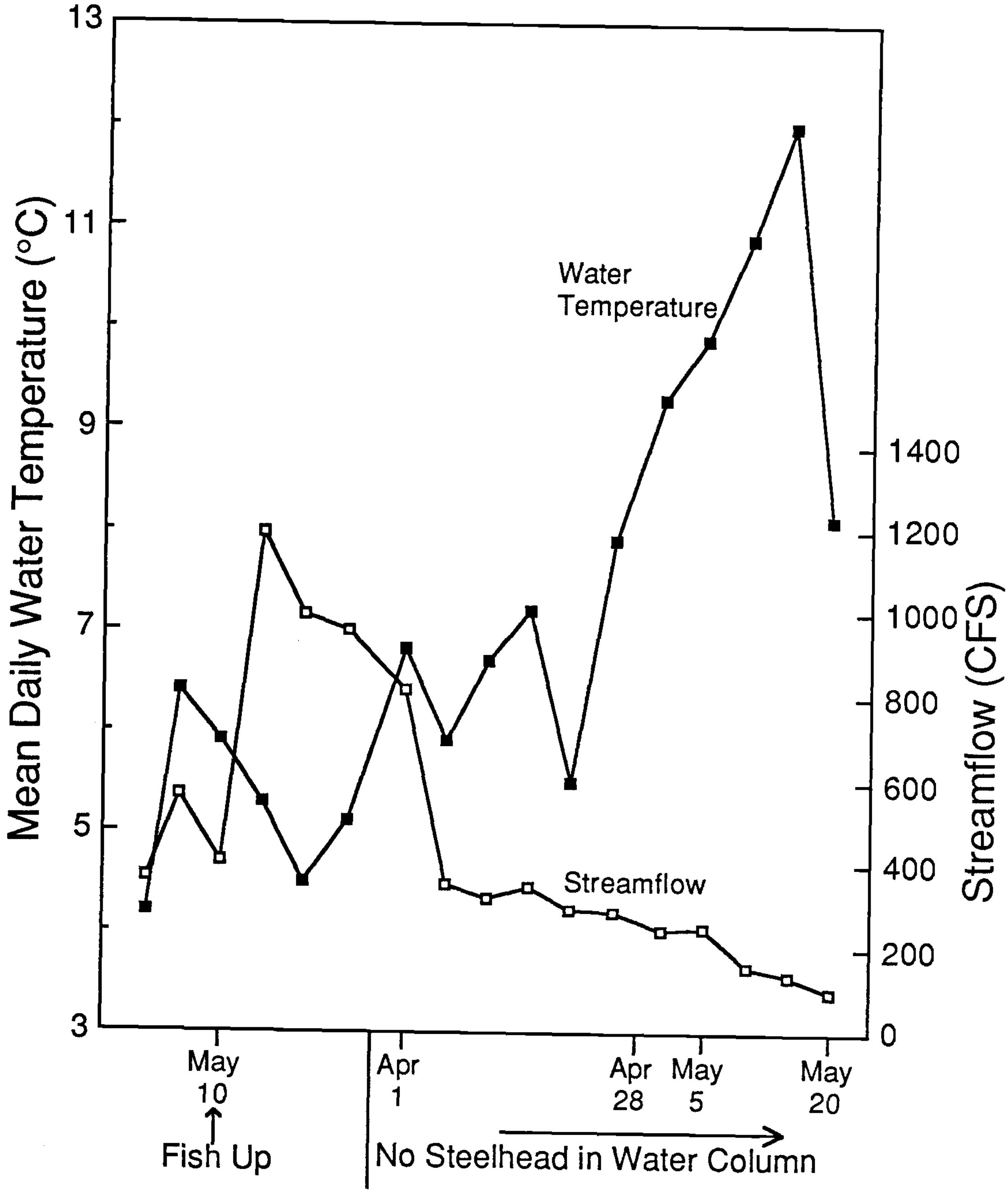


Figure 12. Spring water temperatures (Boulder Creek gaging station) and streamflow(Steamboat Creek gaging station), 1987. The dates listed represent snorkle dives on Little Rock Creek.

active to inactive, might cause additional stress and mortality. This may explain why juvenile steelhead in Little Rock Creek remained in winter hiding for an extended period in the spring.

Once parr entered the water column in spring, they fed voraciously at activity levels substantially higher than summer. The feeding behavior and activity levels were comparable to those observed in the fall. In the spring, steelhead parr preferred structures located near the middle of the channel, regardless of design. Blast pools and lateral scour pools near the thalweg, where drift densities are typically highest, were probably the best locations to take advantage of abundant spring drift.

In the study tributaries of Steamboat Creek, steelhead smolts were rarely seen during the spring evaluation period. However, smolts were readily observed in April and May in the mainstem North Umpqua River. Studies in some basins, have found that a substantial number of steelhead parr migrated downstream in the spring (Chapman and Bjornn 1969, Tredger 1980, Leider et al. 1986). In Gobar Creek Washington, presmolts comprised 86% of the total spring migration (parr and smolts) (Leider et al. 1986). These authors concluded that Gobar Creek offered only partial rearing. They speculated that the mainstem Kalama River provided the balance of rearing prior to smoltification. At the other extreme, parr out-migration in Fish Creek Oregon was minor compared to a large spring migration of smolts (Everest et al. 1986). Fish Creek obviously provided extended rearing for steelhead. Without downstream migrant trapping, the degree of presmolt out-migration or the potential for extended rearing in tributaries of Steamboat Creek is unknown.

CONCLUSIONS

Our initial habitat enhancement efforts were typical of many that have taken place in the last few years. Money suddenly became available and targets were set to install a specified number of instream structures within a certain number of stream miles. Federal and State fish habitat managers are often held accountable for carrying out stream "improvements", but they may not be given the time, money, or personnel to determine what type of modification is appropriate, or to determine if the treatment is effective.

The habitat structures that were evaluated in this study represent a substantial expenditure (Appendix 7). The treatment that had a statistically significant effect (blast pools) on the summer standing crop of juvenile steelhead only increased the 1+ population by a few individuals (Table 1). It is unlikely that this small increase could be biologically significant in terms of increased smolt production or increased adult returns. A higher density of effective structures installed in numerous appropriate reaches would probably be needed in order to generate a significant biological effect. Habitat preservation is undoubtedly the most cost effective option.

We began with a trial-and-error approach of applying habitat structures and followed it up with evaluation. An evaluation of the appropriate product of habitat manipulation, smolt production, is best conducted by measuring smolt production within a treated basin (Everest and Sedell 1984, Bisson 1987). However, a watershed evaluation was beyond the scope of this study. Instead we evaluated the effectiveness of stream structures at the reach and microhabitat level.

Evaluation at the reach level can be misleading. This is particularly true if reach evaluation takes place only during a portion of the year. For instance, Mason (1976) found that an increase in the summer standing crop of juvenile coho salmon as a result of enhancement was later negated by conditions during the winter. Consideration of summer coho abundance alone would have led to erroneous conclusions. Another problem may arise when fish abundance in control reaches is compared with abundance in treated reaches. It is difficult to determine whether the treated sites are responsible for increasing total abundance or just attracting and concentrating fish at the treated sites.

To broaden the potentially narrow prespective of evaluation at the reach level, this study was conducted within four streams during all seasons of the year. In addition, sampling occurred in numerous locations outside of the specified study areas to gain a broader understanding of fish habitat relationships. Detecting a redistribution of fish rather than an actual increase was not a concern in this study. This is because these study streams were thought to be fully seeded. As noted before, under conditions of full seeding, intraspecific competition forces juvenile salmonids to fill all suitable habitats (Chapman 1962). Subordinate fish, which would have been forced to emigrated downstream, can occupy the newly created habitats or move into the vacated territories of fish that have moved to treated sites.

This 1-yr study, initiated shortly after habitat modification, may not have measured the full response of the fish population. Hunt (1976), demonstrated that a brook trout population took several years to fully respond to habitat modification. Due to the extreme year-to-year natural variation in abundance of stream salmonids (Hall and Knight 1981), even long-term studies may not be able to effectively evaluate the fish response to habitat changes (Hall 1984). In my study, the 1985 (pre-treatment) total juvenile densities were substantially higher than the 1986 juvenile densities (Appendix 2). A comparison of pre-treatment with post-treatment densities would have implied that modification was detrimental. To avoid problems of temporal variability, we used post-treatment densities in control reaches as the comparative baseline.

By observing juvenile steelhead use of structures, we learned to build more effective structures in more appropriate locations. Steelhead use of various structure types was strongly dependent on the season and the local hydraulic regime. For instance, structures that provided effective overwintering refuges were generally not used during summer daylight hours. In winter, juvenile steelhead preferred large concentrations of boulders and rubble in quiet water zones (deep natural pools, stream margins, the dam pools of log weirs, and backwater pools). In summer, on the other hand, steelhead preferred the scour pools and cover of structures placed near the center of the channel in swift water.

Therefore, modifications to provide summer habitat for juvenile steelhead should create additional depth (in the form of lateral scour pools and plunge pools) within riffles and glides that are broad and shallow. Though the structures located on stream margins were seldom used by juvenile steelhead during the summer period, they provided important velocity refuges for emergent fry. Moreover, structures on the margins were more effective wintering sites than those located in the middle of the channel. During spring and autumn, steelhead parr used structures both in the thalweg and in quiet water, depending on hydraulic conditions and water temperature.

In an attempt to understand the habitat needs of Steamboat Creek's wild steelhead population we have raised more questions than we have been able to answer. Though we now know what type of modification works best during a particular season, it is unclear whether summer or winter habitat is limiting production in the tributaries of Steamboat Creek.

The basic rearing strategy of Steamboat Creek's wild steelhead stock is also unclear. At this time, evidence suggests that juvenile steelhead in Steamboat have a strategy of partial rearing in the natal streams. Parr apparently leave Steamboat Creek in the spring, summer, or fall of their second year. Out-migrant parr probably spend the remainder of their freshwater rearing stage in the mainstem North Umpqua River or other downstream tributaries. The potential environmental bottlenecks that may await Steamboat's outmigrant parr are unknown. These unknowns complicate the process of determining whether habitat modification in the Steamboat basin actually contributes to increased smolt production. As a theoretical example, assume that pool habitats in downstream tributaries of the North

Umpqua (such as Kelly Creek) are essential to the overwinter survival of the system's parr during their second winter. Harvest of riparian conifers and the loss of large instream wood, responsible for pool formation, would ultimately result in decreased smolt production for the system. It is disconcerting to think that the money spent on habitat management in Steamboat Creek could be negated by poor streamside management on private land many miles downstream.

After a year of study, I enthusiastically agree with the systematic approach to habitat modification recommended by Everest and Sedell (1984) and Bisson (1987). Before work begins, managers should have an understanding of the environmental factors that are most likely limiting production of the target species. Recognizing these elusive factors will be difficult, but we cannot afford to ignore this responsibility. Administrators must fund pre-enhancement projects designed to address the spectrum of possible limiting factors in the basin or river system where modification is to take place. With such funding, managers can conduct on-site examinations of the rearing strategy and seasonal habitat needs of the target species. Existing habitat can be inventoried and assessed in light of known habitat needs. Modification can then be applied to alleviate the identified (or at least highly suspected) deficiencies. Finally, enhancement projects should be followed with evaluation to determine if the objectives of the project were met. Our knowledge of habitat enhancement will not evolve unless evaluation is conducted concurrently.

LITERATURE CITED

Anderson, S., A. Auguier, W.W. Hauck, D. Oakes, W. Vandaele, and H.I. Weisberg. 1980. Statistical methods for comparative studies. John Wiley and Sons, New York. 289 p.

Bisson, P.A., J.L. Nielsen, R.A. Palmason, and L.E. Grove. 1982. A system of naming habitat types in small streams, with examples of habitat utilization by salmonids during low streamflow. Pages 62-73 In N.B. Armantrout, editor. Acquisition and utilization of aquatic habitat inventory information. American Fisheries Society, Bethesda, Maryland.

Bisson, P.A., and J.L. Nielsen 1983. Winter habitat utilization by salmonids in Pacific Northwest streams: The role of channel morphology and woody debris. Weyerhaeser Company internal report. Tacoma, Washington.

Bisson, P.A. 1987. Importance of identification of limiting factors in an evaluation program. Proceedings of the Stream Habitat Evaluation Technical Workshop. Held October 21-23, 1986. Portland, OR. Bonneville Power Administration. (In press).

Bjornn, T.C. 1971. Trout and salmon movements in two Idaho streams as related to temperature, food, streamflow, cover, and population density. Trans. Amer. Fish. Soc. 100:423-435.

Bustard, D.R., and D.W. Narver. 1975. Aspects of the winter ecology of juvenile coho salmon (Oncorhynchus kisutch) and steelhead trout (Salmo gairdneri). J. Fish. Res. Bd. Canada, 32:667-680.

Cederholm, C.J., and W.S. Scarlett. 1982. Seasonal immigrations of juvenile salmonids into four small tributaries of the Clearwater River, Washington, 1977-1981. Pages 98-110 In E.L. Brannon and E.O. Salo, editors. Proceedings of the salmon and trout migratory behavior symposium. School of Fisheries, University of Washington, Seattle

Chapman, D.W. 1962. Aggressive behavior in juvenile coho salmon as a case of emigration. J. Fish. Res. Bd. Canada, 19:1047-1080.

Chapman, D.W. 1966. Food and space as regulators of salmonid populations in streams. Am. Naturalist 100:345-357.

Chapman, D.W., and T.C. Bjornn. 1969. Distribution of salmonids in streams, with special reference to food and feeding. Pages 153-176 In T.G. Northcote, editor. Symposium on salmon and trout in streams. H.R. MacMillian Lectures in Fisheries. University of British Columbia. Vancouver, B.C.

Daniel, W.W. 1978. Applied nonparametric statistics. Houghton Mifflin Co., Boston. 503 p.

Dolloff, C.A. 1983. The relationship of wood debris to juvenile salmonid production and microhabitat selection in small southeast Alaska streams. Ph.D. thesis, Montana State University, Bozeman. 100 p.

Edmundson, E., F.H. Everest, and D.W. Chapman. 1968. Permanence of station in juvenile chinook salmon and steelhead trout. J. Fish Res. Bd. Canada 25:1453-1464.

Everest, F.H. and D.W. Chapman. 1972. Habitat selection and spatial interaction by juvenile chinook salmon and steelhead trout in two Idaho streams. J. Fish. Res. Bd. Canada 29:91-100.

Everest, F.H. 1973. Ecology and management of summer steelhead in the Rogue River. Oregon State Game Commission, Fishery Research Report 7, Corvallis. 48 p.

Everest, F.H. and J.R. Sedell. 1984. Evaluating effectiveness of stream enhancement projects. Pages 246-256 In T. Hassler, editor. Proceedings of Pacific Northwest stream habitat management workshop. Humboldt State University, Arcata, Ca, Oct. 10-12, 1984.

Everest, F.H., J.R. Sedell, G.H. Reeves, and J. Wolfe. 1985. An evaluation of in-channel and off-channel projects, Fisheries enhancement in the Fish Creek basin, annual report, 1984. Bonneville Power Administration, Portland, Oregon. 228 p.

Everest, F.H., G.H. Reeves, J.R. Sedell, J. Wolfe, D. Hohler, and D.A. Heller. 1986. Abundunce, behavior, and habitat utilization by coho salmon and steelhead trout in Fish Creek, Oregon, as influenced by habitat enhancement, annual report, 1985. Bonneville Power Administration, Portland, Oregon 100 p.

Gardiner, W.R., and P. Gebbs. 1980. The effects of body composition on the survival of juvenile salmon. Hydrobiologia 69:67-62.

Hall, J.D. 1984. Evaluating fish response to artificial stream structures: problems and progress. Pages 214-221 In T. Hassler, editor. Proceedings of Pacific Northwest stream habitat management workshop. Humboldt State University., Arcata, Ca. Oct. 10-12, 1984.

Hall, J.D., and N.J. Knight. 1981. Natural variation in abundunce of salmonid populations in streams and its implications for design of impact studies. EPA 600/S3-81-021. U.S. Environmental Protection Agency, Corvallis, Or.

Hall, J.D., and C.O. Baker. 1982. Rehabilitating and enhancing stream habitat: 1. Review and evaluation. In: W.R. Meehan, editor. Influence of forest and rangeland management on anadromous fish habitat in Western North America. USDA Forest Service. Gen. Tech. Rep. PNW-138. 28 p.

Hartman, G.F. 1965. The role of behavior in the ecology and interaction of underyearling coho salmon (*Oncorhynchus kisutch*) and steelhead trout (*Salmo gairdneri*) J. Fish. Res. Bd. Canada, 22:1035-1081.

Heifetz, J., M.L. Murphy, and K.V. Koski. 1986. Effects of logging on winter habitat of juvenile salmonids in Alaskan streams. North Am. J. Fish. Mgmt. 6:52-58.

Hoar, W.S., M.H.A. Keenleyside, and R.G. Goodall. 1957. Reactions of juvenile Pacific salmon to light. J. Fish. Res. Bd. Canada, 14:815-830.

House, R.A., and P.L. Boehne. 1985. Evaluation of instream enhancement structures for salmonid spawning and rearing in a coastal Oregon stream. N. Am. J. Fish. Mgmt. 5:283-295.

Hunt, R.L. 1976. A long-term evaluation of trout habitat development and its relationship to improving management-related research. Trans. Amer. Fish. Soc. 105:361-365.

Johnson, J.H., and P.A. Kucera. 1985. Summer-autumn habitat utilization of subyearling steelhead trout in tributaries of the Clearwater River, Idaho. Can. J. Zool. 63:2283-2290.

Kirk, R.E. 1977. Classification of ANOVA designs. Pages 102-109 In R.O. Collier, editor. Experimental design and interpretation. McCutchan Publ.Co., Berkeley, CA.

Loch, J.J., M.W. Chilcote, and S.A. Leider. 1985. Kalama River studies final report part II. Juvenile downstream migrant studies. Washington State Game Department, Fisheries Management Division, Report No. 85-12. 63 p.

Moreau, J.K. 1984. Anadromous salmonid habitat enhancement by boulder placement in Hurdygurdy Creek, California. Pages 97-116 In T. Hassler, editor. Proceedings of Pacific Northwest stream habitat management workshop. Humboldt State University., Arcata, Ca. October 10-12. 1984.

Leider, S.A., M.W. Chilcote, and J.J. Loch. 1986. Movement and survival of presmolt steelhead in a tributary and the mainstem of a Washington river. N. Amer. J. Fish. Mgmt. 6:526-531.

Mason, J.C. 1976. Response of underyearling coho salmon to supplemental feeding in a natural stream. J. Wildl. Mgmt. 40:775-778.

Overton, K., W. Brock, J. Moreau, and J. Boberg. 1981. Restoration and enhancement programs for anadromous fish habitat and populations on Six Rivers National Forest. Pages 158-168 In T. Hassler, editor. Propagation, enhancement, and rehabilitation of anadromous salmonid populations and habitat in the Pacific Northwest. Proceedings of a symposium, Humboldt Chapter American Fisheries Society, October 15-17, 1981. Humboldt State University, Arcata, Ca.

Petrosky, C.E., and T.B. Holubetz. 1986. Idaho habitat evaluation for off-site mitigation record, Annual report 1985. Bonneville Power Administration, Portland, Or. 284 p.

Platts, W.S., W.F. Megahan, and G.W. Minshall. 1983. Methods for evaluating stream, riparian, and biotic condition. USDA Forest Service Gen. Tech. Rept. INT-138, Intermountain Forest and Range Exp. Sta. Ogden Ut. 70 p.

Ptolemy, R.A. 1980. Habitat developement for salmonids in an urban stream. Pages 1-7 In Proceedings of the trout stream habitat improvement workshop. USDA Forest Service, Trout Unlimited. Asheville, North Carolina.

Reeves, G.H. and T.R. Roelofs. 1982. Rehabilitating and enhancing stream habitat: 2. Field Applications. In W.R. Meehan, editor. Influence of forest and rangeland management on anadromous fish habitat in Western North America. USDA Forest Service. Gen. Tech. Rep. PNW-140. 38 p.

Reeves, G.H., F.H. Everest, and J.D. Hall. 1987. Interactions between the redside shiner (Richardsonius balteatus and the steelhead trout (Salmo gairdneri) in Western Oregon: The influence of water temperature. Can. J. Fish. Aquat.Sci. 44:(in press.)

Reiser, D.W., and T.C. Bjornn. 1979. Habitat requirements of anadromous salmonids. In W.R. Meehan, editor. Influence of forest and rangeland management on anadromous fish habitat in Western North America. Gen. Tech Rep. PNW-96. 54 p.

Tredger, C.D. 1980. Carrying capacity and theoratical steelhead smolt yield from Nuaitch Creek, Nicola River system. Ministry of Environment, Fish and Wildlife Branch, Victoria, Canada 46 p.

Shapovalov, L., and A.C. Taft. 1954. Life histories of steelhead rainbow trout and silver salmon with special reference to Waddell Creek, California and recommendations regarding their management. California Department of Fish and Game. Fish Bull. No. 98.

Sheppard, J.D., and J.H. Johnson. 1985. Probability of use for depth, velocity, and substrate by subyearling coho salmon and steelhead trout in Lake Ontario tributary streams. N. Amer. J. Fish. Mgmt. 5: 227-282.

Slaney, P.A., and T.G. Northcote. 1974. Effects of prey abundance on density and territorial behavior of young rainbow trout (Salmo gairdneri) in laboratory stream channels. J. Fish. Res. Bd. Canada 31: 1201-1209.

Smith, J.J., and H.W. Li. 1982. Energetic factors influencing foraging tactics of juvenile steelhead trout. Pages 173-180 In D. Noakes et al., editors. Predators and prey in fishes. W. Junk Publishers, The Hague, Netherlands.

Swales, S., R.B. Lauzier, and C.D. Levings. 1986. Winter habitat preferences of juvenile salmonids in two interior rivers in British Columbia. Can. J. Zool. 64:1506-1514.

Ward, B.R., and P.A. Slaney. 1981. Further evaluation of the structures for the improvement of salmonid rearing habitat in coastal streams of British Columbia. Pages 99-108 In T. Hassler, editor. Propagation, enhancement, and rehabilitation of anadromous salmonid populations and habitat in the Pacific Northwest. Proceedings of a symposium, Humboldt Chapter American Fisheries Society, October 15-17, 1981. Humboldt State University, Arcata, Ca.

Wilzbach, M.A., K.W. Cummins, and J.D. Hall. 1986. Influence of habitat manipulations on interactions between cutthroat trout and invertebrate drift. Ecology 67(4): 898-911.

APPENDICES

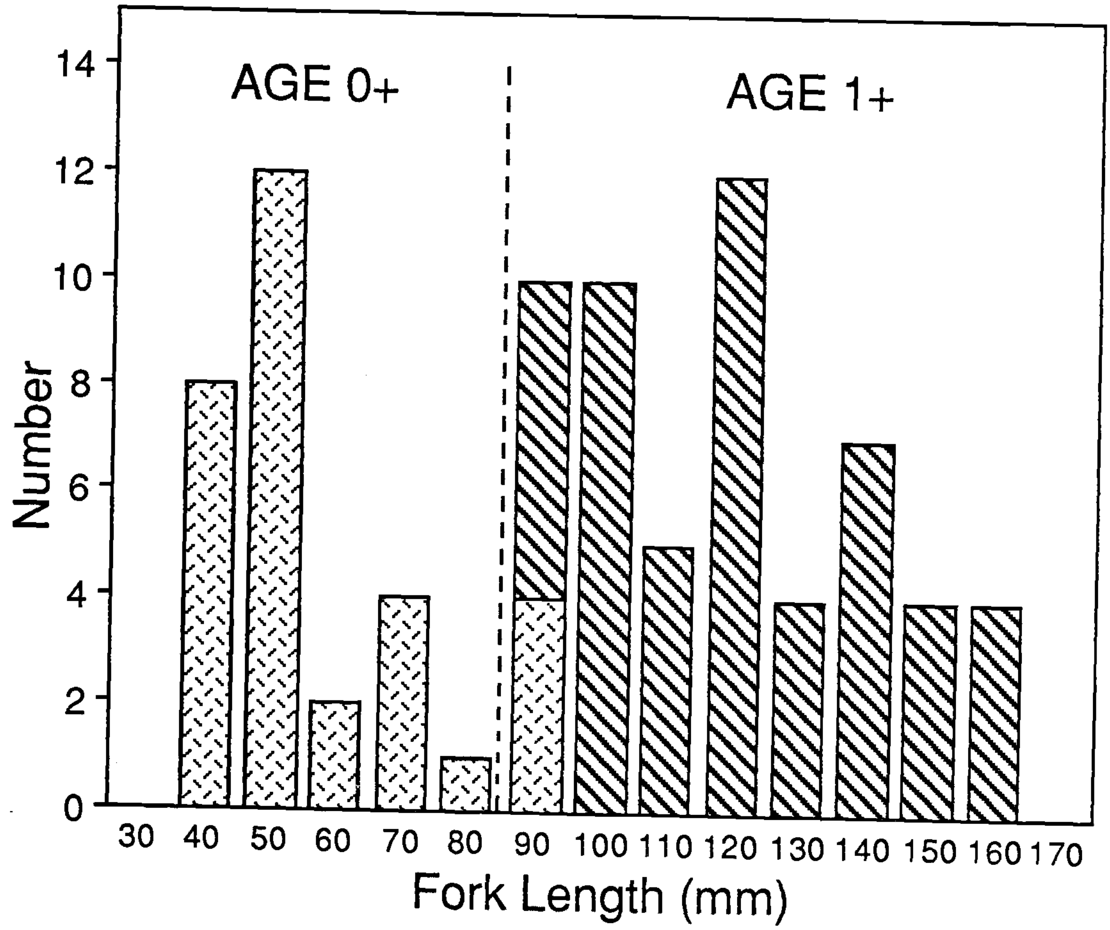
Appendix 1.
Habitat types identified within study streams in the Steamboat Creek Basin. All terms except "blast pool" and "structure cover" were taken from Bisson et al. (1982.)

HABITAT TYPE		DISCRIPTION
Lateral Scour Pool	-	Depression in gravel-cobble streambed created by the deflection of flow around an obstruction such as boulders and angle logs.
Dammed Pool	-	Flow impounded upstream of a channel blockage such as a log weir.
Plunge Pool	-	Flow drops vertically over a channel obstruction causing a deep scour pool - typically found downstream of logs or boulders aligned perpendicular to flow.
Trench Pool	-	Long, deep bedrock pool.
Backwater Pool	-	Quiet water zones downstream of obstructions that are located on channel margins.
Blast Pool	-	A pool blasted out of bedrock - located below a natural slope break or directly below a weir or other scour element.
Glides	-	Even flow lacking surface turbulence.
Riffles	-	Moderate to fast flow with surface white water.
Structure Cover	-	The area immediately within or under an object that is used as cover.

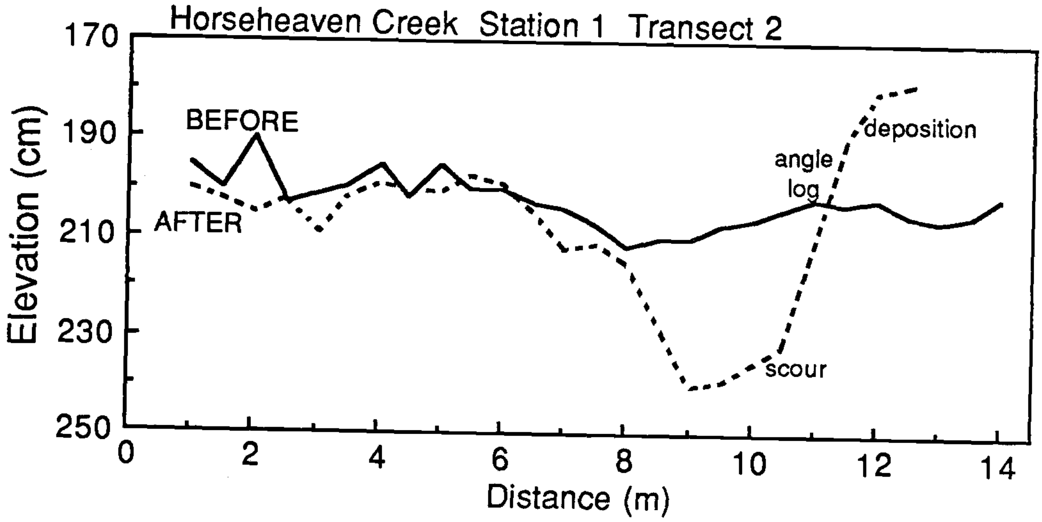
Appendix 2. Juvenile steelhead densities during summer (July 1985 and late August 1986) within 17 gravel-cobble glides of Steamboat and Horseheaven creeks. Reaches 4, 5, and 9 of Steamboat Creek were the angle log treatments that were dropped from the study.

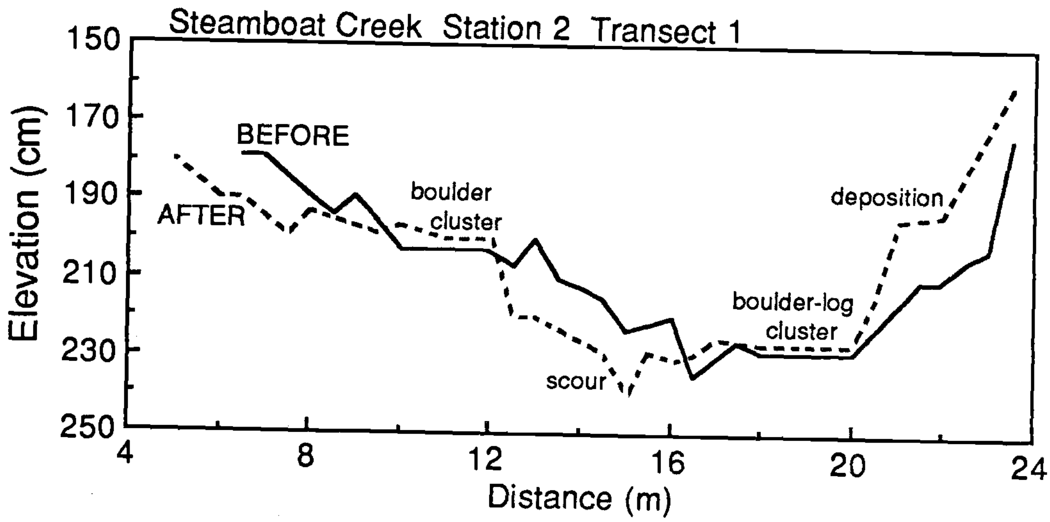
Stream/ Reach No.	treatment type	Reach surface area (m^2)	1986 No. fish 0+	1986 No. fish 1+	1986 fish/m^2 0+	1986 fish/m^2 1+	1985 Total juvenile density (fish/m^2)
Steamboat Creek							
Block 1							
1	boulder-log cl.	742	23	7	0.03	0.01	0.02
2	control	474	7	0	0.01	0.0	0.12
3	boulder cl.	694	40	7	0.06	0.01	0.05
Block 2							
6	control	410	19	2	0.05	0.0	0.15
7	boulder-log cl.	515	18	5	0.04	0.01	0.18
8	boulder cl.	463	11	3	0.02	0.01	0.12
Block 3							
10	boulder cl.	454	16	5	0.03	0.01	0.24
11	boulder-log cl.	415	48	7	0.11	0.02	0.62
12	control	258	24	0	0.09	0.0	0.85
Horseheaven Creek							
Block 1							
1	boulder cl.	106	43	5	0.40	0.05	0.69
2	angle log	157	31	10	0.20	0.06	0.33
3	boulder-log cl.	246	74	5	0.03	0.02	0.80
4	control	160	47	0	0.29	0.0	0.95
Block 2							
5	control	113	45	1	0.04	0.01	0.90
6	boulder-log cl.	141	67	12	0.47	0.08	0.96
7	angle log	140	52	5	0.38	0.04	0.85
8	boulder cl.	158	50	9	0.32	0.06	0.82

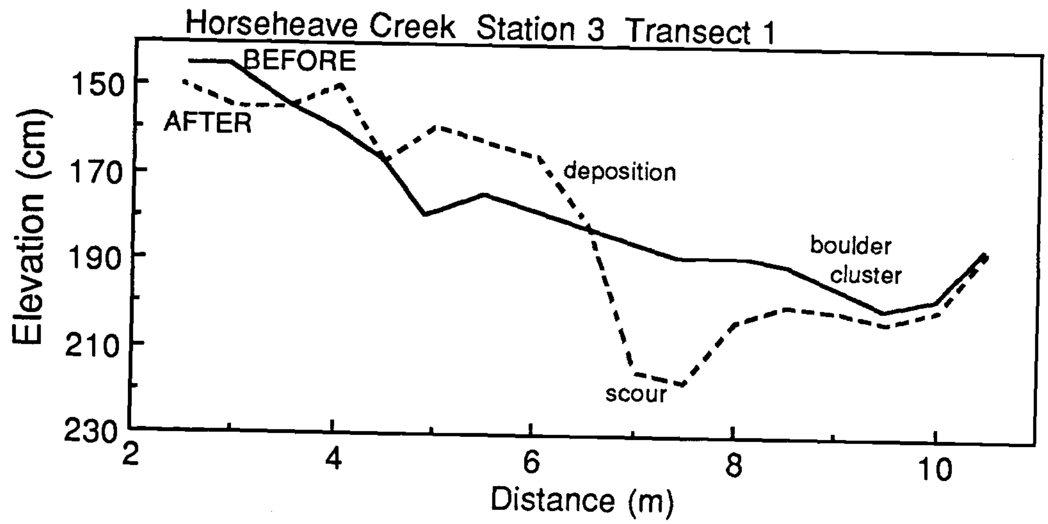
Appendix 3. Length-frequency graph of scales collected from juvenile steelhead in the Steamboat basin during August and September.



Appendix 4. Streambed elevation profiles (before and after) in three treated gravel-cobble reaches. These were chosen for display because the profiles depicted typical scour and deposition zones.







Appendix 5. Juvenile steelhead density and utilization coefficients (U) for all microhabitats on treated glides of Horseheaven, Steamboat, and Little Rock creeks during summer low flow, 1986. Control reaches not included.

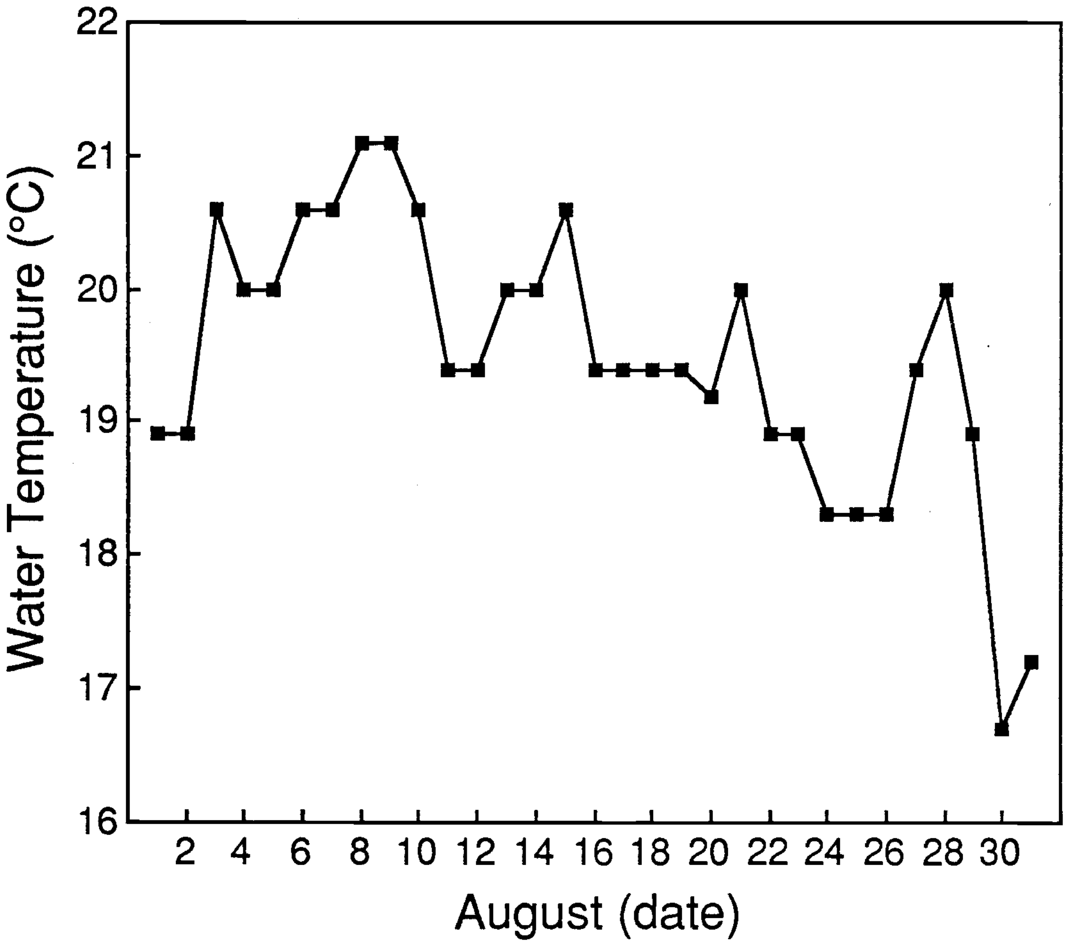
Habitat type	Habitat area (m^2)	Fish abundance No. 0+	$0+/m^2$	No. 1+	$1+/m^2$	Utilization Coefficient 0+	1+
Horseheaven Creek							
Reach 1 (boulder clusters)							
structure cover	5.0	0	0.0	0	0.0	-1.0	-1.0
structure cover	4.0	2	0.5	0	0.0	0.28	-1.0
structure cover	2.0	2	1.0	0	0.0	4.1	-1.0
lateral scour pool	2.8	5	0.56	1	0.36	3.6	6.2
lateral scour pool	3.0	2	0.67	0	0.0	0.69	-1.0
lateral scour pool	0.7	3	4.3	2	2.9	9.9	56.
glide	88.5	27	0.30	2	0.02	-0.21	-0.60
	106						
Reach 2 (angle logs)							
lateral scour pool	10.0	7	0.70	2	0.20	2.5	2.3
lateral scour pool	4.0	3	0.75	3	0.75	2.7	11.
trench pool	3.6	7	1.9	3	0.83	8.7	12.
plunge pool	3.0	1	0.33	2	0.60	0.66	0.65
glide	137.0	13	0.09	0	0.0	-0.55	-1.0
	158						
Reach 3 (boulder-log clust.)							
structure cover	5.0	4	0.80	1	0.20	1.7	9.0
structure cover	3.0	0	0.0	0	0.0	-1.0	-1.0
structure cover	3.0	1	0.33	0	0.0	0.10	-1.0
plunge pool	4.0	14	3.5	3	0.75	10.	36.
lateral scour pool	3.2	0	0.0	0	0.0	-1.0	-1.0
glide	226.0	55	0.24	1	0.004	-0.20	-1.0
	244						

Habitat type	Habitat area (m^2)	Fish abundance No. 0+	$0+/m^2$	No. 1+	$1+/m^2$	Utilization Coefficient 0+	1+
Reach 6							
(boulder-log clust.)							
structure cover	4.0	3	0.75	3	0.75	0.59	8.3
structure cover	3.0	4	1.30	0	0.0	1.7	-1.0
lateral scour pool	12.0	10	0.83	3	0.25	0.76	2.1
lateral scour pool	12	10	0.83	2	0.16	0.76	1.0
lateral scour pool	6.0	7	1.17	1	0.16	1.47	1.0
glide	104.0	33	0.32	3	0.03	-0.32	-0.63
	141						
Reach 7							
(angle logs)							
lateral scour pool	2.4	4	1.61	3	1.25	3.4	30.
lateral scour pool	5.2	7	1.35	1	0.19	2.5	3.7
glide	130.0	41	0.31	1	0.008	-0.18	-1.0
	138						
Reach 8							
(boulder cluster)							
structure cover	3.5	2	0.57	0	0.0	0.57	-1.0
structure cover	3.8	4	1.05	3	0.79	2.2	10.
structure cover	4.1	3	0.73	1	0.24	1.2	2.4
structure cover	4.1	3	0.73	1	0.24	1.2	2.4
lateral scour pool	1.5	4	2.66	3	2.0	7.3	27.
lateral scour pool	2.7	6	2.22	3	1.11	5.9	14.
glide	138.0	28	0.203	0	0.0	-0.37	-1.0
	158						
Steamboat Creek							
Reach 1							
(boulder-log clust.)							
structure cover	14.0	0	0.0	2	0.14	-1.0	13.
structure cover	12.5	0	0.0	0	0.0	-1.0	-1.0
structure cover	12.6	2	0.16	3	0.24	4.3	23.
lateral scour pool	13.2	2	0.15	2	0.15	4.0	14.

Habitat type	Habitat area (m^2)	Fish abundance No. 0+	$0+/m^2$	No. 1+	$1+/m^2$	Utilization Coefficient 0+	1+
glide	689.	0	0.0	0	0.0	0.0	-1.0
	741						
Reach 3 (boulder clusters)							
structure cover	6.1	0	0.0	2	0.33	-1.0	32.
structure cover	5.6	0	0.0	2	0.36	-1.0	35.
structure cover	5.3	0	0.0	0	0.0	-1.0	-1.0
structure cover	3.3	5	1.52	0	0.0	24.	-1.0
structure cover	3.0	0	0.0	0	0.0	-1.0	-1.0
lateral scour pool	0.7	2	2.8	0	0.0	46.	-1.0
lateral scour pool	3.4	3	0.89	0	0.0	13.	-1.0
lateral scour pool	7.5	3	0.40	1	0.13	5.6	12.
lateral scour pool	1.6	1	0.62	0	0.0	9.3	-1.0
lateral scour pool	1.2	0	0.0	2	1.67	-1.0	165.
glide	656.	26	0.039	0	0.0	3.0	-1.0
	693.						
Reach 7 (boulder-log clust.)							
structure cover	20.0	2	0.10	3	0.15	1.5	14.
plunge pool	20.0	13	0.65	2	0.10	15.	9.
glide	475.	3	0.006	0	0.0	-1.0	-1.0
	515						
Reach 8 (boulder cluster)							
structure cover	5.0	2	0.40	0	0.0	19.	-1.0
structure cover	5.3	0	0.0	0	0.0	-1.0	-1.0
structure cover	2.2	0	0.0	1	0.45	-1.0	44.
structure cover	5.0	0	0.0	0	0.0	-1.0	-1.0
lateral scour pool	4.8	0	0.0	1	0.21	-1.0	20.
lateral scour pool	1.1	0	0.0	1	0.90	-1.0	89.
glide	440.	9	0.021	0	0.0	-1.0	-1.0
	462						

Habitat type	Habitat area (m^2)	Fish abundance No. 0+	$0+/m^2$	No. 1+	$1+/m^2$	Utilization Coefficient 0+	1+
Reach 10							
(boulder cluster)							
structure cover	1.2	0	0.0	1	0.83	-1.0	82.
structure cover	6.3	1	0.16	0	0.0	4.3	-1.0
structure cover	8.0	6	0.75	0	0.0	24.	-1.0
lateral scour pool	1.3	0	0.0	1	0.77	-1.0	76.
lateral scour pool	0.5	0	0.0	0	0.0	-1.0	-1.0
lateral scour pool	3.0	4	1.33	3	1.0	43.	99.
glide	434.	5	0.011	0	0.0	0.0	-1.0
	454						
Reach 11							
(boulder-log clust.)							
structure cover	9.4	3	0.32	2	0.21	1.6	20.
structure cover	7.0	0	0.0	0	0.0	-1.0	-1.0
lateral scour pool	6.0	5	0.83	3	0.50	5.9	49.
trench pool	5.0	4	0.80	0	0.0	32.	-1.0
glide	388.	36	0.093	2	0.005	-0.16	-0.50
	415						
Little Rock Creek							
Reach 1							
(blast pools)							
blast pool	20.0	12	0.60	3	0.15	0.93	2.7
blast pool	16.0	8	0.05	0	0.0	0.16	-1.0
blast pool	14.0	14	1.0	3	0.21	2.2	4.2
glide	90.0	10	0.11	0	0.0	-0.64	-1.0
	140						
Reach 2							
(blast pools)							
blast pool	24.0	78	3.25	7	0.29	5.7	6.2
blast pool	14.0	15	1.07	2	0.14	1.1	2.5
blast pool	18.0	6	0.33	0	0.0	-0.31	-1.0
glide	164.	6	0.04	0	0.0	-0.92	-1.0
	220						

Appendix 6. Maximum daily water temperatures in upper Steamboat Creek (river mile 16, near study reaches) during the month of August, 1986.



Appendix 7. Breakdown of the costs of the habitat structures that were evaluated in this study.

Stream	Structure type	Number evaluated	Total cost
Horseheaven	boulder cluster	7	1,923
	angle log	4	960
	boulder-log cluster	6	2,275
Steamboat	boulder cluster	13	4,193
	angle log	6	3,298
	boulder-log cluster	9	4,986
Little Rock	blast pool	10	3,500
	boulder cluster	5	1,200
	interstitial blasting	6	4,416
Cedar	boulder cluster	3	810
	angle log	11	2,200
	single boulder	25	2,000
	boulder pair	10	1,000
		115	$32,761