THE RESPONSE OF STEELHEAD TROUT AND PHYSICAL HABITAT VARIABLES TO STREAM IMPROVEMENT STRUCTURES PLACED IN BROWNS CREEK, CALIFORNIA

by

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IMPROVEMENT PROJECT

by

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ABSTRACT

Eleven types of habitat improvement structures were placed in Browns Creek to increase the amount of juvenile steelhead rearing habitat. During the second year after installation, five habitat improvement structures contained the most juvenile steelhead: rock-v-dam, closed-v-gabion weir, gabion deflector, inclined log, and log crib deflector. Fourteen habitat variables were measured to determine how the added structures influenced stream habitat. Eight variables increased, four variables decreased, and two did not change. Deep-slow water increased 1,600 percent, shallow-fast water increased 49 percent, and gravel increased 101 percent. Escape cover and shallow-slow water decreased by 63 and 11 percent, respectively.

Most of the habitat improvement structures caused the desired changes in the stream primarily by creating a deeper and more constricted channel and by creating large plunge pools. Although the structures created the desired habitats, the numbers of juvenile steelhead in the entire study area, including the control and treated sections, declined by about 23 percent. Further, the numbers of juvenile steelhead in the treated sections of Area B declined by 54 percent compared to pretreatment numbers.

The numbers of young-of-the-year steelhead increased by 3,278 percent which is significant at P = 0.001.

Principal components analysis of the physical habitat data showed that there were weak relationships between the measured variables. Because there is little correlation between the habitat variables in Browns Creek, this suggests that steelhead in Browns Creek respond to each of the variables independently.

The large pools created below some of the structures were typically devoid of cover. Lack of cover in these pools decreased their suitability for juvenile steelhead.

Although the numbers of juvenile steelhead did not increase in the treated areas, the design of the structures was good. Most structures survived without damage during winter flood events. Managers can use the information from this study to increase the success of future stream improvement projects.

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INTRODUCTION

Since 1950, the numbers of anadromous salmonids returning to northern California rivers and streams have drastically declined due largely to habitat degradation and loss (California Department of Fish and Game 1971). For example, runs of chinook salmon (*Oncorhynchus tshawytscha*) and steelhead (*Salmo gairdneri*) in the Trinity River have declined by 80 and 60 percent, respectively (Department of the Interior 1980). Human-caused perturbations such as logging and road construction and natural factors such as severe floods have damaged watersheds and fish spawning and rearing streams. Water development projects have blocked fish access to their spawning and rearing streams and have drastically altered the natural hydrology by storing and diverting water. In addition to blocking access, the projects can negatively affect a major portion of the fish habitat below the project because water storage and diversion significantly alters the quantity and quality of the downstream fish habitat.

Land management agencies such as the U.S. Forest Service and Bureau of Land Management operate under a multiple use philosophy as stipulated by the Multiple Use and Sustained Yield Act of 1960 (Public Law 86-517; 16 U.S.C. 528). This philosophy has a variety of negative effects on fish habitat. Consumptive uses of the resources frequently compromised fish habitat. Poor logging practices and overgrazing have degraded fisheries habitat (Chamberlain 1982 and Platts 1981). Timber harvest and the construction of the associated roads affected the streams by increasing runoff and sedimentation (Chamberlain 1982).

Large storm events cause stream channels to aggrade by eroding the adjacent hillslopes and depositing the material in the channel (Lisle 1981a). Fish habitat is degraded because pools are filled, the channel is widened, and large woody debris is removed from the system. The result of channel aggradation is a wide, shallow channel with monotypic, low quality fish habitat. The negative effects to fish habitat caused by the December, 1964 flood, a 100-year event, is well documented for the South Fork Trinity and Middle Fork Eel Rivers (Buer et al. 1981). After this massive storm event, measurements of the channels in the South Fork Trinity and Middle Fork Eel Rivers showed that the channels aggraded six to nine meters. The severity of the flood effects were partly due to the cumulative effects of intensive logging throughout the watersheds.

Watershed restoration by natural processes requires a long time especially if the watershed was damaged extensively. Methods utilized by fishery managers as "quick fix" or "interim" steps to restore a stream channel and fish production are the removal of migration barriers and the improvement of instream habitat. Instream habitat improvement usually entails the construction or the placement of structures that physically alter stream morphology to provide better habitat diversity. Improvement structures may accentuate the pool-riffle sequence, provide cover habitat, and/or collect spawning gravel.

Browns Creek flows into the upper Trinity River, which, historically, was one of the more productive anadromous salmonid rivers in California. Spawning surveys showed that Browns Creek was the most important chinook salmon and steelhead spawning tributary of the upper Trinity River during the 1960's and early 1970's (La Faunce 1965; and Rogers 1972, 1973). Browns Creek also typifies a stream with a watershed altered due to both natural and man-caused events. Logging, road construction and placement, water diversions, residential encroachment, and severe flood events, such as the 1964 flood, degraded the anadromous salmonid habitat in Browns Creek (Brouha and Barnhart 1981).

The U.S. Bureau of Reclamation's Trinity River Project, consisting of two main stem dams on the Trinity River, was completed in 1963. Steelhead runs declined soon after completion of the project because the dams blocked steelhead access to natal streams upstream of Lewiston Dam (California Department of Fish and Game

1971). An average of 3,034 adult steelhead returned to Lewiston each year during 1958 through 1964 (California Department of Fish and Game 1977). Counts of adult steelhead returning to the Trinity River Hatchery, located at the base of Lewiston Dam, serve as an index to their status. The epitome of this decline was the return of only 13 adult steelhead in 1976-1977 (Bedell 1978). Tributaries, such as Browns Creek, now produce a larger percentage of the natural steelhead production in the upper Trinity River Basin due to the loss of approximately 175 kilometers (km) of available habitat above Lewiston Dam on the main stem. Therefore, increasing the natural steelhead production from streams like Browns Creek becomes more important.

Physical living space typically determined the carrying capacity for juvenile steelhead which usually rear in streams for one to three years (Narver 1976). Juvenile steelhead that migrated downstream when they were Age I, II or III made up the largest percentage of returning adults to west coast streams (Chapman 1958; Shapovalov and Taft 1954; and Withler 1966). Age I or II outmigrant fish made up the majority of adult steelhead returning to their natal streams in the Klamath and Trinity Rivers (Kesner and Barnhart 1974). Habitat degradation often reduced the amount of stream living space for juvenile steelhead which reduced juvenile steelhead survival and production. Salmonid production declined when there was a loss of a proper pool-riffle sequence and cover (Boussu 1954; Elser 1968; Saunders and Smith 1965; and Workman 1975). Conversely, salmonid production increased when cover was increased or a proper pool - riffle sequence was restored (Hunt 1969; Saunders and Smith 1962; Shetter et al. 1946; and Ward and Slaney 1979). Maximum smolt production occurred where there was a diversity of geomorphic characteristics, such as a good pool-riffle sequence, and ample cover (Government of Canada 1980; and Mundie 1974). Roughness elements, such as fallen trees, boulders, and cobbles, within the stream channel also influenced the quantity and quality of fish habitat. Roughness elements are the dominant environmental factor controlling channel configuration and substrate conditions (Lisle 1981b). Because adult steelhead production is a function of the survival and growth of juvenile fish, it is critical to have adequate rearing space available.

The microhabitats that young-of-the-year and juvenile steelhead occupied are well defined for other lotic systems. Young-of-the-year steelhead most frequently occurred in shallow water (0.5 m deep) with low water velocities (0.3 m/sec.) and large rubble substrate (Bustard and Narver 1975; Everest and Chapman 1972; and Cross 1975). Age I+ steelhead moved to deeper water (0.6 m to 0.75 m deep) with higher velocities (0.15 to 0.3 m/sec. near the stream bottom and 0.6 to 0.9 m/sec. near the surface) and the areas had large protruding substrates, with rocks typically 20 cm in diameter and larger. Few I+ steelhead were found in very deep or very shallow riffle areas, nor were they found in areas that lacked cover (Pearlstone 1976). These fish strongly oriented to areas with logs and surface turbulence. This shows that as salmonids grew, they moved to deeper and faster water and increased the size of their territories (Allen 1969a; Chapman and Bjornn 1972; Everest and Chapman 1972; and Lewis 1969). Water velocity and amount of cover accounted for 66 percent of the variation in numbers of rainbow trout (Salmo gairdneri) in pools (Lewis 1969). Cover is the most important factor determining the standing crop of juvenile steelhead in Oregon streams (Nickelson et al. 1979). Once established, juvenile steelhead rarely moved from areas containing adequate habitat during their freshwater rearing phase (Edmondson et al. 1968).

Stream rehabilitation or enhancement through the installation of structures has been done for over 50 years (Hall and Baker 1982). Most successful stream improvement work has occurred in geographic areas such as the midwest that do not have the extreme hydrologic pattern that occurs in the west coast (Hunt 1969). However, documentation of successful projects in the Pacific northwest has appeared in recent literature (House and Boehne 1985; Overton et al. 1981; and Ward and Slaney

1981). Successful projects were those that mimicked the natural conditions necessary for fish survival and production and were also durable enough to withstand winter storm events. Success depended on incorporating a proper blend of biology, hydrology, and engineering (Reeves and Roelofs 1982).

Instream improvement devices have progressed from simple dams that maintain flow levels to more extensive and complex undertakings (Boreman 1974; Burghduff 1934; Ehlers 1956; Hunt 1976; Navarre 1962; Overton et al. 1981; and Ward and Slaney 1979). Handbooks that document successful improvement projects and that describe techniques have been published based on the results of the previous authors and other researchers (White and Brynildson 1967; and Government of Canada 1980).

The U.S. Forest Service carried out a project of rehabilitating and enhancing the habitat in Browns Creek to increase the production of steelhead trout. In this context, "rehabilitate" and "enhance" are used in the sense of Reeves and Roelofs (1982). "Rehabilitate" means to restore or repair degraded habitat and "enhance" means to create habitat that would not occur under natural conditions. To achieve the project goal numerous structures were installed in the channel to change the habitat by the structures themselves and through natural forces acting on the structures. The objectives of this study were to: (1) determine the effectiveness of Browns

Creek stream improvement structures in changing fish habitat characteristics to increase juvenile steelhead trout production; and (2) evaluate the response of the juvenile steelhead trout to these habitat changes in Browns Creek.

STUDY AREA

Browns Creek is a major tributary to the Trinity River in the Klamath Mountain physiographic province of the Coast Range in northern California. Browns Creek joins the Trinity River 9.6 km downstream of the highway 299 bridge near Douglas City, in Trinity County, California. The upper Browns Creek watershed is 56 km southwest of Redding, California (Figure 1). The majority of the watershed lies within the Shasta-Trinity National Forest. Browns Creek drains a 185 square km watershed.

The 2.8 km study area is 28 km upstream from the confluence with the Trinity River. Approximately 47 square km, or 25 percent of the watershed area, lies above the downstream end of the study area. At the most downstream point in the study area, Browns Creek is a third-order stream, as determined from the U.S. Geological Survey 15 minute quadrangle. Chanchelulla Creek and Fox Gulch, both second-order streams, are the most significant tributaries to the study area (Figure 2). The study area includes a 55-meter segment of Chanchelulla Creek because of its contribution to Browns Creek flow and because it contains significant fish habitat. Chanchelulla Creek contributes a quantity of water equivalent to the main stem flow of Browns Creek at their confluence (Ott Water Engineers, Inc. 1980). Although Browns Creek has over

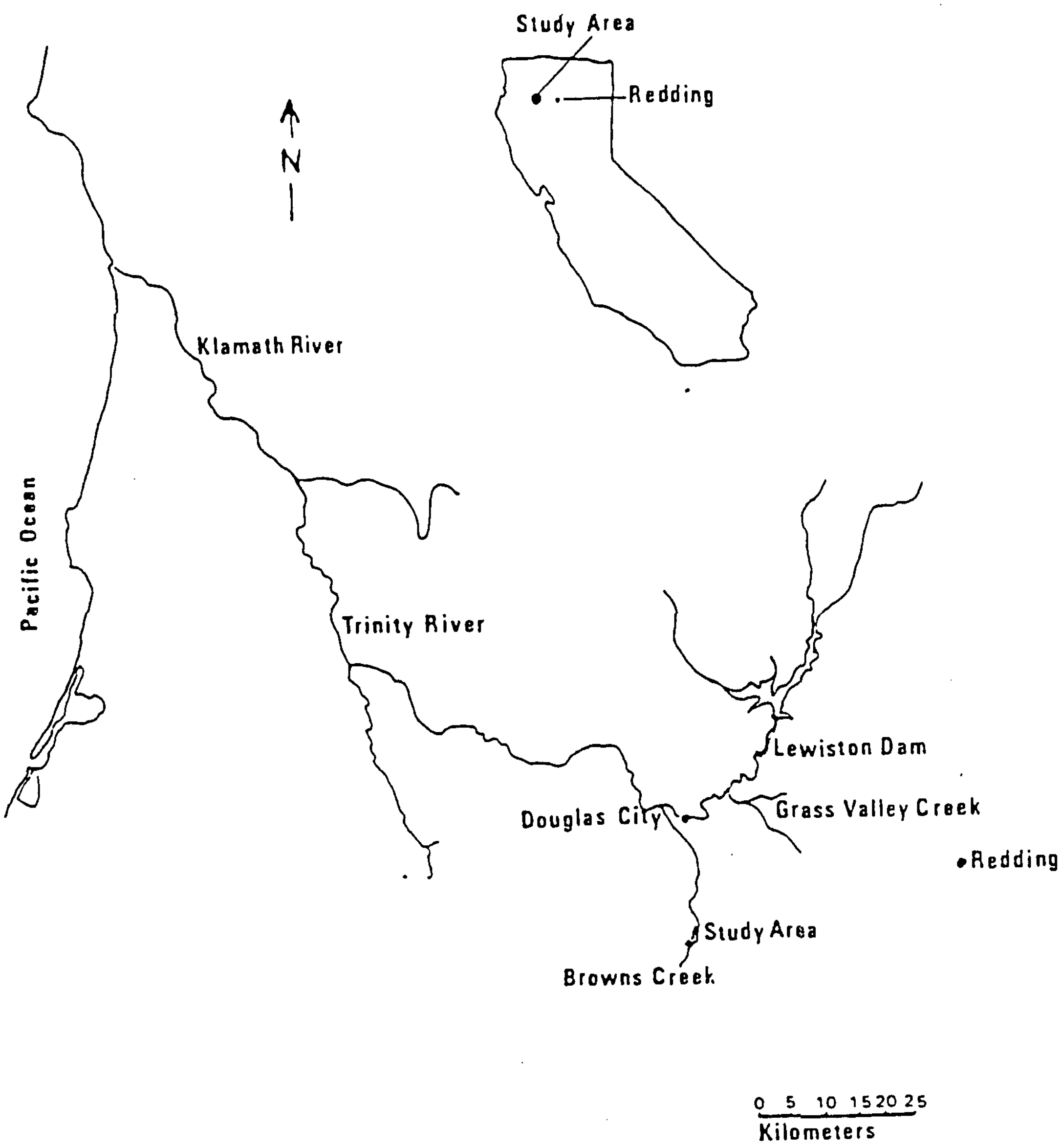

Figure 1. Location of the Browns Creek Study Area Near Douglas City, California.

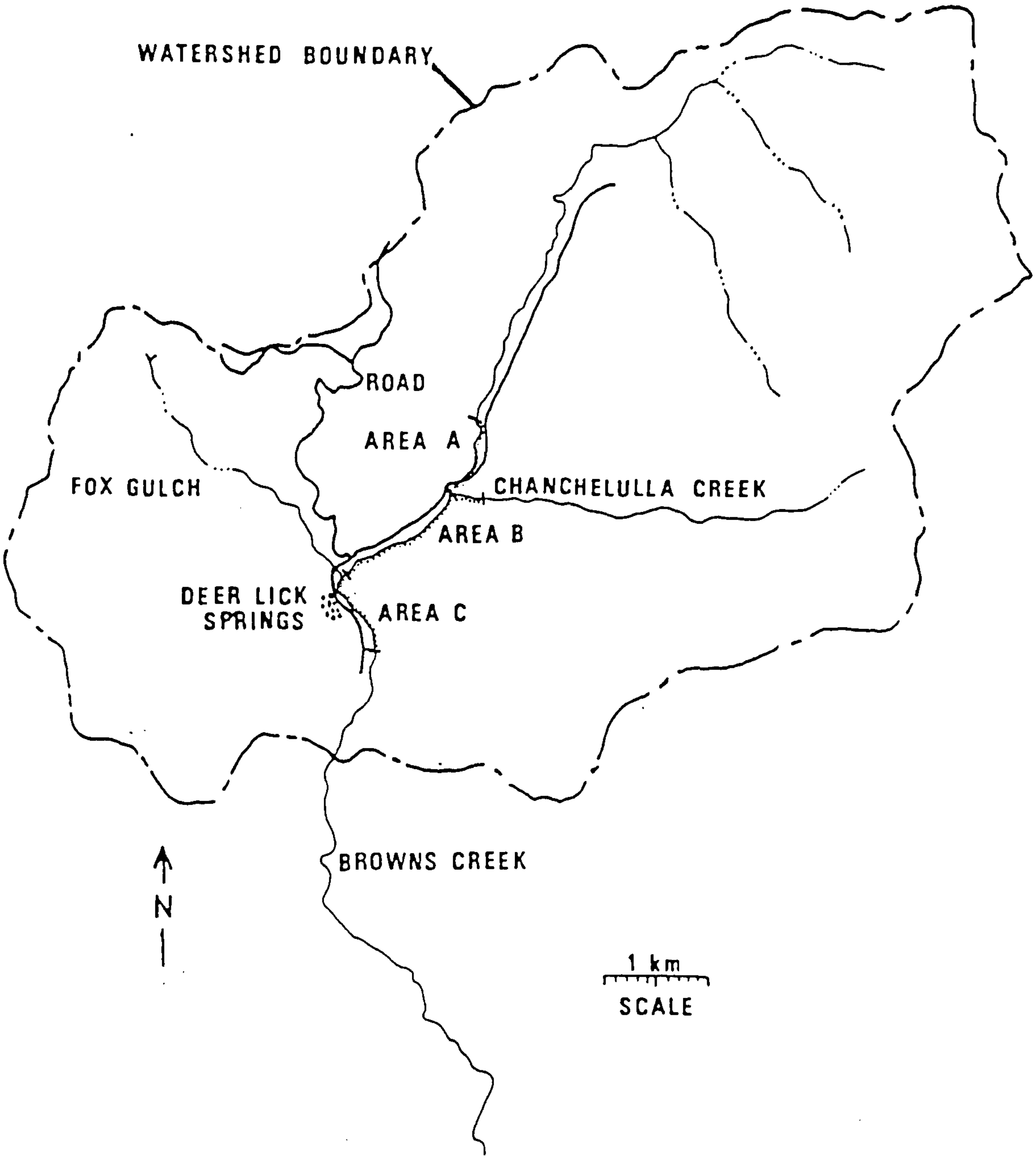

Figure 2. Browns Creek Study Area, Trinity County, California.

twice the watershed area at its confluence with Chanchelulla Creek, their estimated peak discharges are similar.

Browns Creek has a discharge pattern that is typical of Pacific northwest coastal streams. The peak flows occur from December to April and are fed by rain and snow melt. The ten year mean maximum and minimum 24 hour discharges recorded at a gauging station 3.4 km upstream from the mouth are 36.8 m^3/s and 0.8 m^3/s. These high and low flows occurred in February and October, respectively (U.S.G.S. 1971).

Fish fauna and flora of the Browns Creek study area are typical of northern California watersheds inland of the Coast Range (Roberts 1984). Steelhead and Pacific lamprey (Lampetra tridentata) were the only two species of fish observed in the study area and both species have anadromous life histories. The vegetative type in the study area is mixed evergreen forest as defined by Sawyer et al. (1977). Douglas fir (Pseudotsuga menziesii) and western red cedar (Calocedrus decurrens) dominate the primary canopy layer. California hazelnut (Corylus cornuta), bigleaf maple (Acer macrophyllum), red alder (Alnus rubra), Pacific yew (Taxus brevifolia), and mock-orange (Philadelphis lewisii var. Californicus) form a secondary canopy layer in the riparian zone. Horsetail (Equisetum spp.) and sedges (Carex spp.) commonly grow next to the water's edge.

Browns Creek, in the upper 1.7 km of the study area, flows through a narrow, V-shaped canyon. A U.S. Forest Service road parallels this section of the stream on the northwest side. The road fill slope extends down to the stream and much of the fill slope is rip rapped to prevent erosion. Natural stream banks are steep with slope gradients typically exceeding 65 percent. The lower 1.7 km of Browns Creek flows through a wider flood plain. The low flow channel is typically removed from the inner gorge slope. The U.S. Forest Service defines the inner gorge as the stream adjacent slope with a slope gradient in excess of 65 percent with a distinct break in slope from the less steep upslope area. The Browns Creek inner gorge is well developed, typically extending upslope 46 m in elevation.

The upper Browns Creek watershed is moderately unstable. The Hayfork Melange Unit dominates the watershed. This bedrock unit, due to its tectonic history, is locally highly sheared and unstable. Both naturally-occurring and management induced landslides are found in the watershed.

Most unstable areas have small isolated slides upslope of the inner gorge which probably do not contribute much sediment to the Browns Creek bedload. Slides within the inner gorge, however, contribute most of the sediment load of Browns Creek (U.S. Forest Service 1984; March 12, 1984, Timber Sale NEPA process).

METHODS

The 2.8 km study region consisted of three areas. Areas A and C were upstream and downstream control areas. Each control area was 732 m long. Area B was a 1,320 m long treatment area. Area A and the 55 m segment of Chanchelulla Creek were upstream control areas. Area C was used to assess downstream biological responses that may have resulted from habitat changes in Area B.

Each area was further divided into 91.4 m "sections." These sections became the sampling unit for collection of the biological and physical habitat information.

Structure Design

In 1980, an interdisciplinary group consisting of fishery biologists, geologists, engineers, and hydrologists, went to the field to evaluate fish habitat deficiencies in Area B. Sparsity of cover, lack of pools, shallow flow, steep nature of the channel, lack of spawning areas, and the lack of adequate riparian vegetation to shade the stream were noted. Based upon literature review and professional experience, design criteria and assumptions were decided upon to correct the deficiencies in spawning and rearing habitats. Design criteria could not all be met at all times for each structure because of extreme seasonal variations in flow. After initial hydrologic and hydraulic analyses, the assumption was made that the water velocity acting over the entire structure face would be about 3 m/sec. This is an average velocity for a storm event with a 50 year recurrence interval. Additionally, a 10 percent safety factor was applied to structure overturning calculations to resist increased forces of debris fouling and effects of sudden impacts of floating debris. Pools were excavated during construction rather than relying on the hydraulic forces to scour them. The engineers decided to do this because of the large size of the substrate material. The hydraulic forces would keep them scoured. Stream flow and the velocity profile across the stream were determined by 7-10 measurements along a transect at each structure site. The irregular cross section of the stream hampered accurate discharge measurements.

Hydrologic and hydraulic analyses were performed to determine flows and resulting stream forces for structure design. Various flood flow, low flow and exceedence discharges were calculated for the study area (Ott Water Engineers 1979). In addition to being used to determine flood flow forces (overturning moment) at each structure site, hydraulic data were used to evaluate the proposed structures' susceptability to scour and their effectiveness at low flow discharges. The methodology for obtaining parameters for flows up to a 50 year storm event are detailed in a report by Ott Water Engineers (1980). These paramenters included average velocity, engineering modeling factors, critical shear stress and critical grain size (used to compute susceptibility to scour).

Construction was initiated in late October, 1980, and was completed December 8, 1980, with only one delay caused by a storm in early December. Careful supervision during construction, kept disturbance to a minimum. Instream equipment operation was carefully controlled to reduce turbidity generated by excavation work. All disturbed areas above the normal high water mark were seeded to reduce erosion.

Structure Types

Deflector and plunge pool forming structures were designed and built to increase juvenile steelhead rearing capacity and adult steelhead spawning area in Browns Creek. The deflector structures were designed to control stream width and therefore, depth and velocity. The plunge pool structures were designed to alter the grade of the streambed and scour pools at their downstream ends. Most of these structures were also designed to provide instream cover or had features added to accomplish this.

Four types of deflector structures were placed in the stream (Appendix A): (1) a series of three gabion deflectors; (2) a gabion deflector with associated plank cover and cabled floating logs; (3) a gabion deflector and rock levee; and (4) a log crib deflector.

Seven plunge pool forming structures were placed in Browns Creek (Appendix A). These structures alter the grade of the channel by collecting gravel at the upstream end of the structure. Ideally these structures collect gravel of the proper size and promote the hydraulic conditions necessary for steelhead spawning. These structures were: (1) a rock-v-weir; (2) a closed-v-gabion weir; (3) a modified Hewitt ramp and downstream rock dam; (4) an inclined log with associated cabled floating logs; (5) a v-shaped floating log weir; (6) a rock-log dam; and (7) a Hewitt ramp.

In addition to the above structures, two clusters of three boulders were placed in the stream. The purpose of the three boulder configuration was to cause depressions to be scoured at their downstream ends and in between the boulders thus increasing the quantity of fish holding and escape habitat.

Physical Habitat Inventory

The first phase of the physical habitat inventory consisted of preparation of detailed topographic strip maps of Area B. Twenty-four maps at the scale of 2.5 cm = 1.5 m with 30.5 cm contour intervals were prepared under contract to the U.S.Forest Service (Ott Water Engineers 1980). These maps were utilized in the design and placement of the selected instream structures and used as base maps for construction of diagrammatic maps of the physical habitat.

The mapping technique is similar to the diagrammatic mapping method described by Barber et al. (1981). Transects were established at 15.2 m intervals in each 91.4 m section in Area B. Thus, there were six 15.2 m partitions for detailed habitat analysis in each section. Wetted stream width, mean water depth, and mean water velocity were measured at each transect. Depth and velocity were measured in the middle and midway between the middle and each bank. The mean of these three variables and thalweg depth for each transect were computed for each study section. The physical habitat features measured and sketched are listed and defined in Table 1. A base map and two overlays were used to superimpose the various habitat features. The physical habitat mapping was of the wetted channel only.

All of area B was mapped in August, 1980, and 1982, and only those sections containing structures were mapped in August, 1981. Arbitrary semi-permanent features, such as bedrock outcrops, trees or instream improvement structures, were used to locate the respective features. The lack of a defined datum (mean sea level) and standard surveying techniques precluded assessing actual changes in streambed and water surface elevations. The method allowed for assessment of pretreatment and

Table 1. Definitions of Physical Habitat Features Used to Prepare the Diagrammatic Maps for Browns Creek, California.

Class	Feature	Definition
Water Type (Base Map)	1. Shallow-slow	Less than 45.7 cm deep and 30.5 cm/sec velocity.
	2. Deep-slow	Greater than 45.7 cm deep and less than 30.5 cm/sec velocity.
	3. Shallow-fast	Less than 45.7 cm deep and greater than 30.5 cm/sec velocity.
	4. Deep-fast	Greater than 45.7 cm deep and 30.5 cm/sec velocity.
	5. Pool	Pool boundaries were also sketched.
Cover (First Overlay)	1. Overhanging	Within 1.8 m of stream surface.
	2. Undercut bank	Greater than 10 cm width and 15 cm depth.
	3. Velocity Shelter	Logs, boulders, etc., that slow velocity.
	4. Escape	Hiding places (e.g. root wads,logs).
	5. Turbulence	Stream bottom not visible due to surface turbulence.
Substrate (Second Overlay)	1. Boulder	Greater than 30.5 cm.
	2. Rubble	7.6 to 30.5 cm.
	3. Gravel	0.3 to 7.6 cm.
	4. Fines	Less than 0.3 cm.
	5. Bedrock	Large contiguous exposed rock.

posttreatment changes in pool area, substrate area, area of the water types, and area of the cover types. One hundred scour chains were installed in the streambed in the fall, 1979, to qualitatively assess streambed mobility.

Water temperature was monitored during the low flow, high temperature period in August and September. Recording thermographs were installed in Sections B-1 and B-14 in 1980, 1981, and 1982. In 1982, a thermograph was placed in Section A-1 to determine the effect of the lack of an upstream canopy on water temperature in Area B.

Percent of area of a given habitat feature was used to compare pretreatment to posttreatment changes rather than actual area. This was necessary because of the interpretation differences between two different investigators mapping the habitat without a fixed datum. The general equation used to calculate the percentage change between pretreatment and posttreatment periods is illustrated in Appendix B.

Peak discharges are not available for this study period due to faulty discharge gages and improper placement and calibration of crest gages. During the study period, Grass Valley Creek was the only stream near Browns Creek gaged by the U.S. Geological Survey. Grass Valley Creek is assumed to have similar discharge patterns to those in Browns Creek because it originates on the south side of the Trinity River, it is close to the Browns

Creek watershed, and it has the same aspect, and, therefore, the respective storm events are probably similar. The Bureau of Reclamation developed a peak flow-recurrence interval graph for its Grass Valley Creek investigations to design a debris dam (Figure 1, Appendix C) (S. Bradley, personal communication, Bureau of Reclamation, 2800 Cottage Way, Sacramento, California 95825). Therefore, the size of the peak flow events that occurred during the study period was interpolated from these data. This information could be used in conjunction with the peak flow-recurrence interval relationship developed by Ott Water Engineers, Incorporated (1980). This allows one to speculate as to the size of event the improvement structures encountered (Figure 2, Appendix C).

Biological Inventory

Fish populations were sampled in each section in early July and late September with a battery operated backpack shocker. Total length of each fish was measured to the nearest millimeter and weighed to the nearest gram. The adipose fin of fish captured in Area B was clipped to assess inter-area movement. After the length and weight data were recorded, the fish were redistributed into the section from which they were removed.

Due to time constraints in the fall of 1982, sections A-6 through A-8 were sub-sampled by means of a stratified random sample (Schaeffer et al. 1979). For this sampling scheme, each 91.4 m section was divided into three equal units. One unit within each section was randomly selected and sampled by employing the previously described method. Schaeffer et al. (1979) describe the method used to derive the appropriate estimate and variance.

Block nets were set to isolate each 91.4 m sampling section and each structure. Isolating the structures within the treatment areas was done to determine their relative effectiveness for providing juvenile steelhead rearing habitat. Blocking off the sampling sections and structures was necessary to isolate the population in order to meet the assumption of a closed population for estimating the number of fish in an area (Ricker 1975).

Fish population estimates and associated variances were determined by use of the multiple-pass Moran-Zippen method (Ricker 1975). The Moran-Zippen population estimation equation requires that one collect the majority of fish on the first pass with fewer fish being collected on each subsequent pass. If more fish are taken during the second sampling pass than during the first then the equation does not apply (Seber 1973). Also, if sampling abilities are such that the population can not be significantly depleted on the first sampling pass, the resulting confidence interval is very large. For the sections sub-sampled in fall, 1982, the population estimates and variances were extrapolated to yield an estimate for the given section (Schaeffer et al. 1979).

Biomass by date by area was calculated from seasonal mean weight and populations of young-of-the-year and juvenile steelhead (Chapman 1967; 1968). Biomass by area was plotted against time. Percentage change in the biological parameters was calculated in the same manner as with the physical habitat analysis.

During the 1982 summer sampling period, it was discovered that there were sexually mature rainbow trout in Browns Creek. A random sample of rainbow trout were collected and sacrificed to determine their sex and maturity. The hypothesis was that sexually mature fish less than 200 mm were probably not steelhead but resident rainbow trout. Hatchery origin steelhead from the East Fork of the North Fork Mad River and fish from lower Browns Creek, 1.6 km below the study area, were collected for comparative purposes.

Statistical Analysis

A principal components analysis was used to develop a model, using the physical habitat data, that simply describes the relationships between the physical habitat variables. The variables used for this analysis are listed in Table 2. Percent rubble substrate and percent shallow slow variables were removed to eliminate

Table 2. Variables Used in the Principal Components Analysis for the Physical Habitat Domain for Browns Creek, California.

Variable	Definition
Area	Surface area of the transect (m^2).
Pools	Percent pools.[a]
Boulder	Percent boulder substrate.
Gravel	Percent gravel substrate.
Fine	Percent fine substrate.
Bedrock	Percent bedrock substrate.
Deep-slow	Percent deep-slow water.
Shallow-fast	Percent shallow-fast water.
Overhang	Percent overhanging cover.
Undercut	Percent undercut bank cover.
Velocity shelter	Percent velocity shelter cover.
Escape	Percent escape cover.
Turbulence	Percent turbulence cover.
Average velocity	Average water velocity for the transect (m/s).

[a] Percent is the relative percent of area of the variable to the total area.

redundant variables. The goal was to reduce the data into a few descriptive orthogonal factors that were uncorrelated. The subprogram FACTOR of the Statistical Package for the Social Sciences (SPSS) was used to obtain the principal components (Nie et al. 1975). The extracted factors were retained based upon Kaiser's rule (Cooley and Lohnes 1971). According to Kaiser's rule, factors having an eigenvalue greater than or equal to unity were retained. In conjunction with this, intuition incorporating knowledge about stream flow and channel morphology was also used to decide on which factors to retain. For example, positive loadings on high water velocity and silt substrate variables on the same factor would not make sense because one would expect the velocity to remove the silt. The criteria here were to extract the highest proportion of variance in the model and to attain a model having a simple structure. The retained factors should have a simple structure for easy interpretation, account for a high proportion of variance, and retain enough information to identify the fundamental and the meaningful dimensions of the physical habitat domain (Cooley and Lohnes 1971).

The varimax method was used to rotate the factors. Factor method PA1 of the SPSS subprogram was used (Nie et al. 1975). This method simplifies the factor structure and breaks up the first principal component or "general factor." Varimax rotation yields high loadings on a few factors which facilitates factor interpretation (Cooley and Lohnes 1971).

The output from the SPSS subprogram yielded the correlation matrix, factor structure matrix after varimax rotation, and the factor-score coefficient matrix. The factor-score coefficient matrix was used to calculate factor scores for the section physical habitat data via matrix multiplication. The MINITAB program was used to perform the matrix multiplication. Again percent rubble substrate and percent shallow slow variables were not included to remove redundant variables. The resulting factor-scores were then combined with their respective biological data and a correlation matirix was developed. The correlation matrix showed the relationship between the factor-scores of the physical habitat data and the biological data. This allowed one to determine how the physical habitat variables influenced the distribution of fish in Browns Creek.

A two-way analysis of variance (ANOVA) was used to test for significant treatment effects due to the structures. The year that fish were sampled and fish numbers by area were the factors used in the two-way ANOVA. The first null hypothesis was that there were no differences in fish numbers between Areas A, B-untreated, B-treated, and C. This test illustrated differences, if they existed, between the control and treatment areas. The expectation was that there should be a statistically significant difference in fish numbers between the areas due to different habitat conditions. The next null hypothesis was that there were no differences in fish numbers between Areas A, B-untreated, B-treated, and C through time. The expectation was that there should be a statistically significant difference for this test because fish numbers should vary through time. Finally, the year by area interaction term showed whether the improvement structures significantly affected fish distribution (Sokal and Rolf 1969). The premise here was that a significant treatment effect would signify that the number of fish changed, presumably due to the structures influence on the habitat. The above statistical procedures were executed with the ANOVA subprogram of SPSS (Nie et al. 1975).

The data were then recoded into groups on the computer. The groups represent numbers of fish collected in specific areas and by date. For example, Group 6 is the untreated sections in Area B sampled in 1980 and Group 8 is the treated sections in Area B sampled in 1980. The data were recoded in this manner and then run through the ONEWAY subprogram of SPSS (Nie et al. 1975). The Student-Newman-Keuls test and tests for homogeniety of variances are only available with the ONEWAY subprogram and not ANOVA. The Student-Newman-Keuls test was used to find significantly different subsets for the mean number of fish collected for each area by date. Subsets that do not overlap indicate that the means in the two subsets are significantly different at the $\alpha=0.05$ level. For this study, the expectation is that the mean number of fish in the treated sections would shift to a subset apart from the pretreatment levels.

RESULTS

Physical Habitat Changes

The stream habitat improvement structures produced a number of substantial changes in stream morphology and fish habitat in the treated and untreated sections of Area B. Eight of the fourteen variables increased, four decreased, and two did not change (Figure 3). The amount of deep-slow water, undercut bank cover, and gravel increased by greater than 100 percent (Figure 3). Escape cover exhibited the largest decrease. The results of the diagrammatic mapping and measured water velocity for the 1981 and 1982 summer period are included in Tables 1 through 4 (Appendix D).

Few areas of deep-slow water occurred in Browns Creek in 1980. Deep-slow water became much more plentiful after treatment (Figure 4). The largest increases occurred in sections with stream improvement structures. In addition to the changes that occurred between pretreatment and posttreatment years, sections 8, 9, and 13 also had large increases in the amount of deep-slow water between 1981 and 1982. These three sections contain the modified Hewitt ramp, log crib deflector, and Hewitt ramp, respectively. All three structures scour large pools.

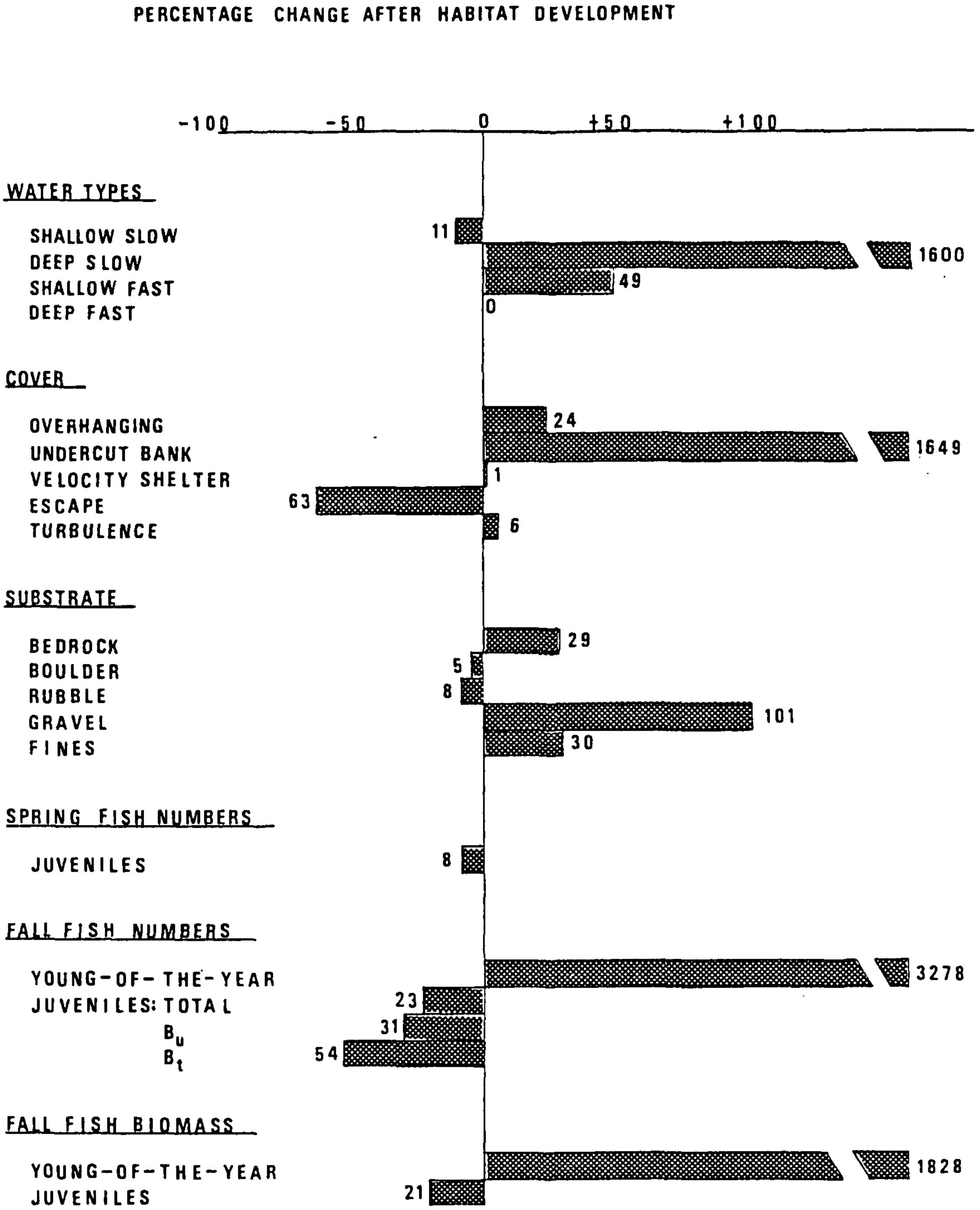

Figure 3. Percentage Change in Physical and Biological Parameters After Habitat Development in Area B in Browns Creek, California. B_u = sections without structures added and B_t = sections with structures added in December, 1980.

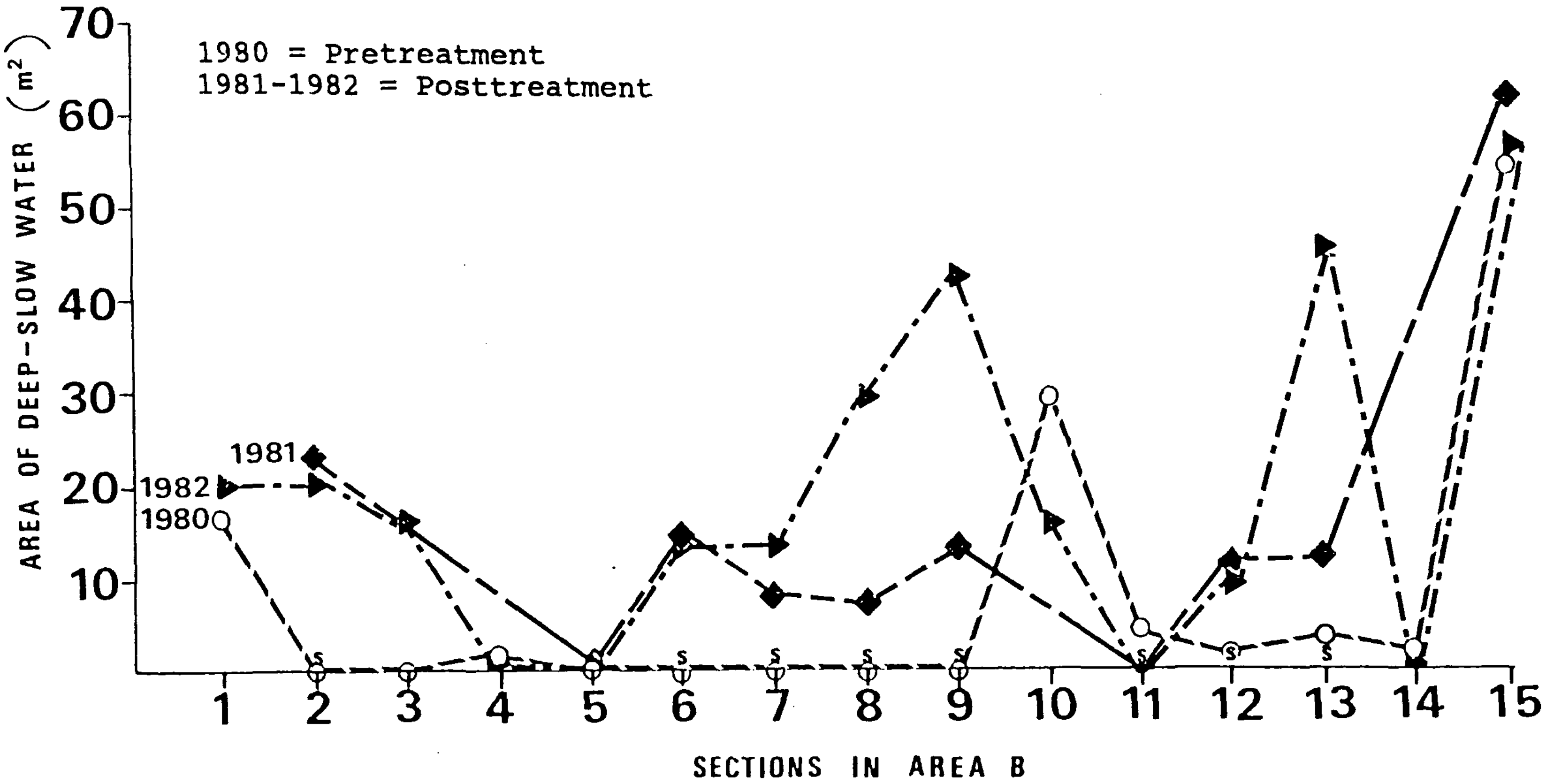

Figure 4. Amount of Deep-slow Water in Area B During 1980 Through 1982 in Browns Creek. The sections denoted with an "s" had habitat improvement structures added in December, 1980.

Sections in Area B with stream improvement structures had more gravel after treatment (Figure 5). The trend appears that gravel accumulations were greatest in the first year after treatment, declining the following year.

In sections 11 and 12, the amount of gravel decreased considerably between 1981 and 1982. These sections contain the floating-log weirs, which scour pools rather than collect gravel. A shift in the low flow channel probably caused the large decrease in gravel area from 1981 to 1982 in sections 8 and 13. These two sections contain the modified Hewitt ramp and Hewitt ramp, respectively. These two large structures collected large volumes of material upstream and this condition did not change from 1981 to 1982.

The amount of escape cover actually measured was greater in 1982 than in 1980 in most of the sections (Figure 6). Although there was more escape cover in 1982 than in 1980, the calculation of percentage change showed that escape cover decreased by about 63 percent from 1980 to 1982 (Figure 3). This result comes from using relative percent in the equation to calculate percentage change.

Undercut bank cover increased by a magnitude similar to that of deep-slow water (Figure 3). This reflects a lack of undercut bank cover in 1980 rather than a tremendous increase of this cover type in 1982. Of the 16.9 m^2 observed in 1982, 12.3 m^2 or 73 percent occurred

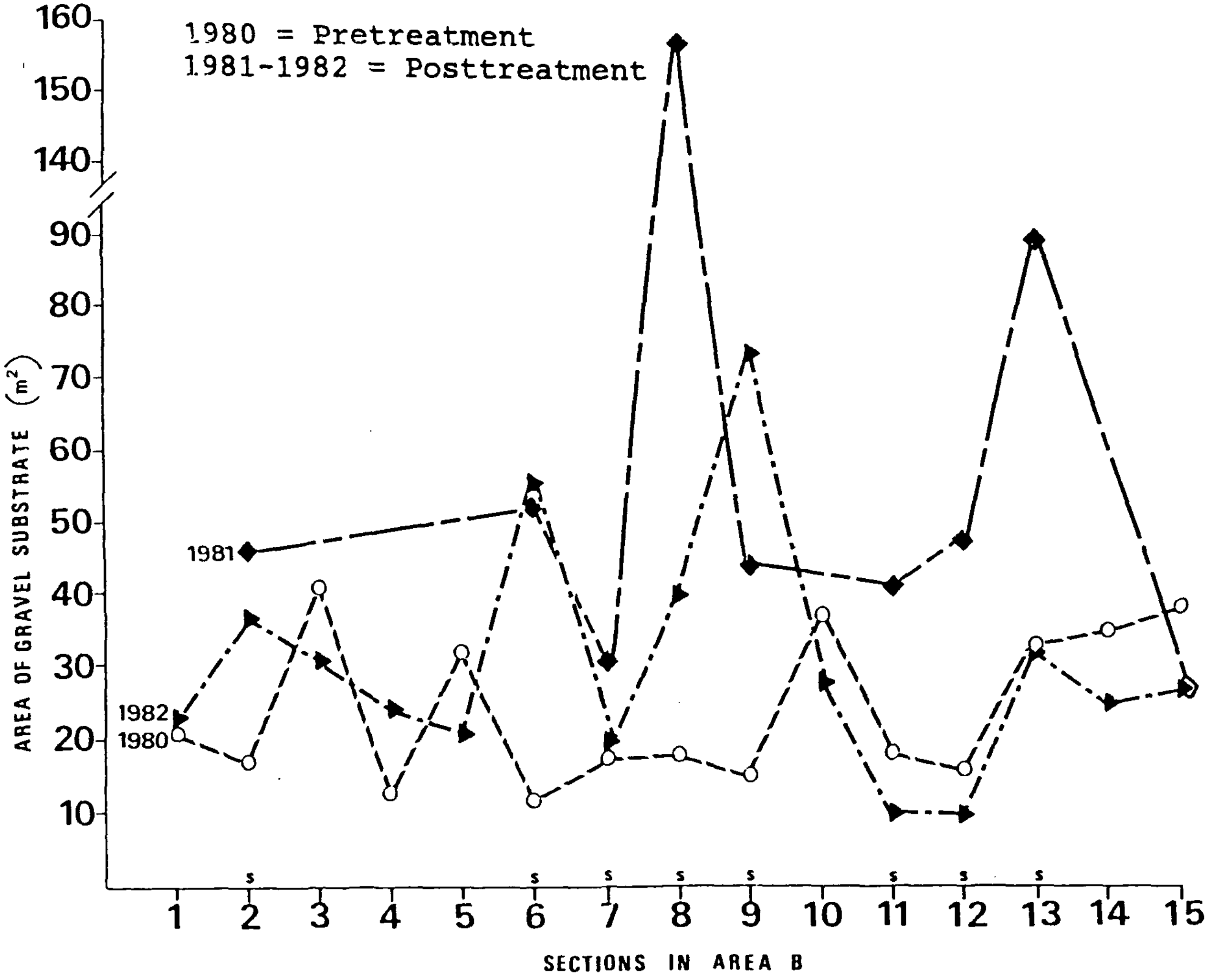

Figure 5. Amount of Gravel Substrate in Area B During 1980 Through 1982 in Browns Creek. The sections denoted with an "s" had habitat improvement structures added in December, 1980.

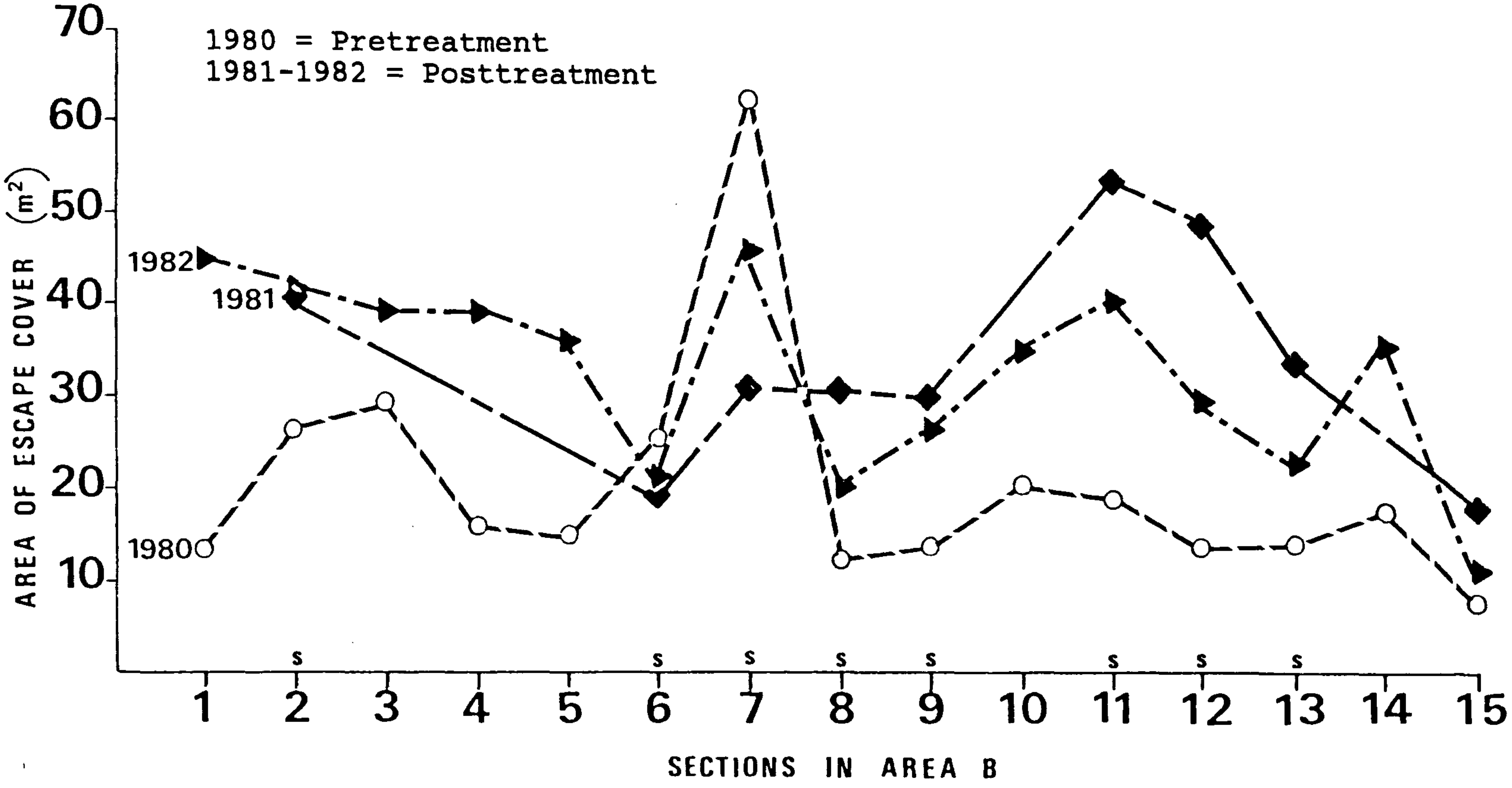

Figure 6. Amount of Escape Cover in Area B During 1980 Through 1982 in Browns Creek. The sections denoted with an "s" had habitat improvement structures added in December, 1980.

in sections 6, 8, 9, and 13. Most of the undercut bank cover occurred in sections 6, 8, 9, and 13 because these sections contain the gabion weir, the modified Hewitt ramp, the log crib deflector, and the Hewitt ramp. The scouring nature of these large structures created undercut bank cover.

Between the 1980 mapping and the 1982 mapping, mean wetted width, during the low flow period, decreased in the treated sections in Area B and increased in the untreated sections in Area B (Table 3). The overall change was a 22 percent reduction in wetted width in the treated sections compared to the untreated. Concurrent with the reduction in wetted width, surface area decreased 3 percent in the treated sections relative to the untreated sections. Changes in the physical characteristics of the stream due to the structures in 1981 versus 1982 are summarized in Table 4.

The surface area and depth of the pools downstream from the three gabion deflectors increased substantially from 1981 to 1982. The gabions forced the stream to the east side of the channel, constricting it and providing a more concentrated volume of flow. This change increased the amount of available habitat for larger fish.

The number of pools downstream of the rock-v-dam increased from one to three between 1981 and 1982. This diversified the localized habitat by increasing the quantity and quality of the rearing and escape habitat.

Table 3. Stream Width (m) at Each Section Marker During the Low-flow Period in Browns Creek, California for the Treated (B_t) and Untreated (B_u) Sections in Area B.

Stream Area	Stream Section	Year 1980	Year 1981	Year 1982
B_t	2	8.1	6.8	4.9
	6	4.6	3.7	3.7
	7	2.1	3.0	6.4
	8	4.9	3.0	5.2
	9	4.6	5.5	4.6
	11	5.2	4.7	4.9
	12	6.1	5.0	3.0
	13	7.6	6.1	4.0
	Average	5.4	4.7	4.6
B_u	1	4.3	4.9	5.3
	3	3.0	5.6	6.1
	4	4.3	3.7	6.4
	5	3.6	4.0	5.2
	10	6.1	5.2	3.4
	14	9.1	5.3	3.5
Chanchelulla Ck.		4.9	4.9	6.1
	Average	5.0	4.8	5.1

Table 4. Physical Habitat Characteristics of Pools Below the Structures Placed in Treatment Area B in Browns Creek, California During the Fall, 1981 and 1982.

Section	Structure	Year	Area (m^2)	Maximum Depth (m)	Area of Deep-slow Water (m^2)
2	3-Gabion Deflector	1981	2.7	0.46	1.4
		1982	28.2	0.64	6.3
	Rock-v-Dam	1981	8.8	0.61	0
		1982			
		(pool a)	1.8	0.25	0
		(pool b)	3.1	0.33	0
		(pool c)	14.3	0.56	0
	Gabion Deflector with a Plank Cover	1981	16.5	0.79	0
		1982	22.2	0.76	0
6	Closed-v-Gabion Weir	1981	30.1	0.62	13.6
		1982	20.7	0.74	13.8
7	Pool downsrtream of Gabion Deflector	1981	2.1	0.17	0
		1982	12.5	0.92	8.2
	Gabion Deflector	1981			
		(pool a)	27.1	0.58	7.9
		(pool b)	10.5	0.53	0
		1982			
		(pool a)	29.1	0.51	4.9
		(pool b)	5.9	0.48	0

Table 4. Physical Habitat Characteristics of Pools Below the Structures Placed in Treatment Area B in Browns Creek, California During the Fall, 1981 and 1982. (continued)

Section	Structure	Year	Area (m^2)	Maximum Depth (m)	Area of Deep-slow Water (m^2)
7	Boulder Group I	1981	10.5	0.36	0
		1982	2.1	0.23	0
	Boulder Group II	1981	8.4	0.25	0
		1982	6.2	0.35	0
8	Rock Dam	1981			
		(pool a)	2.0	0.32	0
		(pool b)	1.6	0.33	0
		1982	9.6	0.41	0
	Modified Hewitt Ramp	1981	42.4	0.66	7.0
		1982	43.8	1.14	29.3
9	Inclined Log	1981	10.3	0.41	5.9
		1982	27.6	0.61	10.2
	Log Crib Deflector	1981	26.6	0.75	7.1
		1982	41.9	1.06	29.4
11	V-Shaped Floating Log Weir I	1981	34.6	0.41	0
		1982			
		(pool a)	11.5	0.48	0.6
		(pool b)	4.2	-	0

Table 4. Physical Habitat Characteristics of Pools Below the Structures Placed in Treatment Area B in Browns Creek, California During the Fall, 1981 and 1982. (continued)

Section	Structure	Year	Area (m^2)	Maximum Depth (m)	Area of Deep-slow Water (m^2)
12	V-Shaped Floating Log Weir II	1981	22.8	0.41	0
		1982	9.5	0.35	0
	Rock Dam	1981	18.7	0.66	9.8
		1982	14.7	0.63	7.2
13	Hewitt Ramp	1981	29.0	0.56	7.6
		1982	34.2	0.71	18.4
	Pool Upstream of Hewitt Ramp	1981	38.5	0.52	1.4
		1982	35.0	0.82	19.0

The increase in pool numbers, coupled with sedge growth, provided excellent rearing habitat and escape cover at the pool margins, especially for young-of-the-year steelhead.

The plank cover-gabion pool did not change much. The amount of fine sediment increased from 0.28 to 9.20 m^2. The downstream end of this pool was wider and deeper in 1982 than in 1981. This provided excellent rearing habitat for young-of-the-year steelhead.

The pool below the gabion weir remained relatively stable. This pool contained a lot of rocks that provided escape cover. The upstream area did not provide good habitat for juvenile steelhead because it was wide and shallow and the substrate was compacted. The only fish observed in this area were young-of-the-year steelhead.

The downstream effects of the gabion deflector located in B-7 were positive. The weir diverted the channel into a bedrock outcropping. This caused a shallow pool located about 10 m downstream to deepen from 0.17 m to 0.92 m (Table 4).

More than 20 fish were seen in the pool below the gabion deflector during the 1982 summer habitat mapping. The morphology of pools directly associated with the gabion deflector remained relatively constant. The only detectable change occurred in the downstream pool where the surface area decreased by about one-half.

The two boulder clusters did not function as planned because the bedload movement within the channel was quite high. The loss of 99 out of the 100 scour chains placed in the channel in 1980 indicated substantial bedload movement. The depressions that developed around these clusters in 1981, filled in during 1982 or the boulders rolled into the depressions and no longer projected high enough above the substrate to be effective. This nearly eliminated the localized fish habitat.

The changes in the pool habitat below the rock dam in B-8 were detrimental to rearing habitat. Large quantities of boulder and rubble material from the west anchor of the modified Hewitt ramp deposited on the east bank side of the rock structure. This decreased the amount of pool space and fish habitat.

Pool depth below the modified Hewitt ramp increased by 73 percent from 1981 to 1982. In addition, the area of deep-slow water increased four-fold. The amount of fish habitat did not increase concurrently with the increase in pool depth. The pool was devoid of any roughness elements, such as logs or rocks, because most of the substrate in the pool was sand and gravel. The lack of three dimensional structure meant that the only cover type in the pool was undercut bank cover provided by the modified Hewitt ramp.

Fish habitat around the inclined log improved substantially. Pool surface area tripled and the area of the deep-slow water doubled.

The area of the pool adjacent to the log crib deflector increased by 50 percent from 1981 to 1982. The pool depth also increased by approximately 40 percent. The area of deep-slow water increased four-fold. These changes improved the physical habitat of the pool. The increase in pool size could be the result of scouring away the west bank.

The floating log weir in B-11 collected a large stump during the winter of 1982. Because of this large roughness element, two pools formed where there had been only one. In addition to this, the root wad projected into the pools and increased the amount of escape cover in the pools.

Habitat changes associated with the floating log weir in B-12 between 1981 and 1982 decreased the amount of fish habitat. Pool area and depth below the weir decreased by 60 and 15 percent, respectively, reducing the amount of fish habitat near the floating log weir.

The habitat did not change substantially in the rock dam pool in B-12 except that the area of deep-slow water increased. This structure provided excellent escape cover because it created a deep, boulder-strewn pool. There was also good escape cover under the log supporting the boulders.

The depth and amount of deep-slow water of the pool downstream from the Hewitt ramp increased from 1981 to 1982. This pool was not as deep as the pool associated with the modified Hewitt ramp because the substrate is bedrock. Escape cover in the pool was limited because it contained relatively featureless exposed bedrock.

The pool upstream of the Hewitt ramp produced positive changes for fish habitat. Pool depth greatly increased and thus the quantity of available habitat also increased.

The two paired floating logs did not affect the quantity of low-flow habitat. The placement of these structures was too far from the primary pool-forming structure. In themselves, these did not provide good habitat. During both posttreatment years, each structure was located half out of the channel. The other end was in shallow water and, because of this, fish could not escape to these structures.

Structure Durability

Most of the instream improvement structures remained intact through the two winters. The modified Hewitt ramp was the only structure requiring extensive repairs. During the winters of 1980-1981 and 1981-1982, flows in Grass Valley creek peaked at 17.3 cubic meters per second (m^3/s) and 29.2 m^3/s, respectively. These flows recur, on the average, every 2 and 3 years (Figure 1, Appendix C). The winter flows of 1980-1981 in Browns Creek peaked at about 12.5 m^3/s (Figure 2, Appendix C). This flow washed away some of the large rocks placed in the west-bank anchoring cribbing. Furthermore, the upstream portion of the ramp was never completely covered by gravel. Water flowed around the sides of the ramp versus down the middle decreasing the amount of scouring in the downstream pool. The winter flows of 1981-1982 peaked at about 14 m^3/s (Figure 2, Appendix C). During this period, the peak flows tore loose the west bank cribbing and eroded a considerable amount of the west stream bank.

The boulder clusters were the only other structures significantly affected. As previously discussed, these structures were almost completely buried in 1982 because of high bedload movement.

Water Temperature

Water temperature was not a problem during the warm, low-flow period in 1980 through 1982 (Table 5). Stream temperatures did not approach the critical level of 28 degrees Celsius (°C) for juvenile steelhead (Moyle 1976). The highest recorded temperature was 24.2 °C in August, 1980. These high temperatures were short term afternoon peaks. The largest diurnal fluctuation of 5.5 °C occurred in August and September, 1982. Based on the 1982 data, the water warms between sections A-1 and B-1. The high water temperatures in B-1 were 4.4 °C warmer than in A-1 while the lows were only 1.7 °C warmer. The

Table 5. Temperature Data for Browns Creek, California During 1980 Through 1982.

Stream Section	Date	Temperature (°C) Maximum	Minimum	Greatest Range
B-1	8/19/80 to 9/23/80	24.2	5.5	7.5
B-1	8/21/81 to 9/18/81	20.0	14.4	4.4
B-14	8/21/81 to 9/18/81	18.9	13.3	3.3
B-1	8/24/82 to 9/09/82	21.1	13.3	5.5
B-14	8/24/82 to 9/09/82	16.7	11.1	2.7

maximum diurnal temperature range in A-1 was only 2.8 °C.

Biological Results

In the four posttreatment sampling periods during 1981 and 1982, about 11,800 fish were caught (Table 6). Of this total, about 57 percent or 6,928 fish were caught during the fall 1982 sampling period. Most of these fish, 90 percent, were young-of-the-year steelhead.

Population estimates for the fall sampling include both young-of-the-year and juvenile fish while population estimates for the spring sampling only include juvenile fish. Juvenile fish are at least one year old. In the fall, young-of-the-year fish are fish less than 98 mm long, total length. Spring young-of-the-year population estimates are not included because any value would underestimate population numbers. In the spring, young-of-the-year fish are typically less than 40 mm long, not easily seen, and consequently are not susceptible to capture by electroshocking. Also, the possibility exists that not all fish have emerged from the gravel due to late spawning or delayed incubation due to cold temperatures.

The estimated number of fish in treated sections of Area B in the spring decreased 8 percent more than those in the control areas (Figure 3). The estimated number of fish in each stream section typically declined during 1981 and 1982 compared to pretreatment numbers. Figures 1, 2, and 3, (Appendix E) show the magnitude of

Table 6. Population Estimates for Young-of-the-Year (Age 0) and Juvenile (Age I+) Steelhead Trout and Variance for 95 Percent Confidence Interval by Area and by Sampling Trip for Browns Creek, California.

		1981			1982		
		July	September		July	September	
		Age					
Area	Section	I+	0	I+	I+	0	I+
A	1	38 (4)[a]	6 (2)	20 (2)	23 (6)	113 (9)	20 (12)
	2	32 (1)	8 (1)	24 (3)	16 (3)	91 (8)	15 (4)
	3	26 (9)	14 (2)	12 (1)	19 (3)	88 (14)	12 (12)
	4	29 (6)	5*[b]	24*	14 (2)	100 (9)	16 (3)
	5	29 (6)	37 (8)	10 (1)	23 (2)	101 (9)	18 (4)
	6	31 (2)	28 (3)	14 (3)	13 (5)	219 (20)	27 (9)
	7	27 (1)	11*	19*	20*	96 (20)	24*
	8	32 (2)	4*	28 (1)	28 (3)	81 (12)	15*
Bu	1	28 (18)	94 (4)	31 (2)	23 (5)	245 (12)	33 (4)
	3	47 (4)	93 (6)	27 (2)	50 (25)	462 (20)	55 (49)
	4	41 (4)	65 (2)	21*	25*	226 (12)	25 (2)
	5	51 (9)	89 (7)	22*	31 (8)	395 (11)	30 (9)
	10	61 (5)	29 (10)	28 (4)	23 (3)	195 (11)	30 (9)
	14	61 (5)	36 (2)	36 (24)	17 (7)	217 (16)	13 (6)
	15	48 (67)	21 (10)	8 (10)	12 (2)	228 (6)	19 (1)
	16a	14*	9 (4)	5*	8 (19)	115 (4)	9 (26)

Table 6. Population Estimates for Young-of-the-Year (Age 0) and Juvenile (Age I+) Steelhead Trout and Variance for 95 Percent Confidence Interval by Area and by Sampling Trip for Browns Creek, California. (continued)

		1981			1982		
		July	September		July	September	
		Age					
Area	Section	I+	0	I+	I+	0	I+
Bt	2	20 (2)	140*	24 (6)	34 (9)	333 (34)	27 (5)
	6	34 (5)	37 (5)	12 (3)	23 (6)	403 (35)	27 (1)
	7	44 (1)	32 (1)	13 (1)	19 (4)	343 (27)	27 (9)
	8	34 (18)	44 (2)	17 (1)	16 (1)	172 (25)	11 (1)
	9	38 (4)	64 (6)	20 (6)	20 (7)	143 (15)	31 (38)
	11	35 (9)	44 (12)	18 (2)	32 (13)	160 (8)	12 (1)
	12	25 (3)	35 (30)	16 (12)	21 (5)	99 (12)	21 (11)
	13	44 (13)	17 (1)	25 (2)	20 (5)	202 (44)	14 (1)
C	1	21 (10)	47 (8)	29 (10)	14 (2)	282 (19)	52 (5)
	2	61 (16)	61 (6)	27 (1)	74(126)	210 (14)	46 (6)
	3	28 (5)	79 (4)	12*	33 (38)	256 (15)	49 (32)
	4	25 (14)	71 (10)	16 (1)	32 (7)	460 (19)	38 (3)
	5	49 (6)	80 (11)	33 (4)	21 (10)	291 (24)	38 (1)
	6	55 (3)	81 (24)	52 (2)	61 (23)	206 (9)	53 (5)
	7	44 (16)	170 (13)	28 (2)	52 (12)	286 (24)	75 (91)
	8	38 (14)	97 (6)	15*	37 (89)	243 (12)	18 (1)

[a]Variance for 95 percent confidence interval. [b]Minimum population estimate.

the decline for each stream area. There is a distinct separation between the pretreatment and posttreatment fish numbers. The higher values correspond to pretreatment fish numbers and the lower values correspond to posttreatment fish numbers.

Confidence intervals for population estimates for fish inhabiting Browns Creek in the spring typically are wider than for the fall estimates. Higher flows in the spring made fish capture more difficult, contributing to the wider intervals.

Results of the two-way ANOVA show that there is no significant area by date interaction (Table 7). The habitat modification did not affect the density of juvenile fish in the spring.

Young-of-the-year steelhead population estimates increased by several magnitudes over those present prior to habitat modification (Figure 3). A significant area by date interaction supports these results (Table 8). These results do not necessarily reflect treatment effects but may be due to spawning stock size or improved incubating conditions and hatching success.

In the fall the estimated number of juvenile fish decreased 23 percent more in the treated versus control areas (Figure 3). Thirty-one percent fewer juvenile steelhead occurred in the control areas, after habitat modification but the number of fish in the treated sections decreased by 54 percent (Figure 3). The average

Table 7. Results of Two-way ANOVA of Spring Juvenile Steelhead Population Estimates by Area by Date for All Sections in Areas B_t, B_u, A, and C for 1979 Through 1982 (n=127).

Source of Variation	Sum of Squares	df	Mean Squares	F	P[a]
Area	3.289	3	1.096	4.932	0.001
Date	25.760	3	8.587	38.630	0.003
2-way interaction (area by date; i.e. treatment effects)	1.108	9	0.123	0.544	0.832
Error	24.672	111	0.222		

[a] P is the siginificance level of the F-value.

Table 8. Results of Two-way ANOVA of Fall Young-of-the-Year Steelhead Population Estimates by Area by Date for All Sections in Areas B_t, B_u, A, and C for 1980 Through 1982 (n=96).

Source of Variation	Sum of Squares	df	Mean Squares	F	P[a]
Area	86.157	3	28.719	7.994	0.001
Date	1535.287	2	767.643	213.687	0.001
2-way interaction (area by date; i.e. treatment effects)	226.598	6	37.766	10.513	0.001
Error	301.760	84	3.592		

[a] P is the siginificance level of the F-value.

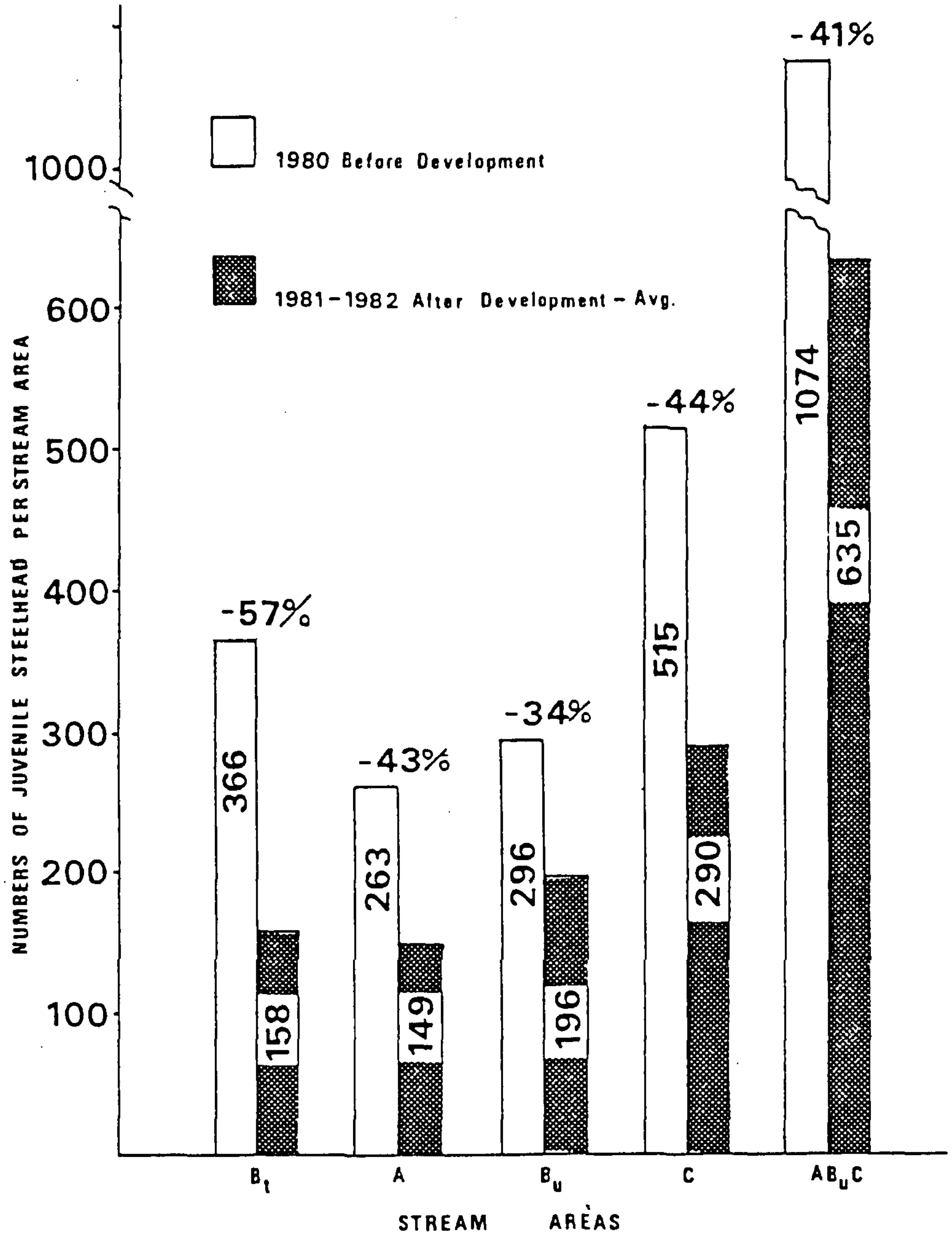

Figure 7. Number of Juvenile Steelhead During 1980 Before Habitat Development and Average Number of Juvenile Steelhead During 1981 and 1982 in Area B in Browns Creek. B_u = sections without structures added and B_t = sections with structures added in December, 1980.

number of juvenile steelhead decreased in all stream areas after habitat modification (Figure 7). Clearly, the greatest difference occurred in the treated sections. Figures 4, 5, and 6, (Appendix E) show the changes in fish numbers for each stream section. Again, the higher values correspond to pretreatment and the lower values to posttreatment fish numbers. Similar to the results for spring fish numbers, the habitat modification did not affect the density of juvenile steelhead in the study area during the fall. The two-way ANOVA of fall fish numbers by area by year resulted in no significant treatment effect (Table 9).

For fall juvenile steelhead numbers, the results of the Student-Newman-Keuls tests did not yield any significantly different subsets that would lead to the conclusion that the stream improvement structures affected the distribution of juvenile steelhead in Browns Creek (Table 10). There were no groupings, other than subset 3, that showed any area specific trends. The results show that seven of the nine means in the first subset apply to the posttreatment period. Area C, during 1980 and 1982, was significantly different than the treated sections in Area B in 1981 and 1982. Subsets 1 and 2 overlap which suggests that there is no significant difference in fall juvenile steelhead numbers in 11 out of 12 areas for the three years. These results support the ANOVA results of no treatment effect.

Table 9. Results of Two-way ANOVA of Fall Juvenile Steelhead Population Estimates by Area by Date for All Sections in Areas B_t, B_u, A, and C for 1980 through 1982 (n=96).

Source of Variation	Sum of Squares	df	Mean Squares	F	P[a]
Area	9.026	3	3.009	10.004	0.001
Date	16.170	2	8.085	26.883	0.001
2-way interaction (area by date; i.e. treatment effects)	2.200	6	0.367	1.219	0.305
Error	25.263	84	0.301		

[a] P is the siginificance level of the F-value.

Table 10. Student-Newman-Keuls Test Results for Fall Juvenile Steelhead Population Estimates for All Sections in Areas B_t, B_u, A, and C for 1980 Through 1982 (α=0.05; n=96).

Area	Year	Mean	Subset 1	Subset 2	Subset 3
C	1980	4.85			*
B_t	1980	4.39		*	*
C	1982	4.35		*	*
B_u	1980	4.02	*	*	
A	1980	3.95	*	*	
C	1981	3.59	*		
B_u	1982	3.57	*		
B_t	1982	3.31	*		
B_u	1981	3.29	*		
A	1981	3.22	*		
A	1982	3.21	*		
B_t	1981	3.20	*		

For fall young-of-the-year steelhead numbers, there is no overlap between subsets 1 through 4 and subset 5 (Table 11). This suggests that the numbers of young-of-the-year steelhead in 1982 were significantly different than the numbers in 1980 and 1981. Except for Area A in 1980 and 1981, the number of young-of-the-year steelhead in Browns Creek was year specific. There are three homogeneous groups with each representing a given year's spawn or good incubating conditions, with 1982 being the highest and 1980 the lowest. As with the fall juvenile steelhead numbers, these results support the ANOVA results.

Biomass of juvenile steelhead in the fall in the treated sections decreased 21 percent below the biomass in the control sections after habitat modification (Figure 3). Conversely, the fall biomass of young-of-the-year fish in the treated sections increased 1,828 percent over the biomass in the control sections after habitat modification (Figure 3). Area C typically had the highest biomass of fish each year in the fall (Figure 8). A similar pattern existed each year with the treated sections in area B being about equal to the biomass in untreated area B but greater than area A (Figure 8). Also, the fall fish biomass was typically less in the posttreatment years.

Average weight of fish in the fall varied by area and by year (Table 12). The juvenile fish tended to be

Table 11. Student-Newman-Keuls Test Results for Fall Young-of-the-Year Steelhead Population Estimates for All Sections in Areas B_t, B_u, A, and C for 1980 Through 1982 ($\alpha=0.05$; n=96).

			Subset				
Area	Year	Mean	1	2	3	4	5
C	1982	14.75					*
B_u	1982	14.19					*
B_t	1982	13.50					*
A	1982	10.29				*	
C	1981	9.22			*	*	
B_u	1981	7.23		*	*		
B_t	1981	7.18		*	*		
A	1980	6.07		*			
C	1980	3.78	*				
A	1981	3.62	*				
B_u	1980	2.73	*				
B_t	1980	1.62	*				

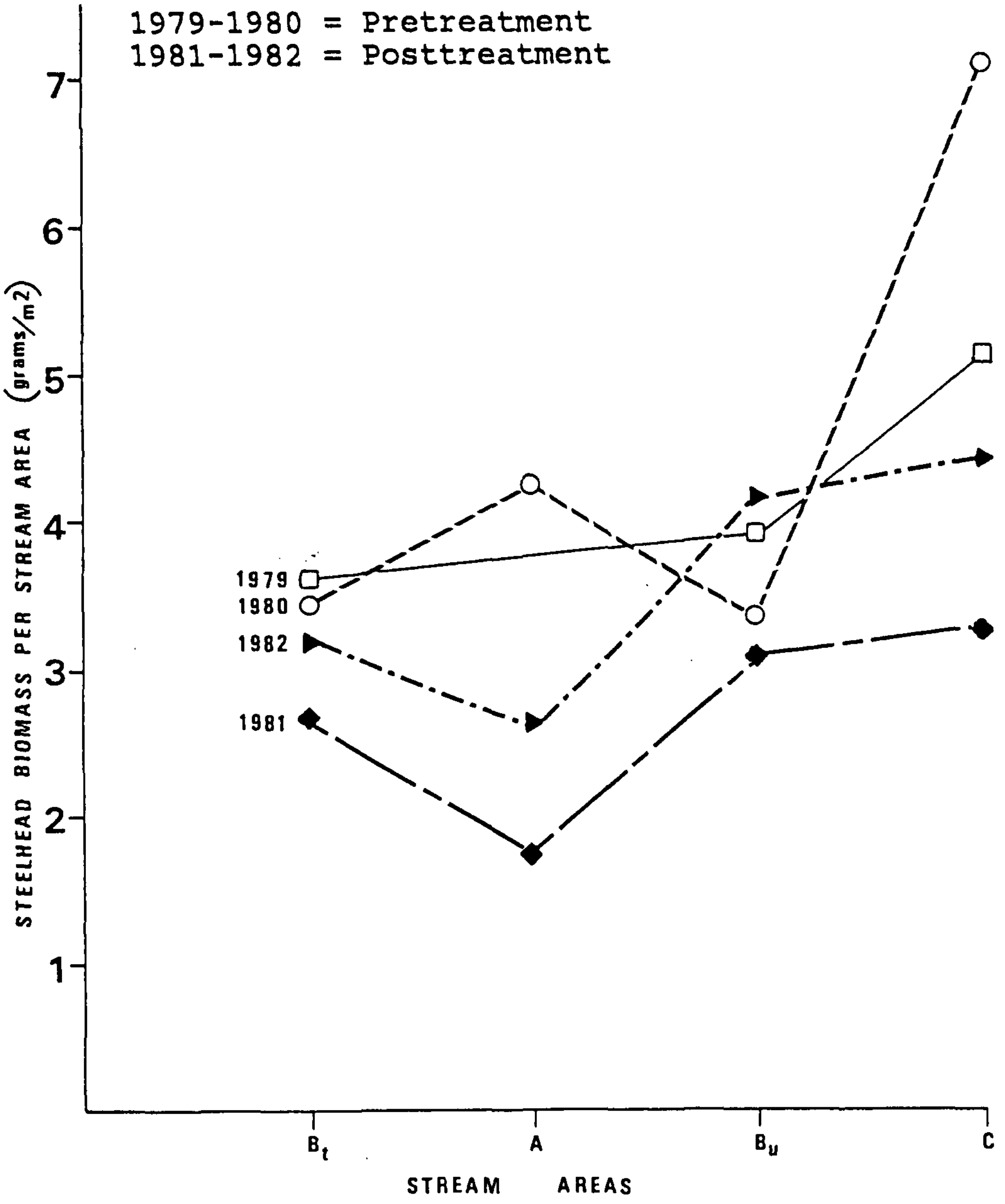

Figure 8. Biomass of Juvenile Steelhead During 1979 Through 1982 in Area B in Browns Creek. B_u = sections without structures added and B_t = sections with structures added in December, 1980.

Table 12. Fall Biomass Estimates for Study Areas A, B-untreated (B_u), B-treated (B_t), and C of Browns Creek Before and After Habitat Development of Area B_t.

Year	Study Area	Age	Population Estimate	Average Weight (g)	Total Weight (kg)[a]	Surface Area (ha)	Biomass[b] Estimate (kg/ha)
1981	A	0[c]	113	5.56	0.628	0.26	2.39
		I+[d]	151	25.97	3.921	0.26	14.93
	B_u	0	436	4.51	1.966	0.24	8.30
		I+	178	29.86	5.315	0.24	22.43
	B_t	0	413	5.03	2.077	0.29	7.05
		I+	145	39.75	5.764	0.29	19.57
	C	0	686	4.41	3.025	0.34	8.97
		I+	212	37.58	7.967	0.34	23.63
1982	A	0	889	3.17	2.818	0.28	9.98
		I+	147	31.37	4.61	0.28	16.33
	B_u	0	2083	3.03	6.311	0.29	21.43
		I+	214	28.27	6.049	0.29	20.55
	B_t	0	1855	3.27	6.066	0.34	18.07
		I+	170	27.45	4.666	0.34	13.90
	C	0	2234	3.37	7.528	0.41	18.36
		I+	369	28.28	10.435	0.41	25.45

[a] Total weight = population estimate x average weight.

[b] Biomass estimate = total weight ÷ surface area.

[c] Age 0 fish are young-of-the-year fish less than 98 mm total length.

[d] I+ fish are juvenile fish greater than 98 mm long.

larger in 1982 than in 1981 while the opposite was true for young-of-the-year fish. Biomass estimates in 1982 were larger than for 1981 principally due to the large numbers of young-of-the-year fish.

Over 92 percent or 896 out of a total of 973 of the adipose-fin-clipped fish collected during 1981 and 1982 were collected in Area B. Only 10 and 67 adipose-fin-clipped fish were collected in Area A and Area C, respectively.

The estimated number of juvenile fish and biomass at each structure changed from 1981 to 1982 (Table 13). The three gabion series, closed-v-gabion weir, gabion deflector and rock levee, and log crib deflector contained more fish in 1982 than in 1981. The estimated number of fish at the inclined log is inflated due to sampling problems. At this structure, ten fish were caught in 1982 compared to only 4 in 1981. The estimated number of fish at the gabion deflector-plank cover pool, and the modified Hewitt ramp declined from the previous year. No fish were found at the two cabled floating logs and one of the boulder clusters.

The biomass of fish at each structure yielded different results when compared to fish numbers (Table 13). The closed-v-gabion weir and the v-shaped floating log weir contained a higher biomass of fish in 1982. Fish biomass in the pools associated with the three gabion

Table 13. Population Estimates and Structure Specific Biomass for Juvenile (Age I+) Steelhead Trout and Variance for 95 Percent Confidence Interval for the Pools Created by Each Structure During the Fall of 1981 and 1982 in Browns Creek, California.

Structure	Year	N[a]		Measured Weight (g)[b]	Pool Surface Area (m²)	Biomass (g/m²)
3-Gabion Deflector	1981	4	(2.9)[c]	127	2.7	47.0
	1982	6	(1.5)	213	28.2	7.5
Rock-v-Dam	1981	2	(0)	131	8.8	14.9
	1982	9	(0)	194	19.2	10.1
Gabion Deflector and Plank Cover	1981	12	(2.4)	544	16.5	33.0
	1982	5	(1.9)	181	22.2	8.2
Closed-v-Gabion Weir	1981	4	(2.9)	157	30.1	5.2
	1982	13	(0.7)	312	20.7	24.0
Gabion Deflector	1981	1	(0)	23	37.6	0.6
	1982	8	(5.8)	238	35.0	6.8
Boulder Group I	1981	2	(0)	58	10.5	5.5
	1982	NS[d]				
Boulder Group II	1981	0	-			
	1982	1	(0)	27	6.2	4.3
Rock Dam	1981	3	(0)	81	3.6	22.5
	1982	3	(0)	68	9.6	7.1

Table 13. Population Estimates and Structure Specific Biomass for Juvenile (Age I+) Steelhead Trout and Variance for 95 Percent Confidence Interval for the Pools Created by Each Structure During the Fall of 1981 and 1982 in Browns Creek, California. (continued)

Structure	Year	N[a]		Measured Weight (g)[b]	Pool Surface Area (m^2)	Biomass (g/m^2)
Modified Hewitt Ramp	1981	11	(0.8)	394	42.4	9.3
	1982	1[e]		7	43.8	0.2
Inclined Log	1981	4	(0)	160	10.3	15.5
	1982	18	(37)	255	27.6	9.2
Log Crib Deflector	1981	5	(1.9)	185	26.6	7.0
	1982	12	(0.7)	424	41.9	10.1
V-Shaped Floating Log Weir I	1981	3	(0)	55	34.6	1.6
	1982	1	(0)	59	15.7	3.8
V-Shaped Floating Log Weir II	1981	2	(0)	44	22.8	1.9
	1982	5	(1.9)	211	9.5	22.2
Rock Log Dam	1981	6	(10.6)	147	18.7	7.9
	1982	4	(6.8)	123	14.7	8.4

Table 13. Population Estimates and Structure Specific Biomass for Juvenile (Age I+) Steelhead Trout and Variance for 95 Percent Confidence Interval for the Pools Created by Each Structure During the Fall of 1981 and 1982 in Browns Creek, California. (continued)

Structure	Year	N[a]		Measured Weight (g)[b]	Pool Surface Area (m^2)	Biomass (g/m^2)
Hewitt Ramp	1981	5	(4)	177	29.0	6.1
	1982	2	(0)	45	34.2	1.3

[a] Estimated number of juvenile steelhead trout.

[b] Actual weight of juvenile steelhead collected at the structure.

[c] Variance for the 95 percent confidence interval.

[d] No fish were collected because the boulders were buried by gravel.

[e] One fish was caught on the second pass, therefore this is not an estimate.

series, gabion deflector and plank cover, inclined log, and Hewitt ramp decreased from 1981 to 1982.

In the Browns Creek study area, 88 percent of the fish collected were mature enough to be sexed. Of these, 79 percent were males. The percent of mature rainbow trout in the study area was about twice the percent of mature fish collected at the comparative sites. Forty-four percent and 34 percent of the rainbow trout sampled from lower Browns Creek and the East Fork Mad River, respectively, could be sexed.

Multivariate Analysis

The principal components analysis reduced the initial 14 physical habitat variables into five factors. The first factor accounted for less than 20 percent of the variation and the other four factors accounted for even less variation, ranging from 8 to 13 percent (Table 14). The five factor model extracted over 70 percent of the variance due to the pool, boulder, deep-slow water, undercut bank cover, velocity shelter, escape cover, and turbulence cover variables (Table 15). Even though the model extracted over 70 percent of the variance for seven of the 14 variables, the five factor model only explained 63 percent of the variation in the physical habitat domain. Further, the factor loadings, which represent regression coefficients between the variables and the individual factors, typically were less than 0.7

Table 14. Eigenvalues, Percent of the Total Variation in the Physical Habitat Domain Explained by Each Factor, and the Cumulative Percent of the Variation Explained in the Physical Habitat Domain in Browns Creek for the 1980 Through 1982 Data.

Factor	Eigenvalue	Percent of Variation Explained	Cumulative Percent
1	2.68	19.2	19.2
2	1.92	13.7	32.9
3	1.70	12.2	45.1
4	1.26	9.0	54.1
5	1.18	8.5	62.6

Table 15. Communality[a] of the Physical Habitat Variables for the Five Factor Model from the Principal Components Analysis for the 1980 Through 1982 Data Collected in Browns Creek.

	Communality
Variable	1980 - 1982
Area	.48
Pools	.75
Boulder	.74
Gravel	.53
Fine	.61
Bedrock	.50
Deep-slow	.70
Shallow-fast	.49
Overhang	.47
Undercut	.74
Velocity shelter	.70
Escape	.73
Turbulence	.75
Average velocity	.55

[a] The communality of a variable from a principal components analysis represents the amount of variation removed by all the factors.

(Table 16). This suggests that the physical habitat variables are uncorrelated because of the weak relationships between the physical habitat variables and the factors. Some of the higher factor loadings could be due to chance. Also, the amount of gravel and boulder substrate, shallow-fast water, undercut bank cover, escape cover, and average water velocity required more than one factor to explain the variation due to the individual variable (Table 16). Given the weak relationships between the physical habitat variables, correlation of the factor-scores with the biological variables was not done.

Table 16. Factor Loadings[a] of the Physical Habitat Variables for the Five Uncorrelated Factors Derived from the Principal Components Analysis for the 1980 through 1982 Data Collected in Browns Creek.

	Factor				
Variable	I	II	III	IV	V
Area			-.67		
Pools	.85				
Boulder		.74	.38		
Gravel	.39	-.47			
Fine	.73				
Bedrock					.66
Deep-slow	.78				
Shallow-fast	-.29		.58		
Overhang					.61
Undercut				.79	-.25
Velocity shelter		.78			.27
Escape	.32		.60		-.50
Turbulence				.76	
Average velocity		.66	-.29		

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[a] Factor loadings represent the correlation coefficient between the factor and the physical habitat variable.

DISCUSSION

The quantity of deep-slow water, gravel substrate, and undercut bank cover more than doubled due to the structures in Browns Creek. Plunge pool structures were primarily responsible for the large increases in these habitat variables. These structures altered the channel gradient and collected gravel on their upstream side. The water spilling over the structures scoured pools and also undercut the structures. Plunge pool structures dramatically changed the local habitat and affected a much larger area than the other types of structures.

Pools below the plunge pool structures were typically large in surface area and commonly exceeded 0.5 m deep. Although the plunge pools provided large amounts of rearing space, we did not collect large numbers of fish in them possibly due to fish habitat requirements, to sampling inefficiency, or to fish behavior. The amount of effective fish habitat in the pools may have been limited due to a lack of cover. Undercut structure cover was the most common cover type in these pools. Resident rainbow and brown trout set up territories in areas where they can quickly swim to cover (Jenkins 1969). This suggests that there is probably some finite distance that a trout will swim to escape cover. Fish behavior would then limit the number of fish in close proximity to the structure and would limit the number of fish in a particular pool. To effectively use the undercut feature, fish would have to remain relatively close to the structure at the upstream end of the pool. Therefore, living space that is devoid of cover and beyond the swimming distance to cover, would be underutilized.

Many of the structure pools were deep and large, thereby presenting logistical problems for wading, shocking, and netting fish. Often several juvenile trout (sometimes as many as 20 individuals), were observed in the gabion-plank cover pool in section B-2 and in the modified Hewitt ramp pool located in section B-8. The pools were isolated with block nets and subsequently sampled. Frequently three or fewer fish were collected. Thus, sampling inefficiency at such locations prevented calculation of a population estimate by the Moran-Zippen method or yielded population estimates in the treated areas with wide confidence intervals.

The steelhead in Browns Creek had restricted home ranges because less than eight percent of the adipose-fin-clipped fish were collected outside of area B. Steelhead in Browns Creek behaved similarly to Gila trout (Salmo gilae) in New Mexico, to rainbow trout in Minnesota, and to brown trout (Salmo trutta) in Pennsylvania (Bachman 1984; Cargill 1980; and Rinne 1982). About 75 percent of the Gila trout remained within 100 m of their initial release sites after 8 months (Rinne 1982). The rainbow trout in Minnesota did not exhibit statistically different movement during a 2.5 year study (Cargill 1980). Most of the rainbow trout were sedentary because almost all of the fish spent most of their lives within the study sections; the shortest study section was 165 m long (Cargill 1980). Since most of the steelhead in Browns Creek were recaptured within the 1,320-m-long Area B, one can conclude that the maximum home range for most of the steelhead in Browns Creek was 1,320 m. The home range for Browns Creek steelhead is probably less because so few fish were collected outside of area B. The results described above support the concept of a restricted home range for Browns Creek steelhead.

The clipping results also indicate a tendency to move downstream. The seven to one ratio of downstream to upstream movement is also similar to results for salmonids in other streams. Less than two percent of Gila trout moved upstream over habitat improvement structures (Rinne 1982). Also, more Gila trout moved downstream than upstream.

These results are important for this study because it shows that the steelhead will utilize a limited stream area during its freshwater residency. Cargill (1980) showed that most of the rainbow trout movement occurred in Minnesota because of reduced habitat quality. The relationship between movement and habitat quality means that fish would also stay in areas with good habitat conditions. If the structures created good habitat in Browns Creek, the steelhead would have remained within a limited area near the structures. The habitat created by some of the structures did not contain enough of the physical attributes favored by juvenile steelhead. Cover was probably the physical attribute missing in most of the large pools.

The modified Hewitt ramp, Hewitt ramp, and the closed-v-gabion weir blocked upstream movement of fish in Browns Creek during low flow periods. Blocking the upstream movement of fish in the late-summer and fall period probably did not affect the steelhead in Browns Creek. It would have little effect on the fish because they would most likely have moved downstream. Most steelhead migrate downstream in the spring (Shapovalov and Taft 1954). Given the sedentary behavior of steelhead in Browns Creek, one would not expect the steelhead to be moving during the low flow period unless the fish were displaced from their home range. Destruction of habitat within the home range of the fish would be the most likely event to cause the fish to move. Destructive events during the late-summer and fall period are rare. Therefore, the effect of the structures on fish movement in Browns Creek would be minor.

In addition to the lack of proper cover in these large pools, fish behavior could affect fish density in the pools. The lack of visual isolation within a pool allows for more fish interaction. Fish behavior, such as territoriality or defense of foraging sites in overlapping home ranges, could regulate the density of fish in a pool. In a Pennsylvania stream, brown trout exhibited more agonistic behavior associated with foraging sites compared to refuge sites (Bachman 1984). Large pools, comparable to the pools associated with the habitat improvement structures in Browns Creek, had limited drift areas because they lacked a significant water current flowing through them. The lack of a drift area limited the amount of foraging areas. This places foraging sites at a premium and would exacerbate competition for them. Fish also set up dominance hierarchies to minimize the amount of energy spent obtaining food (Bachman 1984; and Jenkins 1969). The ability to defend a foraging area or territory is also size dependent. Thus a few larger individuals could dominate a given pool and exclude other individuals (Allen 1969b; Bachman 1984; Chapman 1966; and LeCren 1965). Studies have also shown that fish behavior can regulate the density of I+ age fish in a stream more than recruitment from the previous year class (LeCren 1965).

The amount of gravel substrate doubled due to the placement of the structures in Browns Creek. The most dramatic increases in gravel occurred in stream sections containing the large plunge pool forming structures such as the modified-Hewitt ramp, Hewitt ramp, and gabion weir.

More gravel accumulated upstream of the structures than downstream. Obviously, the amount of upstream accumulation depended on the size of the structure and the extent it elevated the channel.

The plunge pool structures functioned as designed by altering the channel grade upstream. The area of influence upstream of the structure depends on structure height and stream gradient. A given structure has less influence on steeper gradient stream sections. For this study, the two ramp structures collected more gravel than the gabion weir or rock dams.

The large increase in numbers of young-of-the-year steelhead trout in both posttreatment years could be indirectly linked to the increase in available spawning gravel or the increase could be due to factors that were not considered in this study. These factors include an increase in the escapement of adult steelhead to Browns Creek, a concentration of spawning in the study area, an increase in gravel quality, which would increase egg to emergent fry survival, or an increase in the amount of fry habitat. The only factor evaluated in this study was the quantity of fry habitat and habitat mapping showed that this increased.

The number of juvenile steelhead decreased more in the treated sections than the untreated sections of Browns Creek. This decrease could be due to a number of factors. The first factor relates to the above discussion on gravel. Increases in gravel quantity may have reduced juvenile fish habitat. The gravel could fill the spaces between the cobble and boulder substrate in the deeper areas in the channel. The stream sections containing the large plunge pool forming structures had the largest decreases in the number of juvenile steelhead. Converting the stream from cascades with cobbles and boulders to large pools negatively affected the number of juvenile steelhead.

The plunge pool structures were designed to scour large pools. Ideally, these large pools would provide increased rearing and escape habitat for juvenile steelhead. But, their large exposed surface area may have detracted from their suitability as juvenile steelhead habitat. Had these pools provided good quality juvenile steelhead rearing habitat, they could have compensated for the habitat buried by gravel accumulations. As discussed above, the pools lacked cover. The addition of cover, in the form of root wads, half logs, rocks, a plank cover such as in section B-2, or other devices, could increase the capacity of the pools to attract and hold juvenile steelhead.

The principal components analysis yielded five factors from the original fourteen physical habitat variables. Although the principal components analysis reduced the physical habitat domain by about one-third, the reduction provided little utility in understanding how physical habitat features affected fish distribution in Browns Creek. The weak relationships between the physical habitat variables suggest that it is not useful to reduce the physical habitat domain from the original fourteen habitat variables. Therefore, one must consider the relationship between individual physical habitat variables and fish distribution.

Analysis of the individual physical habitat variables in conjunction with the fish population estimates provides for a general understanding of the physical habitat requirements of the steelhead in Browns Creek. In 1982, the young-of-the-year steelhead were more concentrated in stream sections with a lot of gravel and deep-slow water such as in sections 2, 6, 7, 8, and 13 of Area B. These stream sections had the large plunge pool forming structures that also created shallow gravel areas at their upstream ends. In 1982, the highest concentrations of juvenile steelhead occurred in Sections 1, 2, 3, 5, 6, 7, 9, and 10 of Area B. These sections typically had water velocities of around 0.2 m/s, large quantities of escape cover, the highest amounts of shallow-slow water, and abundant boulder and rubble substrate.

The habitat characteristics that affected the different age classes of steelhead in Browns Creek were similar to those reported in the literature. Observations during the habitat mapping and fish sampling revealed that young-of-the-year steelhead occurred in lower velocity areas, primarily the margins of pools and wide shallow gravel bars. Juvenile steelhead concentrated in narrow areas with higher water velocities and with boulder and rubble substrate which also acted as velocity shelters and provided cover.

It is obvious from the results that large, exposed pools negatively affected rearing habitat for juvenile steelhead in Browns Creek. In Montana, cover and water velocity were the two most important factors affecting fish abundance in pools (Lewis 1969). The above discussion does not suggest that pools are not important for juvenile steelhead rearing. In Oregon streams, pools were important for juvenile steelhead rearing. Undercut banks and pools with cover were the most significant habitat components used by juvenile steelhead (House and Boehne 1985). In Oregon streams, cover almost always was a determinant in the distribution of juvenile steelhead and studies have shown that cover is the most important factor (Nickelson et al. 1979).

Pool structure, rather than its mere presence is essential to understanding why the density of juvenile steelhead decreased more in the treated sections. Although some authors try to isolate certain factors to explain fish distribution, the answer probably is that the fish select for a combination of factors. Other studies show that stream surface area, water velocity, substrate type, and cover as well as drift areas are important for fish survival (Burns 1971; Everest and Chapman 1972; Lewis 1969; and Nickelson et al. 1979). The interaction of the physical and the biological components, as well as fish behavior, are important determinants of fish density. This study suggests that large, deep pools, with low water velocity and limited cover, do not provide the necessary requirements for good juvenile steelhead rearing habitat.

The number of juvenile steelhead declined in all areas from 1980 to 1982. Examination of the results for individual structures showed that certain structures provided more juvenile steelhead habitat than others. Most of the juvenile steelhead were found near structures that provided habitat diversity and abundant cover.

The number of juvenile steelhead increased from 1981 to 1982 in the plunge pools below the rock dam, gabion weir, inclined log, and one of the v-shaped floating log weirs. In 1981 there was one large pool below the rock dam. In 1982, the stream width increased and three separate pools replaced the one large pool. The pool below the gabion weir had the same surface area in 1981 and 1982 but the depth increased from 0.6 m to 0.74 m. The abundant boulder and rubble substrate in this pool provided abundant escape cover.

In 1981 a channel bar formed upstream of the inclined log and filled up one-third of its upstream side. This change in elevation forced more water over the log which scoured a larger, deeper pool that spanned the entire width of the stream. In 1981, the pool occurred on the east bank against the rip rap used to stabilize the road fill. This appeared to be a positive change because the amount of overhanging cover increased. Fish could now escape under the inclined log along the entire width of the pool.

The pool below the downstream v-shaped floating log weir changed dramatically from 1981 to 1982. A large stump lodged in the upstream side of the apex of the weir. This forced the stream flow to split, forming a central channel bar downstream which split the pool. Although the total surface area of the two pools was less than the one large pool, there was more habitat diversity. The stump and the debris it collected also provided good escape cover. The increase in habitat diversity and complexity probably accounted for the increase in the number of juvenile fish using these pools.

More juvenile steelhead occupied the habitat created by the three gabion series, gabion deflector and rock levee, and log crib deflector in 1982 than in 1981. All three of these structures were successful at narrowing and deepening the channel. In doing this, larger pools formed downstream of the three gabion series and log crib deflector. The pool below the log crib deflector doubled in size. The log crib deflector, because of its lateral configuration, provided more cover per unit pool area than the large plunge pool structures. The gabion deflector and rock levee and the log crib deflector also provided good escape cover. These two structures also contained higher fish biomass in 1982 than in 1981. Furthermore, pools associated with the latter two structures had higher water velocities at the upstream ends than the other larger pools. The closed-v-gabion weir had the highest fish biomass of all the habitat near the structures in 1982. Similar to the results described by Lewis (1969), the combination of cover and a significant velocity component probably contributed to the increased use by juvenile steelhead of the habitat created by these structures. Conversely, the large pools below the modified Hewitt ramp and Hewitt ramp had the lowest biomass estimates for 1982. These two pools had little current flowing through them and the structures provided the only cover in the pools. This supports the contention that cover is essential in large pools to provide good rearing habitat for juvenile steelhead.

Fish biomass for the Browns Creek study sections were not appreciably different than those for other streams. The biomass of fish in the treated areas of Browns Creek averaged 2.9 g/m^2. The biomass of fish in the control Areas, A, Bu, and C, averaged 2.9 g/m^2, 3.6 g/m^2, and 5.0 g/m^2, respectively. In a coastal Oregon stream, the salmonid biomass averaged 4.2 g/m^2 and 4.1 g/m^2 in the treated and control areas, respectively (House and Boehne 1985). The biomass of steelhead parr, in the Keogh River in British Columbia, averaged 5.9 g/m^2 and 2.4 g/m2 in the treated and control areas, respectively (Ward and Slaney 1981). The biomass of fish in untreated Area C was higher than all but the treated area in the Keogh River and 70 percent higher than in the treated area in Browns Creek. This suggests that the treated areas in Browns Creek could support a higher fish biomass than was found.

The structures placed in Browns Creek were unsuccessful at increasing the production of juvenile steelhead trout biomass. On the other hand, the structures apparently created habitat favorable for the production of steelhead trout fry. Increasing the production of young-of-the-year steelhead trout ensures that there are sufficient numbers to seed all available habitat. As stated earlier, the highest percentage of adult steelhead originated from juvenile steelhead that smolted at Age I, II, or III, depending on geographic area (Chapman 1958; Kesner and Barnhart 1974; Shapovalov and Taft 1954; and Withler 1966). Therefore, habitat that produces juvenile steelhead is necessary to increase the number of returning adults. The benefit in egg to fry emergence and enhanced habitat conditions for young-of-the-year steelhead in Browns Creek would be negated unless the increased numbers of young-of-the-year steelhead survive to smolt.

Two plausible explanations for the lower than expected fish biomass based on an almost two-fold difference in standing crops between Areas A and C are: (1) the posttreatment study period overlapped a period of low fish abundance or the pretreatment study period overlapped a period of high fish abundance, and (2) the structures did not create habitat conducive to producing juvenile steelhead trout. This latter explanation has been extensively discussed above.

Salmonid stocks in streams show great natural variation in abundance (Hall and Knight 1981). Annual variation in fish abundance can mask the influence of the changes in the physical characteristics of a stream (Hall and Knight 1981). The study on the effects of stream improvement on brook trout (Salvelinus fontinalis) in a Wisconsin stream is a good example of this. Brook trout numbers and biomass were higher in the three to six years after treatment than in the first three years after treatment (Hunt 1976). Based on these results, Hunt (1976) suggested that there should be planned waiting periods between data collection. This allows wild trout populations to adjust to the aquatic system which is also adjusting to the physical perturbation. This does not suggest that with long-term monitoring the annual variation in steelhead abundance in Browns Creek could be explained or predicted.

According to Hall and Knight (1981), the four year Browns Creek study, two pretreatment and two posttreatment years, had three main disadvantages. These disadvantages were: (1) there was little opportunity to observe year to year variation; (2) the results may not have been representative of a longer time sequence; and (3) the treatment was vulnerable to unusual weather. For the Browns Creek study, there was no way to assess whether the pretreatment fish abundance was high or whether the posttreatment fish abundance was low. It does appear, however, that fish abundance in the pretreatment years was distinctly higher than posttreatment fish numbers, but the difference was not statistically significant. This, along with the 41 percent reduction in fish numbers in the untreated areas suggests that the pretreatment period was a time of higher fish abundance.

The data did show that there was a shift in the relative distribution of fish in Browns Creek. Regardless of fish abundance in a given year, the results suggested that the shift in the distribution of fish from the treated areas to the control areas was due to unfavorable habitat conditions in the treated areas.

It is important to note that the information gained through this study refines our knowledge about juvenile steelhead trout habitat requirements. In the future, managers can use this information to design projects having a higher probability of success to increase the production of juvenile steelhead trout.

The placement and design of the structures used in this study was good. The only structure requiring extensive repairs after winter high stream flows was the modified Hewitt ramp. The modified Hewitt ramp and the log crib deflector caused considerable erosion during the high flows in 1981 and 1982. The structural integrity of the west bank cribbing for the modified Hewitt ramp failed which probably channeled water down the west side. This eroded a steep stream bank having loose soil. This probably contributed a lot of sediment to the Browns Creek channel and could have degraded more habitat than created by the modified Hewitt ramp. Sedimentation due to erosion has a number of negative effects to anadromous salmonid rearing spawning and rearing habitat (Reiser and Bjornn 1979). Situations where habitat is degraded while attempting to improve habitat should be avoided.

Structure placement or incomplete design of the log crib deflector complex caused the other erosion problem. The log crib deflector forced water away from a precipitous bank into an unprotected bank with loose soil. In this case, the structure functioned too well. This problem would not have occurred if the structure deflected water into a very stable stream bank or if the design included armoring the opposite bank.

The important thing to note is that most of the structures survived at least bank full discharges. The bank full discharge is the most effective channel-forming flow (Wolman and Miller 1960). It takes at least a bank full discharge to move the bedload and this occurs on the average every 1.5 years (Bovee 1982). Inferring from the peak flow-recurrence interval relationships developed for Grass Valley Creek and Browns Creek, the graphs showed that the structures survived flows with recurrence intervals of two to three years. Therefore, most of the structures withstood predominant channel-forming events during both seasons which was a positive outcome of this study.

The design and construction techniques for this study were basically sound. The extensive planning and design incorporating biology, hydrology, and engineering should serve as a model for future efforts. This study along with other recent undertakings shows that current technologies exist for successful stream improvement projects in coastal streams of western North America (Hall and Baker 1982; House and Boehne 1985; Overton et al. 1981; and Ward and Slaney 1981).

Management Considerations

Several points are evident from the results of this study relative to the planning of stream improvement projects.

First, and foremost, determine the need to improve the habitat. The habitat in Browns Creek appeared to lack several key habitat components. But, after the project was planned and sampling started, it was discovered that Browns Creek had good pretreatment fish populations. Because of this, there was almost a statistically significant decline in juvenile steelhead numbers following treatment. Stream improvement work is expensive and it is incumbent on the managers to do preproject surveys to determine if the work is needed. Managers should not try to improve streams that already provide adequate habitat. Current knowledge concerning fish habitat requirements is not so refined that managers can "fine tune" an adequate system.

Second, managers must consider the specific habitat requirements of the target species, then select structure sites and structure designs to duplicate those requirements. Most of the structures placed in Browns Creek created large pools, but the number of juvenile steelhead declined in those treated areas with large pools. The results showed that juvenile steelhead in Browns Creek occurred in areas with higher water velocity and with large substrate elements which also provided cover. The large pools did not provide the habitat necessary for juvenile steelhead. The remedy now may be as simple as placing cover objects in the pools. The lack of knowledge about juvenile steelhead requirements in

Browns Creek contributed to the limited effectiveness of the improvement structures.

Third, managers should, by design, provide diversity within each habitat component created. For example, placing different cover types in the created pools to provide overhead cover, escape cover, and a combination of the two might identify particularly successful designs for a common habitat component.

Finally, stream improvement structures should be studied from a long-term perspective to provide additional information regarding structure durability and their influence on the fish populations. As other researchers have pointed out, several years may be required for the habitat modifications and the fish populations to adjust to the initial habitat perturbation.