AN ABSTRACT OF THE THESIS OF

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Title: Distribution, Abundance, and Emigration of Juvenile Steelhead (*Oncorhynchus mykiss*), and Analysis of Stream Habitat in the Steamboat Creek Basin, Oregon

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James D. Hall

Snorkel dive estimates and an inventory of stream habitat of the juvenile steelhead (*Oncorhynchus mykiss*) population in the Steamboat Creek basin were made in the summers of 1987 and 1988. Emigration was monitored by fish trapping from spring through fall of 1988. Distribution, abundance, and habitat utilization of juvenile steelhead were affected by stream size and temperature. The majority (65%) of age >1 fish were in two mainstem channels, whereas numbers of age 0 fish were more evenly distributed throughout the basin. Age >1 fish significantly ($P<0.005$) increased their use of riffles with depth, and avoided shallow riffles. Where riffles were apparently too shallow, age >1 steelhead utilized pool habitat to a greater extent. Age >1 steelhead greatly avoided glides in all sizes of channels. Age 0 steelhead appeared to be less restricted in their choice of habitat than age >1 fish. Age 0 fish, presumably by virtue of a smaller body size, showed only slightly increased use of riffles with depth. Both age 0 and >1 steelhead increased their use of riffles in streams with higher temperature regimes. Densities of age >1 fish in channels with large boulder substrate increased significantly ($p=0.02$) with mean riffle depth, probably as a function of more wetted area being useable in streams with deep riffles, and more feeding microhabitats being afforded by rough channels. Densities of age 0 fish did not appear to be affected by the range of stream sizes studied, or by channel roughness, but were low in all channels with high stream temperatures.

Compared to other steelhead producing streams, Steamboat Creek had low summer rearing densities, small smolts, and an exceptionally high proportion of fish emigrating as parr (considered to be at least one year away from development of smolt characteristics). Roughly 120,000 age 0 steelhead, 60,000 parr, and 4,100 steelhead smolts were estimated to have emigrated from the basin. Most parr emigrated in the spring when stream flows were high, whereas the majority of age 0 fish emigrated during summer base flow recession. I suggest that parr emigration from Steamboat Creek may be a life history adaptation that takes advantage of rearing conditions downstream in the North Umpqua River.

Distribution, Abundance, and Emigration of Juvenile Steelhead (*Oncorhynchus mykiss*), and Analysis of Stream Habitat in the Steamboat Creek Basin, Oregon

by

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With respect and love I dedicate my thesis to the living memory of Danielle Zumbrun,...her braids touch the earth.

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CHAPTER 1. INTRODUCTION

Management History of Steamboat Creek Basin

Steamboat Creek is the largest spawning tributary in the North Umpqua River drainage for summer- and winter-run steelhead (*Oncorhynchus mykiss*). As early as the 1850's hydraulic mining of hill slopes and dredging of stream channels for gold occurred in the Steamboat Creek basin (Gerry Williams, USDA Forest Service, Umpqua National Forest, 2900 Stewart Parkway, Roseburg, Oregon 97470; personal communication). In 1893 the Steamboat Creek basin was placed in the Cascade Range Forest Reserve. Five years later the basin was divided into holdings of the United States Forest Service (USFS), Bureau of Land Management, and private ownership. Adult summer steelhead laying in summer resting pools in the basin were an easy food source for early homesteads and mining camps. In 1932 Steamboat Creek was closed to angling and mining to provide an unmolested refuge for summer-run adults. During the mid-1950's major networks of logging roads began to spread through the basin. In 1959 a partial barrier at river kilometer 9.5 (Steamboat Falls) was laddered, which improved access to eight major tributaries in the basin.

Fish habitat was not protected from the effect of logging practices from the beginning of forest harvest in the basin. Downhill clear-cut logging left adjacent reaches of stream channels unshaded and filled with logging debris, and channels often served as skid roads for log transport (Clare and Marston 1968). These practices received nationwide attention through the distribution of a privately made film entitled "Pass Creek" (Department of Fisheries and Wildlife, Oregon State University, Corvallis, Oregon 97331) that documented logging in Pass Creek, a tributary of the Steamboat Creek basin.

Public outcry and congressional action moved the Bureau of Land Management and United States Forest Service to reform logging practices nationwide, and especially to protect anadromous fish habitat within the basin (Clare and Marston 1968, Clark et al. 1969). Research was also initiated. Brown et al. (1971) completed a 3-year study that described the dynamics of stream temperatures in the basin, and demonstrated the importance of riparian shade in maintaining low stream temperatures in summer.

As did many streams throughout the Pacific Northwest (Sedell et al. 1982, Bryant 1983), Steamboat Creek experienced removal of large woody debris as part of standard logging operations. This has reduced stream structure important for steelhead spawning and rearing habitat (Hall and Baker 1975). It has been proposed that a natural lack of spawning gravel (Anderson et al. 1986), or of summer and winter rearing habitat (Fontaine 1987) might limit juvenile steelhead production. In 1985 the USFS began intensive habitat modification to improve summer and winter rearing habitat in the basin. Prior to my study, over 500 habitat modification structures were placed in the Steamboat Creek basin.

Research Requirements

In Steamboat Creek, stream habitat enhancement has often been carried out without clear indication of the factors limiting production of steelhead smolts. Stream habitat enhancement efforts should follow a thorough pre-work inventory of fish populations and habitat to identify potential factors limiting smolt production (Everest and Sedell 1984). Seasonal shifts in habitat utilization (Bjornn 1971, Everest et al. 1985, Johnson and Kucera 1985), and movements of fish within an entire river system (Leider et al. 1986) should be considered so that critical habitat is available where and when it is most needed. As Bisson (In press) states, "recognition of key constraints on smolt yield will require detailed and accurate information on the area of concern, knowledge of the life history patterns of the species of interest, an appreciation of the complexity of the stream ecosystem, and a perspective that is basin oriented".

To provide a framework for conducting stream enhancement efforts in Steamboat Creek within a basin context this study was initiated to: 1) describe habitat utilization and rearing ecology of juvenile steelhead, 2) quantify steelhead smolt production in the basin, 3) identify habitat characteristics limiting steelhead smolt production, 4) make recommendations for management of steelhead habitat.

Basin Description

The Steamboat Creek basin (Figure 1.1) drains 590 km^2 of the west slope of the Oregon Cascades into the North Umpqua River (longitude 122.7° W, latitude 43.3° N), 265 river kilometers from the ocean. The basin is 30 km long and 38 km wide, and ranges in elevation from roughly 350 m to 1600 m above sea level. Most of the drainage is covered with old-growth Douglas-fir forest, though approximately 30 percent has been harvested since 1955, when the first logging roads accessed the basin. Steep montane topography is formed within consolidated volcanic tuff, ash, and mudflows that overlie andesite and basalt bedrock. Annual precipitation averages 140 cm at the mouth. Nearly 70% of the precipitation occurs from November through March; much of this is snow followed by rain that creates flashy storm flows. Summer base flows generally occur from June through October. The maximum flow recorded during this study was 280 m^3/s (January 10, 1988), and the minimum was 0.91 m^3/s (October 13, 1987). Steamboat Creek is a 5th order basin (Strahler 1957) at its mouth, as determined from 1:62,500 scale United States Geological Survey map.

The Steamboat Creek basin supports populations of winter- and summer-run steelhead (*Oncorhynchus mykiss*), and resident rainbow trout (*O. mykiss*), sea-run and resident cutthroat trout (*O. clarki*), coho salmon (*O. kisutch*), and chinook salmon (*O. tshawytscha*). Coho and chinook salmon use only the lower reaches of mainstem segments, while steelhead, resident rainbow trout, and sea-run and resident cutthrout

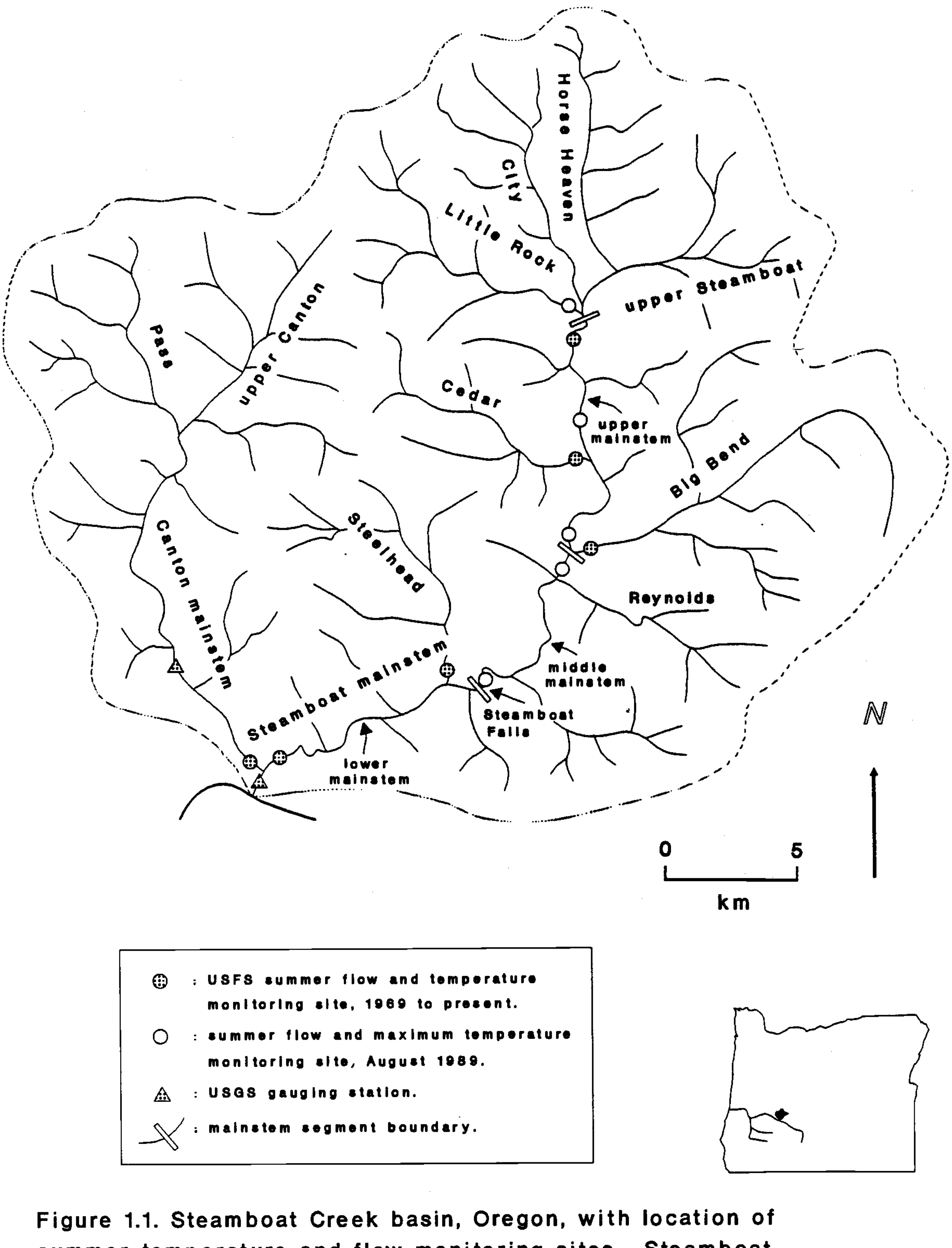


Figure 1.1. Steamboat Creek basin, Oregon, with location of summer temperature and flow monitoring sites. Steamboat Creek enters the North Umpqua River at 265 river kilometers from the Pacific Ocean, at longitude 122°.7 west and latitude 43°.3 north.

trout use both mainstem and tributary channels. Minor numbers of juvenile brown trout (*Salmo trutta*), and brook trout (*Salvelinus fontinalis*) were observed in the basin during the study. Redside shiner (*Richardsonius balteatus*), suckers (*Catostomus spp.*), Umpqua long-nose dace (*Rhinichthys evermanni*), and Umpqua squawfish (*Ptychocheilus umpquae*) occurred only in mainstem channels, while sculpins (*Cottus* spp.), speckled dace (*Rhinichthys osculus*), and juvenile Pacific lamprey (*Lampetra tridentata*) were found in both tributary and mainstem channels.

CHAPTER 2. DISTRIBUTION AND ABUNDANCE OF JUVENILE STEELHEAD, AND ANALYSIS OF STREAM HABITAT IN THE STEAMBOAT CREEK BASIN, OREGON

Introduction

In any population study, a spatial scale should be used that encompasses the entire range of habitat used within the life cycle of a species (Connell and Sousa 1983). Li et al. (1987) contend that for juvenile populations of anadromous salmonids and their associated communities, entire basins are the most meaningful unit of study. Fish assemblages in Pacific Northwest streams are strongly organized along a longitudinal continuum of the physical factors of channel gradient, water temperature, and stream size (Vannote et al. 1980). Within this continuum, interspecific competition arranges the distribution of fishes at a localized level through shifts in microhabitat utilization (Li et al 1987).

Juvenile steelhead must reach a critical length of 140 mm before they can become seaward-migrating smolts (Wagner et al. 1963) that are able to adapt to high ocean salinity (Conte and Wagner 1965). In Oregon Cascade streams little or no growth occurs during the cold winter months (Everest et al. 1986). Utilization of summer habitat by salmonids can be expected to involve strategies that maximize growth (Fausch 1984). In a study of summer microhabitat selection, Everest and Chapman (1972) found that as juvenile steelhead grow in length they maintain swifter and deeper focal points, and that higher velocities carry higher quantities of invertebrate drift. They suggest that juvenile steelhead occupy focal points that maximize food supply and minimize the energetic cost of swimming. Consequently, optimum focal points are usually in calm water pockets adjacent to swift flow. Such foci for age > 1 steelhead are often associated with large-scale roughness elements, such as large boulders (diameter $\geq$ 1 m). When submerged, large boulders create tumbling flow (Peterson and Mohanty 1960), and when protruding through the surface they create lateral flow accelerations (Herbich and Shulits 1964).

Fish are ectothermic and their standard metabolism increases with water temperature (Beamish 1964, Fry 1971). Crowder and Magnuson (1983) demonstrated that if fish are to have a sustained rate of growth at higher temperatures, then they must increase their food supply; if an increased food source is not attainable, then cooler temperatures must be sought. Smith and Li (1983) found that juvenile steelhead occupied swifter focal point velocities at higher temperatures. They showed that the benefit of a greater food supply could compensate for the greater energetic cost of faster swimming speeds. Temperature can also control the outcome of competitive interactions between fish species with different preferred temperature ranges (Baltz et al. 1982, Reeves et al. 1987).

Methods

Habitat Survey

Habitat surveys were conducted in stream channels that supported juvenile steelhead populations (Figure 2.1). Stream channels were divided into habitat units defined as pools, glides, and riffles (Bisson et al. 1982). References to channel segments follow the classification of Frissell et al. (1986). In the mainstem of Steamboat Creek cascades were treated as a separate riffle type, as they were found to support uniquely high densities of juvenile steelhead. Little Rock Creek was not surveyed in the summer of 1987, due to channel modification work that made the stream too turbid to effectively snorkel dive.

Habitat and fish population inventories were patterned after the methods developed by Hankin and Reeves (1988). Length, mean width, and mean depth of each habitat unit were visually estimated to calculate wetted area and volume. Visual estimates were verified with direct measurements in 4% of the habitat units in 1987 and 8% in 1988. Lengths were measured down the middle of each habitat unit. Widths were averaged from one to three transects that were judged to represent a mean, and depths were measured in three or more equidistant points along each width transect. Verifications were used to calculate variance and calibration factors for habitat area and volume estimates (Hankin and Reeves 1988).

Confidence limits were calculated for estimates of steelhead habitat in tributaries combined and mainstems combined; this was dictated by the need for a minimum sample size of at least 10 verified units to derive the correction factor for an estimate (David Hankin, Humboldt State University, Arcata, California 95521; personal communication). Confidence limits were applied to total basin estimates by adding variance from mainstems and tributaries. By combining the verifications of habitat size across tributaries and mainstems the assumption was made that there was no difference in visually estimating dimensions of habitat between each tributary, or

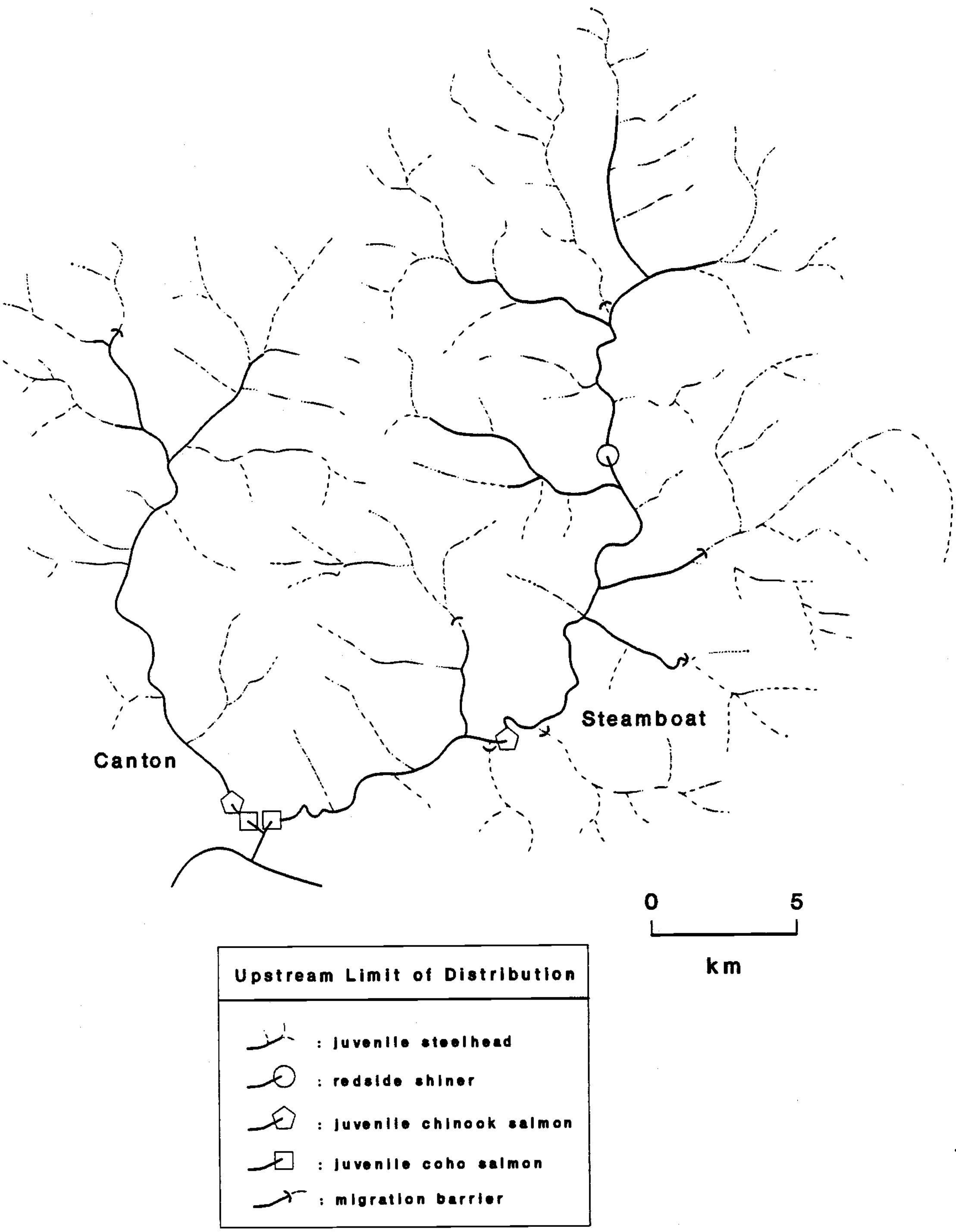


Figure 2.1. Distribution of fishes in the Steamboat Creek basin, Oregon, summer of 1987 and 1988. Redside shiner were found only in the mainstem of Steamboat Creek.

each mainstem. This is a departure from the method described by Hankin and Reeves (1988), which requires a separate estimation of error in every location stratum. This likely resulted in a misappropriation of the total variance among individual location strata (David Hankin, personal communication). A more accurate estimation of variance, involving the combining of location strata verifications, could have been made using the "combined ratio estimate" (Cochran 1977).

Substrate in all habitat units was characterized by the sediment sizes that dominated the wetted channel. The most abundant size class by area was called dominant, and the next most abundant was called codominant. The size classes were: large boulder (≥100 cm), small boulder (≥25 cm, <100 cm), large cobble (≥13 cm, <25 cm), small cobble (≥6.4 cm, <13 cm), coarse gravel (≥1.6 cm, <6.4 cm), medium gravel and smaller (<1.6 cm), and bedrock (after Lane 1947). In each tributary and mainstem channel, the area of each habitat type attributed to a sediment size class was individually summed for both the dominant and codominant categories. The summed dominant and codominant areas for each size class, s, were then averaged and expressed as percent dominance (D):

(1)

$$D_s = \frac{(\sum_s \textit{area of dominant} + \sum_s \textit{area of codominant})}{(2 \times \textit{total area})} \times 100 \ .$$

A channel with large boulder substrate dominating 2 percent of the total area, and codominating 18 percent of the total area, would receive a dominance value of 10 percent for large boulder substrate. Dominance values are not synonymous with percent area of the stream channel, but represent an average of two sets of proportions drawn from the same channel area.

The area of good and marginal quality spawning gravel (size 1.6-6.4 cm) within the active channel was inventoried during the summer of 1987. Good quality gravel lacked cobble-sized substrate and was in the channel center.

Temperature and Flow Monitoring

A record was available of summer stream temperatures and flows at seven sites (Figure 1.1) that were established in 1969 by Brown et al. (1971) and have since been routinely monitored each year by the USFS. Daily maximum and minimum temperatures were recorded with Partlow and Ryan thermographs, and streamflow was gauged four to six times each summer with Price and Pygmy current meters. Continuous records at United States Geological Survey gauging stations in Canton Creek above its mouth and in Steamboat Creek below Canton Creek, provided daily flow records. Between 9 July and 3 August 1989 maximum stream temperatures were recorded at five additional sites (Figure 1.1) with Taylor self-registering thermometers. These data were matched with records from USFS temperature stations to describe the temperature regime of different stream reaches.

Fish Population Estimates

The habitat and fish population survey progressed from the mouth of the basin upstream into the tributaries during each summer in 1987 and 1988. The survey was halted in the upper tributaries when there was less than one age >1 steelhead per pool, or when it appeared that the fish community was dominated by resident rainbow or cutthroat trout. This usually coincided with a decline in the ratio of age 0 to >1 fish from 10:1 to a ratio approaching 2:1. Darker body colors and a greater condition factor appeared to distinguish resident rainbow trout from age >1 steelhead.

Abundance estimates of fishes were made by direct observation while snorkel diving. Steelhead, cutthroat trout, chinook and coho salmon, and redside shiner were each counted. Counts of resident rainbow trout were taken but are not included in this analysis. Steelhead were separated into classes of age 0 and age >1 on the basis of relative size. Age 0 and probably a few age >1 cutthroat trout were not discernable from like-sized steelhead, and were added to estimates of steelhead numbers. I believe that this error is minor compared to total numbers of steelhead counted. Estimates of fish numbers were made by one or two divers in 10 to 50 percent of each habitat type, in habitat units systematically selected (Hankin and Reeves 1988). Habitat units were approached from the downstream end with the dive team moving carefully upstream. Each diver made an independent estimate of fish numbers, resulting in paired counts. Habitat units too large or complex for paired counts were longitudinally divided, with each diver making separate counts; small habitat units were censused by a single diver.

Electrofishing was used to verify dive counts of juvenile steelhead; counts of other fishes were not verified. Moran-Zippin methodology (Zippin 1958), a multiple-pass removal technique, was applied with the objective of obtaining a 90% reduction in numbers of fish caught between passes. This provided narrow confidence intervals around the estimates of fish numbers in a unit, which were used to verify dive counts. Verified dive counts were used to generate calibration factors for adjusting population estimates.

Verified units were chosen nearly equally from the mainstem of Canton Creek and from other tributaries that were accessible, that could be electrofished with a 3-5 person crew, and that were known to contain both age 0 and >1 steelhead. This was a departure from the formal methodology of verifying units censused in the basin survey (Hankin and Reeves 1988). Large habitat units could not be effectively electrofished, and this potentially introduced a bias into calculating the calibration factor for fish population estimates.

A habitat unit to be electrofished was first block-netted with 7-mm mesh at the lower and upper boundaries. Thirty minutes after block-netting, snorkel divers made paired counts of fish, subsequent to which a gasoline-powered backpack electrofisher was used in multiple passes to remove the fish from the habitat unit. A single pass consisted of carefully electrofishing from the downstream to upstream net in the habitat unit, and then back to the downstream net with approximately 1/4 of the effort used while moving upstream. Captured fish were anesthetized with MS-222, and their fork lengths measured to the nearest millimeter. From these length-frequency data the division in fork length between age 0 and >1 steelhead was determined. When high temperatures caused excessive stress, captured fish were quickly sorted and counted by age class, with only individuals close to a length division being measured. Fish were returned to the stream after they recovered.

Habitat Utilization

Ivlev's electivity index (Ivlev 1961) was used to describe utilization of habitat by fishes. In this application it is defined as:

(2)

$$E_i = \frac{(r_i - p_i)}{(r_i + p_i)} ,$$

where E is the value of electivity, r is the proportion of fish in a habitat type i, and p is the proportion of habitat area. The index has a possible range of -1 to +1 and is asymptotic towards its extremes. Negative values describe avoidance, positive values describe preference, and values near zero indicate no selection.

The words "avoidance" and "preference" must be interpreted with caution. Some habitats may not be utilized due to physical limitations, such as habitat units too shallow to occupy; others may not be used because of biological limitations, such as competitive interactions. Five classes of electivity were created to rank habitat utilization: high avoidance (-1 to -0.31) moderate avoidance (-0.30 to -0.11), neutral selection (-0.10 to +0.10), moderate preference (+0.11 to +0.30), and high preference (+0.31 to +1).

Results

Fish Distribution

Eight tributaries and four mainstem segments supported juvenile steelhead populations in the summers of 1987 and 1988. A total of 85 km of stream channel was considered to be important for summer rearing of age >1 juvenile steelhead, and received complete habitat and fish population surveys (Figure 2.1). Cutthroat trout were found throughout the majority of the area surveyed (Appendix Table 2.2). Chinook salmon reared in the lower 10 km of Steamboat Creek and in the lower 1 km of Canton Creek, but coho salmon reared only in the lower 1 km of Canton Creek. Redside shiner were observed in 22 km of the Steamboat Creek mainstem, from the mouth to half-way into the upper segment. In addition, a small number were observed a few hundred meters into Cedar Creek and Canton Creek. The distribution of speckled dace and Umpqua longnose dace was noted while electroshocking for dive count verifications. Umpqua longnose dace were sampled only from mainstem segments, while speckled dace were found in both mainstems and tributaries throughout the basin. Cottid species were observed throughout the entire area surveyed.

Habitat Availability

The 1987 and 1988 basin-wide estimates of total area of habitat available were not significantly different (Figure 2.2, Table 2.1). Little Rock Creek, which was not surveyed in 1987, contributed 3.0% to the total basin area in 1988; subtracting that from the total area of the 1988 survey leaves a difference between years of 0.55%. Total pool area in the basin was similar in both summers though there were great differences in riffle (35%) and glide (23%) area between years (Table 2.1). These differences amount to less than 7% of the total basin area. Estimates of area and volume of habitats in each tributary and mainstem segment are presented in Appendix Table 2.1. Year-to-year differences in habitat area can be attributed to changes in channel structure, in flow levels, or in the interpretation

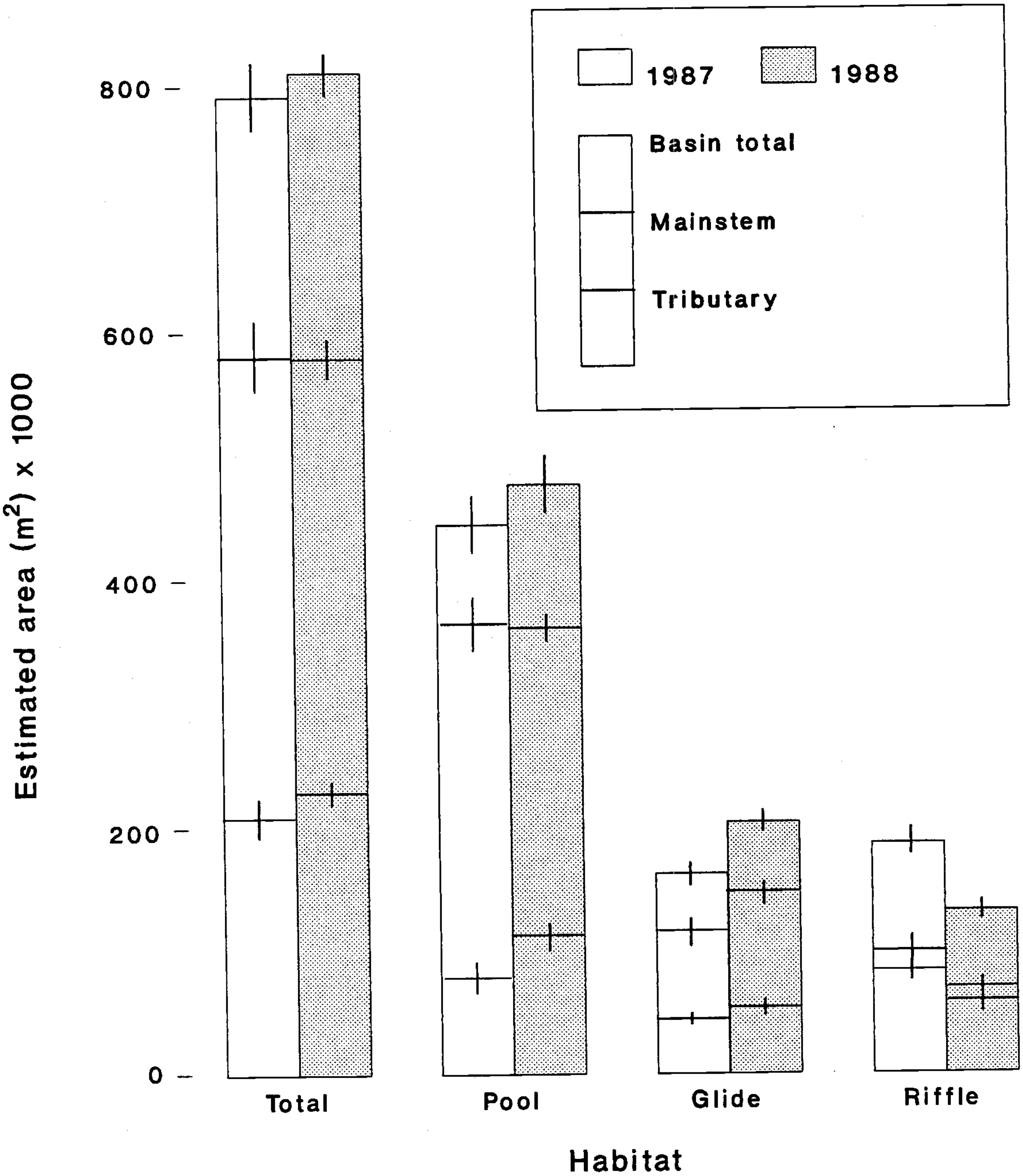


Figure 2.2. Area of habitat visually estimated in tributaries and mainstem channels, with 95% confidence limits, in the Steamboat Creek basin, Oregon, summer 1987 and 1988.

Table 2.1. Estimated area of habitat utilized by fishes in the Steamboat Creek basin, Oregon, in the summers of 1987 and 1988. Included are 95 percent confidence intervals (+/-) for juvenile steelhead habitat.

		Area (m^2)					
Habitat	Year	Steelhead	+/-	Cutthroat Trout	Chinook Salmon	Coho Salmon	Redside Shiner
Mainstem Segments							
Pool	1987	364960	22640	364960	107170	15720	252890
	1988	362410	10390	362410	123590	21290	230270
Glide	1987	116670	9320	116670	30440	6200	59640
	1988	148090	8720	148090	41360	2380	98130
Riffle	1987	100410	12740	100410	23280	3720	55290
	1988	70500	6750	70500	13410	3510	31740
Total	1987	582040	26640	582040	160890	25640	367820
	1988	581000	14770	581000	178360	27180	360140
Tributaries							
Pool	1987	79130	12820	73100			
	1988	114600	8060	108560			
Glide	1987	45060	4650	42850			
	1988	55080	5620	52950			
Riffle	1987	84850	6910	72860			
	1988	60080	4970	53790			
Total	1987	209040	14840	188810			
	1988	229760	10820	215300			
Total Basin							
Pool	1987	444090	25280	438060			
	1988	477010	13140	470970			
Glide	1987	161730	9770	159520			
	1988	203170	10100	201040			
Riffle	1987	185260	13970	173270			
	1988	130580	8230	124290			
Total	1987	791080	30190	770850			
	1988	810760	18140	796300			

of classification criteria. Channel structure was not appreciably altered by 1987 winter flows. An analysis comparing flow levels at time of survey and habitat area estimates for individual tributaries and segments showed no consistent change in the composition of habitat types at different flows. The most likely explanation is a change in the classification of riffle and glide habitat. Many habitat units appeared to have characteristics of both glides and low gradient riffles. Probably more of these units were classed as riffles in 1987 and as glides in 1988.

An average of total habitat area between 1987 and 1988 gives a pool to glide to riffle ratio of 57:23:20. Mainstem and tributary channels had an average habitat ratio of 62:23:15 and 44:23:33 respectively. Mainstem and tributary channels occupied 73 percent and 27 percent respectively of the total basin area.

Substrate Dominance and Spawning Gravel

Boulder, cobble, and bedrock dominated the substrate of all channels (Table 2.2). Large boulder substrate was of low dominance throughout the basin, except in Big Bend Creek, where it had the second highest dominance value next to boulder substrate. Dominance of large boulder substrate of even a few percent was an important indicator of channel roughness. Single habitat units dominated by large boulders were often in geomorphically distinct reaches that were hydraulically rough and complex, even though large boulders did not dominate the surface area of adjacent habitat units.

A total of 1,800 m^2 of good quality, and 3,100 m^2 of marginal quality spawning gravel (4,900 m^2 total) was inventoried in the basin (Table 2.2). Fifty-eight percent of all spawning gravel was in the mainstem segments of Steamboat Creek and Canton Creek. The upper mainstem segment of Steamboat Creek had the greatest proportion (23%) of gravel of any mainstem segment or tributary. Steelhead Creek, upper Steamboat Creek, and Reynolds Creek had only minor amounts of spawning gravel.

Table 2.2. Percent dominance D[a] of substrate classes, and area of good (GQ) and marginal (MQ) quality spawning gravel in tributary and mainstem channels of Steamboat Creek, Oregon, 1987. Percent dominance is an average of the two most prevalent sediment sizes (dominant and codominant) in stream habitat units; R: bedrock, B: large boulder, b: small boulder, C: large cobble, c: small cobble, G: coarse gravel, g: medium gravel and smaller (after Lane 1947).

	Substrate Size Class							Spawning Gravel (m^2)		
	R	B	b	C	c	G	g			
diameter (cm):		≥100	≥25	≥13	≥6.4	≥1.6	<1.6	GQ	MQ	Total
Steamboat Creek upper mainstem	37	0.2	26	17	4	2	14	350	780	1130
Steamboat Creek middle mainstem	39	0.2	31	14	6	1	8	190	350	540
Steamboat Creek lower mainstem	32	5	27	14	8	2	12	190	270	460
Canton Creek mainstem	22	8	42	25	2	0.6	1	250	480	730
Pass Creek	17	2	44	35	2	0.4	0.1	110	110	220
upper Canton Creek	21	1	28	23	18	8	1	87	230	320
Steelhead Creek	39	1	33	20	4	0.7	3	8	39	47
Cedar Creek	29	2	30	32	3	3	0.5	200	180	380
Little Rock Creek	39	4	30	21	4	2	0	200	140	340
Horse Heaven Creek	24	0.5	41	29	4	0.8	1	46	220	270
upper Steamboat Creek	47	2	28	21	2	0.1	0.5	6	90	100
Big Bend Creek	14	19	47	17	1	0	1	89	130	220
Reynolds Creek	19	0.8	41	30	4	0.7	4	71	84	160
Total								1800	3100	4900

a

$$D_s = \frac{(\sum_s \textit{area of dominant} + \sum_s \textit{area of codominant})}{(2 \times \textit{total area})} \times 100 ,$$

where s is each sediment size class.

Summer Water Temperatures and Flow

Summer temperatures in the Steamboat Creek basin are quite high for salmonid rearing. Daily maximum temperatures in all tributaries and mainstem segments that were monitored exceeded the reported preferred range for juvenile steelhead (Figure 2.3). Daily maximum temperatures in the mainstem of Steamboat Creek also exceeded reported

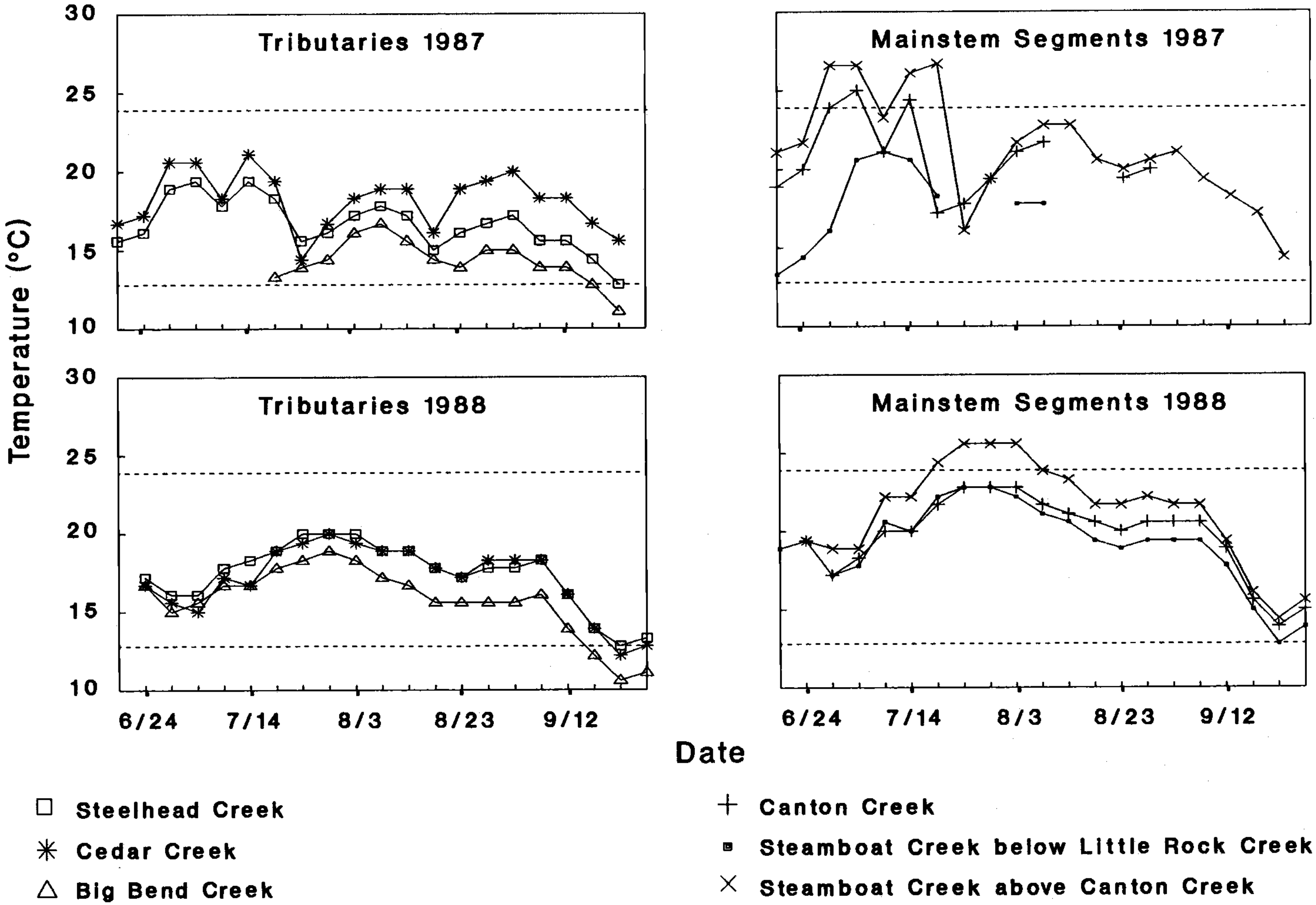


Figure 2.3. Five-day mean maximum temperature in tributaries and mainstem segments of Steamboat Creek, Oregon, 1987 and 1988. Dotted lines indicate temperatures reported as lethal limit (24°C) and preferred upper limit (13°C) for juvenile steelhead (Bell 1986).

lethal limits for days at a time. That these temperatures did not cause absolute mortality in the mainstem of Steamboat Creek could be a result of diel variation; daily minimum temperatures were as much as 5°C lower than maximum temperatures. Also the reported lethal limits in Figure 2.3 are from laboratory experiments that may have utilized stocks of juvenile steelhead that were adapted to temperatures lower than those to which fish in Steamboat Creek have adapted. Water temperatures were reduced in July 1987 by a series of storms that created two peak flow events and increased base flows over the entire summer (Figure 2.4).

There are distinct flow and temperature regimes in the basin (Figure 2.5). The mainstem of Steamboat Creek above Big Bend Creek and above the confluence of Canton Creek had the highest recorded temperatures in the basin. A relatively large volume of cold water supplied by Big Bend Creek quadruples the flow and reduces the mainstem temperature by as much as 3°C. Gradual reheating occurs below Big Bend Creek and the previous temperature maximum is again reached above the confluence of Canton Creek. Canton Creek is comparatively cooler, with temperatures at its mouth similar to temperatures at the top of the upper segment of the Steamboat Creek mainstem.

Calibration of Population Estimates and Variance Analysis

Confidence intervals based only on first-stage variance were calculated for total basin estimates of juvenile steelhead. Second-stage variance could not be calculated since too few verifications of dive counts were obtained (n′, Table 2.3). Ideally, at least 10 verifications should be obtained in any habitat stratum, as a lesser number would likely underestimate the variance associated with the calibration factor (David Hankin, personal communication). First-stage variance reflects natural variation in fish numbers within types of habitat; second-stage variance reflects error associated with

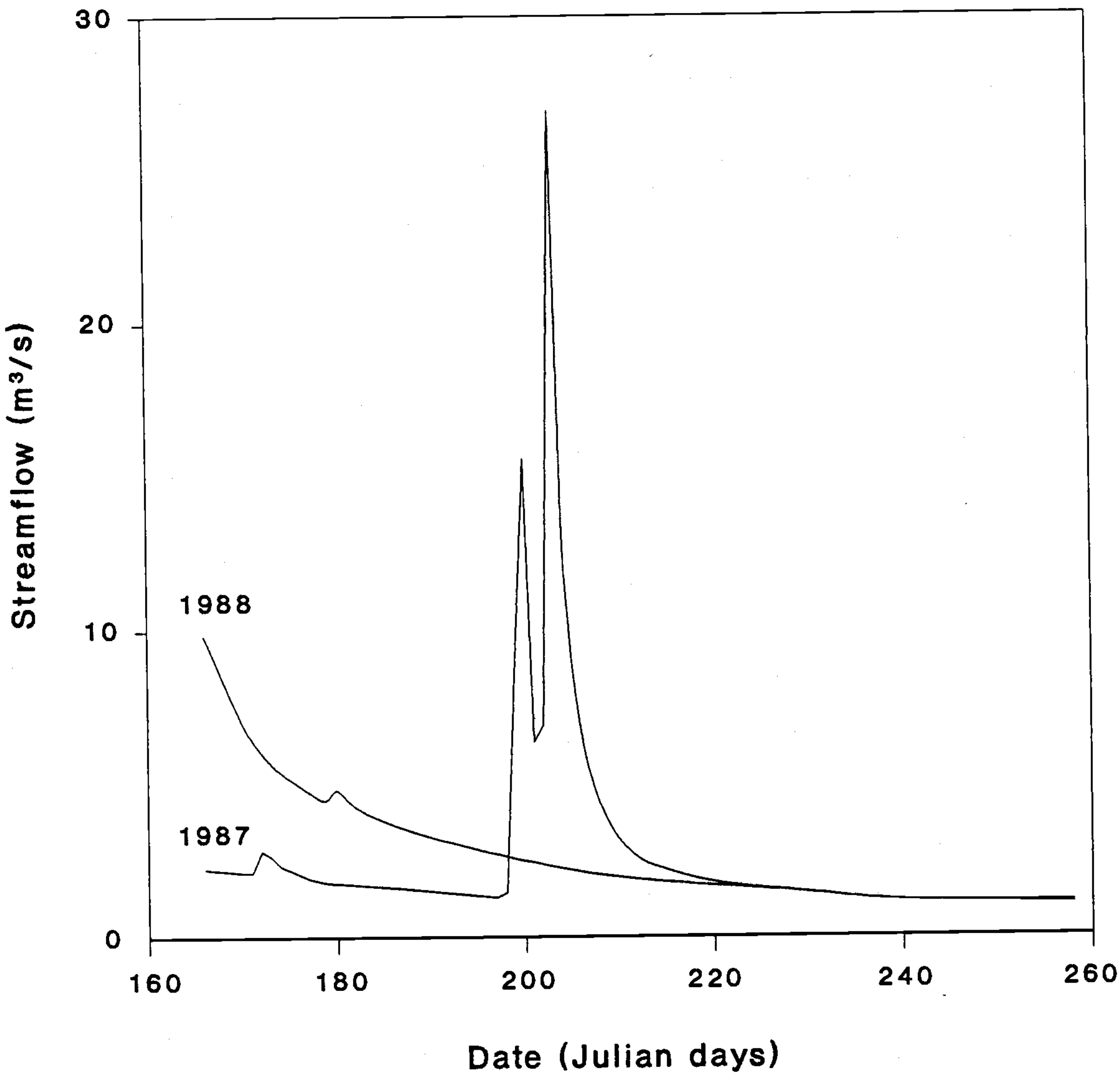


Figure 2.4. Streamflow from Steamboat Creek basin, Oregon, June 15 to September 15, 1987 and 1988.

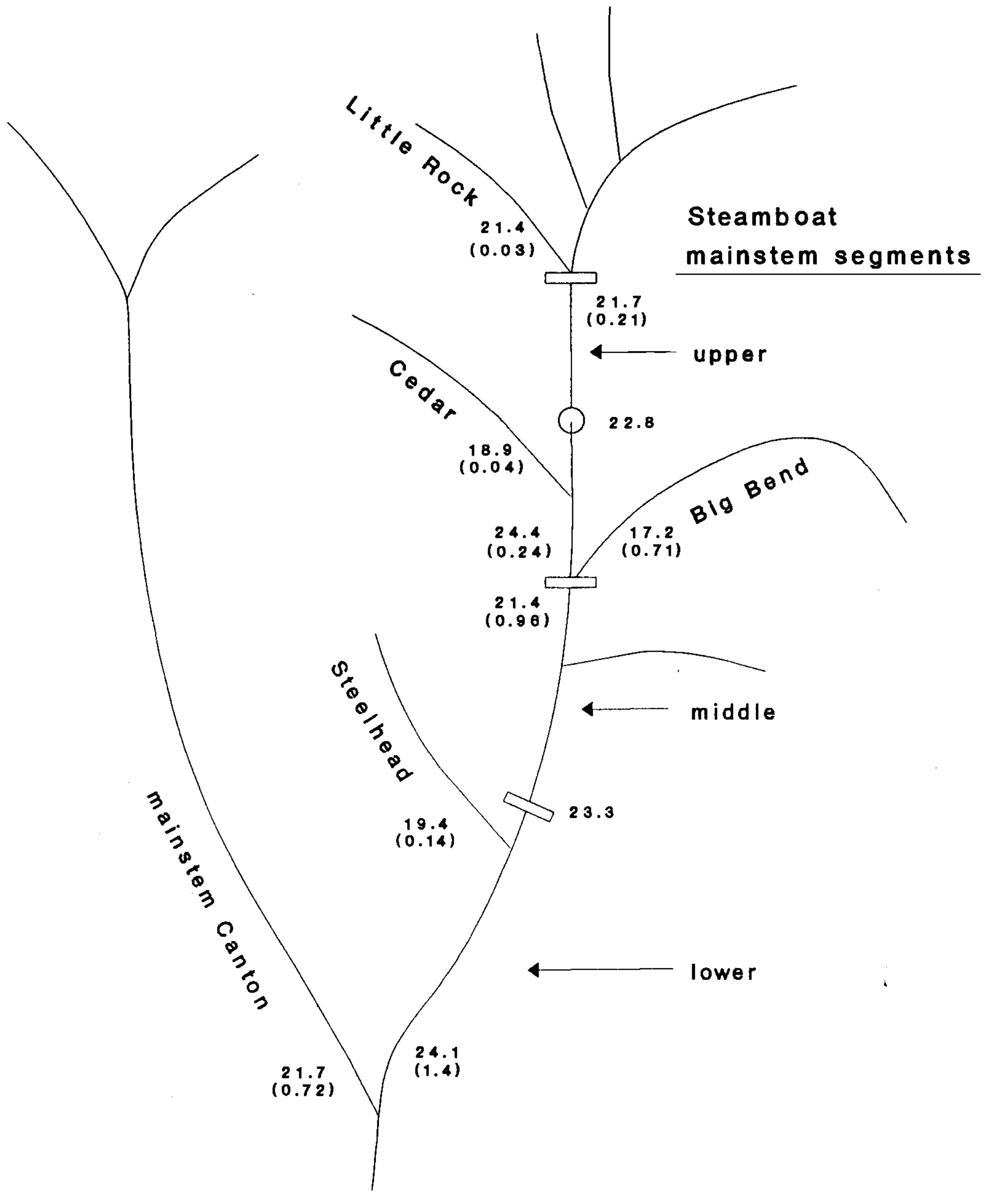


Figure 2.5. Temperature regime (°C) and flow (m^3/s, in parentheses) in the Steamboat Creek basin, Oregon. Temperatures are maximums recorded during July 9 - August 3, 1989; flow measured on August 2 - 9, 1989. Open bars denote segment boundaries; open circle denotes upstream limit of redside shiner in the upper mainstem segment of Steamboat Creek, during the summers of 1987 and 1988.

Table 2.3. Correction factors $\hat{R}^a$ used to calibrate steelhead population estimates, with 95% confidence limits (+/-). N: total number of habitat units inventoried, n: number of habitat units censused by snorkel diving, and n':number of habitat units with snorkel dive counts verified by electrofishing.

Habitat		1987					1988				
		N	n	n'	$\hat{R}$	+/-	N	n	n'	$\hat{R}$	+/-
age 0	Pool	1589	274	11	0.93	0.17	2085	296	7	0.98	0.20
	Glide	770	76	8	0.97	0.26	819	92	4	0.69	0.05
	Riffle	1135	124	6	1.22	0.36	1083	139	5	1.56	0.37
	Total	3494	474	25			3987	527	16		
age >1	Pool			11	1.08	0.34			7	1.06	0.35
	Glide			8	1.09	1.02			4	0.89	0.11
	Riffle			7	1.02	0.25			7	1.36	0.23
	Total			26					18		

[a] values less than 1.0 indicate divers undercounting fish, values greater than 1.0 indicate overcounting.

estimation of true numbers of fish within types of habitat. Both first- and second-stage variance are affected by the degree of subsampling of the total number of habitat units (Hankin and Reeves 1988). Excluding second-stage variance from calculations of confidence limits makes the implicit assumption that there was no error in my estimation of true numbers of fish. Therefore the resulting confidence limits were reduced. Inclusion of second-stage variance can increase the total variance by as much as 20% (Hankin and Reeves 1988).

Dive count calibration factors indicated that, in general, visual estimates of juvenile steelhead numbers were close to electrofishing estimates (i.e. $\hat{R}$ near 1.0, Table 2.3). Calibration factors were used to adjust all dive estimates of fish numbers in each habitat type. Even though these calibration factors were based on a relatively small number of verifications, I believe it was reasonable to use them to adjust dive counts. For instance, compared to other habitats, juvenile steelhead in riffles were generally undercounted the most, both in 1987 and 1988 (Table 2.3). This is consistent with the experience of other divers (Hicks 1990; Steve Johnson, Oregon

Department of Fish and Wildlife, Corvallis, Oregon 97333; personal communication).

Estimated Numbers and Densities of Juvenile Steelhead

Estimated total numbers of juvenile steelhead were similar between the summers of 1987 and 1988 (Table 2.4). Populations of age 0 steelhead averaged 196,000 fish between years. Populations of age >1 steelhead were roughly one-tenth of age 0 steelhead populations, averaging 21,200 fish. Pool and riffle habitats supported greater numbers of fish than did glides. Based on my conservative estimate of variance, the only significant difference (nonoverlapping confidence intervals) in fish numbers between years in a habitat type was a 46% increase in the number of age >1 steelhead in pools in 1988. Even though estimates of variance were without contribution of second-stage error, natural variation in fish numbers between units (first-stage variance) was so large in the fraction of units sampled, that there was little significance in the difference in fish numbers between

Table 2.4. Estimated numbers of fishes in the Steamboat Creek basin, 1987-1988. Juvenile steelhead numbers with 95 percent confidence intervals (+/-) based only on first-stage variance[a].

Habitat	Year	Steelhead Age 0	+/-	Steelhead Age >1	+/-	Cutthroat Trout	Chinook Salmon	Coho Salmon	Redside Shiner
Pool	1987	79380	8580	8270[b]	1240	800	1660	1240	4080
	1988	92650	9040	12080[b]	1640	440	1040	16	10770
Glide	1987	54460	16570	2640	2330	180	84	290	530
	1988	29010	14850	2100	1160	26	150	0	2010
Riffle	1987	82180	21470	9190	3510	310	100	17	0
	1988	56780	13130	8350	5790	110	4	15	35
Total	1987	216020	28450	20100	4390	1290	1840	1550	4610
	1988	178440	21780	22530	6130	580	1190	31	12820

[a] estimation of variance calculated without contribution of second-stage variance (Hankin and Reeves 1988), which results in an underestimation of the true variance.
[b] nonoverlapping confidence intervals.

years. Numbers of juvenile steelhead in habitats of each tributary and mainstem segment for 1987 and 1988 are presented in Appendix Table 2.2.

The changes in estimated area of glide and riffle habitat (Table 2.1) did not produce a concomitant change in fish numbers, as fish numbers decreased in both glides and riffles in 1988, though not significantly ($p>0.05$). Habitat units that were classified differently between years, low gradient riffles and glides, generally supported low numbers of fish and had little effect on total numbers in each habitat. There were large between-year differences in numbers of juvenile steelhead in individual tributaries and mainstem segments (Table 2.5), but only age 0 steelhead in Reynolds Creek were significantly different between years (i.e., confidence limits nonoverlapping).

Table 2.5. Estimated numbers of age 0 and >1 steelhead in 1987 and 1988 in tributaries and mainstem segments of Steamboat Creek. With approximate 95 percent confidence intervals (+/-) based only on first-stage variance[a], percent difference between years (%): (1988-1987)/((1988+1987)/2)*100; ms: mainstem.

Tributary or mainstem segment	Age 0					Age >1				
	1987	+/-	1988	+/-	%	1987	+/-	1988	+/-	%
Steamboat Creek upper ms	14610	4650	12720	2610	-14	200	130	310	150	+43
Steamboat Creek middle ms	16410	7080	17920	12760	+9	1050	640	2080	640	+66
Steamboat Creek lower ms	10830	3820	11460	2630	+6	6530	2200	7750	2200	+17
Canton Creek ms	78450	20980	54130	14570	-37	7210	2430	6670	1570	-8
Pass Creek	24850	14040	17980	5600	-32	1730	610	860	260	-67
upper Canton Creek	14660	2120	13220	4150	-10	540	160	500	140	-8
Steelhead Creek	4880	4960	3520	670	-32	180	80	130	70	-32
Cedar Creek	15610	5790	9140	2090	-52	710	220	690	310	-3
Little Rock Creek[b]			12260	2250				830	270	
Horse Heaven Creek	13500	4190	10950	2280	-21	890	370	680	250	-27
upper Steamboat Creek	5670	2760	9090	4110	+46	260	260	530	490	+68
Big Bend Creek	10670	8150	3210	3210	-107	550	390	1280	1720	+80
Reynolds Creek	5880	1810	2840	780	-70[c]	250	190	220	120	-13
Basin total	216020		177150		-20	20100		22530		+11

[a] estimation of variance calculated without contribution of second-stage variance (Hankin and Reeves 1988), which results in an underestimation of the true variance.
[b] Little Rock Creek was surveyed only in 1988.
[c] nonoverlapping confidence intervals.

In general, densities in glides were lower in 1988 than in 1987, while densities in pools and riffles did not change appreciably between years (Table 2.6). The reduced glide densities and the nearly equal riffle densities resulted from more habitat area being classed as glides and less as riffles in 1988, while estimated fish numbers in both glides and riffles were lower in 1988. Densities of juvenile steelhead in habitats of each tributary and mainstem segment for 1987 and 1988 are presented in Appendix Table 2.3.

Table 2.6. Densities (number per m^2) of juvenile steelhead in mainstem, tributary, and total basin habitats in Steamboat Creek, Oregon, 1987 and 1988, with between year mean.

		Age 0			Age >1		
	Habitat	1987	1988	mean	1987	1988	mean
Mainstem	Pool	0.14	0.13	0.13	0.016	0.024	0.020
	Glide	0.26	0.13	0.19	0.016	0.012	0.014
	Riffle	0.39	0.42	0.40	0.073	0.089	0.080
	Total	0.21	0.17	0.19	0.026	0.029	0.027
Tributary	Pool	0.37	0.40	0.36	0.030	0.029	0.028
	Glide	0.53	0.17	0.31	0.018	0.005	0.010
	Riffle	0.51	0.46	0.47	0.022	0.034	0.026
	Total	0.46	0.36	0.39	0.024	0.025	0.023
Basin	Pool	0.18	0.19	0.18	0.019	0.025	0.022
	Glide	0.34	0.14	0.22	0.016	0.010	0.013
	Riffle	0.44	0.44	0.44	0.050	0.064	0.055
	Total	0.27	0.22	0.24	0.025	0.028	0.026

Because there was generally no significant difference between fish numbers or habitat area between years, data for 1987 and 1988 from individual tributaries and mainstem segments were combined and expressed as an average in the following analyses of basin-wide patterns of distribution, abundance, and habitat utilization.

<u>Basin-Wide Distribution of Juvenile Steelhead</u>

Age 0 steelhead were widely distributed throughout the basin, though stream temperature appeared to limit abundance in some areas. In the upper and lower mainstem of Steamboat Creek, where stream temperatures were the highest in the basin (Figure 2.5), densities of age 0 steelhead were four times less than the basin average elsewhere (combined densities of age 0 steelhead were 0.084 m^{-2} in the upper and lower mainstem of Steamboat Creek, and 0.34 m^{-2} for the total basin elsewhere). Greater densities were supported by the middle segment, which had a cooler temperature regime (Table 2.7). The mainstem of Canton Creek supported 33% of the age 0 steelhead in the basin, while all tributaries combined supported 46%. Only 21% of age 0 fish were in the mainstem of Steamboat Creek, which had 51% of total habitat area.

The distribution of age >1 steelhead in the basin can be characterized as being concentrated in the mainstem channels of Canton Creek and lower Steamboat Creek. Mainstem segments supported the highest densities of age >1 steelhead in the basin, and mainstem channels in general contained more wetted area per length of channel than tributaries (Table 2.7). Together the mainstem segments of Canton Creek and lower Steamboat Creek supported 65% of all age >1 steelhead in 41% of the total habitat area, and 29% of the total stream length. Only 8% of the age >1 steelhead population reared in the upper and middle mainstem of Steamboat Creek, which together had 31% of the basin area, and 21% of total stream length. Pass Creek, Horse Heaven Creek, and Big Bend Creek also had relatively high densities of age >1 steelhead, but they held only a minor portion of the population. Though tributaries comprised 50% of total stream length in the basin, they held only 27% of the total wetted area, and 27% of the age >1 steelhead population.

Table 2.7. Two-year (1987-1988) means of juvenile steelhead densities (#/m^2) in tributaries and mainstem segments (ms) of the Steamboat Creek basin. With channel slope[a], proportion basin total channel length (85 km), habitat area (800900 m^2), and area of spawning gravel (4900 m^2); Little Rock Creek data for 1988 only.

		Proportion of basin total (%)			Age 0		Age >1	
	Channel Slope[a]	Channel Length	Habitat Area	Spawning Gravel	#/m^2	Percent Population	#/m^2	Percent Population
Steamboat Creek upper ms	0.78	12	17	23	0.098	6.8	0.0018	1.2
Steamboat Creek middle ms	0.76	8.5	14	11	0.15	8.5	0.014	7.2
Steamboat Creek lower ms	1.0	11	20	9.2	0.068	5.5	0.044	33
Canton Creek ms	1.6	18	21	15	0.40	33	0.042	32
Pass Creek	3.0	5.7	4.5	5.2	0.61	11	0.037	6.0
upper Canton Creek	1.6	5.5	4.3	6.4	0.40	6.9	0.015	2.4
Steelhead Creek	2.1	3.6	2.0	1.0	0.26	2.1	0.010	0.72
Cedar Creek	3.0	8.9	3.5	7.5	0.45	6.1	0.025	3.3
Little Rock Creek	2.2	7.2	3.0	7.0	0.45	5.4	0.029	3.2
Horse Heaven Creek	2.7	6.1	2.7	5.2	0.56	6.0	0.036	3.6
upper Steamboat Creek	2.0	4.7	3.5	2.0	0.27	3.7	0.014	1.8
Big Bend Creek	3.6	4.0	3.3	4.3	0.27	3.4	0.035	4.2
Reynolds Creek	5.3	4.2	2.2	3.2	0.25	2.2	0.013	1.1
Basin Average					0.24		0.026	

a: measured from a 1:62,500 scale USGS map.

The greatest density of age >1 steelhead in the basin was seen in cascade riffles in the mainstem of Steamboat Creek. An extraordinary example was found in a 60 x 20 m cascade riffle in the lower mainstem of Steamboat Creek that supported an average (1987-1988) of 200 age >1 steelhead. This rivals the total number of age >1 steelhead estimated in some tributaries, and in the upper mainstem segment of Steamboat Creek (Table 2.5).

Basin-Wide Pattern of Habitat Utilization by Juvenile Steelhead: the Effect of Stream Depth and Temperature

Habitat utilization by juvenile steelhead differed between age classes and between mainstems and tributaries. In mainstems, electivity values for age 0 and >1 steelhead increased with the slope of habitat types, from pools and glides to riffles and cascades (Table 2.8). The opposite trend occurred in tributaries for age >1 steelhead, which preferred pools and generally avoided riffles. Age >1 steelhead highly avoided glide habitats in most tributaries and mainstem segments. A more neutral utilization of habitat types by age 0 steelhead was apparent in tributaries. Habitat electivity values of juvenile steelhead in each tributary and mainstem segment for 1987 and 1988, are presented in Appendix Table 2.4.

Table 2.8. Summary of frequencies of habitat electivity[a] E (Ivlev 1961) of juvenile steelhead in four mainstem segments and fourteen tributaries of Steamboat Creek, Oregon. From means of 1987 and 1988 data.

	Age 0				Age >1			
Electivity	Pool	Glide	Riffle	Cascade	Pool	Glide	Riffle	Cascade
Mainstems								
High avoidance	0	0	0	0	1	3	0	0
Moderate avoidance	3	0	0	0	2	1	0	0
Neutral selection	1	3	0	0	1	0	0	0
Moderate preference	0	1	2	1	0	0	2	0
High preference	0	0	2	2	0	0	2	3
Tributaries								
High avoidance	1	6	1		0	10	6	
Moderate avoidance	2	3	2		1	3	1	
Neutral selection	7	5	5		3	1	5	
Moderate preference	4	0	4		6	0	1	
High preference	0	0	2		4	0	1	

[a] classes used to rank electivity: high avoidance (-1 to -0.31) moderate avoidance (-0.30 to -0.11), neutral selection (-0.10 to +0.10), moderate preference (+0.11 to +0.30), and high preference (+0.31 to +1).

Stream size and water temperature affected habitat utilization of juvenile steelhead in Steamboat Creek. A regression of riffle electivity by age >1 steelhead on mean riffle depth (Figure 2.6) has high significance ($p=0.0004$, $r^2=0.58$). The same regression for age 0 steelhead ($p=0.05$, $r^2=0.22$) shows only a slight effect of depth on riffle utilization for the size of streams studied. These relationships imply that juvenile steelhead cannot fully use shallow riffles, and that shallow riffles are used less by older larger fish. Age >1 steelhead appeared to have free access to riffles with mean depths greater than 0.2 m. Where riffles were apparently too shallow, age >1 steelhead utilized pool habitat to a greater extent, but greatly avoided glides in all sizes of channels (Table 2.8). Age 0 steelhead appeared to be less restricted in their choice of habitat than age >1 fish.

While snorkel diving I noticed that densities of juvenile steelhead in riffles were high in channels with warm temperatures, and suspected that riffle utilization was affected by temperature. I used the maximum temperature recorded at a site to represent a temperature regime, which was regressed with riffle utilization. To insure that riffle utilization was not affected by depth (Figure 2.6), only stream channels with mean riffle depths $\geq$0.2 m were considered (i.e., all four mainstem segments and Big Bend Creek). Ivlev's electivity index was inappropriate to relate to stream temperature since it is affected by the relative proportion of habitat area (p in equation (2)). I discovered that there was an unexplained negative correlation between p for riffles and temperature regime in the five deep streams. Vanderploeg and Scavia's (1979) selectivity coefficient was chosen instead, because it is unaffected by the relative size of p (Lechowicz 1982); it is calculated by:

(3)

$$W_i = \frac{\frac{r_i}{p_i}}{\sum_i \frac{r_i}{p_i}} \quad .$$

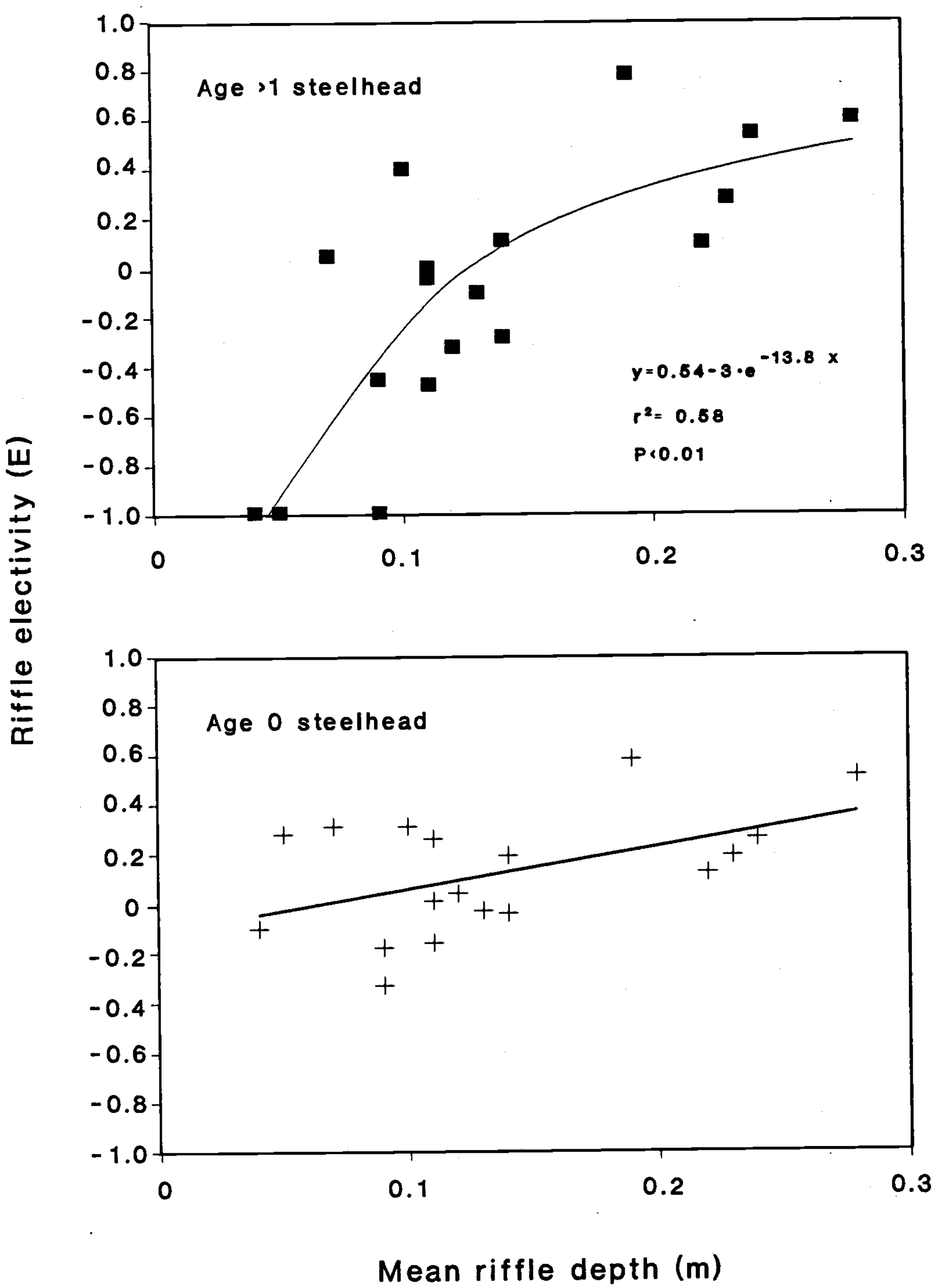
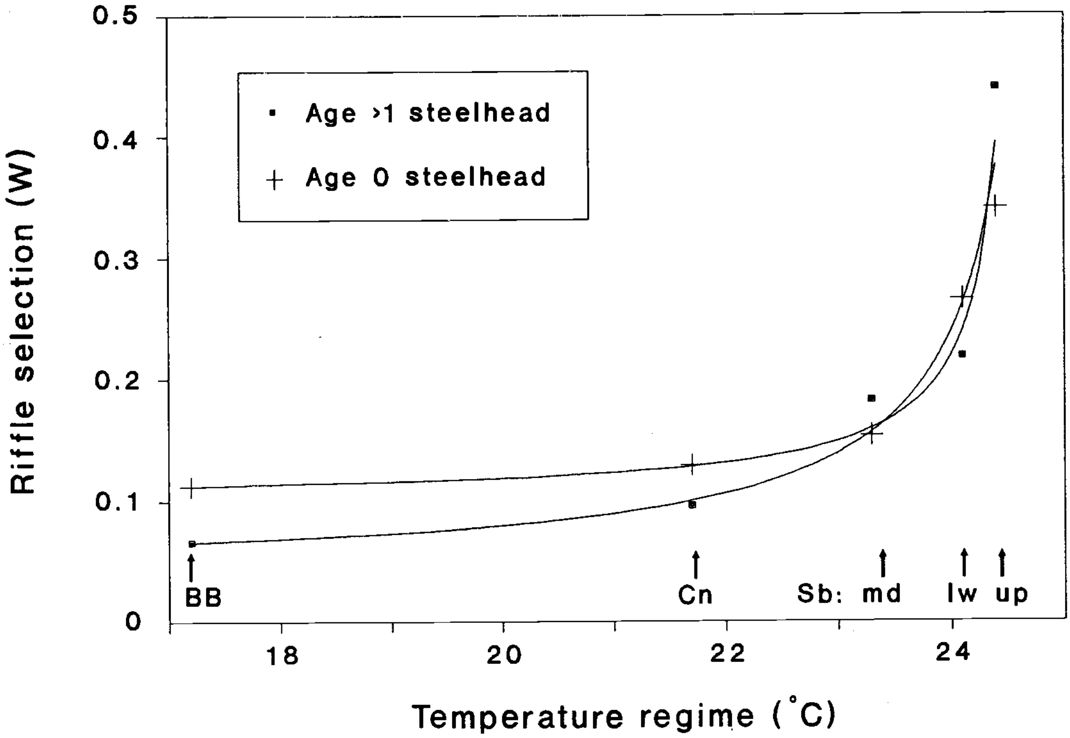


Figure 2.6. Relation of riffle electivity E (Ivlev 1961) to riffle depth for juvenile steelhead in stream channels of the Steamboat Creek basin, Oregon.

Both age 0 and age >1 steelhead increased their selection of riffle habitats exponentially at higher temperature regimes (Figure 2.7). This can be explained by feeding energetics. Increases in temperature cause increases in metabolic rate and hence food demand; the swifter velocities encountered in riffles provide, on average, greater invertebrate drift (Smith and Li 1983). I postulated that riffles might also have higher dissolved oxygen concentrations. But this was discounted when water samples taken from turbulent riffles, and from tailouts of long deep pools, in each mainstem segment of Steamboat Creek, all had dissolved oxygen levels near 10.2 ppm (+/- 0.6 ppm), as determined by the Winkler method for dissolved oxygen measurement (Welch 1948).

Diel shifts in habitat utilization were commonly observed during snorkel diving. Repeated snorkel counts of juvenile steelhead in habitat units showed many fish to hold benthic positions in substrate crevices during the morning hours, which made them difficult if not impossible to count. Fish in benthic positions were dislodged by turning over cobble and boulder substrate. Fish were not oriented into the flow until stream temperatures began to rise, usually after 10 a.m.. Fish maintained flow-oriented positions until late afternoon, when falling temperatures coincided with their resuming benthic positions. When heavy cloud cover reduced stream heating, the majority of fish were observed to maintain benthic positions for the entire day. Repeated dives in 19 habitat units in Steelhead Creek during 1987 revealed a total morning (12.8°C) count of 130 age 0 steelhead, and 1 age >1 steelhead. By the afternoon (16.1°C) the total count had risen to 308 age 0 steelhead, and 23 age >1 steelhead. This phenomenon was observed in both shaded and unshaded habitat units, so light could not be implicated as the cause. Because of this phenomenon fish counts were performed during only relatively sunny days after 10 a.m., after stream temperatures had begun to rise. Electrofishing confirmed that dive counts of steelhead obtained during these times were close to actual numbers.



	r			
	Age 0 fish	Age >1 fish	p	Tr (°C)
BB:	0.90	0.85	0.70	17.2
Cn:	0.32	0.39	0.22	21.7
Sb md:	0.34	0.65	0.19	23.3
Sb lw:	0.31	0.42	0.10	24.1
Sb up:	0.29	0.60	0.07	24.4

Figure 2.7. Relation of riffle selection W (Vanderploeg and Scavia 1979) to temperature regime, for juvenile steelhead in streams with mean riffle depths ≥0.2 m. BB: Big Bend, Cn: Canton mainstem, Sb: Steamboat mainstem, lw: lower, md: middle, up: upper. Listed are proportion of fish in riffles (r), proportion of habitat area in riffles (p), and temperature regime (Tr) of each stream.

Effect of Channel Roughness and Mean Riffle Depth on Juvenile Steelhead Abundance

The plot of total densities of age >1 steelhead in each stream channel versus mean riffle depth of that channel revealed two groups of stream channels (Figure 2.8A). Stream channels with relatively high (>$0.02/m^2$) and low abundances (<$0.02/m^2$) of age >1 steelhead were separated, with some overlap, by the relative amount of large boulder substrate. Channels with dominance of large boulder substrate of less than 2% supported low abundances of age >1 steelhead, with the exception of Horse Heaven Creek and upper Steamboat Creek. The link between the dominance of large boulder substrate and age >1 steelhead abundance is probably through more feeding microhabitats being associated with rough channels. Considering only channels with high abundances (>$0.02/m^2$) of age >1 steelhead, there was a significant positive relationship ($p=0.02$ $r^2=0.69$) between mean riffle depth and the total density of fish in the channel. This increase in total stream density is likely caused by an increase in the useable area of riffles with depth. There is a positive relationship between mean riffle depth and density of age >1 fish in riffles (Figure 2.8C), which probably results from more useable area occurring in deep riffles. Thus abundances of age >1 steelhead throughout the basin appear to be ordered both by stream size and channel roughness. A plot of age 0 steelhead density against mean riffle depth (Figure 2.8B) revealed a negative relationship. Though this relationship was significant ($p=0.03$, $r^2=0.36$), I believe it was confounded with temperature. The three stream segments with the highest temperatures (the three mainstem segments of Steamboat Creek) also had the lowest densities of age 0 steelhead. Exclusion of these mainstem channels from Figure 2.8 makes the regression of mean riffle depth on age 0 steelhead density insignificant ($p>0.05$). Therefore the density of age 0 steelhead did not appear to be affected by the range of channel size encountered in this survey. Also, channel roughness as described by dominance of large boulder substrate did not appear to order the relative abundance of age 0 steelhead.

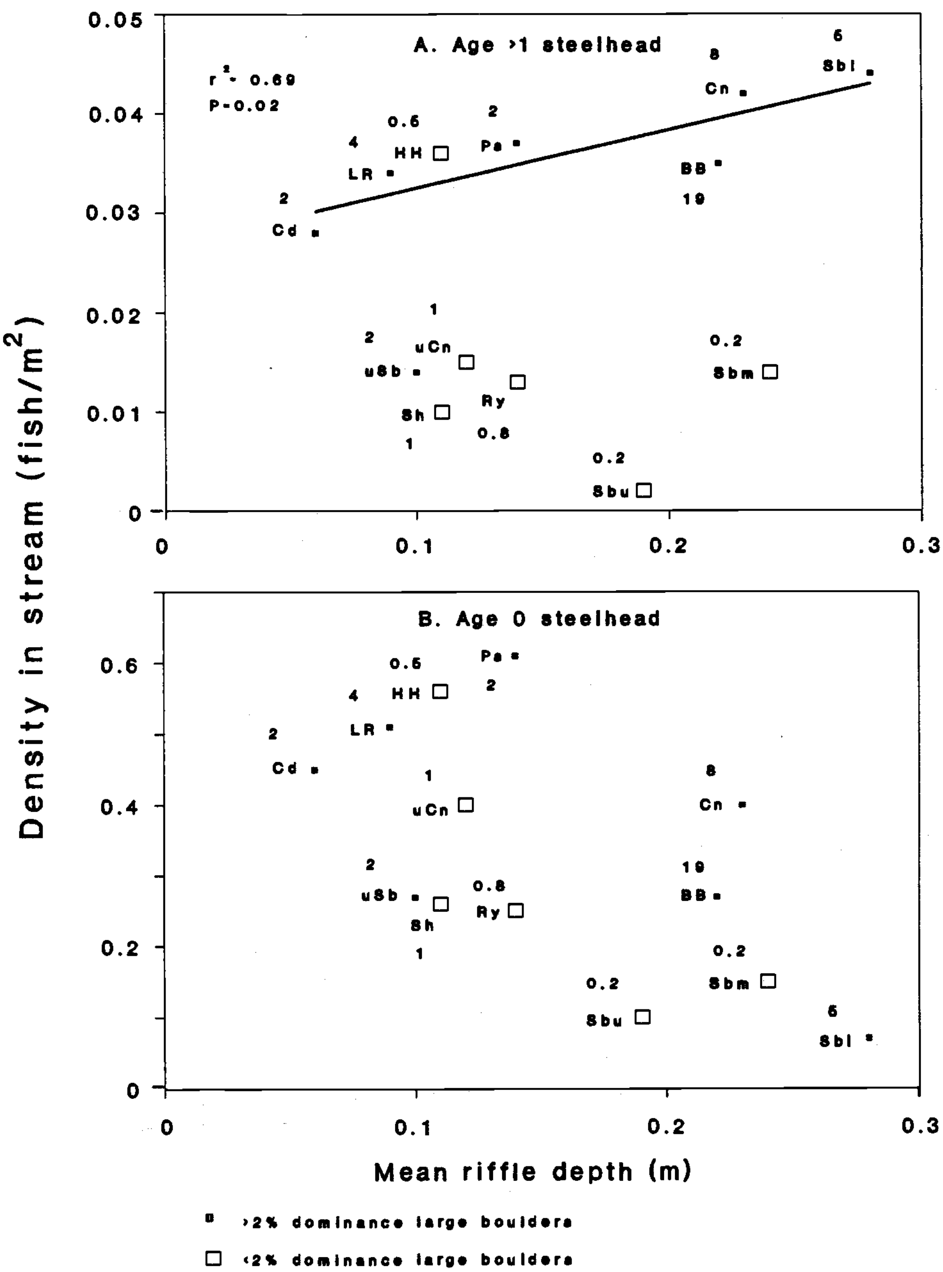


Figure 2.8. Total stream density of (A) age >1 and (B) age 0 steelhead versus riffle depth, in the Steamboat Creek basin, Oregon. Rough and smooth channels are denoted by amount of large boulder substrate (diameter >100 cm), and percent dominance of large boulders is shown next to each channel. The relationship shown for age >1 fish pertains to streams with densities greater than 0.02 fish/m². Tributaries: Ps: Pass, uCn: upper Canton, Sh: Steelhead, Cd: Cedar, LR: Little Rock, HH: Horse Heaven, uSb: upper Steamboat, BB: Big Bend, Ry: Reynolds; mainstem segments: Cn: Canton, Sbu: Steamboat upper, Sbm: Steamboat middle, Sbl: Steamboat lower.

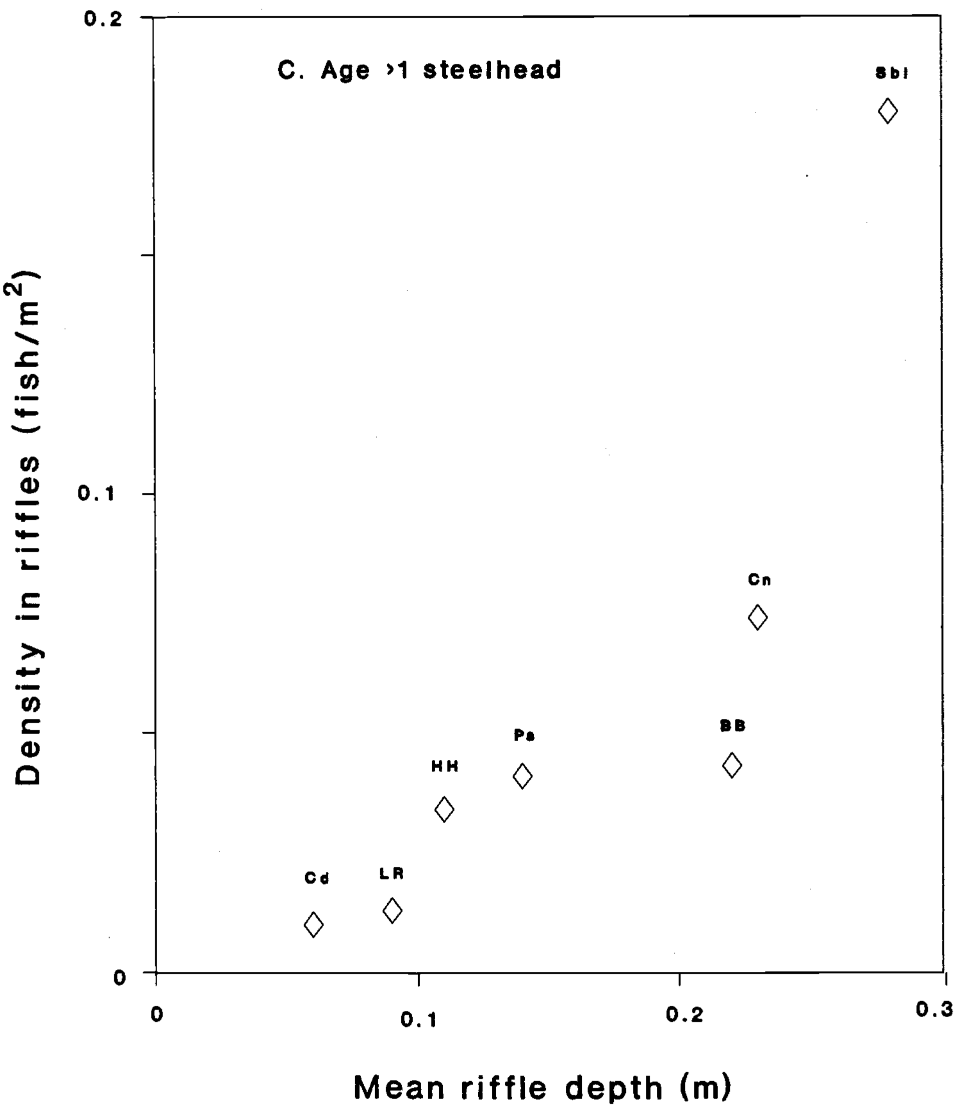


Figure 2.8 continued. Density of (C) age >1 steelhead in riffles versus mean riffle depth, for stream channels with total stream densities greater than 0.02 fish/m^2.

Summer densities of age 0 steelhead were not explained by availability of spawning gravel; a regression of the density of age 0 fish on spawning gravel density was not significant ($p=0.06$, $r^2=0.29$). Most notably the upper mainstem segment of Steamboat Creek had 23% of total available spawning gravel, but supported some of the lowest densities of age 0 fish in the basin (Table 2.7). If spawning of adults was focused towards stream reaches with the greatest availability of gravel, than age 0 steelhead must have become well dispersed to other reaches by time of the survey.

Abundance of Other Salmonids and Their Habitat Utilization

From 1987 to 1988 there was a large decrease in estimated numbers of chinook and coho salmon, and age >1 cutthroat trout (Table 2.4). Pool habitat supported the largest numbers of these fishes. Cutthroat trout (age >1) in mainstems preferred riffle habitats, but chinook and coho strongly avoided riffles (Table 2.9). In tributaries age >1 cutthroat trout switched to a moderate avoidance of riffles and a moderate preference for pools, in a manner similar to age >1 steelhead (Table 2.8).

Redside Shiner and Age >1 Steelhead in the Mainstem Segments of Steamboat Creek

The highest densities of redside shiner occurred in the upper segment of Steamboat Creek. Redside shiner were virtually absent from the middle segment, but occurred at relatively moderate densities in the lower segment. From 1987 to 1988 there was nearly a three-fold increase in estimated numbers of redside shiner in the basin (Table 2.4).

Distribution of redside shiner in the basin appeared to be strongly influenced by temperature. Redside shiner occurred only in stream channels with temperature regimes above 23°C (Figure 2.5, Table 2.10). Only a 3°C difference in temperature regime separated their highest abundance in the upper mainstem of Steamboat Creek and their virtual absence from the middle mainstem segment. Only a 2.4°C

Table 2.9. Habitat electivity E (Ivlev 1961) of age >1 cutthroat trout, and juvenile chinook and coho salmon in Steamboat Creek, Oregon. From means of 1987 and 1988 data.

	Mainstem			Tributary
	Age >1 Cutthroat Trout	Juvenile Chinook Salmon	Juvenile Coho Salmon	Age >1 Cutthroat Trout
Pool	0.06	0.13	0.06	0.14
Glide	-0.75	-0.47	0.07	-0.04
Riffle	0.16	-0.45	-0.74	-0.25

difference existed between the lower mainstem of Steamboat Creek, where redside shiner were abundant, and in Canton Creek, where only a very few were observed above its confluence with Steamboat Creek.

Table 2.10. Number (#), number per 100 m^2, and habitat electivity E (Ivlev 1961) of age >1 steelhead and redside shiner in mainstem segments of Steamboat Creek, Oregon. From means of 1987 and 1988 data.

		Age >1 Steelhead			Redside Shiner		
Steamboat Creek Mainstem Segments	Habitat	#	E	#/ 100 m^2	#	E	#/ 100 m^2
Upper	Pool	100	-0.28		5870	0.16	
	Glide	5	-0.85		450	-0.56	
	Riffle	150	0.78		2	-0.99	
	Total	255		0.18	6322		6.4
Middle	Pool	440	-0.34		7	---	
	Glide	110	-0.56		0	---	
	Riffle	1020	0.54		10	---	
	Total	1570		1.4	17		0.020
Lower	Pool	3040	-0.23		1550	-0.03	
	Glide	1130	-0.14		820	0.24	
	Riffle	2970	0.60		6	-0.96	
	Total	7140		4.4	2376		1.5

A high density of age >1 steelhead in the lower mainstem segment of Steamboat Creek appeared to have constrained the abundance and habitat utilization of redside shiner. Where age >1 steelhead were scarce in the upper mainstem segment, redside shiner occurred in relatively high densities and showed a moderate preference for pools and a high avoidance of glides (Table 2.10). In the lower mainstem segment, where densities of age >1 steelhead were high, redside shiner occurred in relatively moderate abundance, and exhibited only a neutral selection of pools and a moderate preference for glides. Redside shiner avoided riffle habitats almost completely in both the upper and lower mainstem segments of Steamboat Creek (Table 2.10). Competition for pool inlets was likely the controlling mechanism. In the upper mainstem segment of Steamboat Creek I observed age >1 steelhead and redside shiner when alone (i.e. the other species not seen in the entire pool) to occupy pool inlets. When together in the same pool, age >1 steelhead always dominated pool inlets, while redside shiner occupied slow deep areas adjacent to the thalweg of pool inlets. This same phenomenon was documented by Reeves et al. (1987) in the lower mainstem of Steamboat Creek.

Densities of age >1 steelhead in the mainstem of Steamboat Creek appeared to be greatly affected both by temperature and channel structure. Though the upper and lower mainstem segments both had exceptionally high temperature regimes (Figure 2.5), their channel structure was different, which resulted in dramatically different carrying capacities for age >1 steelhead. The exceptionally low density of age >1 steelhead in the upper mainstem segment coincided with a channel gradient of 0.78% slope and the smoothest channel in the basin (as defined by percentage dominance of large boulder substrate, Table 2.2). A preliminary survey of this segment in mid-June 1987 was followed three weeks later by the regular survey. During this time stream temperatures were approaching their summer maximum. The second survey revealed a large drop in fish numbers. Many focal points formerly maintained by age >1 steelhead were at that time occupied by relatively large age 0 steelhead. This suggests that age >1 steelhead emigrated from this segment, possibly in response to increasing temperatures. Fontaine (1987) also observed a reduction in numbers of age >1 steelhead within this segment as temperatures increased during the summer of 1986. In the lower mainstem segment of Steamboat Creek there is a slightly greater channel gradient (1.0%

slope) and a rougher channel (Table 2.2), and there densities of age >1 steelhead were the highest in the basin. The greater carrying capacity of this reach is likely a result of more feeding microhabitats being afforded by the rougher and slightly steeper channel. In comparison, the moderate densities of age >1 steelhead in the middle mainstem segment may have represented a trade-off between a smooth, flat channel (0.76% slope) and a cooler temperature regime (as much as 3°C lower than the upper mainstem segment).

Discussion

Fish Abundance and Habitat Utilization

Patterns of fish abundance and habitat utilization in Steamboat Creek were influenced by stream temperature, stream size, and channel roughness. These patterns also appear to be involved with energetic factors affecting the selection of focal points profitable for growth (Everest and Chapman 1972; Fausch 1984). Temperatures throughout the basin are relatively high for juvenile steelhead (Bell 1986). This exacts a high metabolic cost (Beamish 1964), which is probably compensated for by securing increased food supply through occupancy of swifter focal points (Smith and Li 1983) in riffle habitats. Juvenile steelhead may also have emigrated out of warm channels in search of cooler temperatures or more profitable feeding microhabitats that could sustain a growth rate (Crowder and Magnuson 1983) sufficient to bring them to a critical length for smoltification (Wagner et al. 1963).

To view fish populations with a basin perspective, the relative importance of a stream channel to the total fish population in a basin must be measured by the proportion of the population rearing there. In the Elk River basin, Oregon, major zones of age >1 steelhead production are located in relatively small areas of the basin that are geomorphically unique, and appear to offer greater food production and habitat diversity (Gordon Reeves, USDA Forest Service, Pacific Northwest Research Station, 3200 Jefferson Way, Corvallis, Oregon 97331; unpublished data). In the Steamboat Creek basin, high densities of age >1 steelhead in relatively small areas of the basin, though of interest in terms of habitat quality, made only minor contributions to total numbers. The majority of age >1 steelhead were concentrated in two mainstem segments that had relatively deep riffles and relatively rough channels. Age 0 steelhead were distributed more evenly throughout tributaries and the mainstem of Canton Creek as a function of their relatively free access to all habitat types throughout the basin, although their densities were relatively low in the mainstem segments of Steamboat Creek.

In mainstem segments both age 0 and >1 steelhead increased their utilization of riffle habitat with temperature in a similar manner (Figure 2.7), however the densities they maintained in each segment were quite different (Table 2.7). The lowest densities of age 0 steelhead in the basin occurred in the two warmest segments of Steamboat Creek (upper and lower mainstem segments, Figure 2.5), but the slightly cooler middle mainstem segment held moderately greater densities of age 0 fish. Similar to age 0 fish, age >1 fish occurred at their lowest density in a warm segment (upper mainstem of Steamboat Creek), and at a moderate density in the cooler middle mainstem segment. However age >1 fish occurred at their highest density in the basin in the warm lower mainstem segment, while age 0 fish occurred at their lowest density there. This mainstem segment is rougher and slightly steeper than the upper and middle mainstem segments, which presumably benefits age >1 fish but not age 0 fish. It is not likely that age 0 steelhead were excluded from this segment by high densities of age >1 fish, since in the mainstem of Canton Creek, which is cooler by comparison, relatively high densities of both age 0 and >1 fish occurred together (Table 2.7). Hence, while both age 0 and age >1 steelhead increased their use of riffle habitat with temperature, high temperatures appeared to severely limit the density of age 0 fish. However age >1 fish were able to maintain high densities in one of the warmest channels in the basin, presumably by virtue of its channel structure.

The distribution of redside shiner in the basin appeared to be greatly affected by different temperature regimes throughout the basin. Their habitat utilization and abundance also appeared to be constrained by competition with age >1 juvenile steelhead. Age >1 steelhead were observed to always dominate pool habitat, even in warm temperature regimes in which, in laboratory channels, Reeves et al. (1987) observed redside shiner to dominate preferred habitat. In Steamboat Creek Reeves et al. (1987) observed juvenile steelhead to dominate swift focal points at the inlet of a pool in the presence of redside shiner at a temperature range of 18-21°C. Pool inlets were the preferred habitat of both juvenile steelhead and redside shiner. Redside shiner were restricted to slower and deeper positions away from the pool inlet during the morning and evening hours when temperatures were cool. During midday, when temperatures were warmer, many redside shiner moved into swifter focal points, but remained subordinate to steelhead. I also observed this behavior while snorkel diving in the mainstem of Steamboat Creek during this study. In laboratory stream channels Reeves et al. (1987) found juvenile steelhead being displaced from preferred focal points by redside shiner in a constant warm water regime (19-22°C), but dominating preferred positions in a constant cool water regime (12-15°C). This discrepancy between field and laboratory temperatures at which redside shiner dominated preferred habitat might have resulted from natural diel temperature fluctuations that were absent in the laboratory channels (Gordon Reeves, personal communication). Juvenile steelhead in Steamboat Creek that occupied preferred positions in the morning when temperatures were cool may have had a short-term advantage of "prior residence" (see p. 1059, Chapman 1962) over redside shiner during unfavorable midday temperatures. Thus the temperature regimes in the upper and lower mainstem segments of Steamboat Creek are likely near the lower limit of that preferred by redside shiner. In slightly higher temperatures redside shiner can be expected to dominate pool inlets over age >1 steelhead.

Critique of Survey Results and Methods

The potential for bias in estimates of fish numbers due to the inability to verify dive counts in the mainstem of Steamboat Creek and deep pools in the mainstem of Canton Creek is not considered to be important to the results of this study. It is my opinion that the most likely error in dive counts of fish is underestimation, not overestimation. In the mainstem segments of Canton Creek and lower Steamboat Creek, diver counts of juvenile steelhead were the highest in the basin. If actual fish numbers in mainstem habitats were greatly higher than estimates, then it would only further the contention that these segments held the majority of age >1 steelhead population during the summer. Also, there is no reason to believe that dive counts were biased towards undercounting steelhead in pools of the middle and upper mainstem segments of Steamboat Creek, where the counts were the lowest in the basin, and not in the mainstem segments of Canton Creek and lower Steamboat Creek, where counts of age >1 steelhead were the highest.

The application of the Hankin and Reeves (1988) survey method in this study suffered from an inadequate number of verifications of both habitat dimensions and fish numbers. Not having a minimum of at least 10 verifications for each habitat type in each location stratum precluded proper variance calculations. More labour dedicated towards dive count verifications would have greatly improved the quality of the population estimates in this study. Future work would also benefit from protocol that outlines the best approach for dealing with rare habitat types within location strata, and the selection of habitat units for dive count verification when units cannot be chosen randomly from those censused in the snorkel survey.

Comparisons with Other Streams

Summer densities of age 0 and age >1 juvenile steelhead in the Steamboat Creek basin were generally low in comparison to other streams (Table 2.11). Densities of age 0 fish were similar to some streams in Idaho, though age >1 densities were less than half of those reported in the same streams (Reiser and Bjornn 1979). The ranges of age 0 and >1 fish density in Steamboat Creek tributaries were generally much lower than a range reported by Burns (1971) in three small streams in northern California. Densities of age 0 steelhead in the Steamboat Creek basin are half, and age >1 steelhead densities are an order of magnitude less, than densities in Fish Creek, Oregon, which is also a west slope Cascade drainage of similar stream order and elevation (Everest et al. 1987).

Table 2.11. Range of summer densities of juvenile steelhead reported in streams in the western United States, with low summer flow.

	(fish/m^2)		
	age 0	age >1	Reference
Northern California (1967-1969)			Burns (1971)
(all < 0.04 m^3/s)			
Goodwood Creek	0.07-0.14	0.02-0.04	
South Fork Yager Creek	0.60-0.92	0.10-0.13	
Casper Creek	0.47-1.61	0.02-0.04	
Idaho streams			
Two small streams	0.11-0.26	0.086-0.13	Reiser and Bjornn (1979)[a]
One medium size stream	0.23	0.12	
Fish Creek, Oregon (1982-1986, 0.5 m^3/s)	0.24-0.80	0.09-0.14	Everest et al. (1987)
Steamboat Creek, Oregon (1987-1988)			This study
Mainstem segments (0.24-1.4 m^3/s)	0.17-0.21	0.026-0.029	
Tributary segments (0.03-0.71 m^3/s)	0.36-0.46	0.024-0.025	
Basin total	0.22-0.27	0.025-0.028	

[a] review of other studies, references cited but stream names not given.

In Steamboat Creek, riffle utilization by juvenile steelhead in temperature regimes lower than 23°C was comparable to that in Fish Creek (Everest et al. 1987), where both age 0 and age >1 fish exhibited neutral selection of riffles in similar temperatures. My finding of low riffle electivity by age >1 steelhead in shallow streams, and a comparatively greater use of shallow riffles by age 0 fish, is consistent with studies of small streams by Bisson et al. (1982 and 1988), and suggests a depth limitation for larger fish in shallow riffles.

Considering the effect of habitat size on habitat utilization demonstrated in this study, habitat "preference" or "selection" must first be prefaced by the concept of useable area. One cannot simply compare habitat "types" without also considering differences in stream size. Large streams, by virtue of depth, may have relatively more area available for occupation than small streams. In a study of microhabitat parameters throughout a full size range of channels in the John Day basin, Oregon, calm water pockets in large stream riffles were found to be more similar (as determined from cluster analysis) to pools in small streams, than they were to riffles in small streams (Hiram Li, Department of Fisheries and Wildlife, Oregon State University, Corvallis, Oregon 97331; unpublished data).

Previous studies at the habitat unit level have not related habitat utilization to the factors of temperature or stream size. The varied conditions encountered in my study permitted such comparison, and demonstrated habitat utilization by juvenile steelhead being affected by both of these factors. The effect of temperature on habitat is likely to be important in streams that are in the upper limits of the range preferred by steelhead. Such streams will likely be encountered most often in the southern part of the range of steelhead distribution in North America (i.e., in Oregon and California).

CHAPTER 3. EMIGRATION OF JUVENILE STEELHEAD FROM THE STEAMBOAT CREEK BASIN, OREGON

Introduction

To understand the ecology of juvenile steelhead populations at a basin scale, it is necessary to know the magnitude and pattern of their emigration. Juvenile steelhead culminate their stream residency with smoltification and emigration to the ocean, usually at 2 or 3 yrs of age. However steelhead smolts at younger and older ages occur as life history types in most populations (Withler 1966). Scales taken from adult North Umpqua River steelhead, from both winter and summer runs between 1984-1989, which were either sport caught, or trapped at the Winchester dam fish ladder, showed a nearly equal proportion of fish having spent 2 or 3 years in stream residence prior to smoltification and ocean entry (52% age 2, and 48% age 3; N=65). None were determined to have completed ocean entry after shorter or longer stream residencies (Oregon Department of Fish and Wildlife, Research and Development Section, 850 SW 15th Street, Corvallis, Oregon 97333; unpublished data).

The number of smolts leaving a basin is an important measure of the quality and quantity of the rearing habitat in that basin, and is fundamental in calculating seasonal mortality. The size of smolts leaving a basin is another measure of rearing potential. The physiological process of smoltification is size dependent. Parr-smolt transformation usually occurs in fish 140-160 mm in fork length (Wagner et al. 1963, Chrisp and Bjornn 1978). Survival to maturity increases with smolt size, and drops off severely for smolts under a 140-mm fork length threshold (Wagner et al. 1963). Most fish less than 120 mm cannot osmoregulate in seawater, and would die within a few weeks after ocean entry (Conte and Wagner 1965).

Age 0 and age >1 steelhead that are not smolting frequently emigrate from natal streams in numbers equal to or greater than numbers of smolts. These fish have been shown to utilize downstream habitats for the remainder of their freshwater residency (Shapovalov and Taft 1954, Chrisp and Bjornn 1978, Leider et al. 1986), or to reenter natal or adjacent tributaries for winter residence (Everest 1973). Juvenile steelhead readily migrate between stream systems in search of winter habitat (Bjornn 1971, Everest 1973), but will overwinter in areas of previous summer residence when suitable cover is available (Edmundson et al. 1968, Bjornn 1971).

Methods

The downstream migration of juvenile steelhead from the Steamboat Creek basin was monitored with Humphreys traps (McLemore et al. 1989) from April 11 to November 21, 1988. Two sizes of traps were used. A "full-size" model made of steel had a 1.5-m wide traveling screen that was mechanically driven by a paddle wheel. A "3/4-size" model made of aluminum had a 1.1-m wide traveling screen driven by an electrical motor with two 12-volt deep cycle batteries. A rotating screened drum in the rear of the holding bins removed debris from the 3/4-size trap, but proved ineffective in the full-size Humphreys trap that I operated. Two trapping stations were maintained; one in Canton Creek just above its mouth, and one in Steamboat Creek just above the confluence of Canton Creek.

From November 19 to December 19, 1988 an Archimedean screw trap was deployed in Steamboat Creek 0.3 km below the confluence of Canton Creek to estimate the number of juvenile steelhead emigrants from the entire basin. It consisted of a conical screw, with a solid fiber-glass helical interior wing encased by an exterior wall of 10 mm wire mesh, which was supported by two aluminum pontoons. When the conical screw was submerged to its central axis, the current pushed against the interior helical wing causing it to rotate. The trap was placed at the head of a pool with a calm unconstrained thalweg. Fish passively entered into the mouth of the trap and were captured in a volume of water enclosed by the leading edge of the rotating helical wing. Fish were screened into a decreasing volume as water flowed out of the meshed exterior wall, and were conveyed toward the stern into a submerged holding bin equipped with a rotating debris drum.

Trap Operation

Traps were held in the thalweg by an open cable system with snatch blocks that were anchored to trees or cable holds secured in bedrock with epoxy cement (Fontaine and Merritt 1988). The free end of the cable system reached a paved road, which allowed traps to be maneuvered with the aid of a small four-wheel-drive truck. The positions of the traps were adjusted to keep them centered in the thalweg; during high flows they were pulled to the side. Both sizes of Humphreys traps were easily deployed when total basin flows were below 26 m^3/s, (the flow in Steamboat Creek generally comprises 72% of the basin total, and that of Canton Creek 28%) but were operated with heightened risk to equipment and personal safety up to 39 m^3/s. A full-size trap was used in Steamboat Creek when its flow was above 3 m^3/s, below this a 3/4-size trap was used. In Canton Creek a 3/4-size trap was used at all times. The Archimedean screw trap was operated effectively in flows ranging from 6.5 to 31 m^3/s.

The full-size Humphreys and the Archimedean screw traps were usually operated 24 hours a day, though virtually all emigrants were captured during the night. To conserve the electrical charge of batteries, the 3/4-size Humphreys traps were operated only during the night; periodic tests confirmed the absence of daytime captures.

The stern holding bins in the Archimedean screw trap, and in both the full-size Humphreys trap in Steamboat Creek and the 3/4-size Humphreys trap in Canton Creek, efficiently retained captured juvenile steelhead. Initially the 3/4-size Humphreys trap deployed in Steamboat Creek on July 1, 1988 retained juvenile steelhead. But on October 6, 1988 juvenile steelhead were discovered to have escaped from its holding bin through a gap periodically exposed by a surface dent in the rotating debris drum. Since it could not be determined when the holding bin became ineffective at retaining fish, all data collected from this trap were disregarded.

The 3/4-size Humphreys trap in Canton Creek had a measurable capture efficiency from April 19 to August 16, 1988, when it caught its last recapture of the summer. From August 17 to November 3, 1988 this trap caught eight additional age >1 steelhead, though no recaptures were obtained from these few fish. Fish captured throughout the summer and up to November 3 were, on average, larger than those caught during the previous spring, even though approach velocities on the traveling screen were quite low compared to spring flows. On November 3, flows increased from the summer base level by storm runoff, and after this time catches in the 3/4-size Humphreys trap in Canton Creek were extremely low compared to those in the full-size Humphreys trap that was again deployed in Steamboat Creek. Nighttime inspection revealed that age >1 steelhead were capable of swimming off of the traveling screen against current velocities similar to those that successfully impinged them the previous spring. Since trap efficiency could not be measured, all data collected from the Canton Creek 3/4-sized Humphreys trap after November 3, 1988 were disregarded.

Unless otherwise specified, all further reference to the full-size Humphreys trap in Steamboat Creek and the 3/4-size Humphreys trap in Canton Creek will be more simply the Steamboat Creek trap, and the Canton Creek trap. A summary of trapping operations is presented in Table 3.1.

Table 3.1. Schedule of fish trap operations in Steamboat and Canton Creek, Oregon, 1988.

Trap	Steamboat Creek	Canton Creek
Full-size Humphreys	April 11-June 28	
	November 4-21	
3/4-size Humphreys	June 29-October 11[a]	April 19-November 3
	October 12-November 3	November 4-8[a]
	Total Basin	
Archimedean screw	November 19-December 18	

[a] trap deployed but efficiency was too low to use capture data.

Emigrant Classification and Length Measurement

All captured juvenile steelhead were visually identified and separately enumerated as parr (considered to be at least one year away from development of smolt characteristics), intermediate smolts, or smolts. Identification criteria were similar to those adopted by

Wagner (1970). They were based wholly on physical appearance; no effort was made to discern physiological stage of smoltification or age. Most fish classed as parr had lived through a least one winter, though based on size it was obvious that a few had lived through a second winter. The three classes were distinguished by the following criteria:

Parr: No silvering of body color, parr marks dark and distinct, pectoral and pelvic fins opaque and often with orange cast and thin white leading edge, caudal fin lacking black posterior edge.

Intermediate Smolt: Moderate silvering of body color, parr marks light and indistinct, pectoral and pelvic fins translucent with no coloration, caudal fin lacking black posterior edge.

Smolt: Heavy silvering of body color, parr marks nearly or completely indistinct, pectoral and pelvic fins translucent with no coloration, caudal fin often with black posterior edge. If only moderately silvered body, but with black posterior edge on caudal fin, then classed as a smolt.

Fish were anesthetized with MS-222 and their fork lengths measured to the nearest millimeter. On three days when hundreds of fish were caught, only a randomly selected fraction of steelhead parr was measured.

Measurement and Analysis of Trap Efficiency

Trap efficiency was monitored by releasing up to 50 marked juvenile steelhead 0.4 km upstream of the trap from which they were captured, and recording the number of recaptured fish over subsequent days of trapping. Fish were marked with a partial clip to either the upper or lower caudal fin, to denote Steamboat Creek and Canton Creek respectively. Another partial clip to a pectoral or pelvic fin, or no additional clip, allowed for five mark codes to be changed daily. The mark code of recaptured fish was used to determine the number of days elapsed since upstream release. All fish not used for trap efficiency tests were released downstream of the traps after recovery from anaesthesia.

There were sufficient mark-recapture data generated from operation of the Steamboat Creek and Canton Creek traps for a detailed analysis of the number of days elapsed from release to recapture, and of the effects of streamflow and steelhead size on trap efficiency. Humphreys trap efficiency was calculated only for age >1 steelhead. Only a small amount of data was acquired from operating the Archimedean screw trap in the fall, which allowed for only a crude analysis of its efficiency in capturing both age 0 and age >1 steelhead.

All recaptured and virtually all other captured juvenile steelhead were caught only during hours of darkness in routine day and night operation of the Steamboat Creek trap, and in daytime test operations of the Canton Creek trap. Therefore night-only operation of the Canton Creek trap did not introduce any demonstrable error into the data.

Nearly 90% of all marked and recaptured juvenile steelhead were caught during the first night after their release in both the Steamboat Creek and Canton Creek traps (Figure 3.1). The remaining recaptures were caught within four additional nights, except for three fish recaptured in Canton Creek after lapses in trap operation that exceeded the 5-day cycle of mark codes.

Mark-recapture data of juvenile steelhead from the Steamboat and Canton Creek Humphreys traps were sorted both into fish length and streamflow classes. Since all marked fish were released only 0.4 km upstream from the traps, if they started their downstream migration with nightfall they would be expected to be some of the first fish caught. This phenomenon was observed on the two nights when traps could be monitored during the first hours of darkness. The flow most applicable to mark-recapture data then was the one for the day of release, even though the nighttime operation of the traps spanned the midnight time interval used to calculate mean daily flow at the USGS gauging station. Since 88% of all marked fish were recaptured during

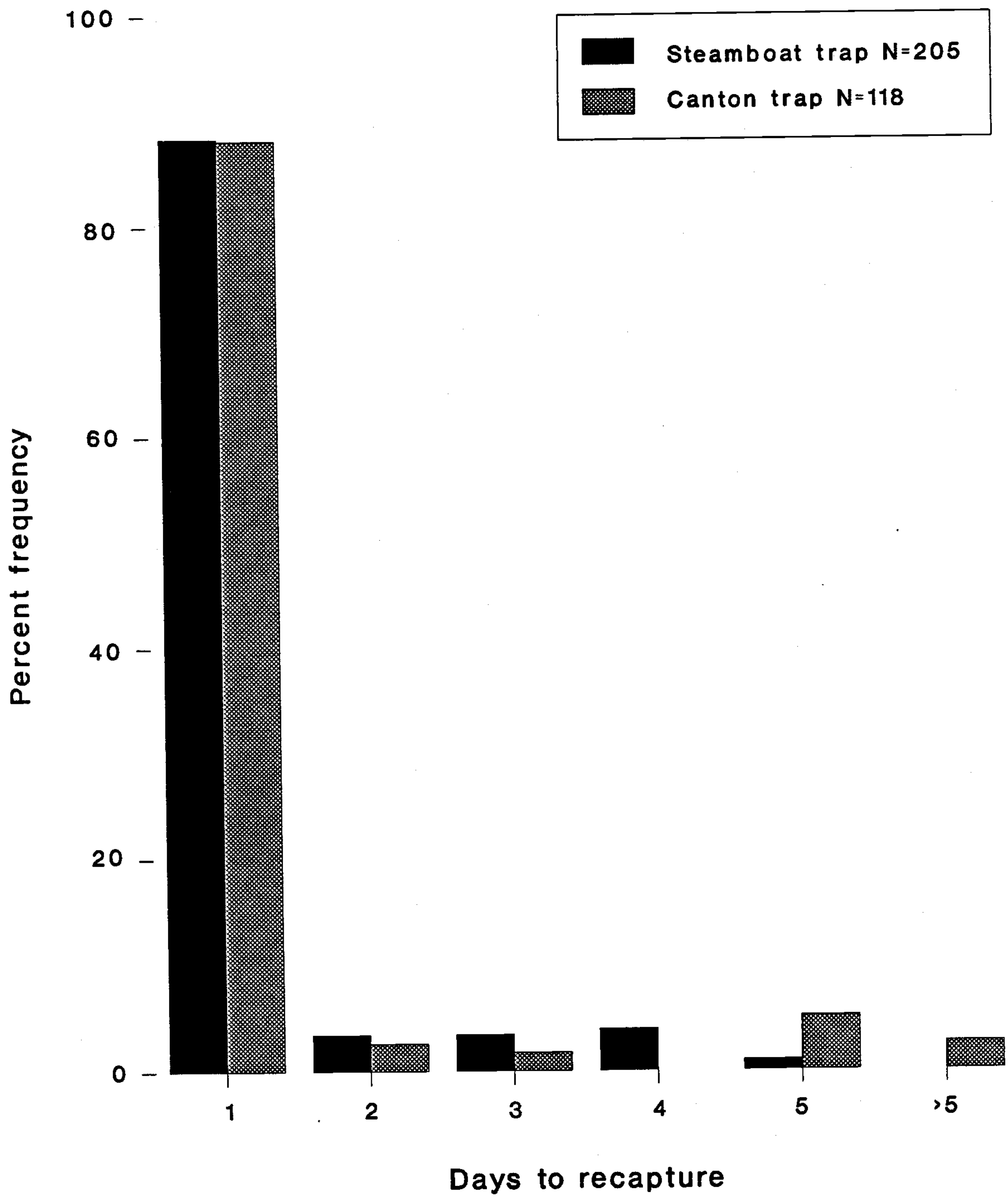


Figure 3.1. Number of days to recapture for age ›1 steelhead. Fish were marked and released 0.4 km upstream of Humphreys traps in Steamboat and Canton Creek, Oregon, April 11 to December 19, 1988.

the first night, the remaining 12% could have been placed into an incorrect flow class. When few or no recaptured fish occurred in a length or flow class, data from adjacent classes were combined. Trap efficiency was calculated by dividing the total number of recaptures (grouped by both length and flow classes) by the total number of marked fish in each class.

For the Steamboat Creek trap the relationship between capture efficiency and fish length showed two regions of efficiency divided at about 105 mm fork length (Figure 3.2A). Mark-recapture data from the Steamboat Creek trap were separated at 105 mm fork length into two data sets, from which two separate relationships of trap efficiency and flow were graphically constructed (Figure 3.2B). The relationships of trap efficiency and streamflow were first adjusted for the effects of fish length by the following method:

1. The unweighted mean efficiency for "each" relationship of trap efficiency and flow (E_f; "each" refers to the two size groupings of fish) was computed from a series of interpolated points equidistant along the flow axis.

2. This mean efficiency for flow (E_f) was then averaged with the corresponding mean efficiency for fish length (E_l), to give a mean efficiency (E_m), as described by:

(4)

$$E_m = \frac{(E_f + E_l)}{2} .$$

This mean efficiency accounts for the effect of fish length and the effect of streamflow on trap efficiency.

3. Each relationship of trap efficiency and flow was then adjusted by subtraction so that it was equal to the mean efficiency:

(5)

$$E_{fa} = E_f - (E_f - E_m) ,$$

where the adjusted mean efficiency for flow $E_{fa} = E_m$. This resulted in 0.007 and 0.002 being subtracted from the data points in the relationships of trap efficiency versus flow for fish >105 mm and <105

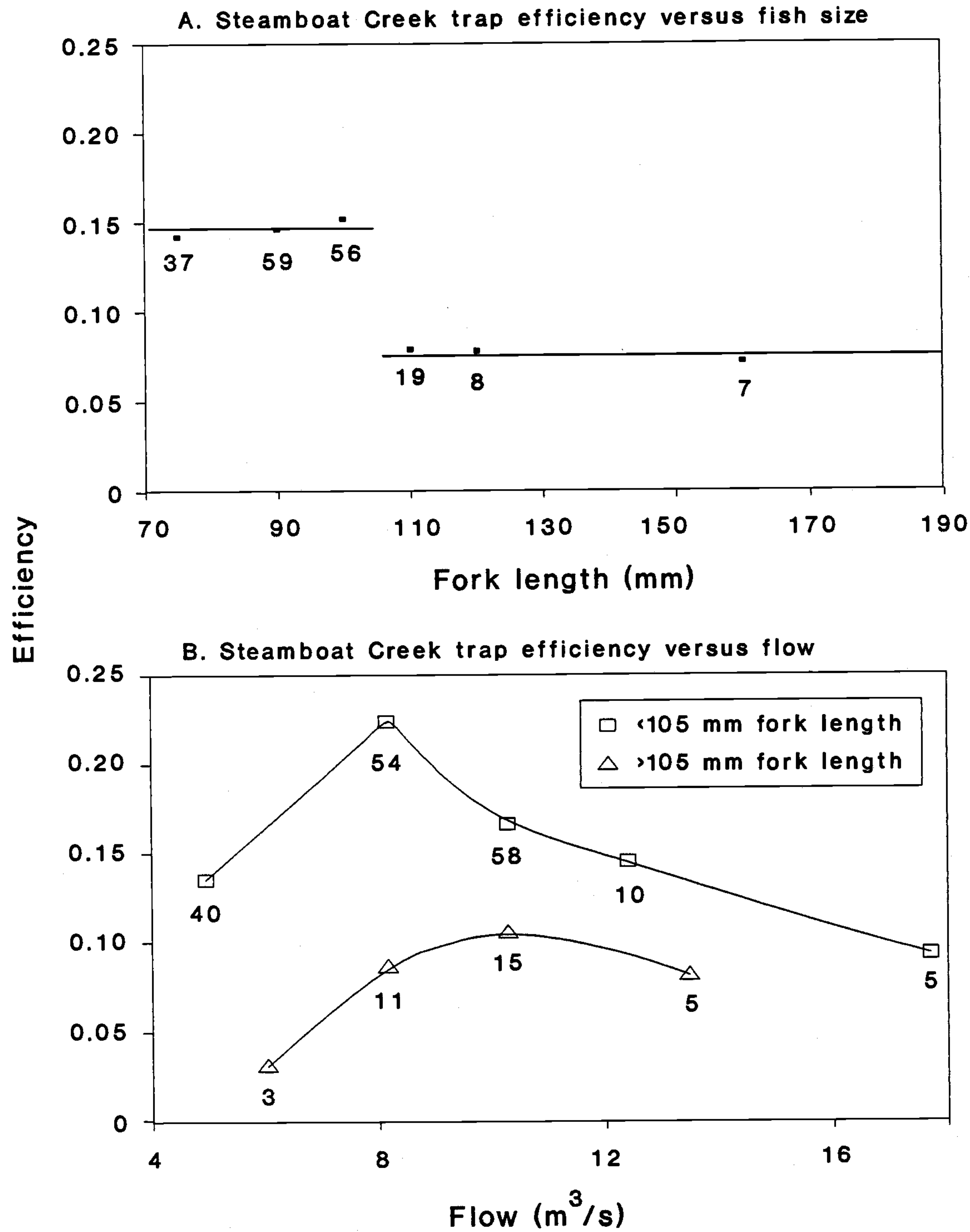


Figure 3.2. Efficiency of Humpreys trap in capture of juvenile steelhead in Steamboat Creek, Oregon, April 11 to July 3, 1988, versus (A) fish size and (B) flow, for fish less and greater than 105 mm fork length. Number of recaptures is shown for each point.

mm, respectively. This adjustment was equivalent to an integration of fish length and streamflow, since the effect of fish length was constant within each relationship of trap efficiency and flow. If it had not been constant, an independent covariate would have been required to integrate the effects of fish length and streamflow, and a three-dimensional response surface would have represented the effects of fish length and streamflow upon trap efficiency.

The relationships of trap efficiency and streamflow from Steamboat Creek (Figure 3.2B) can be meaningfully interpreted. Trap efficiency increases with flow on the left side of the curves as fish are more effectively impinged on the traveling screen by higher thalweg velocities. A peak efficiency is reached after which trap efficiency declines, with proportionately less of the thalweg being intercepted at higher flows. Larger fish avoid the traveling screen with greater burst swimming speeds, or perhaps by traveling lower in the water column, thus fewer are captured.

Trap efficiency in Canton Creek appeared to be affected by fish length, but data for flow were too variable to determine a relationship (Figure 3.3). Capture efficiency of fish less than 115 mm fork length decreased with length. The mark-recapture data for fish greater than 115 mm fork length were combined into a single length class.

<u>Expansion of Capture Data</u>

Trap efficiencies were applied to all capture data to estimate the total number of emigrants during trap operation. Capture data from the Steamboat Creek trap were sorted first into two groups: fish less than or equal to 105 mm fork length, and fish greater than 105 mm fork length. Each group was then sorted into flow classes and corresponding efficiencies were applied to estimate the total number of emigrants during trap operation. Canton Creek capture data were similarly treated with efficiencies applied only to length classes.

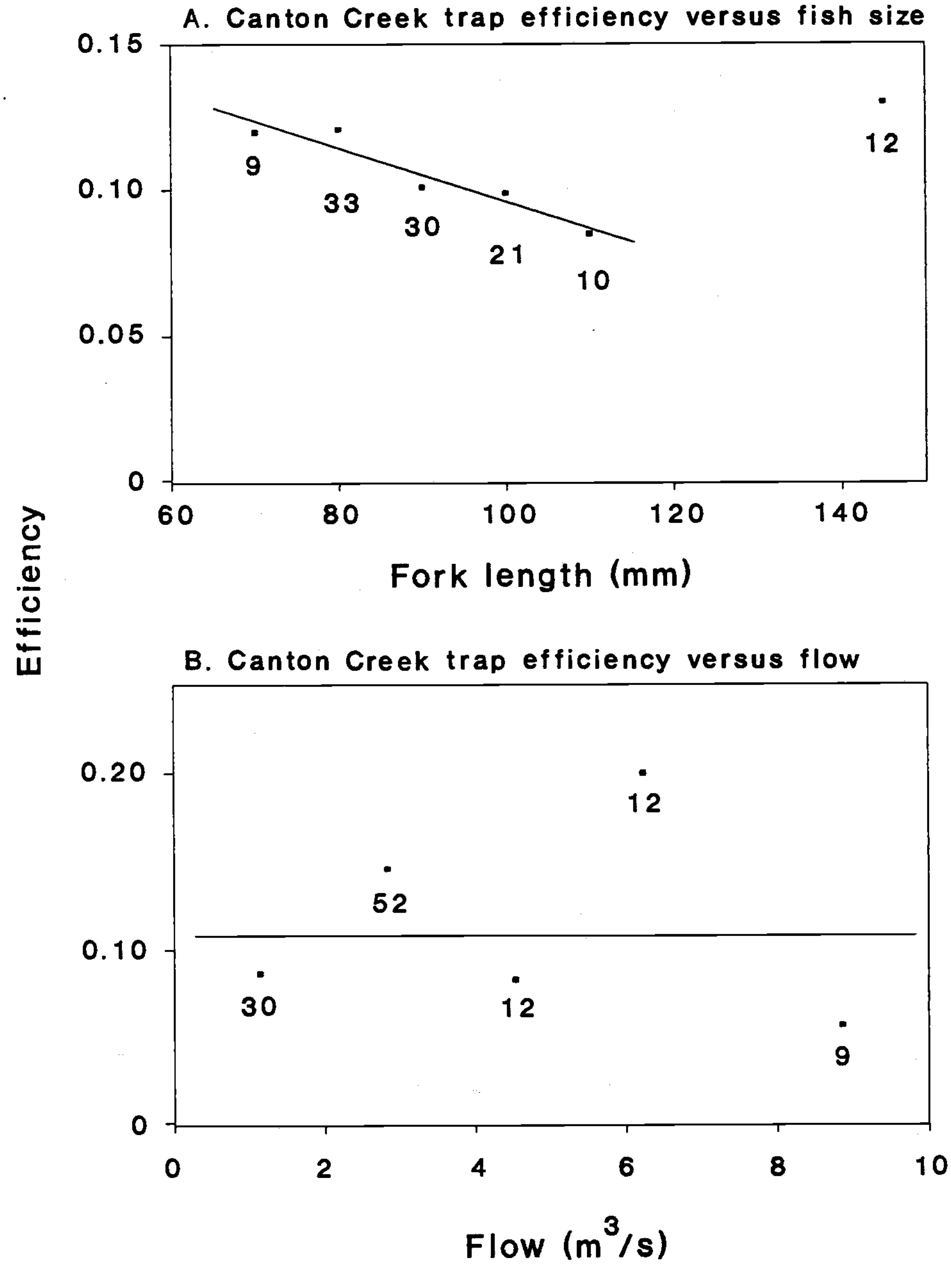


Figure 3.3. Efficiency of Humpreys trap in capture of juvenile steelhead in Canton Creek, Oregon, April 11 to July 3, 1988, versus (A) fish size and (B) flow. Number of recaptures is shown for each point. In A the efficiency for fish greater than 115 mm is excluded from relationship, no relationship between trap effeciency and flow is interpreted in B.

The Humphreys traps were often damaged by violent spring flows. A rational method was needed to estimate the number of juvenile steelhead emigrating during periods of trap repair. The estimated number of parr emigrants, and the combined estimated number of smolts and intermediate smolts, were plotted against flow for both the Steamboat and Canton Creek traps. All of these plots, except for smolts and intermediate smolts in Canton Creek, revealed relationships that were approximated as bell-shaped curves skewed toward lower flows (Figure 3.4). This approximation was accomplished by visually placing a smooth curve through another curve generated by a computer graphics program (Harvard Graphics; Software Publishing Corporation, 1901 Landings Drive, Mountain View, California 94039) that used a robust locally weighted regression technique (Cleveland 1979). For smolts and intermediate smolts in Canton Creek I decided that the most rational approximation of a relationship would be a straight line through the data. These relationships are not considered to be independent of seasonal effects on emigration, such as physiological development of smolts; rather they likely reflect volitional movement within a broad time span when fish are induced by seasonal behaviors to migrate downstream.

The streamflow for times of no trapping was used to graphically estimate the number of parr emigrants, and smolt and intermediate smolt emigrants combined. This method was only applied to the Steamboat and Canton Creek traps from April 11 to June 14, 1988 (65 nights) when traps were under repair. It was applied to 12 nights for the Steamboat Creek trap, and 26 nights for the Canton Creek trap. Additional parr estimated by streamflow constituted 14%, smolts 16%, and intermediate smolts 13% of the adjusted basin total for the entire time of trapping from April 11 to December 19, 1988. No estimates of emigrants were made when streamflows exceeded those of the data set; this occurred for the same nine nights in both Steamboat and Canton Creek.

The Canton Creek trap was operated approximately every other week, from July 3 to November 3, 1988. This was done to conserve

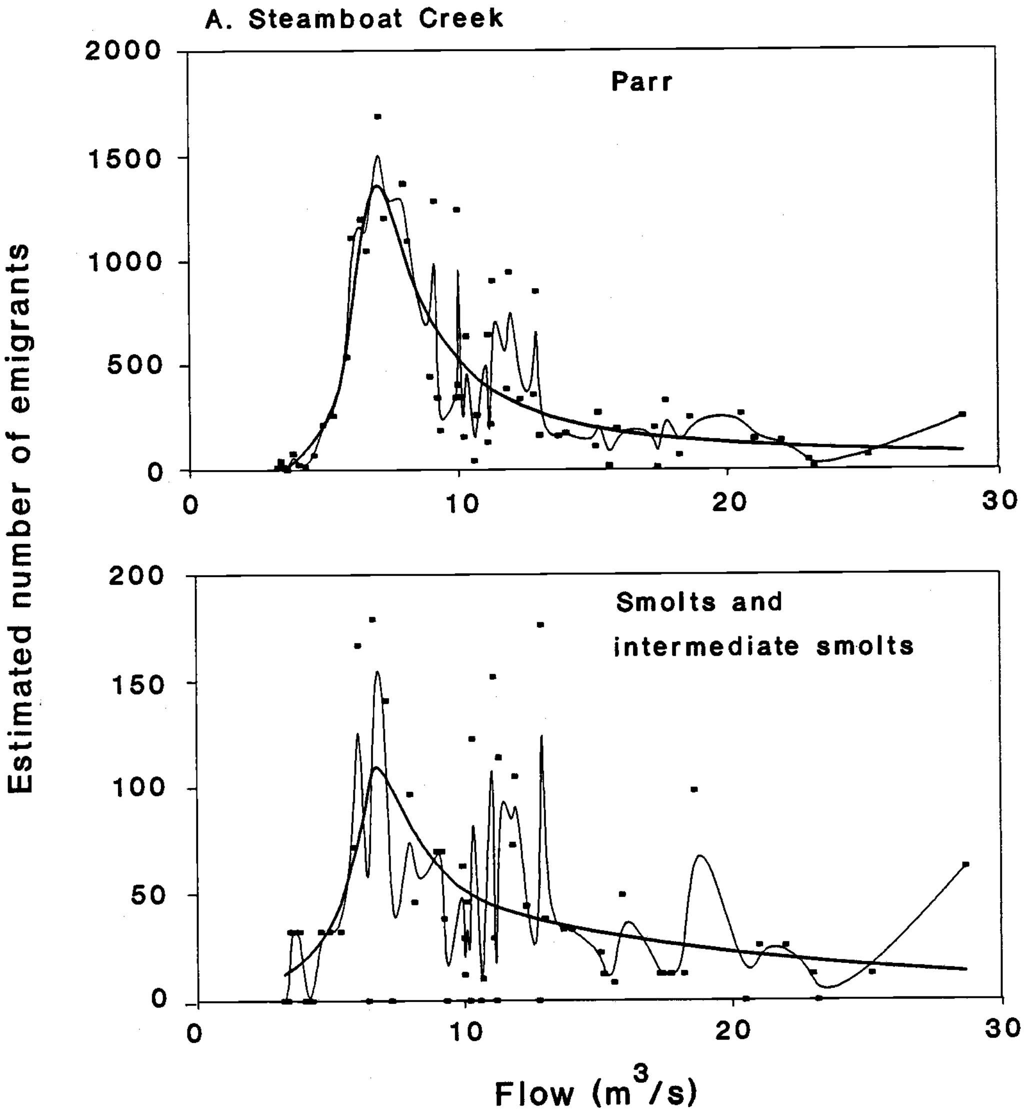


Figure 3.4. Relation between estimated number of juvenile steelhead emigrants and flow. (A) for Steamboat Creek, Oregon, April 11 to July 3, 1988. Thin lines were drawn by locally weighted regression, thick lines were visually placed and used to estimate emigration for times of trap repair.

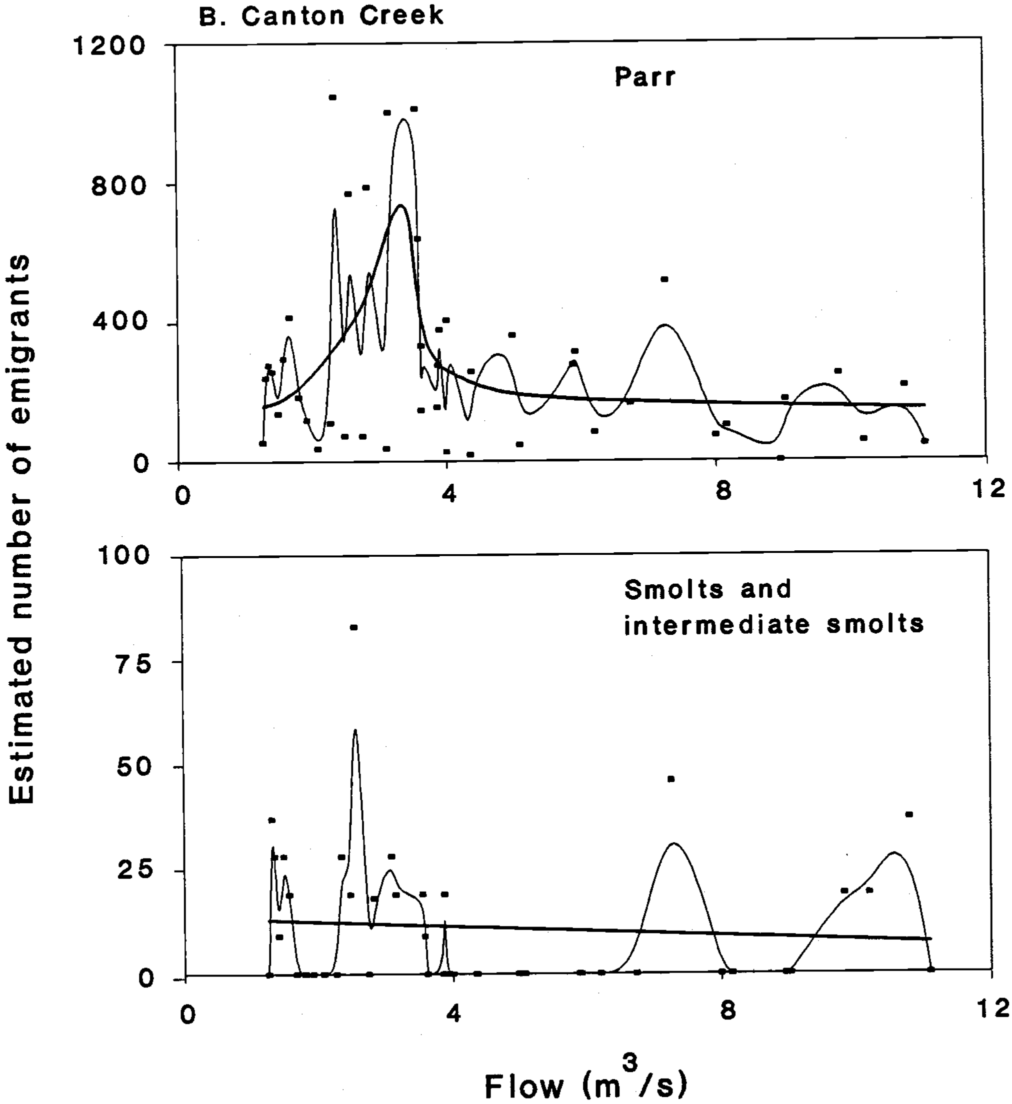


Figure 3.4 (continued). Relation between estimated number of juvenile steelhead emigrants and flow. (B) for Canton Creek, Oregon, April 11 to July 3, 1988. Thin lines were drawn by locally weighted regression, thick lines were visually placed and used to estimate emigration during times of trap repair.

labour for basin fish and habitat surveys. The relationships for flow and emigration used for data prior to July 3 (Figure 3.4) were not used to expand for periods of no trapping, since they were considered as being valid only for springtime emigration. During the summer, flow did not vary greatly and time-related factors such as water temperature or food availablity could also have been important to emigration. Therefore a time-averaged method was used to expand the data for periods of no trapping. Estimates of emigration during times of no trapping were made by separately calculating the average number of emigrants from the trapping periods immediately before and after. A mean of these two averages was then calculated and applied to the intervening days. This allowed each period of trapping to independently contribute to two adjacent periods of no trapping. This same method was also used to estimate emigrants for six nights in Steamboat Creek, during times of trap repair, from November 4 to 21, 1988. The numbers of fish estimated from this method were divided into smolt and intermediate smolt categories and into length classes in proportion to numbers estimated from actual captures by two-week intervals. This accounted for an additional 4% of parr, 0.6% smolts, and 0.8% intermediate smolts being included into the total basin estimates (see Appendix Table 3.1).

Estimation of Age 0 Emigration

No attempt was made to calculate trapping efficiencies for age 0 steelhead, though the number captured each day was recorded during routine trap operations. Length-dependent efficiencies documented for the smallest size class of parr (Figures 3.2 and 3.3) were applied to the daily capture data of age 0 steelhead from both traps. The average number of age 0 steelhead captured per day over two-week intervals was used to estimate emigration for days of no trapping within each two-week interval.

Proportional Substitution of Trap Data

To give a crude estimate of the number of steelhead emigrants from Steamboat Creek during the 14 weeks in the summer when the 3/4-size Humphreys trap was unreliable, data from Canton Creek were substituted based on proportions derived from the first 12 weeks of trapping when traps in both streams were successfully operated. During this time parr from Canton Creek comprised 41%, and Steamboat Creek 59% of the basin total. Estimated numbers from Canton Creek were multiplied by 1.44 (0.59/0.41) to generate an estimate of approximately 4700 Steamboat Creek parr emigrants. Similarly, this method was applied to a two-week period in the fall when the Canton Creek trap was in disrepair, which added approximately 1700 parr emigrants to the basin total. Together these additional parr constituted 10% of the increased basin total. By the same method additions of smolts were 7%, intermediate smolts 4%, and age 0 emigrants 50% of the increased basin totals (see Appendix Tables 3.1 and 3.2).

Results

Length-frequency of Emigrant Steelhead

The majority of juvenile steelhead migrating out of the Steamboat Creek basin were parr (Figure 3.5); estimated numbers of smolts and intermediate smolts were an order of magnitude less than parr. The majority of parr were probably one year old, based on size. Intermediate smolts were smaller on average than fully developed smolts. They ranged from 95 mm to 170 mm in fork length, with a mean of 125 mm. Smolts ranged from 95 mm to 220 mm in fork length, with a mean of 138 mm. Two fish captured in the Archimedean screw trap on November 19 exhibited full smolt characteristics, and one was the largest sized emigrant (255 mm) captured during the entire nine months of trapping. Length-frequency data are presented in Appendix Table 3.3.

The length of emigrants changed over the course of trapping operations (Figure 3.6). Trends differed between developmental classes, and there were differences between parr from Steamboat Creek and Canton Creek. The average length of steelhead parr generally increased at a rate that is presumably a result of normal growth. During the first six weeks of trapping, intermediate smolts from Steamboat Creek averaged 128 mm in fork length, and then decreased to 111 mm by the twelfth week of trapping; smolts decreased from 165 mm to 121 mm by the tenth week of trapping. These decreases coincided with changes in the minimum size of fish displaying full smolt characteristics. During the first six weeks of trapping, the absolute minimum length measured for a fully developed smolt was 138 mm. This is just 2 mm less than what is considered to be a minimum fork length for steelhead smoltification (140 mm, Wagner et al. 1963). After the sixth week emigrants as small as 95 mm exhibited full smolt characteristics.

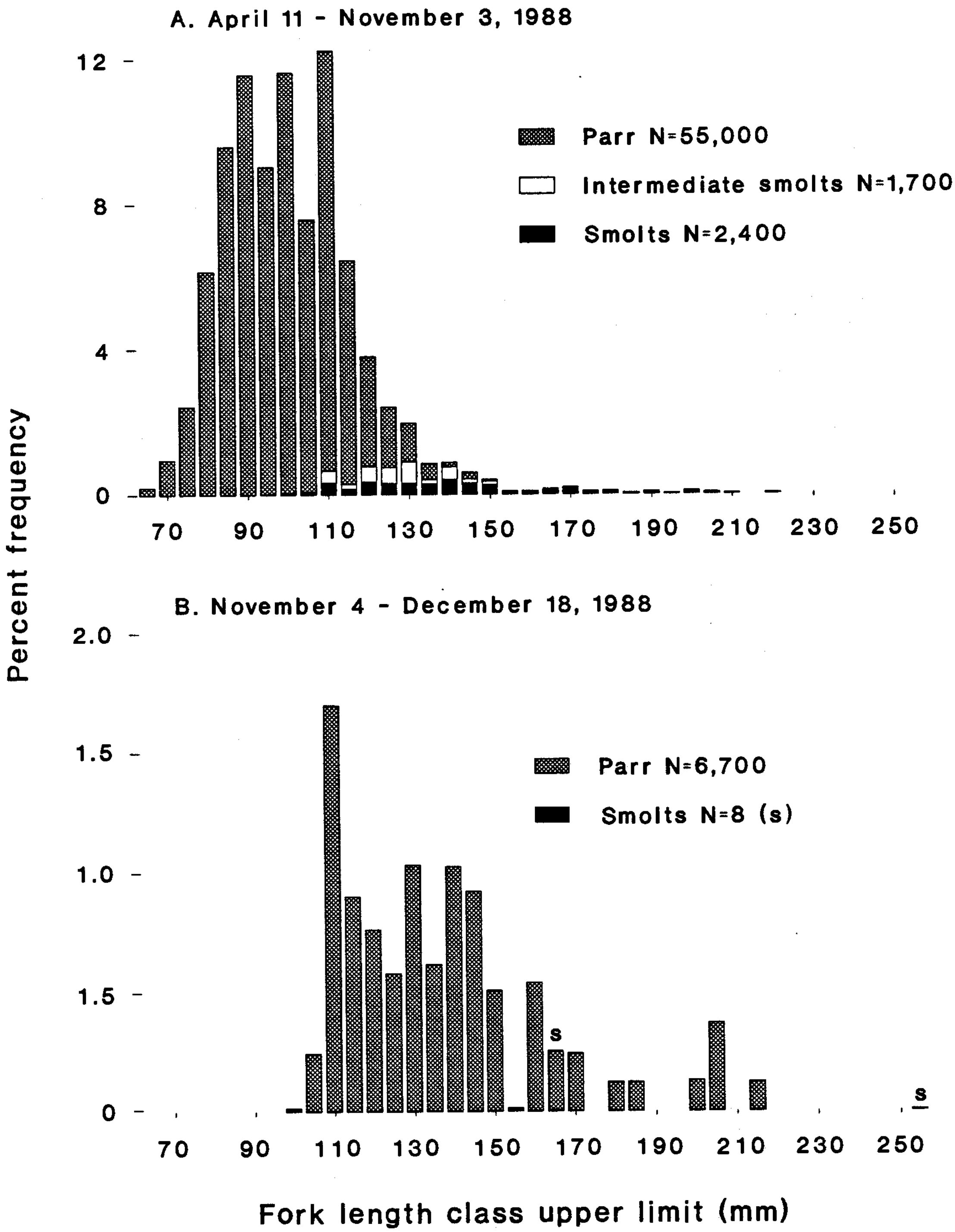


Figure 3.5. Length-frequency distribution of age >1 steelhead emigrants from Steamboat and Canton Creek, Oregon. (A) April 11 to November 3, and (B) November 4 to December 18, 1988, with total estimated number. Percent frequency is based on total emigration April - December.

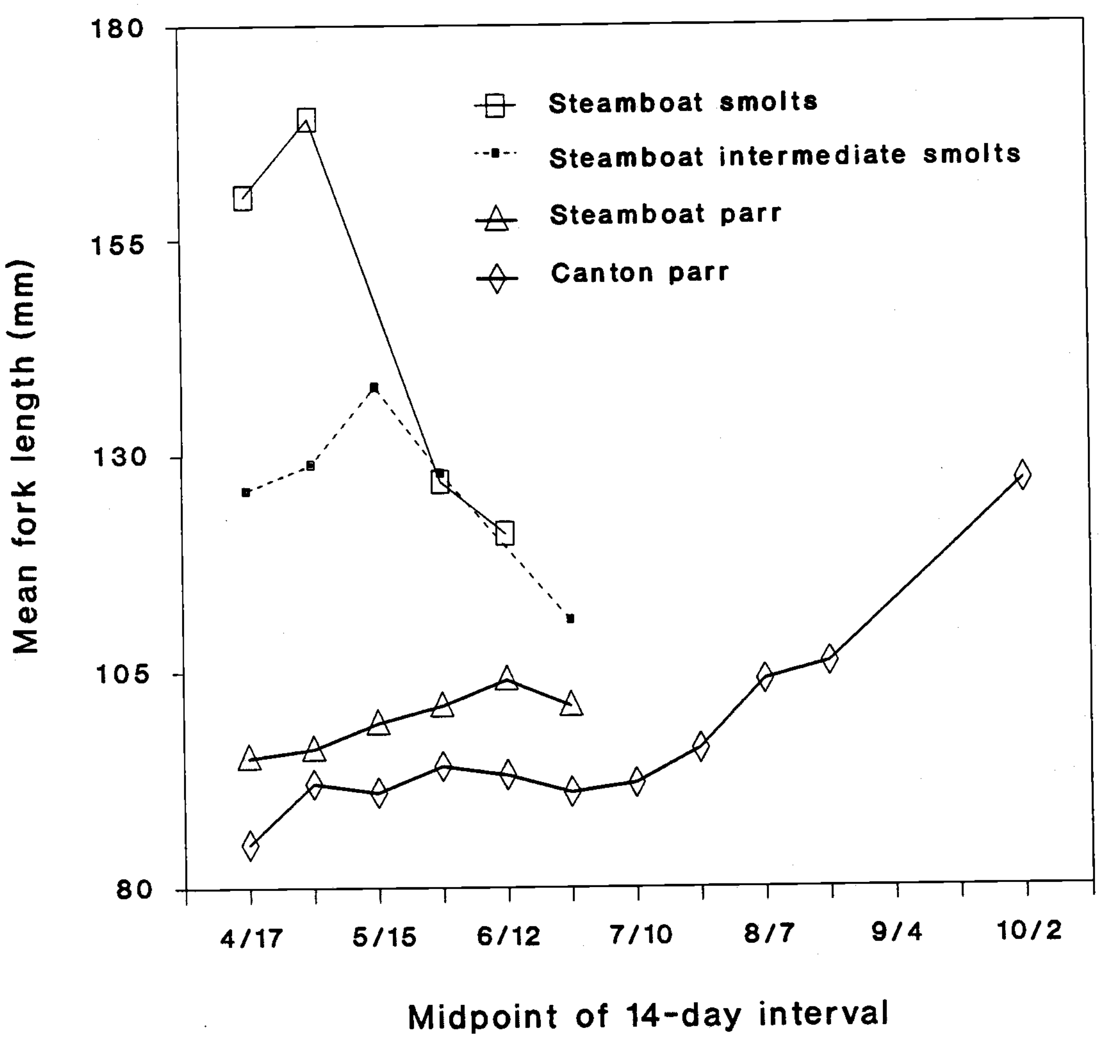


Figure 3.6. Mean fork length of juvenile steelhead emigrants from Steamboat and Canton Creek, Oregon, April 11 to October 9, 1988. Data omitted if mean from less than 80 estimated emigrants.

Estimated Numbers of Emigrant Steelhead

From April 11 to December 18, 1988 roughly 61,000 steelhead parr were estimated to have emigrated from the Steamboat Creek basin (Figure 3.7). Of these fish 76% left with emigrating smolts, 13% over the remaining summer, and 11% in the fall. The emigration of parr peaked in late May and ceased completely in September. Parr emigration twice increased from zero levels in late summer and fall when streamflows increased above base level by storm flow (Figure 3.8). The final decline in parr emigration in late November coincided with water temperatures in the basin dropping below 7°C.

There were roughly 2,400 smolt and 1,700 intermediate smolt emigrants estimated from trapping operations (Figure 3.7). The combined emigration of smolts and intermediate smolts reached its greatest level in late May and ended by July 1, except for two fish exhibiting smolt characteristics that were captured on November 19. Steamboat Creek and Canton Creek, respectively, contributed 81% and 19% of the smolts, 82% and 18% of the intermediate smolts, and 59% and 41% of the parr migrating out of the Steamboat Creek basin. Since large numbers of emigrants were captured from the very beginning of trap operation, considerable numbers probably left prior to April 11, and these estimates underrepresent actual numbers.

An estimated 122,000 age 0 steelhead left the Steamboat Creek basin during trap operations (Figure 3.7C). Newly emerged steelhead fry with fork lengths of 33 mm were first captured from Canton Creek on April 26. The first age 0 steelhead were captured from Steamboat Creek 19 days later on May 15, and averaged 32 mm in fork length. This difference in timing of first capture may simply be due to proximity of redds above the traps. Large numbers of age 0 steelhead were not captured until early June, when streamflow approached base level. Like older emigrants, virtually all age 0 steelhead were captured during the night, and their emigration also appeared to be lower when flows were high and turbid. The emigration of age 0 steelhead peaked in early August, and dropped to zero in the middle of September. Two minor peaks of age 0 emigration in late summer and

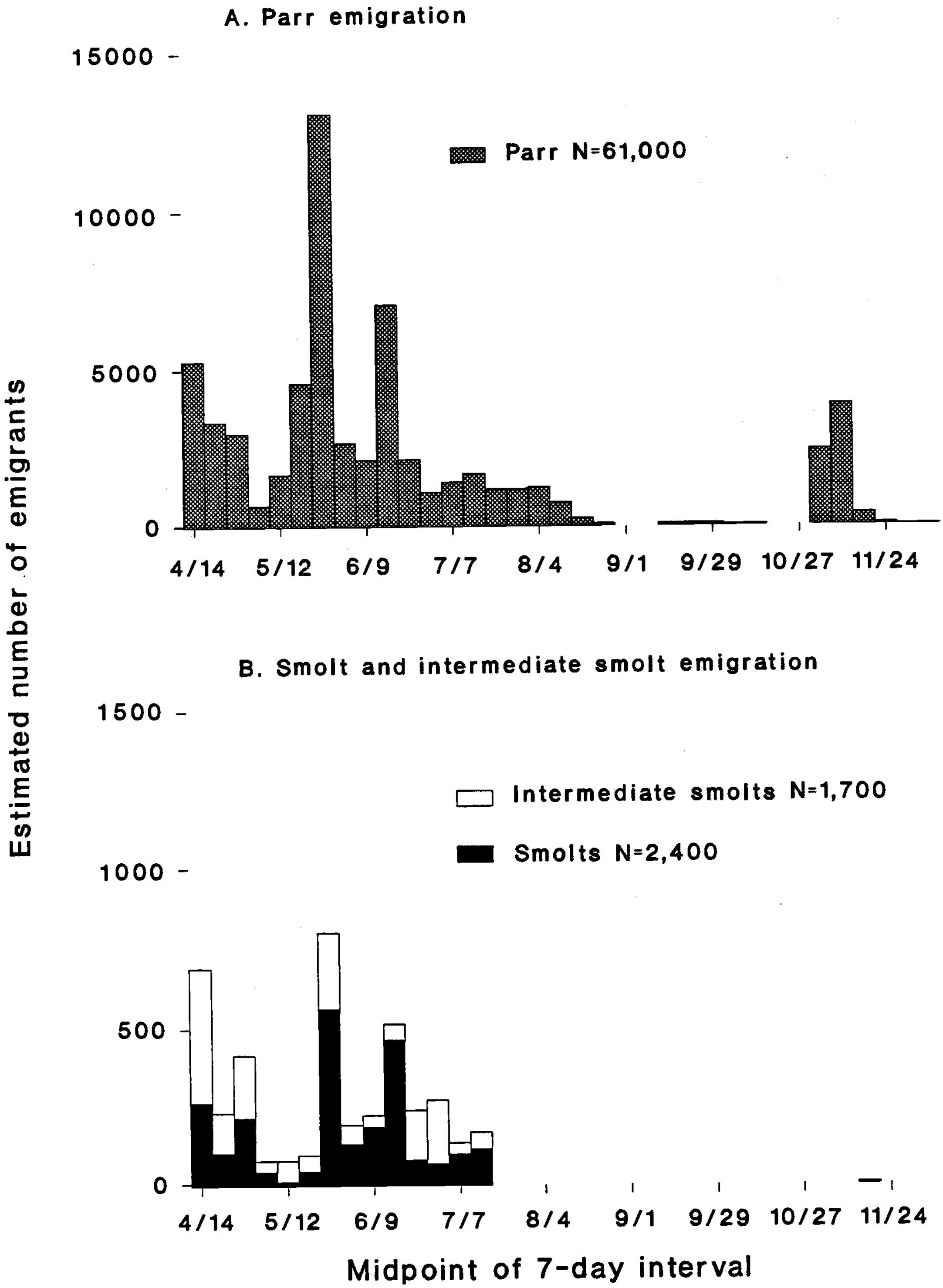


Figure 3.7. Emigration of steelhead (A) parr, and (B) smolts and intermediate smolts from Steamboat Creek basin, Oregon, April 11 to December 19, 1988. Note the different y-axis scale for A and B.

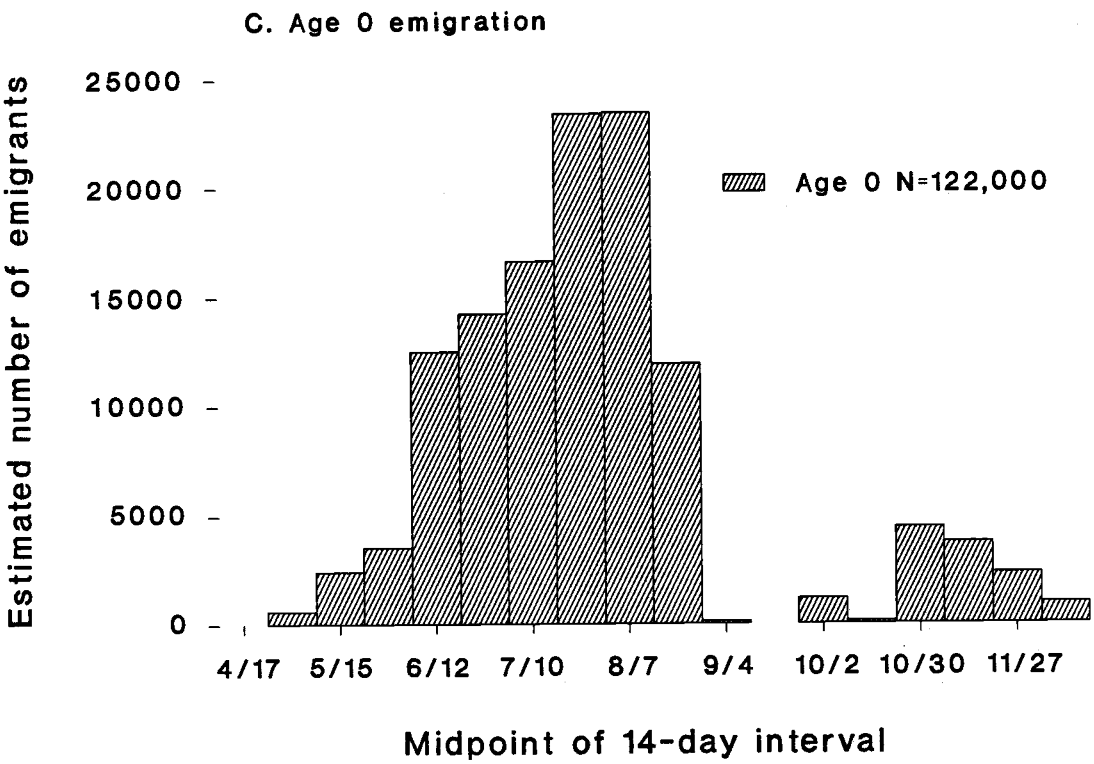


Figure 3.7 (continued). Emigration of (C) age 0 steelhead from Steamboat Creek basin, Oregon, April 11 to December 1988.

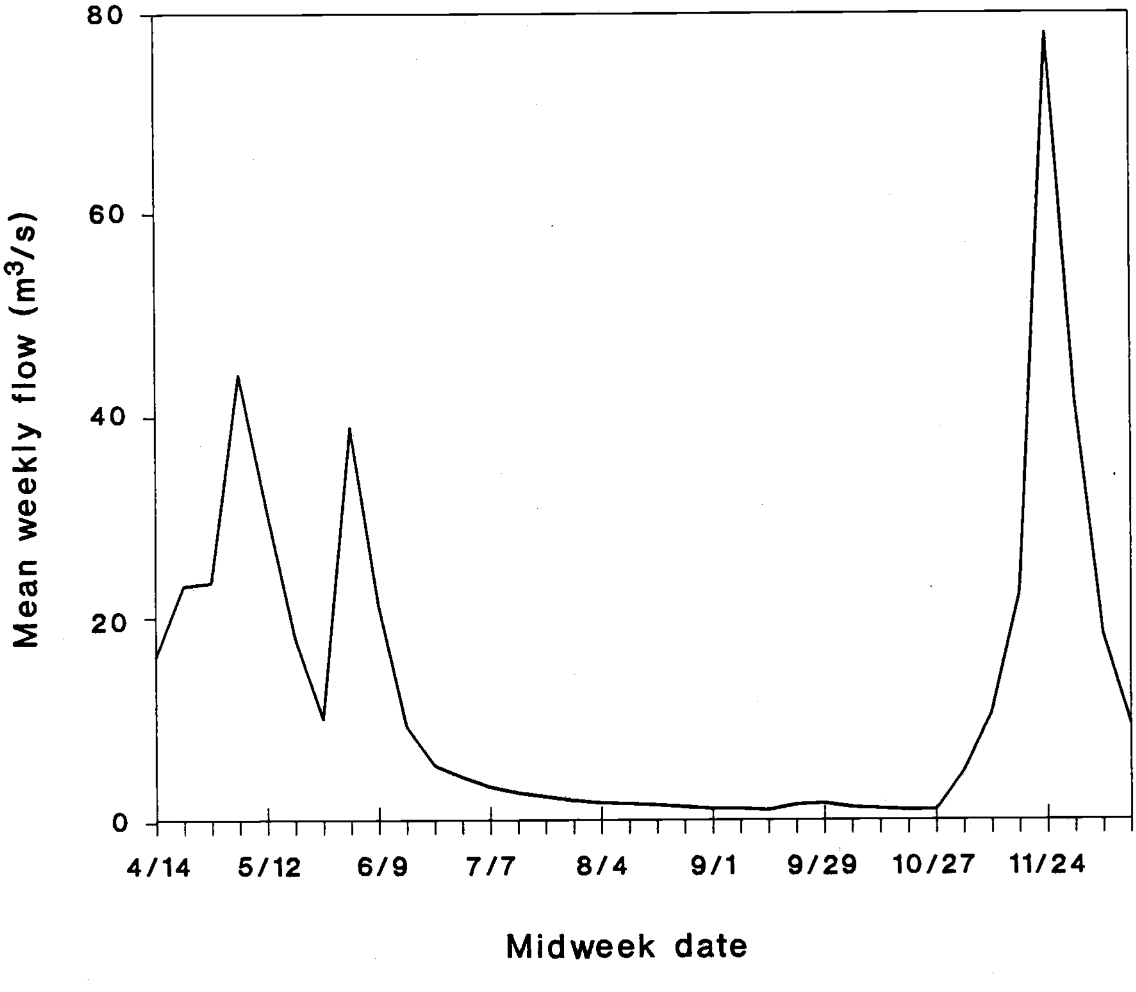


Figure 3.8. Mean weekly flows from Steamboat Creek basin, Oregon, April 11 to December 19, 1988. Data from USGS mean daily flow records.

fall coincided with increased flow, a similar phenomenon to that recorded for parr emigrants. But unlike parr emigrants, modest numbers of age 0 fish were captured after water temperatures dropped below 7°C in late November. During the last four weeks of trap operations age 0 steelhead ranged in fork length from 44 mm to 96 mm, and averaged 70 mm. Estimates of age >1 and age 0 steelhead emigration from Steamboat and Canton Creek are presented in Appendix Tables 3.1 and 3.2, respectively.

Basin Analysis: Rearing, Emigration, and Mortality of the 1987 Cohort

By combining basin fish population estimates in 1987 and 1988 from Chapter 2 with the above emigrant estimates, a numerical chronology can be constructed that details the fate of the 1987 cohort of newly emerged juvenile steelhead (Figure 3.9). Emigrant smolt and intermediate smolt numbers from the spring of 1988 were applied to 1989, and age 0 emigrants from 1988 were applied to 1987 to portray a full 2-year cycle of stream residence. Such a chronology is necessarily based upon a number of assumptions: That 1) the number of juvenile steelhead emigrating as age 0 fish, smolts, and intermediate smolts does not vary from year to year, (this assumption is supported by the relatively equal estimates of total numbers of age 0 and age >1 steelhead in the basin for 1987 and 1988, Table 2.4); 2) no fish emigrated before or after the trapping period; 3) there is no net migration of juvenile steelhead into the basin; 4) all mortality occurs during the winter; 5) all fish classed as parr were age 1, and all smolts and intermediate smolts were age 2.

Many of the above assumptions are not fully met. Some number of fish emigrated before trapping started, and significant mortality can probably be attributed to summertime predation by mergansers (a frequently observed activity) or disease. Both lead to inflated estimates of winter mortality. Also, the possibility that half of the smolts are of age 3 (see introduction of this chapter) further complicates this analysis. At best this chronology portrays the fate of juvenile steelhead in the Steamboat Creek basin by approximate

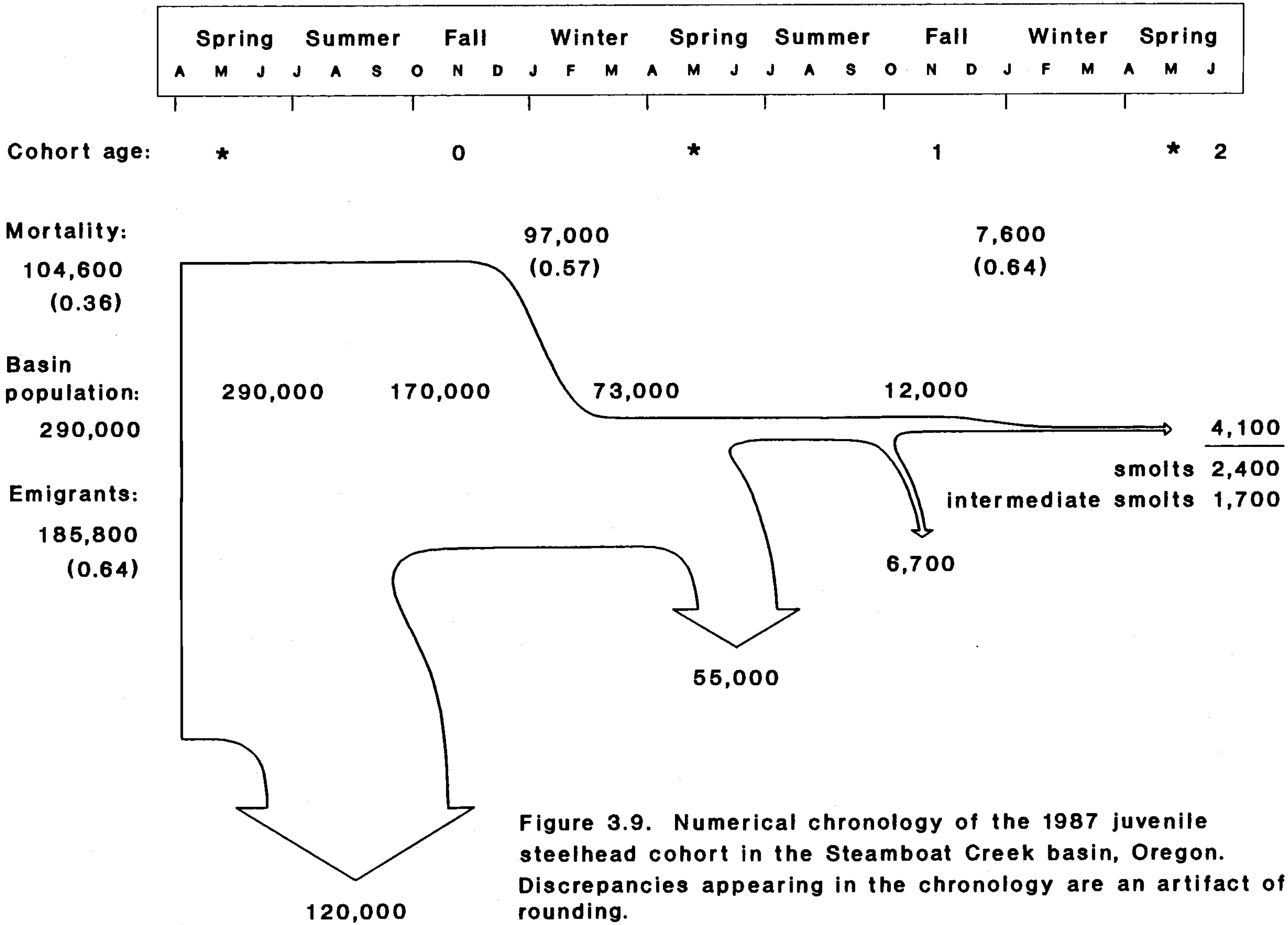


Figure 3.9. Numerical chronology of the 1987 juvenile steelhead cohort in the Steamboat Creek basin, Oregon. Discrepancies appearing in the chronology are an artifact of rounding.

magnitude only. Small discrepancies appearing in the chronology are an artifact of rounding.

Starting with 290,000 newly emerged steelhead fry, 42% left the basin during the spring, summer and fall. The mortality of age 0 fish in the basin during the first winter was 57%. Of the survivors, 75% left the basin in the spring and summer and 9% in the fall; only 16% lived in the basin as age 1 fish through the next fall. The mortality of age 1 fish in the basin during the second winter was 64%. The surviving smolts and intermediate smolts totaled 1.4% of the original population, and were 3.4% of age 0 emigrants and 6.7% of the emigrants that left after surviving their first winter in the basin. Of the original cohort of 290,000, 36% was lost to mortality and 64% emigrated.

The amount of spawning gravel required to produce the 1987 natal population can be calculated by applying a range of high and low production factors. Assuming a range of fecundity of 2,000 to 4,000 eggs per female spawner (Bell 1986), and a range of egg to fry survival of 10% to 50%, a possible 145 to 1,450 female steelhead produced the 1987 cohort. Assuming a need of 4 m^2 of spawning gravel per female, a total of 580 to 5,800 m^2 of spawning gravel would have been required. A total of 4,900 m^2 (1,800 m^2 good quality, 3,100 m^2 marginal quality) of spawning gravel was inventoried in the basin in 1987 (Table 2.2).

In 1986 a total of 18,200 wild steelhead adults were estimated to have passed above the Winchester Dam, 74 river kilometers downstream of Steamboat Creek in the North Umpqua River (Oregon Department of Fish and Wildlife, Umpqua District, 4192 North Umpqua Highway, Roseburg Oregon; unpublished data). Assuming a male to female sex ratio of 50% for these wild adult steelhead, the estimated range of females needed to produce the 1987 cohort constituted 1.6% to 16% of the total wild female escapement above Winchester Dam in 1986.

Escapement of wild adult summer and winter steelhead into the North Umpqua River was relatively high for the years producing the age 0 cohorts in this study. During 1986 and 1987, counts of wild adult summer steelhead over Winchester Dam were 7,700 and 5,400, respectively; counts of wild winter steelhead were 10,500 and 8,100, respectively. From 1946 to 1990, counts of wild summer steelhead adults ranged between 1,300 and 8,300, and averaged 3,500. Counts of wild winter steelhead ranged between 3,800 and 11,200, and averaged 7,200.

Discussion

Studies of juvenile steelhead migration commonly focus on movements of smolts, with less attention given to younger age classes. Fewer still are accompanied by estimates of the total juvenile steelhead population rearing above trapping sites. An ideal comparison with Steamboat Creek is afforded by Everest et al. (1988), who summarize 6 yrs of total basin population estimates of juvenile steelhead, and 3 yrs of emigrant estimates from Fish Creek, Oregon, which is also a west slope Cascade basin of similar elevation. Other studies of juvenile steelhead emigrations useful for comparison are from Waddell Creek, California (Shapovalov and Taft 1954), Gobar Creek (Lieder et al. 1986) and Snow Creek, Washington (Loch et al. 1988), the Keogh River and Quinsam Creek, Vancouver Island (Pat Slaney, Ministry of Environment and Parks, Recreational Fisheries Branch, 2204 Main Mall, Vancouver B.C. V6T 1W5; personal communication), Big Springs Creek and the Lemhi River, Idaho (Bjornn 1971, Chrisp and Bjornn 1978), and from small tributaries of the Rogue River (Everest 1973, Faudskar 1980).

Mortality Estimates

My estimate of 57% winter mortality for age 0 steelhead in Steamboat Creek is below the range of 60 to 86% mortality reported for Fish Creek over five consecutive years (Everest et al. 1988). In Fish Creek age 0 winter mortality appears to be related to a fixed amount of suitable winter habitat, with a relatively constant age >1 population produced each summer despite a widely fluctuating age 0 population. My estimate of 64% winter mortality for age >1 steelhead in Steamboat Creek is extreme compared to Fish Creek, which has ranged from 18 to 60% (Everest et al. 1988). The mortality estimate of 60% in Fish Creek was associated with a large flood event, while the lowest estimate was associated with moderate winter flows. In Steamboat Creek the winter flows in 1987 were relatively moderate. High age >1 steelhead mortality during this year implies that winter habitat for age >1 steelhead in Steamboat Creek may be quite poor. But it must be cautioned that the estimate for age >1 mortality relies in part upon substitution of 1988 estimates of summer and fall parr emigration to 1987. Furthermore my estimates of emigration lack confidence limits.

Age 0 Steelhead Emigration

Age 0 steelhead comprised the largest portion (65%) of steelhead migrating from Steamboat Creek. The peak emigration of age 0 steelhead from Steamboat Creek coincided with stream flows receding to base level in the summer, while two small pulses in emigration coincided with the increase of streamflow above base level in the fall. A large magnitude of age 0 emigration is commonly reported in other studies as well. Age 0 fish totaled 40% of all steelhead emigrants from Waddell Creek, with peak migration occuring in the summer (Shapovalov and Taft 1954). A major portion of age 0 steelhead populations migrated out of small intermittent tribuaties of the Rogue River in concert with summer flow recession (Everest 1973, Faudskar 1980), and large numbers of age 0 fish emigrated from Big Springs Creek during the fall and winter in search of large substrate suitable for winter habitat (Bjornn 1971, and Chrisp and Bjornn 1978).

Parr Emigration: the Influence of Basin Size and Downstream Rearing Potential

That large numbers of steelhead parr emigrate from small basins has recently been emphasized by Leider et al. (1986) and Loch et al. (1988) in studies of Gobar Creek, a third-order basin in western Washington, where parr comprised 77% of age >1 emigrating steelhead. Leider et al. (1986) reported that the majority of parr that left Gobar Creek did not pass below a trapping site 14 km downstream in the mainstem of the Kalama River. Many parr emigrants successfully reached smolt stage, presumably rearing in the Kalama River mainstem. Only about seven percent emigrated back into Gobar Creek. Loch et al. (1988) suggest that downstream rearing conditions are important to the relative magnitude of the parr emigration, and demonstrated that, compared to Gobar Creek, relatively few parr left Snow Creek, a third order basin that directly enters Puget Sound, Washington.

Results from other trapping studies also suggest that the proportion of age >1 juvenile steelhead emigrants may be related to basin size (Table 3.2). Shapovalov and Taft (1954) reported parr to comprise 67% of the total number of age >1 steelhead emigrants from Waddell Creek, a third order basin in California, over a nine year study period. Age 2 emigrants comprised 31% of age >1 emigrants, with age 3 and age 4 emigrants totaling 1.7 and 0.063% each. Upstream migrants totaled only 8% of downstream migrants. Fish that were not immediately destined for ocean entry were presumed to have overwintered in the 1 km of stream below the trap and in a lagoon that was intermittently open to the ocean, and which fluctuated in depth from a few centimeters to a few meters. Of the 116 returning adults that were marked as age 1 emigrants, 92% (107) were determined, from scale analysis, to have spent an additional year rearing downstream of the trap before ocean entry; the remaining 8% entered the ocean as age 1 fish and survived to return to Waddell Creek as mature adults.

Unpublished data (Pat Slaney, personal communication) from Quinsam Creek, a third order stream in Vancouver Island, show parr totaling up to 75% of the age >1 emigrants in the spring. Approximately 160 km to the north in the Keogh River, up to 50% of the spring emigration of age >1 fish were parr (Pat Slaney, personal communication).

Data presented by Chrisp and Bjornn (1978) show parr in Big Springs Creek, a second order stream in Idaho, to emigrate concurrently with smolts during spring months. They comprised 51% of the total age >1 steelhead emigrants. Twenty five kilometers downstream in the fourth order mainstem of the Lemhi River, only 7% of the emigrants were parr during the spring migration of smolts. Large numbers of parr did not migrate down the Lemhi River mainstem until fall, possibly in search of larger sized substrate suitable for winter

Table 3.2. Comparison of parr and smolt proportions in the emigration of juvenile steelhead from nine streams.

Stream and downstream environment	Percent of Age >1 Emigrants: parr	Percent of Age >1 Emigrants: smolts	Stream Order at Trap	Reference
Steamboat Cr., Oregon Large river mainstem	94	6	4	This study
Gobar Cr., Washington Large river mainstem	86	14	3	Loch et al. 1988
Waddell Cr., Califronia Tidal stream mouth and lagoon	67	33	3	Shapovalov & Taft 1954
Quinsam Cr., Vancouver Island Large river mainstem	62[a]	38	3	Unpublished data[b]
Big Springs Cr., Idaho Large river mainstem	51	49	2	Chrisp and Bjornn 1978
Keogh R., Vancouver Island Tidal stream mouth	30[c]	70	3	Unpublished data[b]
Snow Cr., Washington Ocean	20	80	3	Loch et al. 1988
Lemhi R., Idaho Large river mainstem	7	93	5	Chrisp and Bjornn 1978
Fish Cr., Oregon Large river mainstem	5[d]	95	5	Everest et al. 1987

[a] midpoint of a range of approximately 50%-75%.

[b] Pat Slaney, personal communication.

[c] midpoint of a range of approximately 10% to 50% for three years; the year with 10% parr emigration was after a large flood in the basin.

[d] a minor number of parr have been observed to emigrate from Fish Creek, though their numbers have not been included in past reports, the percentage of parr emigrants is near 5% (Fred Everest, personal communication)

habitation (Chapman and Bjornn 1969, Bjornn 1971). Only a minor number of parr emigrated from the Fish Creek basin over a three-year period (Fred Everest, USDA Forest Service, Pacific Northwest Research Station, 3200 Jefferson Way, Corvallis, Oregon 97331; personal communication).

In summary, the additional comparisons of studies in Table 3.2 support the contention of Leider et al. (1986) and Loch et al. (1988) that the emigration of parr can be significant in relatively small basins (Waddell Creek, Quinsam Creek, Keogh Creek, Big Springs Creek, Steamboat Creek). They further demonstrate that the downstream migration of parr during spring smolt migrations can be comparatively less out of larger basins (Fish Creek) or through large mainstem river channels (Lemhi River).

The proportion of parr (94%) in the emigration of age >1 juvenile steelhead from the Steamboat Creek basin represents an extreme compared to other studies (Table 3.2). Only a minor number of parr emigrate from the Fish Creek basin, and summer rearing densities of age >1 steelhead in Fish Creek are an order of magnitude greater than densities in Steamboat Creek (Everest et al. 1987, Table 2.6). This suggests that not only basin size, but also the relative quality of summer rearing habitat is an important factor in determining the relative magnitude of steelhead parr emigrations.

Selection Advantages for Early Emigration of Parr

Is the emigration of steelhead parr mediated by environmental conditions or innate behavior? Both factors are implicated from the comparison of Gobar and Snow Creek (Loch et al. 1988). In Snow Creek, which has no available downstream rearing, the proportion of emigrating parr is the smallest reported for a small basin, and peak parr emigration occurred with the advent of low flows. These parr could thus be characterized as reluctant emigrants responding to the environmental pressure of receding flow. In Gobar Creek, which has ample downstream rearing, large numbers of parr emigrated during the spring with smolts. Though no flow data were available, it is presumed that this springtime migration occurred prior to base flow recession. Since good growth rates have been documented for parr rearing in the downstream Kalama River mainstem it is possible that this life history pattern is actively selected for, and the springtime emigration of parr is controlled by inheritable behavior.

The peak in parr migration appears to be influenced by the nature of the downstream rearing environments. In Waddell Creek, which has an unpredictable downstream rearing potential in a lagoon that fluctuates widely in depth and salinity, parr emigration often peaked in concert with the dropping of streamflows to summer base levels, usually after peak smolt migration. Parr that migrated below the fish trap in the Keogh River did so before low summer flows. These fish had 0.3 km of tidally influenced stream to occupy above the ocean, which apparently provides some measure of rearing, as many of these fish were later observed to migrate back above the trap (Pat Slaney, personal communication). Below the trap at Quinsam Creek is approximately 16 km of a large mainstem channel, and parr also emigrated during the spring when flows were high. Parr migrated out of Big Springs Creek without regard to flow levels (Bjornn 1971) and had free access to the Lemhi River mainstem. Parr leaving Steamboat Creek, which has ample downstream rearing opportunities in the North Umpqua River, peaked in concert with smolts when flows were still high and fluctuating from storm events (Figures 3.7 and 3.8). Hence in small basins, when downstream rearing opportunities are comparatively low or unpredictable, the timing of parr emigration coincides with flows dropping to summer base levels (Waddell Creek, and Snow Creek). And of the streams compared, the smallest proportion of parr emigrants left Snow Creek, which has no downstream rearing opportunities. When the opportunity for downstream rearing is greater, so is the magnitude of the parr emigration, and peak migration occurs prior to low flow recession (Steamboat Creek, Quinsam Creek, Big Springs Creek, Keogh River, and probably Gobar Creek).

Behavior that prolongs use of natal streams until smoltification should be favored by natural selection when downstream rearing conditions produce lower survival for early emigrants. The heritability of such behavior is thought to minimize the loss of juveniles from resident rainbow trout populations above impassable falls (Northcote 1981). In Waddell Creek the survival of marked steelhead from the time of their movement below the trap as age 1 emigrants to the time of their upstream migration as adults was calculated to be 2.4%, compared to 5.8%, 18.1%, and 16.7% survival for juveniles that passed the trap as age 2, 3, and 4 emigrants, respectively (Shapovalov and Taft 1954). These estimates refer only to survival once fish pass below the trap, and do not account for losses accrued by a cohort during stream residence above the trap. I calculate that if 41% or more of the age 1 steelhead that remain above the trap survive to become age 2 emigrants, then that life history pattern would be favored by natural selection. Such a level of overwinter survival is reasonable in a coastal stream such as Waddell Creek. In Snow Creek the emigration of parr is selected against, since all emigrants directly enter the ocean and very few could be expected to survive (Conte and Wagner 1965).

Therefore where downstream rearing opportunities limit survival, emigrating parr should be responding only to environmental and competitive forces, such as those associated with the advent of low summer base flows. In relatively small streams with ample downstream rearing opportunities, survival rates of parr emigrants may approach or exceed those that remain in natal rearing areas. The early emigration of parr in these basins could constitute a successful life history adaptation, and parr may actively emigrate ahead of environmental or competitive constraints. Such an adaptation requires that parr emigrants must be able to return as adults to their natal stream, after rearing at least an additional year elsewhere. Everest (1973) found summer steelhead in the Rogue River acquiring homing imprints after 1 year of age and before smoltification. Natal streams were abandoned by age 0 fish shortly after emergence from the gravel due to streams drying in early summer. Everest speculated that parr emigrants remaining in the mainstem of the Rogue River for an additional year, close to and downstream of the mouth of their natal basin, would likely return as adults to that same section of mainstem. Returning adults would also be most apt to choose their natal basin to spawn in, since it would be the nearest one upstream of their homing site. Quinn (1989) demonstrated a sequential order of imprinting in hatchery reared coho subjected to different water sources from early life to release as smolts. During returning migration adults appeared to seek water sources in an order reversed from that encountered during juvenile rearing, and were able to reach water sources previously encountered as age 0 fish. Whether returning adults of parr emigrants from Steamboat Creek are imprinted while in Steamboat Creek or only in the North Umpqua River has important management considerations. The highest concentration of wild adult summer steelhead holding in the North Umpqua River during the summer is located within the first 300 m downstream of the mouth of Steamboat Creek, in what is commonly referred to by fly fishers as the "Camp Water". It has been standard practice for as many as 60,000 hatchery reared steelhead smolts and intermediate smolts to be released in the North Umpqua River 0.9 km upstream of Steamboat Creek in the spring (Oregon Department of Fish and Wildlife, Umpqua District; unpublished data). It is possible that hatchery smolts might displace smaller parr from Steamboat Creek further downstream in the mainstem North Umpqua than they would normally venture, through competitive interactions. This could shift the homing site of returning wild adults and affect the natural pattern of escapement into Steamboat Creek.

Juvenile steelhead leaving Steamboat Creek selected relatively moderate flow levels for migration; they were not involutarily flushed out of the basin during high and turbid flows. A similar observation was noted in Waddell Creek (see p. 157, Shapovolov and Taft 1954), and Fish Creek (Fred Everest, personal communication). Though there was no monitoring of upstream migration, the data suggest that large numbers of emigrant parr did not reenter the Steamboat Creek basin and stay until April, since very few left as smolts.

Stream temperatures encountered in the North Umpqua River during the summer can be as much as 4°C cooler than the mainstem of Steamboat Creek. Given comparable food availability, summer rearing in the North Umpqua River would afford fish a higher rate of growth than in Steamboat Creek, by virtue of lower metabolic rates (Beamish 1964, Crowder and Magnuson 1983). If parr that emigrate from Steamboat Creek experience higher rates of growth in the mainstem of the North Umpqua River than those that remain, then more might become smolts at 2 years of age instead of 3, and avoid another winter's mortality. If they become larger than the smolts from Steamboat Creek, then they would also have a greater chance of survival to maturity (Wagner et al. 1963, Ward and Slaney 1988). Thus cooler temperatures in the North Umpqua River could favor the early emigration of steelhead parr.

Environmental Pressures for Early Emigration of Parr

It can be argued that the springtime emigration of parr from Steamboat Creek resulted from high seeding levels and poor habitat quality. Age 0 populations in a small basin with good downstream rearing can be bolstered by a large escapement of adults that were originally parr emigrants. Thus the early emigration of parr from a basin such as Steamboat Creek could be caused by environmental factors associated with overseeding and a lack of spring habitat. In small basins with poor downstream rearing potential (i.e. Snow Creek), it is possible that parr do not emigrate during the spring because those basins are underseeded. Small basins without adult returns from parr emigrants may not be fully seeded.

A lack of habitat could be caused by parr emerging from winter cover during the spring needing larger territories than during the preceding summer and fall. For this to occur would require a large increase in the habitat requirements of parr during the spring. In Steamboat Creek I estimated a 57% mortality for age 0 fish during the winter of 1987 (Figure 3.9), and there was at least 10 times the streamflow in the spring of 1988 as there was in the fall of 1987

(Figures 2.4 and 3.8). For habitat to have been limited for parr during the spring of 1988 would have meant that their habitat requirements were over 20 times greater (based on streamflow, and not habitat area) in the spring than in the preceding summer and fall. It seems doubtful that habitat requirements would so greatly increase. Juvenile steelhead typically select feeding loci based upon microhabitat factors of depth, substrate size, and velocity that increase as a function of body length (Everest and Chapman 1972). Juvenile steelhead in the west slope of the Cascades grow very little if at all during the winter (Everest et al. 1987), so based on body length their habitat requirements should not be greatly different from the preceeding fall.

From this study there is no way to conclusively prove whether environmental or life history adaptations motivated the large springtime emigration of steelhead parr from Steamboat Creek. A good test of this question could be provided by manipulating population levels in certain tributaries or reaches of stream in conjunction with emigrant trapping. Another approach would be to repeat this study during a series of years where escapement is so low as to cause underseeding. For comparison, similar work could also be done in streams with limited downstream rearing opportunites.

Winter Emigration and Habitat Use

Age 0 fish were still emigrating after stream temperatures dropped below 7°C in November, while age >1 were not. In mid-December only age 0 steelhead, and no age >1 fish, were caught by electrofishing in Little Rock Creek during daylight hours. At night while snorkel diving with flashlights, with water temperatures at 0.5°C, numerous age >1 steelhead were observed in pool habitat that had been repeatedly electrofished the previous day. I assume that age >1 fish were deep in boulder crevices during the day.

These observations agree with experiments on winter habitat use of juvenile steelhead from Fish Creek, where it was observed that age >1 steelhead sought winter habitat many days before age 0 fish. In a laboratory stream channel age >1 steelhead shifted to substrate crevice cover when stream temperatures fell below 7°C, while age 0 fish delayed use of cover until temperatures approached 2°C (Everest et al. 1986).

Fish that left the Steamboat Creek basin during the initial decrease of stream temperatures may have been suffering from physiological stress. Brook and brown trout in the Credit River, southern Ontario, experience great stress during their physiological acclimation to lowering stream temperatures in the early winter (Cunjak 1988). It is much easier for fish to acclimate to increasing rather than decreasing temperatures (Fry 1971, Cunjak 1988), so the emigration of Steamboat Creek parr in the spring is likely not a consequence of stress from rising stream temperature.

Size of Juvenile Steelhead Emigrants

The changes in emigrant size over time noted in Steamboat Creek are common in other streams. An increase in the average length of parr emigrants over time was demonstrated in Waddell Creek (Shapovalov and Taft 1954). And a decrease in the average length of migrating smolts occurs during the last few weeks of the smolt migration in Fish Creek (Everest et al. 1987), and Gobar Creek (Loch et al. 1988). In Gobar Creek the later and smaller smolts have been shown to be from younger cohorts (Loch et al. 1988).

Smolts and intermediate smolts emigrating from Steamboat Creek were exceptionally small, both in average and minimum size. The average fork length of steelhead smolts is usually close to 160 mm fork length (Wagner et al. 1963; Chrisp and Bjornn 1978; Everest et al. 1986, 1987, 1988; Loch et al. 1988). The average fork length of Steamboat Creek intermediate smolts averaged 125 mm, smolts averaged 138 mm, and combined they averaged 133 mm. The minimum size at which emigrating steelhead show intermediate smolt or smolt characteristics has commonly been reported to be 140 mm fork length by Wagner et al. (1963), Chrisp and Bjornn (1978), and Everest et al. (1987). Fish less than this size usually represented only a small proportion of emigrants in the above studies, though roughly 30% of the smolts leaving Fish Creek were less than 140 mm in 1987 (Everest et al. 1988). In Steamboat Creek fish less than 140 mm fork length represented a majority of the total number of smolts and intermediate smolts; 90% of intermediate smolts, 62% of smolts, and 73% combined were less than 140 mm fork length. Few of the fish less than 140 mm would survive to return as adults if they entered the ocean at that size. Survival of smolts to adult age is strongly size dependent and is related to an optimal size at ocean entry. Wagner et al. (1963) found that the highest survival to maturity was obtained for hatchery-reared smolts released at fork lengths greater than or equal to 160 mm; smaller smolts, especially those below 140 mm fork length, experienced poor survival to maturity.

CHAPTER 4. MANAGEMENT CONSIDERATIONS

Basin Perspective

The Steamboat Creek basin offers only partial juvenile-to-smolt rearing for the majority of steelhead originating in the basin. In comparison to other steelhead streams, Steamboat Creek ranks low in summer densities of juveniles. The basin is a poor producer of smolts, as scaled by the relative proportion of parr to smolts, and in terms of smolt size. Also, estimates of winter mortality are high. But emigrant parr rearing outside of the Steamboat Creek basin, presumably in the North Umpqua River, may represent an active life history adaptation that contributes significantly to adult returns back into the basin. This necessarily extends the definition of a biologically meaningful "basin" to also include the North Umpqua River.

Summer Habitat

What benefit can enhancement of summer habitat be expected to have upon the steelhead population in the Steamboat Creek basin? The answer to this question can be extracted, in part, from Figure 2.8. Stream size (as described by mean riffle depth) apparently creates an upper limit on density of age >1 steelhead rearing during the summer in stream channels of presumably good habitat quality. Habitat quality here is related to channel roughness associated with large boulder substrate. But beyond this natural form of channel roughness, habitat quality can be increased through the placement of boulder and log structures, and the creation of pools and interstitial crevice cover through blasting bedrock with explosives (Fontaine 1987). As an example of increased carrying capacity, blast pools were estimated to hold 17% (140 fish) of the total number of age >1 steelhead in Little Rock Creek during the summer of 1988. These pools were placed in shallow reaches of bedrock that previously lacked age >1 steelhead

(Fontaine 1987). Unfortunately it was not possible to document the effect of other types of habitat structures placed in Little Rock Creek, since they augmented previously utilized reaches.

The middle and upper mainstem segments of Steamboat Creek are not viable candidates for habitat enhancement efforts because of their low channel gradients (0.76% and 0.78% slope respectively). These segments are dominated by long deep pools, where increases in log or boulder structure will have little effect in creating tumbling flow (Peterson and Mohanty 1960) or lateral flow accelerations (Herbich and Shulits 1964) important for feeding microhabitats (Smith and Li 1983). What little riffle habitat that was available was already heavily utilized by age >1 steelhead due to the high temperatures of those reaches (Figure 2.7). In the upper segment of Steamboat Creek many age >1 steelhead abandoned riffle habitats, and apparently left the entire segment when stream temperatures were increasing to the summer maximum, hence it is likely that extreme temperatures limit the summer carrying capacity in that segment.

Four tributaries are possible candidates for summer habitat enhancement: upper Canton Creek, Steelhead Creek, upper Steamboat Creek, and Reynolds Creek; all have channel gradients of 1.6% to 5.3% slope. Combined these streams had a summer population of 1,300 age >1 steelhead (these figures and the following analysis are based upon means of 1987 and 1988 data). Assuming habitat enhancement efforts were extraordinarily effective in increasing summer carrying capacity, the maximum density that could be realized would be described by the following equation:

(6)
$$y = 0.026 + 0.060\ x\ ,$$

where y = density (number/m^2) of age >1 steelhead in entire channel, and x = mean riffle depth (m) (Figure 2.8).

Given maximum density, there would be an increase of 1,890 age >1 steelhead rearing in these four streams during the summer. This added number would constitute 8% of the total summer population rearing in the basin. Given a winter mortality rate of 0.65 (Figure 3.9) an additional 660 smolts would be produced. Assuming a rate of 0.10 for survival of smolts to maturity (Ward and Slaney 1988), an additional 66 adults would comprise the total net benefit of enhancement efforts in these four streams.

In comparing expected adult returns from natural production with the potential increased production from enhancement (given the same survival rates), the 62,000 emigrant parr that presumably could rear to a smolt stage in the North Umpqua River would yield a net return of 2,170 adults. The expected return from 4,100 emigrant smolts and intermediate smolts would be 410 adults, giving a total projected return of 2,580 adults from natural production. Thus, maximizing the carrying capacity of the four tributaries would increase total adult escapement by only 2.6%. By any measure of a cost/benefit analysis an additional 66 adults cannot be considered a profitable return for the immense effort that would be required to bring these streams to maximum summer rearing density.

The projected increase of adult escapement mentioned above is based upon three assumptions that maximize the benefits of enhancement efforts. Any deviation away from these assumptions would further minimize the number of returning adults expected as a benifit to enhancement efforts. These assumptions are that: 1) maximum summer densities of age >1 steelhead would be achieved with habitat enhancement efforts; 2) winter survival of age >1 steelhead in the North Umpqua River would not exceed that in the Steamboat Creek basin (estimated at 0.35 for winter of 1987); and 3) emigrant parr reared to smolt stage in the North Umpqua River would not grow to a size larger than those reared in the Steamboat Creek basin, and thereby would not experience higher survival to maturity. It is likely that these assumptions are not always true.

Winter Habitat

Though this study examined juvenile steelhead and their habitat only during the summer, winter habitat must also be considered. In

Pacific Northwest streams, as water temperatures drop below 7°C, juvenile steelhead begin to occupy zones of slow current velocities and seek cover in the interstitial crevices of the stream substrate (Everest et al. 1986). The substrate size used is age-class specific, with age 0 fish occupying interstices of cobble size substrate (Bjornn 1971, Bustard and Narver 1975, Johnson and Kucera 1985, Everest et al. 1985 and 1986), and age >1 fish occupying interstices of boulder size substrate (Bustard and Narver 1975, Everest et al. 1985 and 1986). Juvenile steelhead have been shown to readily migrate between stream systems in search of winter habitat (Bjornn 1971, Everest 1973), but will remain in areas of previous summer residence when suitable cover is available (Edmundson et al. 1968, Bjornn 1971).

Everest et al. (1985 and 1986) reported that the highest winter densities of age >1 steelhead in Fish Creek were found in pools that contained interstices formed by complexes of boulder and cobble sized substrate. Age >1 steelhead sought winter cover before age 0 fish, and remained within the low summer flow perimeter of the stream. In winter, age 0 fish were observed to be concentrated in interstices along pool and riffle margins, predominantly outside of the summer flow perimeter.

Fontaine (1987) evaluated juvenile steelhead utilization of various log, boulder, and blast pool structures in the Steamboat Creek basin and found the highest winter densities of age >1 fish to be within clusters of 3 or more boulders placed in pools. Structures placed in riffles, and those with fewer boulders, held very few or no age >1 fish during the winter. Age 0 steelhead exhibited a less restricted utilization, and were found to inhabit crevices of various structures in both riffles and pools. Juvenile steelhead were observed to first occupy crevice cover when stream temperatures dropped below 7°C.

My estimate of 64% mortality for age >1 steelhead over the winter of 1987 is quite high. Reductions in winter mortality would produce a direct benefit of increased smolt production from the basin. Is it possible to improve winter habitat in Steamboat Creek to an extent that is important to smolt production?

In Steamboat Creek, channels with sufficient amounts of large boulder substrate supported the greatest abundance of age >1 steelhead during the summer. Based on observations of Everest et al. (1985 and 1986) and Fontaine (1987), these same channels should also provide good winter habitat, and fish should not have to migrate in search of cover. After stream temperatures in the basin approached and fell below 7°C in November of 1988, only a small number of age >1 steelhead were observed to emigrate. This observation suggests that sufficient winter habitat was available within the basin to provide at least initial winter residency up to December 19, 1988, when trapping ceased. If fish did not move far within the basin to seek winter habitat, then the pattern of age >1 steelhead distribution and abundance in the summer would serve as a template for the winter. During the summer the greatest portion (65%) of age >1 steelhead reared in the mainstem segments of Canton Creek and lower Steamboat Creek.

If enhancement of winter habitat is to be attempted, it should be within these two segments, where the greatest proportion of age >1 steelhead are found in the summer. If enhancement structures are to reduce the winter mortality of age >1 fish in the basin, they must surpass the ability of natural cover to retain fish over the winter, either through the nature of crevices provided, or in permanence at high flows. By nature of the physical scale involved, it is very doubtful that present day enhancement structures can compete with natural channel structure in these two mainstem segments to provide superior crevice cover, or be of greater permanence given the extreme fall and winter flows that occur in the basin.

While it would be possible to build winter habitat enhancement structures that could effectively function in smaller tributary channels, I find no biological or economic rationale for doing so. As noted before, juvenile steelhead had sufficient winter habitat within the basin to preclude their emigration during the advent of winter.

Therefore the amount of winter habitat for age >1 fish apparently was not limiting in the basin. Utilization of habitat enhancement structures may only mean that natural habitat is not being used. To be a net benefit, enhancement structures must be superior to natural cover in providing safe refuge for age >1 steelhead, and fish must occupy it in preference over available natural habitat. Also, any enhancement of winter habitat should not interfere with summer habitat; eg. creation of pools for winter habitat should not eliminate riffle habitat important to the summer carrying capacity of warm streams.

Spawning Habitat

The Steamboat Creek basin can be considered as being fully seeded under the present habitat conditions. The 1987 and 1988 populations of age 0 steelhead were nearly ten times that of age >1 fish (Table 2.4), and it is estimated that emigration of age 0 fish in the summer was as high as 41% of the natal population (Figure 3.9). The projected need for 960 m^2 to 5,800 m^2 of gravel (Chapter 3, page 73) to produce the 1987 cohort compares closely with the 4,900 m^2 inventoried. Therefore spawning gravel did not appear to limit the population.

ODFW stream surveyors inventoried over 54,000 m^2 of spawning gravel in the basin from 1965 to 1967 (Bauer et al. 1967). Thus, in-channel storage of gravel may have decreased by a full order of magnitude during the last 20 yrs (Figure 4.1). During the first survey, channels may have been filled with sediments that entered streams during the great flood of December 1964 (>200 yr recurrence interval), and gravels may have been transported out of the basin in the 20 yrs since. But it is also possible that the actual amount of gravel stored has not decreased as much as the alluvial surfaces have become "armoured" (Richards 1982) through removal of gravel particles, leaving a surface of cobble and boulder substrate. If this trend continues, by either of these two processes, then it is possible that

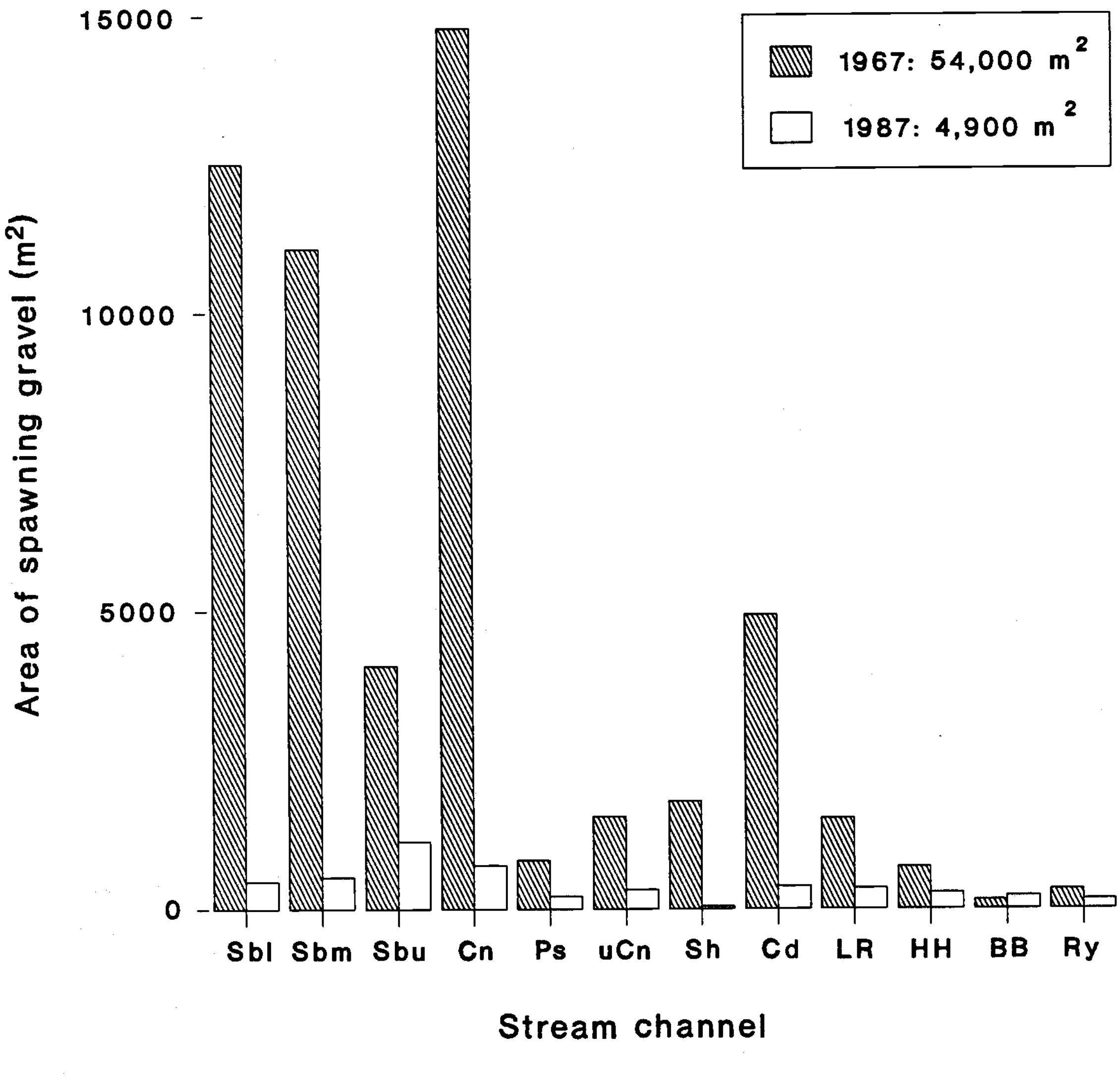


Figure 4.1. Area of spawning gravel inventoried in 1967 (Bauer et al. 1967) and 1987 in stream channels of Steamboat Creek basin, Oregon. Mainstem segments: Sbl: Steamboat lower, Sbm: Steamboat middle, Sbu: Steamboat upper, Cn: Canton, tributaries: Ps: Pass, uCn: upper Canton, Sh: Steelhead, Cd: Cedar, LR: Little Rock, HH: Horse Heaven, BB: Big Bend, Ry: Reynolds; upper Steamboat not shown, it was not completely surveyed in 1967.

a lack of spawning gravel will eventually limit the population of juvenile steelhead in the basin. Enhancement projects aimed at increasing the availability of spawning gravels are recomended if there is less than full seeding of age 0 steelhead. Two criteria to determine less than full seeding are 1) densities of age 0 fish below 0.025 fish/m^2, or 2) a ratio of number of age 0 to age >1 fish near or less than 3 to 1. The first criterion uses summer rearing densities from the years of this study as a comparative base line, while the second is based upon providing a reasonable excess of age 0 steelhead for recruitment into the next age class. These two criteria assume that less than full seeding is not first caused by insufficient escapement. Though it has not been determined if counts of wild adult steelhead over Winchester Dam are indicative of escapement into Steamboat Creek, comparing wild escapement over the dam to age 0 numbers in the following year might be useful in determining if escapement or spawning habitat is limited in the basin. Structures built to retain spawning gravels need to be carefully engineered to be balanced with the stream power at each site. For example, a series of 11 gabions constructed in Pass Creek in the 1970's have retained only large cobble and boulder substrate due to the high stream power in the reach.

In Steamboat Creek large woody debris structure was almost completly lacking in all stream channels surveyed, and this undoubtedly contributes to high sediment transport rates in the basin. Net storage of gravel in stream channels is balanced by sediment supply and transport, and is regulated in part by large woody debris. Large woody debris can form the dominant storage elements of first-, second-, and third-order channels when there is a sufficient supply of wood from old-growth forests, but in larger streams woody debris has little effect on sediment storage (Swanson and Fredriksen 1982). As a matter of scale, structures built to retain spawning gravel in the Steamboat Creek basin will likely meet with greater success in tributaries, where stream power is lower.

It must be appreciated that efforts to increase storage of in-channel sediment are usually far outweighed by large-scale and long-term cycles of sediment supply. In general the high transport capacity of mountain streams can be expected to make them supply limited (Kelsey 1982). Benda (1990) demonstrates a sediment supply cycle with a 6000-yr recurrence interval in a sandstone Oregon Coast Range basin. Progression through states of aggradation and degradation creates channels dominated, respectively, by gravel-bed and boulder-and-bedrock morphology, even in basins with undisturbed old-growth forest cover. The Steamboat Creek basin is dominated by a boulder-and-bedrock morphology (Table 2.2), and in this context is in a state of channel degradation. The permanence of an aggraded state is largely a function of the amount of storage elements in first-, second-, and third-order channels. The storage and regulation of future large-scale inputs of sediment into the basin will depend upon the amount of old-growth trees entering the stream channel from riparian zones. Long-term management of stream habitat in the Steamboat Creek basin should place a premium on protection and development of old-growth trees in riparian areas, even in streams that lack fish.

Effects of Post-1969 Riparian Protection on Stream Temperatures

With the cessation of logging of riparian zones in 1969, stream temperatures have been decreasing in the Steamboat Creek basin (Figure 4.2). I consider the mean maximum temperature for the 10 warmest consecutive summer days used in Figure 4.2 to represent the time of greatest temperature stress for salmonids. The greatest temperature decrease has occurred in Cedar Creek, which has shown a 7.4°C drop from 1973 to 1989. This is a site-specific response to riparian regrowth following complete removal of all trees from the entire valley floor of the north fork of Cedar Creek in 1963. This most drastic case of clear-cutting was in preparation for a reservoir to supplement a proposed Oregon State Game Commision fish hatchery that

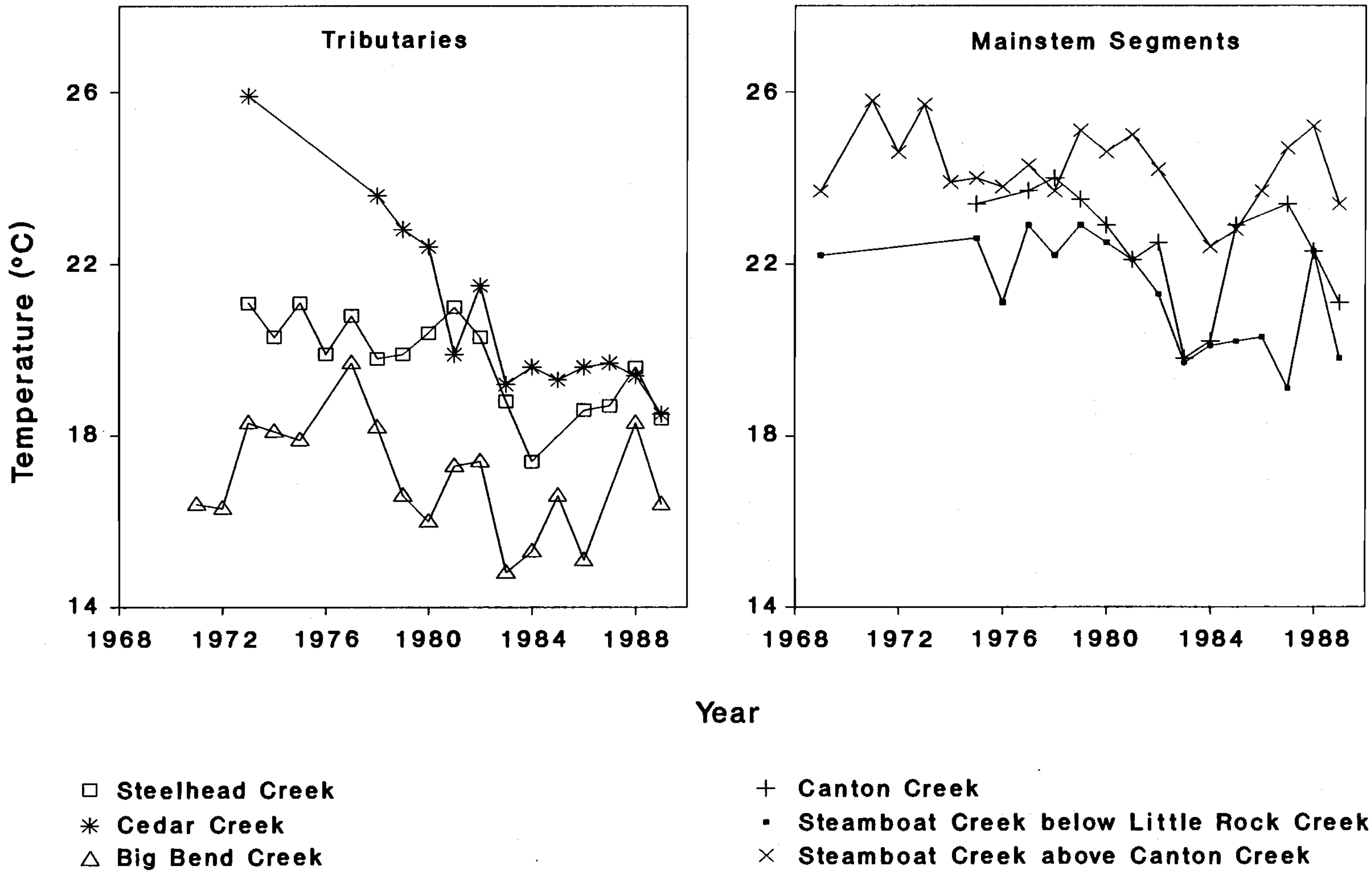


Figure 4.2. Mean 10-day maximum summer temperature in tributaries and mainstem segments of Steamboat Creek, Oregon, 1969 to 1989. Means are of the 10 warmest consecutive days. Data from USFS temperature monitoring sites.

was later judged infeasible and abandoned. Maximum summer temperatures in Cedar Creek from 1963 to 1972 were undoubtedly much higher than those in figure 4.2, and could have been lethal for juvenile steelhead. A long-term decrease appears to be evident in maximum temperatures in Steelhead Creek, in the mainstems of Canton Creek, and in the upper and lower segments of Steamboat Creek, though maximum temperatures for the most recent years appear to rise. These decreases represent a cumulative response from recovery of multiple clear-cut sites upstream of the temperature monitoring stations.

Hostetler (In press) analysed and modeled the stream temperature record for the Steamboat Creek basin, 1969 to 1989, and concluded that a significant decrease in stream temperatures has occurred since 1969 in Cedar Creek, Steelhead Creek, the Canton Creek mainstem, and the upper and lower mainstem of Steamboat Creek. The decrease can be attributed to recovery of riparian zones from pre-1969 logging. In Big Bend Creek, which is fed by deep soil aquifers and has remained largely unlogged, no significant change in temperature has occurred. A rise in temperature in recent years was not explained by climatic factors, and warrants further monitoring and analysis.

During this century, pre-logging stream temperatures in the bedrock dominated mainstems of the Steamboat Creek basin were probably always near or above the upper limit of that preferred by juvenile steelhead. But if ever the mainstems were dominated by an alluvial morphology, as is possible under long-term (thousands of years) fluctuations in sediment supply and storage (Benda 1990), then it is likely that temperatures could have been much lower. Streamflow through an alluvial mainstem channel could have been cooled by intragravel flow, and possibly even received greater shade from a narrower canopy opening. Logging practices from 1955 to 1969 dramatically increased temperatures in the basin almost certainly to the detriment of juvenile steelhead. Stream temperatures are starting to stabilize, though it is not certain if they have returned to pre-logging levels (Hostetler, In press). The distribution, abundance, and habitat utilization of juvenile steelhead were greatly affected by summer water temperature during the two years of this study.

It is my judgement that the single most important factor limiting juvenile steelhead production in the Steamboat Creek basin is high summer water temperatures. The riparian zones of all stream channels, even those of low order streams lacking fish, should be protected to maintain healthy steelhead populations downstream; this should be the single most important management objective in the basin. In particular the Big Bend Creek drainage should receive careful protection so as not to diminish its unique and important function of providing a high volume of cool flow to the mainstem of Steamboat Creek. The cooler middle mainstem segment is targeted by adult summer steelhead for occupancy of resting pools (Wrobles and Roelofs 1985), and a major portion (40%) of age >1 steelhead in the basin benefit from the buffering of high temperatures in the middle and lower segments by Big Bend Creek.

Interative Effects of Stream Temperature and Flow

Interaction between the factors of stream depth and temperature can have important implications for land management. Increasing the temperature regime of a stream can force age >1 steelhead to seek swifter focal points in riffles. In small streams, riffles can be too shallow to use, and fish would likely emigrate in search of deeper riffles or cooler temperatures for a sustained rate of growth. Thus in small streams the net effect of losses of riparian shade can be a reduced carrying capacity for age >1 steelhead.

Timber harvest can decrease summer base flows. Hicks et al. (In press) show that after clearcut and slash-burn logging in a small westslope Cascade basin, similar in elevation and hydrology to Steamboat Creek, mean August streamflows increased 159% above prelogging levels for 8 yrs (1962-1969), but for the next 19 years (1970-1988) mean August streamflow decreased an average of 25% below prelogging levels. Such a decrease in streamflow would decrease depths of riffles to a greater extent than glides and pools (Hicks 1990). It would also cause a 25% potential temperature increase from a given input of solar radiation (Brown et al. 1971). Reduced streamflows would also decrease mean current velocities (Richards 1982), resulting in fewer feeding microhabitats and less available benthic drift (Everest and Chapman 1972, Smith and Li 1983). The net result of all these effects would be a decreased carrying capacity for juvenile steelhead.

Poaching Losses of Adult Summer Steelhead

Wrobles and Roelofs (1985) document that adult summer steelhead have long been threatened by poaching in the Steamboat Creek basin. They report that as many as 30 adults were probably lost to poaching with blasting caps from the Five-Mile pool of Canton Creek in the summer of 1984, and as many as 80 were apparently lost from the Upper Bend Creek pool of Steamboat Creek that same summer. In the summer of 1986 I documented the loss of 75 adult summer steelhead from the Lower Bend Creek pool of Steamboat Creek by poaching with blasting caps; in 1987 I documented the loss of 80 adults from the Beaver pool of Canton Creek by poaching with snagging gear. These losses can constitute a large proportion of the total number of adults in the basin during the summer; the total number of adults counted in resting pools during eight summers from 1969 to 1984 ranged from 219 to 585 fish (Wrobles and Roelofs 1985). Adults that hold in resting pools within the basin during the summer may represent a unique portion of the population, and their protection should be regarded as important to insuring genetic or life history diversity. In context with the above analysis of benefits to adult escapement, a curtailment of poaching losses of this magnitude would constitute a benefit that would exceed the best possible efforts to enhance summer habitat.

BIBLIOGRAPHY

Anderson, D.M., D.P. Liscia, and D.W. Loomis. 1986. North Umpqua River (below Soda Springs Dam) fish management plan. Oregon Department of Fish and Wildlife, Roseburg, Oregon. 56 pp.

Baltz, D.M., P.B. Moyle, and N.J. Knight. 1982. Competitive interactions between benthic stream fishes, riffle sculpin, *Cottus gulosus*, and speckled dace, *Rhinichthyes osculus*. Canadian Journal of Fisheries and Aquatic Sciences 39:1502-1511.

Bauer, J.A., F. Oliver, D. Taylor, and D. Carleson. 1967. A report on stream surveys of Steamboat Creek and tributaries. Oregon Department of Fish and Wildlife, Roseburg, Oregon. 117 p.

Beamish, F.W.H. 1964. Seasonal changes in the standard rate of oxygen consumption of fishes. Canadian Journal of Zoology 42:189-194.

Bell, M.C. 1986. Fisheries handbook of engineering requirements and biological criteria. US Army Corps of Engineers, Portland, Oregon. 290 p.

Benda, L. 1990. The influence of debris flows on channels and valley floors in the Oregon Coast Range, U.S.A.. Earth Surface Processes and Landforms 15:457-466.

Bisson, P.A. In press. Importance of identification of limiting factors in an evaluation program. Proceeding of the Stream Habitat Evaluation Technical Workshop. Bonneville Power Administration, Portland, Oregon. 22 p.

Bisson, P.A., J.L. Nielson, R.A. Palmason, and L.E. Grove. 1982. A system of naming habitat types in small streams, with examples of habitat utilization by salmonids during low streamflow. p. 62-73 *In* N.B. Armantrout [ed.] Acquisition and utilization of aquatic habitat inventory information. Western Division, American Fisheries Society, Bethesda, Maryland. 376 p.

Bisson, P.A., K. Sullivan, and J.L. Nielsen. 1988. Channel hydraulics, habitat use, and body form of juvenile coho salmon, steelhead, and cutthroat trout in streams. Transactions of the American Fisheries Society 117:262-273.

Bjornn, T.C. 1971. Trout and salmon movements in two Idaho streams as related to temperature, food, stream flow, cover, and population density. Transactions of the American Fisheries Society 100:423-438.

Brown, G.W., G.W. Swank, and J. Rothacher. 1971. Water temperature in the Steamboat drainage. USDA Forest Service Research Paper, PNW-

119. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon. 17 p.

Bryant, M.D. 1983. The role and management of woody debris in West Coast salmonid nursery streams. North American Journal of Fisheries Management 3:322-330.

Burns, J.W. 1971. The carrying capacity for juvenile salmonids in some northern California streams. California Fish and Game 57:44-57.

Bustard, D.R., and D.W. Narver. 1975. Aspects of the winter ecology of juvenile coho salmon (Oncorhynchus kisutch) and steelhead trout (Salmo gairdneri). Journal of the Fisheries Research Board of Canada 32:667-680.

Chapman, D.W. 1962. Aggressive behavior of juvenile coho salmon as a cause of emigration. Journal of the Fisheries Research Board of Canada 19:1047-1080.

Chapman, D.W., and T.C. Bjornn. 1969. Distribution of salmonids in streams, with special reference to food and feeding. p. 153-180 *In* T.G. Northcote [ed.] Symposium on salmon and trout in streams. University of British Columbia, Vancouver. 388 p.

Chrisp, E.Y., and T.C. Bjornn. 1978. Parr-smolt transformation and seaward migration of wild and hatchery steelhead trout in Idaho. USDI Fish and Wildlife Service Contribution Number 80. Forest, Wildlife and Range Experiment Station, Moscow, Idaho. 118 p.

Clare, H.C., and R.B. Marston. 1968. Forestry practices in the North Umpqua River basin, Oregon. Report submitted to Federal Water Pollution Control Administration, USDI Northwest Regional Office. Portland, Oregon. 25 p.

Clark, T., A.J. Rice, S. Buell, B. Johnson, and C.S. Collins. 1969. Effect of current logging practices on anadromous fish habitat within the Steamboat Creek watershed. Multiple-Use Sub-Committee Report, submitted to Roseburg District, Bureau of Land Management, Roseburg, Oregon. 14 p.

Cleveland, W.S. 1979. Robust locally weighted regression and smoothing scatterplots. Journal of the American Statistical Association 74:829-836.

Cochran, W.G. 1977. Sampling techniques. John Wiley and Sons, New York, New York. 428 p.

Connell, J.H., and W.P. Sousa. 1983. On the evidence needed to judge ecological stability or persistence. American Naturalist 121:789-823.

Conte, F.P., and H.H. Wagner. 1965. Development of osmotic and ionic regulation in juvenile steelhead trout *Salmo gairdneri*. Comparative Biochemistry and Physiology 14:603-620.

Crowder, L.B., and J.J. Magnuson. 1983. Cost-benefit analysis of temperature and food resource use: a synthesis with examples from the fishes. p. 189-221 *In* W.P. Aspey and S.I. Lustick [eds.] Behavioral Energetics. Ohio State University Press, Columbus, Ohio.

Cunjak, R.A. 1988. Physiological consequences of overwintering in streams: the cost of acclimatization? Canadian Journal of Fisheries and Aquatic Sciences 45:443-452.

Edmundson, E., F.H. Everest, and D.W. Chapman. 1968. Permanence of station in juvenile chinook salmon and steelhead trout. Journal of the Fisheries Research Board of Canada 25:1453-1464.

Everest, F.H., and D.W. Chapman. 1972. Habitat selection and spatial interaction by juvenile chinook salmon and steelhead trout in two Idaho streams. Journal of the Fisheries Research Board of Canada 29:91-100.

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

Everest, F.H., and J.R. Sedell. 1984. Evaluating effectiveness of stream enhancement projects. p. 246-256 *In* T.J. Hassler [ed.] Pacific Northwest Stream Habitat Management Workshop. California Cooperative Fishery Research Unit, Arcata, California.

Everest, F.H., J.R. Sedell, G.H. Reeves, and J. Wolfe. 1985. Fisheries enhancement in the Fish Creek basin: an evaluation of in-channel and off-channel projects. Annual Report 1984, U.S. Department of Energy, Bonneville Power Administration, Portland, Oregon. 228 p.

Everest, F.H., G.H. Reeves, J.R. Sedell, J. Wolfe, D. Hohler, and D.A. Heller. 1986. Abundance, behavior, and habitat utilization by coho salmon and steelhead trout in Fish Creek, Oregon, as influenced by habitat enhancement. Annual Report 1985, U.S. Department of Energy, Bonneville Power Administration, Portland, Oregon. 100 p.

Everest, F.H., G.H. Reeves, J.R. Sedell, and D.B. Hohler. 1987. The effects of habitat enhancement on steelhead trout and coho salmon smolt production, habitat utilization, and habitat availability in Fish Creek, Oregon, 1983-1986. Annual Report 1986, U.S. Department of Energy, Bonneville Power Administration, Portland, Oregon. 128 p.

Everest, F.H., G.H. Reeves, J.R. Sedell, D.B. Hohler, and T.C. Cain. 1988. Changes in habitat and populations of steelhead trout, coho salmon, and chinook salmon in Fish Creek, Oregon, 1983-1987, as related to habitat improvement. Annual Report 1987, U.S. Department of Energy, Bonneville Power Adminstration, Portland, Oregon. 115 p.

Faudskar, J.D. 1980. Ecology of underyearling summer steelhead trout in intermittent streams tributary to the Rogue River, Oregon. M.S. thesis. Oregon State University, Corvallis, Oregon. 85 p.

Fausch, K.D. 1984. Profitable stream positions for salmonids: relating specific growth rate to net energy gain. Canadian Journal of Zoology 62:441-451.

Fontaine, B.L. 1987. An evaluation of the effectiveness of instream structures for steelhead trout rearing habitat in the Steamboat Creek basin. M.S. thesis, Oregon State University, Corvallis, Oregon. 68 p.

Fontaine, B.L., and T.D. Merritt. 1988. An anchoring system for fish habitat structures: field technique, evaluation, and application. Research Note PNW-RN-481. USDA Forest Service, Pacific Northwest Research Station, Corvallis, Oregon.

Frissell, C.A., W.J. Liss, C.E. Warren, and M.D. Hurley. 1986. A hierarchical framework for stream habitat classification: viewing streams in a watershed context. Environmental Management 10:199-214.

Fry, F.E.J. 1971. The effect of environmental factors on the physiology of fish. p. 1-98 *In* W.S. Hoar and D.J. Randall [eds.] Fish Physiology, Volume 6. Academic Press, New York.

Hall, J.D., and C.O. Baker. 1975. Biological impacts of organic debris in Pacific Northwest streams. *In* Logging debris in streams workshop, September 9-10, 1975. College of Forestry, Oregon State University, Corvallis, Oregon. 13 p.

Hankin, D.G., and G.H. Reeves. 1988. Estimating total fish abundance and total habitat area in small streams based on visual estimation methods. Canadian Journal of Fisheries and Aquatic Sciences 45:834-844.

Herbich, J.B., and S. Shulits. 1964. Large-scale roughness in open-channel flow. Journal of the Hydraulics Division, Proceedings of the American Society of Civil Engineers 90:203-230.

Hicks, B.J. 1990. The influence of geology and timber harvest on channel morphology and salmonid populations in Oregon Coast Range streams. Doctoral thesis, Oregon State University, Corvallis, Oregon. 199 p.

Hicks, B.J., R.L. Beschta, and R.D. Harr. In press. Long-term changes in streamflow following logging in western Oregon and associated fisheries implications. Water Resources Bulletin.

Hostetler, S. In press. Analysis and modeling of long-term water temperatures on the Steamboat drainage, Oregon: implications for land use and fish habitat. Water Resources Bulletin.

Ivlev, V.S. 1961. Experimental ecology of the feeding of fishes. *Translated from the Russian by* D. Scott. Yale University Press, New Haven, Connecticut.

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

Kelsey, H.M. 1982. Influence of magnitude, frequency, and persistence of various types of disturbance on geomorphic form and process. p. 150-153 *In* F.J. Swanson, R. Janda, T. Dunne, and D.N. Swanston [eds.] Workshop on sediment budgets and routing in forested drainage basins. General Technical Report PNW-141. USDA Forest Service, Pacific Northwest Forest and Range Experiment Station, Portland, Oregon. 165 p.

Lane, E.W. 1947. Report of the subcommittee on sediment terminology. Transactions of the American Geophysical Union 28:936-938.

Lechowicz, M.J. 1982. The sampling characteristics of electivity indices. Oecologia 52:22-30.

Leider, S.A., M.W. Chilcote, and J.L. Loch. 1986. Movement and survival of presmolt steelhead in a tributary and mainstem of a Washington river. North American Journal of Fisheries Management 6:526-531.

Li, H.W., C.B. Schreck, C.E. Bond, and E. Rexstad. 1987. Factors influencing changes in fish assemblages of Pacific Northwest Streams. p. 193-202 *In* W.J. Matthews and D.C. Heins [eds.] Community and Evolutionary Ecology of North American Stream Fishes. University of Oklahoma Press, Norman, Oklahoma. 310 p.

Loch, J.L., S.A. Leider, M.W. Chilcote, R. Cooper, and T.J. Johnson. 1988. Difference in yield, emigration-timing, size, and age structure of juvenile steelhead from two small western Washington streams. California Fish and Game 74:106-118.

McLemore, C.E., F.H. Everest, W.R. Humphreys, and M.F. Solazzi. 1989. A floating trap for sampling downstream migrant fishes. USDA Forest Service Research Note PNW-RN-490. Pacific Northwest Research Station, Portland, Oregon. 7 p.

Northcote, T.G. 1981. Juvenile current response, growth, and maturity of above and below waterfall stocks of rainbow trout, *Salmo gairdneri*. Journal of Fish Biology 18:741-751.

Peterson, D.F., and P.K. Mohanty. 1960. Flume studies of flow in steep, rough channels. Journal of the Hydraulics Division, Proceedings of the American Society of Civil Engineers 86:55-76.

Quinn, T.P., E.L. Brannon, and A.H. Dittman. 1989. Spatial aspects of imprinting and homing in coho salmon, *Oncorhynchus kisutch*. Fishery Bulletin 87:769-774.

Reeves, G.H., F.H. Everest, and J.D. Hall. 1987. Interactions between the redside shiner (*Richardsonius balteatus*) and the steelhead trout (*Salmo gairdneri*) in western Oregon: the influence of water temperature. Canadian Journal of Fisheries and Aquatic Sciences 44:1603-1613.

Reiser, D.W., and T.C. Bjornn. 1979. Habitat requirements of anadromous salmonids. *In* W.R. Meehan [ed.] Influence of forest and rangeland management on anadromous fish habitat in the western United States and Canada. USDA Forest Service General Technical Report PNW-96. Pacific Northwest Forest and Range Experiment Station, Portland, Oregon. 54 p.

Richards, K.S. 1982. Rivers: form and process of alluvial channels. Methuen and Company Limited, New York. 358 p.

Sedell, J.R., F.E. Everest, and F.J. Swanson. 1982. Fish habitat and streamside management: past and present. p. 244-255 *In* Proceedings of the Society of American Foresters, Annual meeting September 27-30, 1981, Bethesda, Maryland.

Shapovalov, L., and A.C. Taft. 1954. The life histories of the steelhead rainbow trout (*Salmo gairdneri gairdneri*) and silver salmon (*Oncorhynchus kisutch*) with special reference to Waddell Creek, California, and recommendations regarding their management. Fish Bulletin Number 98. California Department of Fish and Game, Sacramento. 375 p.

Smith, J.J., and H. Li. 1983. Energetic factors influencing foraging tactics of juvenile steelhead trout, *Salmo gairdneri*. p. 173-180 *In* D.L.G. Noakes et al. [eds.] Predators and prey in fishes. Dr. W. Junk Publishers, The Hague, The Netherlands.

Strahler, A.N. 1957. Quantitative analysis of watershed geomorphology. Transactions of the American Geophysical Union 38:913-920.

Swanson, F.J., and R.L. Fredriksen. 1982. Sediment routing and budgets: implications for judging impacts of forestry practices. p. 129-137 *In* F.J. Swanson, R. Janda, T. Dunne, and D.N. Swanston [eds.] Workshop on sediment budgets and routing in forested drainage basins. General Technical Report PNW-141. USDA Forest Service, Pacific Northwest Forest and Range Experiment Station, Portland, Oregon. 165 p.

Vanderploeg, H.A., and D. Scavia. 1979. Two electivity indices for feeding with special reference to zooplankton grazing. Journal of the Fisheries Research Board of Canada 36:362-365.

Vannote, R.L., G.W. Minshall, K.W. Cummins, J.R. Sedell, and C.E. Cushing. 1980. The river continuum concept. Canadian Journal of Fisheries and Aquatic Sciences 37:130-137.

Wagner, H.H. 1970. The parr-smolt metamorphosis in steelhead trout as affected by photoperiod and temperature. Doctoral thesis, Oregon State University, Corvallis, Oregon.

Wagner, H.H., R.L. Wallace, and H.J. Campbell. 1963. The seaward migration and return of hatchery-reared steelhead trout, *Salmo gairdneri* Richardson, in the Alsea River, Oregon. Transactions of the American Fisheries Society 92:202-210.

Ward, B.R., and P.A. Slaney. 1988. Life history and smolt-to-adult survival of Keogh River steelhead trout (*Salmo gairdneri*) and the relationship to smolt size. Candian Journal of Fisheries and Aquatic Sciences 45:1110-1122.

Welch, P.S. 1948. Limnological Methods. McGraw-Hill Book Co., Inc. New York. 381 p.

Withler, I.L. 1966. Variability in life history characteristics of steelhead trout (*Salmo gairdneri*) along the Pacific coast of North America. Journal of the Fisheries Research Board of Canada 23:365-393.

Wrobles, J.J., and T.D. Roelofs. 1985. Seasonal movements of adult summer steelhead in Steamboat and Canton Creeks, North Umpqua River, Oregon. Report to North Umpqua Ranger District, USDA Forest Service, Glide, Oregon. 43 p.

Zippin, C. 1958. The removal method of population estimation. Journal of Wildlife Management 22:82-90.

APPENDIX

Appendix Table 2.1. Area and volume of stream habitat used by juvenile steelhead in segments of the Steamboat Creek basin in the summer of 1987 and 1988. Shown also are N, number of habitat units, and habitat proportions.

		1987					1988				
Stream segment	Habitat type	N	area (m^2)	volume (m^3)	proportion area	proportion volume	N	area (m^2)	volume (m^3)	proportion area	proportion volume
Steamboat upper mainstem	Pool	144	114816	115887	0.731	0.933	137	75460	34180	0.625	0.800
	Glide	76	31274	6397	0.199	0.051	72	35802	6475	0.296	0.152
	Riffle	50	7340	1062	0.047	0.009	52	7048	1433	0.058	0.034
	Cascade	19	3681	882	0.023	0.007	9	2456	640	0.020	0.015
	Total	289	157111	124230			270	120767	42728		
Steamboat middle mainstem	Pool	70	68694	78397	0.557	0.863	84	58271	33596	0.571	0.735
	Glide	30	27793	6890	0.225	0.076	31	26714	7129	0.262	0.156
	Riffle	27	10146	1534	0.082	0.017	27	8895	2265	0.087	0.050
	Cascade	19	16730	3977	0.136	0.044	15	8093	2720	0.079	0.059
	Total	146	123363	90798			157	101974	45710		
Steamboat lower mainstem	Pool	75	101993	115598	0.678	0.899	92	122149	105071	0.691	0.874
	Glide	46	27614	7823	0.184	0.061	40	41303	10917	0.234	0.091
	Riffle	32	14747	3262	0.098	0.025	23	6959	2056	0.039	0.017
	Cascade	11	5969	1870	0.040	0.015	11	6263	2129	0.035	0.018
	Total	164	150324	128554			166	176673	120174		
Canton mainstem	Pool	252	79452	50401	0.525	0.757	307	106532	57773	0.587	0.749
	Glide	106	29984	7079	0.198	0.106	91	44274	11282	0.244	0.146
	Riffle	165	41801	9109	0.276	0.137	111	30782	8120	0.170	0.105
	Total	523	151237	66589			509	181588	77175		
Pass lower segment	Pool	94	6305	2461	0.272	0.435	156	14820	4645	0.433	0.647
	Glide	72	6582	1399	0.284	0.247	67	10342	1467	0.302	0.204
	Riffle	80	10311	1793	0.444	0.317	74	9064	1064	0.265	0.148
	Total	246	23198	5653			297	34226	7176		
Mellow Moon	Pool	19	947	315	0.318	0.485	23	631	142	0.326	0.499
	Glide	5	723	108	0.243	0.167	6	255	31	0.132	0.111
	Riffle	21	1307	226	0.439	0.348	18	1051	111	0.543	0.390
	Total	45	2978	649			47	1937	284		
upper Pass	Pool	29	1028	248	0.249	0.371	32	843	175	0.414	0.581
	Glide	8	530	79	0.128	0.119	7	260	36	0.128	0.118
	Riffle	26	2566	341	0.622	0.510	23	933	90	0.458	0.301
	Total	63	4123	668			62	2036	301		
East Fork Pass	Pool	17	893	223	0.440	0.682	20	1075	261	0.553	0.742
	Glide	4	110	12	0.054	0.037	7	313	39	0.161	0.110
	Riffle	14	1029	92	0.506	0.281	14	556	52	0.286	0.148
	Total	35	2032	327			41	1944	352		
upper Canton	Pool	113	14039	5026	0.507	0.738	192	21532	6031	0.516	0.680
	Glide	41	6157	825	0.222	0.121	71	12566	1897	0.301	0.214
	Riffle	73	7493	956	0.271	0.140	89	7602	944	0.182	0.106
	Total	227	27689	6807			352	41699	8872		
Steelhead	Pool	85	8686	2741	0.534	0.737	83	9752	6245	0.625	0.898
	Glide	21	1168	187	0.072	0.050	17	1973	277	0.126	0.040
	Riffle	61	6423	792	0.395	0.213	44	3886	436	0.249	0.063
	Total	167	16276	3719			144	15612	6957		

Appendix Table 2.1 (continued).

Stream segment	Habitat type	1987 N	1987 area (m^2)	1987 volume (m^3)	1987 proportion area	1987 proportion volume	1988 N	1988 area (m^2)	1988 volume (m^3)	1988 proportion area	1988 proportion volume
Cedar lower segment	Pool	78	8791	2623	0.484	0.747	123	9017	2367	0.642	0.839
	Glide	50	5472	590	0.301	0.168	57	3128	337	0.223	0.119
	Riffle	56	3887	297	0.214	0.085	61	1896	118	0.135	0.042
	Total	184	18150	3511			241	14041	2822		
South Fork Cedar	Pool	45	1156	275	0.350	0.608	40	1257	305	0.381	0.665
	Glide	46	978	110	0.296	0.243	31	1063	100	0.323	0.218
	Riffle	58	1166	67	0.353	0.149	37	976	54	0.296	0.117
	Total	149	3300	452			108	3296	459		
North Fork Cedar	Pool	78	4360	978	0.468	0.701	109	4485	1025	0.609	0.846
	Glide	67	3226	309	0.347	0.221	52	1667	144	0.226	0.119
	Riffle	75	1722	108	0.185	0.077	74	1217	41	0.165	0.034
	Total	220	9308	1394			235	7369	1211		
Little Rock[a]	Pool	--	--	--	--	--	189	12626	4298	0.522	0.773
	Glide	--	--	--	--	--	89	7435	887	0.308	0.159
	Riffle	--	--	--	--	--	87	4115	374	0.170	0.067
	Total	--	--	--	--	--	365	24176	5559		
Horse Heaven	Pool	179	8551	2351	0.330	0.510	181	9731	2209	0.559	0.798
	Glide	107	9484	1099	0.366	0.238	78	3355	261	0.193	0.094
	Riffle	134	7912	1163	0.305	0.252	120	4321	300	0.248	0.108
	Total	420	25947	4614			379	17406	2769		
upper Steamboat	Pool	134	11866	4315	0.474	0.724	147	16175	4282	0.535	0.726
	Glide	58	7584	1100	0.303	0.185	66	8991	1053	0.297	0.178
	Riffle	84	5588	544	0.223	0.091	70	5081	566	0.168	0.096
	Total	276	25038	5960			283	30247	5901		
Big Bend	Pool	49	6474	3467	0.210	0.329	57	6616	2650	0.311	0.532
	Glide	6	835	249	0.027	0.024	11	1595	318	0.075	0.064
	Riffle	41	23459	6815	0.762	0.647	49	13094	2009	0.615	0.404
	Total	96	30768	10531			117	21305	4977		
Reynolds	Pool	128	6035	2513	0.298	0.506	113	6036	2119	0.417	0.677
	Glide	27	2214	372	0.109	0.075	26	2134	265	0.148	0.085
	Riffle	89	11986	2084	0.592	0.419	75	6289	745	0.435	0.238
	Total	244	20235	4969			214	14460	3128		

[a] Little Rock Creek was surveyed only in 1988.

Appendix Table 2.2. Numbers of juvenile steelhead and age >1 cutthroat trout estimated in segments of the Steamboat Creek basin during the summer of 1987 and 1988.

		1987			1988		
		Juvenile Steelhead		Cutthroat Trout	Juvenile Steelhead		Cutthroat Trout
Stream Segment	Habitat Type	age 0	age >1	age >1	age 0	age >1	age >1
Steamboat upper mainstem	Pool	5889	63	50	6382	134	0
	Glide	4917	10	0	2328	0	0
	Riffle	2948	99	29	2643	121	15
	Cascade	859	30	18	1367	57	0
	Total	14613	202	97	12719	312	15
Steamboat middle mainstem	Pool	7844	220	39	4826	657	63
	Glide	3713	60	0	6274	156	0
	Riffle	3252	486	0	1407	286	5
	Cascade	1599	281	33	5409	983	15
	Total	16408	1047	72	17917	2082	83
Steamboat lower mainstem	Pool	3070	2176	41	5306	3901	21
	Glide	4388	885	0	2539	1374	0
	Riffle	2244	1088	11	1304	396	0
	Cascade	1127	2381	41	2317	2073	13
	Total	10829	6530	92	11465	7745	34
Canton mainstem	Pool	33619	3404	386	29900	3978	129
	Glide	17624	854	19	8806	304	15
	Riffle	27212	2953	38	15423	2385	59
	Total	78455	7211	443	54129	6667	204
Pass lower segment	Pool	4961	496	54	8428	540	27
	Glide	4965	255	41	2288	92	0
	Riffle	12905	791	40	7257	228	0
	Total	22830	1543	136	17975	860	27
Mellow Moon[a]	Pool	230	41	0	436	41	0
	Glide	56	0	0	31	3	0
	Riffle	307	43	0	316	12	0
	Total	593	84	0	783	56	0

[a] Cutthroat trout were not observed in short section of channel surveyed, it is possible that they were actually present in the stream but were missed by the snorkel survey.

Appendix Table 2.2 (continued).

Stream Segment	Habitat Type	1987 Juvenile Steelhead age 0	1987 Juvenile Steelhead age >1	1987 Cutthroat Trout age >1	1988 Juvenile Steelhead age 0	1988 Juvenile Steelhead age >1	1988 Cutthroat Trout age >1
upper Pass[a]	Pool	542	32	0	255	19	0
	Glide	52	0	0	24	0	0
	Riffle	317	13	0	294	0	0
	Total	911	45	0	574	19	0
East Fork Pass[a]	Pool	415	56	0	196	21	0
	Glide	48	0	0	14	0	0
	Riffle	51	0	0	116	0	0
	Total	514	56	0	327	21	0
upper Canton	Pool	5775	326	42	7541	347	22
	Glide	5869	165	0	2092	90	0
	Riffle	3011	53	21	3584	65	0
	Total	14655	544	63	13216	501	22
Steelhead	Pool	1292	133	11	2226	80	0
	Glide	166	0	0	100	0	0
	Riffle	3421	52	0	1190	50	7
	Total	4879	185	11	3515	130	7
Cedar lower segment	Pool	3191	221	31	2992	215	29
	Glide	3819	0	0	629	8	0
	Riffle	4233	0	0	1301	111	0
	Total	11243	221	31	4922	334	29
South Fork Cedar[a]	Pool	100	28	70	301	78	0
	Glide	21	25	92	80	0	0
	Riffle	543	0	29	130	0	0
	Total	664	53	191	511	78	0
North Fork Cedar	Pool	1938	305	57	2444	282	20
	Glide	1237	129	22	739	0	0
	Riffle	532	0	0	528	0	0
	Total	3707	433	80	3710	282	20

[a] Cutthroat trout were not observed in short section of channel surveyed, it is possible that they were actually present in the stream but were missed by the snorkel survey.

Appendix Table 2.2 (continued).

Stream Segment	Habitat Type	1987 Juvenile Steelhead age 0	1987 Juvenile Steelhead age >1	1987 Cutthroat Trout age >1	1988 Juvenile Steelhead age 0	1988 Juvenile Steelhead age >1	1988 Cutthroat Trout age >1
Little Rock[b]	Pool	-	-	-	8467	639	54
	Glide	-	-	-	1058	0	0
	Riffle	-	-	-	1448	53	0
	Total	-	-	-	10972	692	54
Horse Heaven	Pool	5106	358	10	6258	553	36
	Glide	5212	240	0	881	9	0
	Riffle	3181	291	0	3806	122	0
	Total	13499	888	10	10946	684	36
upper Steamboat	Pool	3110	204	10	3890	177	20
	Glide	1514	0	0	865	49	11
	Riffle	1050	54	0	4337	299	0
	Total	5674	257	10	9092	525	31
Big Bend	Pool	428	93	0	845	159	14
	Glide	23	0	0	119	20	0
	Riffle	10216	458	48	2250	1104	0
	Total	10668	551	48	3213	1283	14
Reynolds[c]	Pool	1868	112	0	1550	197	0
	Glide	832	19	0	209	0	0
	Riffle	3176	118	0	1076	20	0
	Total	5877	249	0	2836	217	0

[b] Little Rock was surveyed only in 1988.
[c] No cutthroat trout were observed in Reynolds Creek in 1987 and 1988.

Appendix Table 2.3. Juvenile steelhead density (#/m^2) in stream segments of Steamboat Creek, Oregon, in the summer of 1987 and 1988. Shown also are between year means.

Stream Segment	Habitat Type	age 0			age >1		
		1987	1988	mean	1987	1988	mean
Steamboat upper mainstem	Pool	0.051	0.085	0.064	0.00055	0.0018	0.0010
	Glide	0.16	0.065	0.11	0.00032	0	0.00015
	Riffle	0.35	0.42	0.38	0.012	0.019	0.015
	Total	0.093	0.11	0.098	0.0013	0.0026	0.0018
Steamboat middle mainstem	Pool	0.11	0.083	0.10	0.0032	0.011	0.0069
	Glide	0.13	0.23	0.18	0.0022	0.0058	0.0040
	Riffle	0.18	0.40	0.27	0.028	0.075	0.046
	Total	0.13	0.18	0.15	0.0085	0.020	0.014
Steamboat lower mainstem	Pool	0.030	0.043	0.037	0.021	0.031	0.027
	Glide	0.16	0.061	0.10	0.032	0.033	0.033
	Riffle	0.16	0.27	0.21	0.17	0.19	0.18
	Total	0.072	0.065	0.068	0.043	0.044	0.044
Canton mainstem	Pool	0.42	0.28	0.34	0.043	0.037	0.040
	Glide	0.59	0.20	0.36	0.029	0.0069	0.016
	Riffle	0.65	0.50	0.59	0.071	0.078	0.074
	Total	0.52	0.30	0.40	0.048	0.037	0.042
Pass	Pool	0.79	0.57	0.63	0.079	0.036	0.049
	Glide	0.75	0.22	0.43	0.039	0.0089	0.021
	Riffle	1.2	0.80	1.0	0.077	0.025	0.053
	Total	0.98	0.52	0.71	0.067	0.025	0.042
Mellow Moon	Pool	0.24	0.69	0.42	0.043	0.065	0.052
	Glide	0.077	0.12	0.089	0	0.012	0.0031
	Riffle	0.24	0.30	0.26	0.033	0.011	0.023
	Total	0.20	0.40	0.28	0.028	0.029	0.029
upper Pass	Pool	0.53	0.30	0.43	0.031	0.023	0.027
	Glide	0.098	0.092	0.096	0	0	0
	Riffle	0.12	0.32	0.18	0.0051	0	0.0037
	Total	0.22	0.28	0.24	0.011	0.0093	0.010
East Fork Pass	Pool	0.47	0.18	0.31	0.063	0.020	0.039
	Glide	0.44	0.045	0.15	0	0	0
	Riffle	0.050	0.21	0.11	0	0	0
	Total	0.25	0.17	0.21	0.028	0.011	0.019

Appendix Table 2.3 (continued).

Stream Segment	Habitat Type	age 0			age >1		
		1987	1988	mean	1987	1988	mean
upper Canton	Pool	0.41	0.35	0.37	0.023	0.016	0.019
	Glide	0.95	0.17	0.43	0.027	0.0072	0.014
	Riffle	0.40	0.47	0.44	0.0071	0.0086	0.0078
	Total	0.53	0.32	0.40	0.020	0.012	0.015
Steelhead	Pool	0.15	0.23	0.19	0.015	0.0082	0.012
	Glide	0.14	0.051	0.085	0	0	0
	Riffle	0.53	0.31	0.45	0.0081	0.013	0.0099
	Total	0.30	0.22	0.26	0.011	0.0083	0.0099
Cedar lower segment	Pool	0.36	0.33	0.35	0.025	0.024	0.025
	Glide	0.70	0.20	0.52	0	0.0026	0.00093
	Riffle	1.1	0.69	0.96	0	0.059	0.019
	Total	0.62	0.35	0.50	0.012	0.024	0.017
South Fork Cedar	Pool	0.086	0.24	0.17	0.024	0.062	0.044
	Glide	0.021	0.075	0.049	0.026	0	0.012
	Riffle	0.47	0.13	0.31	0	0	0
	Total	0.20	0.16	0.18	0.016	0.024	0.012
North Fork Cedar	Pool	0.44	0.55	0.50	0.070	0.063	0.066
	Glide	0.38	0.44	0.40	0.040	0	0.026
	Riffle	0.31	0.43	0.36	0	0	0
	Total	0.40	0.50	0.45	0.047	0.038	0.043
Little Rock[a]	Pool	--	0.67	--	--	0.051	--
	Glide	--	0.14	--	--	0	--
	Riffle	--	0.35	--	--	0.013	--
	Total	--	0.45	--	--	0.029	--
Horse Heaven	Pool	0.60	0.64	0.62	0.042	0.057	0.050
	Glide	0.55	0.26	0.47	0.025	0.0027	0.019
	Riffle	0.40	0.88	0.57	0.037	0.028	0.034
	Total	0.52	0.63	0.56	0.034	0.039	0.036
upper Steamboat	Pool	0.26	0.24	0.25	0.017	0.011	0.014
	Glide	0.20	0.096	0.14	0	0.0055	0.0030
	Riffle	0.19	0.85	0.51	0.0097	0.059	0.033
	Total	0.23	0.30	0.27	0.010	0.017	0.014
Big Bend	Pool	0.066	0.13	0.097	0.014	0.024	0.019
	Glide	0.028	0.075	0.058	0	0.013	0.0082
	Riffle	0.44	0.17	0.34	0.020	0.084	0.043
	Total	0.35	0.15	0.27	0.018	0.060	0.035

[a] Little Rock Creek was surveyed only in 1988.

Appendix Table 2.3 (continued).

Stream Segment	Habitat Type	age 0			age >1		
		1987	1988	mean	1987	1988	mean
Reynolds	Pool	0.31	0.26	0.28	0.019	0.033	0.026
	Glide	0.38	0.098	0.24	0.0086	0	0.0044
	Riffle	0.27	0.17	0.23	0.0098	0.0032	0.0076
	Total	0.29	0.20	0.25	0.012	0.015	0.013

Appendix Table 2.4. Habitat electivity E (Ivlev 1961) of juvenile steelhead in stream segments of the Steamboat Creek basin, in the summer of 1987 and 1988. Shown also is between year average.

Stream Segment	Habitat Type	age 0 1987	age 0 1988	age 0 Average	age >1 1988	age >1 1987	age >1 Average
Steamboat upper mainstem	Pool	-0.29	-0.11	-0.21	-0.40	-0.19	-0.28
	Glide	0.26	-0.24	0.05	-0.60	-1.00	-0.85
	Riffle	0.62	0.56	0.60	0.83	0.74	0.78
	Cascade	0.43	0.68	0.57	0.73	0.80	0.77
Steamboat middle mainstem	Pool	-0.08	-0.36	-0.21	-0.45	-0.29	-0.34
	Glide	0.00	0.14	0.09	-0.59	-0.56	-0.56
	Riffle	0.41	-0.05	0.23	0.70	0.22	0.49
	Cascade	-0.16	0.58	0.30	0.33	0.71	0.57
Steamboat lower mainstem	Pool	-0.41	-0.20	-0.29	-0.34	-0.16	-0.23
	Glide	0.38	-0.03	0.19	-0.15	-0.14	-0.14
	Riffle	0.36	0.49	0.41	0.26	0.13	0.22
	Cascade	0.45	0.70	0.61	0.80	0.77	0.79
Canton mainstem	Pool	-0.10	-0.03	-0.08	-0.05	0.01	-0.02
	Glide	0.06	-0.20	-0.06	-0.25	-0.68	-0.46
	Riffle	0.11	0.25	0.19	0.19	0.36	0.28
Pass lower segment	Pool	-0.11	0.04	-0.06	0.08	0.18	0.08
	Glide	-0.13	-0.41	-0.25	-0.26	-0.48	-0.34
	Riffle	0.12	0.21	0.19	0.07	0.00	0.11
Mellow Moon	Pool	0.10	0.26	0.20	0.21	0.38	0.29
	Glide	-0.44	-0.54	-0.52	-1.00	-0.42	-0.81
	Riffle	0.08	-0.15	-0.03	0.08	-0.43	-0.10
upper Pass	Pool	0.41	0.04	0.28	0.48	0.41	0.45
	Glide	-0.38	-0.51	-0.43	-1.00	-1.00	-1.00
	Riffle	-0.28	0.06	-0.16	-0.37	-1.00	-0.47
East Fork Pass	Pool	0.29	0.04	0.19	0.39	0.29	0.34
	Glide	0.27	-0.58	-0.18	-1.00	-1.00	-1.00
	Riffle	-0.67	0.11	-0.33	-1.00	-1.00	-1.00
upper Canton	Pool	-0.13	0.05	-0.04	0.08	0.15	0.11
	Glide	0.29	-0.31	0.03	0.15	-0.25	-0.05
	Riffle	-0.14	0.20	0.04	-0.47	-0.17	-0.32
Steelhead	Pool	-0.34	0.01	-0.16	0.15	-0.01	0.08
	Glide	-0.36	-0.63	-0.51	-1.00	-1.00	-1.00
	Riffle	0.28	0.15	0.26	-0.17	0.21	0.00

Appendix Table 2.4 (continued).

Stream Segment	Habitat Type	age 0			age >1		
		1987	1988	Average	1988	1987	Average
Cedar	Pool	-0.26	-0.03	-0.18	0.35	0.00	0.17
lower	Glide	0.06	-0.27	0.01	-1.00	-0.81	-0.90
segment	Riffle	0.27	0.32	0.31	-1.00	0.42	0.05
South	Pool	-0.40	0.21	-0.03	0.20	0.45	0.38
Fork	Glide	-0.81	-0.35	-0.57	0.23	-1.00	-0.24
Cedar	Riffle	0.40	-0.08	0.28	-1.00	-1.00	-1.00
North	Pool	0.05	0.04	0.05	0.20	0.24	0.22
Fork	Glide	-0.02	-0.06	-0.05	-0.08	-1.00	-0.24
Cedar	Riffle	-0.13	-0.07	-0.10	-1.00	-1.00	-1.00
Little[a]	Pool	--	0.19	--	--	0.28	--
Rock	Glide	--	-0.52	--	--	-1.00	--
	Riffle	--	-0.13	--	--	-0.38	--
Horse	Pool	0.07	0.01	0.05	0.10	0.18	0.16
Heaven	Glide	0.03	-0.41	-0.09	-0.15	-0.87	-0.30
	Riffle	-0.13	0.17	0.01	0.04	-0.16	-0.04
upper	Pool	0.07	-0.11	-0.03	0.25	-0.23	-0.02
Steamboat	Glide	-0.06	-0.52	-0.30	-1.00	-0.52	-0.65
	Riffle	-0.09	0.48	0.31	-0.03	0.54	0.40
Big Bend	Pool	-0.68	-0.08	-0.47	-0.11	-0.43	-0.29
	Glide	-0.85	-0.34	-0.64	-1.00	-0.66	-0.62
	Riffle	0.11	0.07	0.12	0.04	0.17	0.10
Reynolds	Pool	0.03	0.13	0.06	0.20	0.37	0.31
	Glide	0.13	-0.33	-0.02	-0.18	-1.00	-0.51
	Riffle	-0.05	-0.07	-0.04	-0.11	-0.65	-0.28

[a] Little Rock Creek was surveyed only in 1988.

Appendix Table 3.1A. Daily estimates of age >1 juvenile steelhead classed as parr (P), intermediate smolts (I), and smolts (S), emigrating from Steamboat and Canton Creek, April 11 to December 19, 1988. Steamboat and Canton Creeks generally comprise 72% and 28% of basin flow, respectively. All estimates were made with a Humphreys floating fish trap, except for the use of an Archimedean-screw trap, as noted in the months of November and December. Note data and summary codes for different techniques used to calculate estimates. Te - trap efficiency: e, calculations using fish length and flow dependent trap efficiency, and t, those using time averaged efficiencies; ? denotes times when traps where deployed, but data were not used because efficiencies were not known. Sb - substitution of data for days of no trapping: f, estimates derived from relationships of flow and emigration, a, estimates derived from average of adjacent days when trapping occurred, and x, for days when no substitution of data was made. Summary codes denote methods used to calculate total basin emigration: s, summed daily estimates from Steamboat and Canton Creek; ms and mc, proportional multipliers used to expand total estimates in time periods when only one trap was in use, for Steamboat and Canton Creek, respectively. Multipliers based upon the proportion of fish emigrating from Steamboat and Canton Creek before June 28. Parr from Steamboat and Canton Creek were 59% and 41%, and smolts and intermediate smolts were 80% and 20%, respectively (parr ms=1.44, mc=0.69; smolts and intermediate smolts ms=4.0). Total basin estimate from Archimedean-screw trap: as. Small discrepancies in totals are due to rounding.

		Steamboat Creek					Canton Creek					Basin total			
Date 1988	Basin Flow (m^3/s)	Data code Te	Data code Sb	Emigrant class P	I	S	Data code Te	Data code Sb	Emigrant class P	I	S	Summary codes	Emigrant class P	I	S
Apr. 11	17.1	e		175	11	22		f	180	9	0	s	355	20	22
12	15.7	e		337	22	22		f	195	9	0	s	532	31	22
13	14.7	e		904	86	28		f	215	9	0	s	1119	95	28
14	17.9	e		38	0	0		f	191	9	0	s	229	9	0
15	16.6	e		853	77	99		f	188	9	0	s	1041	86	99
16	15.5	e		944	58	47		f	200	9	0	s	1145	67	47
17	14.8	e		646	105	48		f	220	9	0	s	866	114	48
18	13.8	e		259	10	0		f	288	9	0	s	548	19	0
19	12.9	e		407	19	10	e		270	15	0	s	677	34	10
20	12.9	e		185	0	0	e		144	0	0	s	329	0	0
21	31.4		f	651	32	26	e		324	0	0	s	975	32	26
22	39.9		f	111	11	9		f	164	7	0	s	275	18	9
23	29.1	e		247	25	37	e		45	0	0	s	292	25	37
24	22.2	e		145	0	25	e		99	0	0	s	244	0	25
25	18.1	e		195	12	37	e		86	0	0	s	281	12	37
26	15.5	e		161	29	10	e		48	0	0	s	209	29	10
27	14.3	e		127	10	19	e		19	0	0	s	147	10	19
28	14.3	e		155	0	0	e		29	0	0	s	184	0	0
29	25.9	e		638	49	74	e		421	0	0	s	1059	49	74
30	38.8	e		248	37	62	e		536	36	0	s	784	73	62
May 1	37.6		f	89	5	8	e		220	22	8	s	309	28	16
2	38.2		f	91	5	9		f	156	5	1	s	247	10	10
3	54.0		f	89	5	7		f	156	5	1	s	245	10	9
4	44.1		x	--	--	--		x	--	--	--		--	--	--
5	36.5		x	--	--	--		x	--	--	--		--	--	--
6	32.0		f	96	6	9	e		57	8	8	s	153	13	17
7	54.0	e		44	0	12	e		0	0	0	s	44	0	12
8	50.4		x	--	--	--			--	--	--		--	--	--
9	42.7		x	--	--	--			--	--	--		--	--	--
10	35.1		x	--	--	--			--	--	--		--	--	--
11	32.2	e		66	12	0	e		254	8	8	s	320	20	8
12	28.6	e		11	0	0	e		179	0	0	s	190	0	0
13	30.5	e		263	0	0	e		75	0	0	s	339	0	0

Appendix Table 3.1 (continued).

Date 1988	Basin Flow (m^3/s)	Steamboat Creek					Canton Creek					Basin total			
		Data code		Emigrant class			Data code		Emigrant class			Summary codes	Emigrant class		
		Te	Sb	P	I	S	Te	Sb	P	I	S		P	I	S
May 14	24.7	e		136	25	0		f	164	4	4	s	300	28	4
15	21.0	e		327	12	0		f	176	4	4	s	503	16	4
16	21.1		f	200	21	10		f	183	4	4	s	383	26	14
17	24.0	e		271	0	12	e		320	0	0	s	591	0	12
18	21.0	e		201	12	0	e		169	0	0	s	370	12	0
19	17.8	e		110	0	22	e		282	0	0	s	393	0	22
20	15.6	e		358	0	0	e		367	0	0	s	725	0	0
21	13.9	e		218	0	0	e		264	0	0	s	482	0	0
22	12.7	e		1244	12	0	e		386	0	0	s	1630	12	0
23	11.3	e		1284	58	12	e		1042	0	17	s	2326	58	28
24	10.1	e		1096	46	0	e		1032	0	17	s	2129	46	17
25	9.14	e		1203	0	0	e		812	0	16	s	2015	0	16
26	8.41	e		1048	6	173	e		793	0	74	s	1842	6	247
27	7.99	e		1112	64	103	e		1080	0	25	s	2192	64	127
28	9.54		f	521	23	38		f	322	0	11	s	843	23	49
29	12.8		f	1291	40	68		f	444	0	11	s	1735	40	79
30	13.7	e		344	0	38	e		659	0	8	s	1003	0	46
31	13.4	e		344	35	29	e		162	0	0	s	507	35	29
June 1	71.9		x	597	21	35			327	0	10	s	924	21	45
2	59.1		x	--	--	--			--	--	--		--	--	--
3	42.2		x	--	--	--			--	--	--		--	--	--
4	38.2		x	--	--	--			--	--	--		--	--	--
5	34.2		f	89	4	8		f	156	0	7	s	245	4	14
6	28.6		f	99	2	15		f	160	1	5	s	259	3	20
7	25.3		f	123	1	12		f	168	1	6	s	291	3	18
8	24.2	e		66	0	12		f	174	2	6	s	240	2	19
9	21.6	e		10	0	12		f	176	2	6	s	186	2	19
10	19.0	e		16	8	0		f	178	2	7	s	194	10	7
11	16.4	e		159	0	33		f	193	2	7	s	352	2	40
12	14.1	e		388	16	57		f	215	2	7	s	603	17	64
13	12.4	e		347	0	46		f	274	2	8	s	621	2	54
14	11.0	e		446	0	70		f	612	2	8	s	1058	2	77
15	9.83	e		1368	0	97	e		38	8	15	s	1406	8	112
16	8.89	e		1690	0	141	e		75	0	0	s	1765	0	141
17	8.13	e		1199	0	0	e		75	0	15	s	1275	0	15
18	7.45	e		539	40	32	e		113	0	0	s	652	40	32
19	6.88	e		257	0	32	e		38	0	0	s	294	0	32
20	6.43	e		215	32	0	e		123	0	0	s	338	32	0
21	5.98	e		69	32	0	e		189	0	0	s	258	32	0
22	5.64	e		15	0	0	e		425	0	0	s	440	0	0
23	5.32	e		22	0	0	e		302	10	8	s	324	10	8
24	5.04	e		77	32	0	e		142	0	25	s	218	32	25
25	4.84	e		0	32	0	e		264	10	0	s	264	42	0
26	4.70	e		15	0	32	e		283	10	17	s	298	10	49
27	4.50	e		40	0	0	e		246	10	25	s	285	10	25
28	4.36	e		7	0	0	e		57	0	0	s	64	0	0
29	4.56	?		--	--	--	t		94	19	0	ms	230	97	0
30	4.25	?		--	--	--	t		57	10	8	ms	138	48	45
July 1	4.02	?		--	--	--	t		85	10	0	ms	207	48	0
2	3.88	?		--	--	--	t		66	0	0	ms	161	0	0
3	3.85	?		--	--	--		a	0	0	0	ms	0	0	0
4	3.74	?		--	--	--		a	75	3	3	ms	183	13	13
5	3.57	?		--	--	--		a	75	3	3	ms	183	13	13
6	3.43	?		--	--	--	t		48	0	0	ms	117	0	0
7	3.31	?		--	--	--	t		96	0	0	ms	234	0	0
8	3.17	?		--	--	--	t		96	0	8	ms	234	0	40
9	3.06	?		--	--	--		a	93	1	3	ms	226	5	17

Appendix Table 3.1 (continued).

Date 1988	Basin Flow (m^3/s)	Steamboat Creek Data code Te	Sb	Emigrant class P	I	S	Canton Creek Data code Te	Sb	Emigrant class P	I	S	Basin total Summary codes	Emigrant class P	I	S
July 10	2.95	?		--	--	--		a	93	1	3	ms	226	5	17
11	2.89	?		--	--	--		a	93	1	3	ms	226	5	17
12	2.89	?		--	--	--	t		48	0	0	ms	117	0	0
13	2.78	?		--	--	--	t		115	0	8	ms	281	0	40
14	2.72	?		--	--	--	t		106	8	8	ms	257	38	40
15	2.69	?		--	--	--	t		153	0	0	ms	374	0	0
16	2.63	?		--	--	--		a	85	1	2	ms	207	5	10
17	2.58	?		--	--	--		a	85	1	2	ms	207	5	10
18	2.46	?		--	--	--		a	84	0	0	ms	205	0	0
19	2.41	?		--	--	--	t		57	0	0	ms	139	0	0
20	2.32	?		--	--	--	t		38	0	0	ms	93	0	0
21	2.21	?		--	--	--	t		95	0	0	ms	232	0	0
22	2.15	?		--	--	--		a	69	0	0	ms	168	0	0
23	2.12	?		--	--	--		a	69	0	0	ms	168	0	0
24	2.10	?		--	--	--		a	69	0	0	ms	168	0	0
25	2.07	?		--	--	--		a	69	0	0	ms	168	0	0
26	1.98	?		--	--	--		a	69	0	0	ms	168	0	0
27	1.93	?		--	--	--		a	69	0	0	ms	168	0	0
28	1.93	?		--	--	--		a	69	0	0	ms	168	0	0
29	1.87	?		--	--	--		a	69	0	0	ms	168	0	0
30	1.84	?		--	--	--		a	69	0	0	ms	168	0	0
31	1.81	?		--	--	--		a	69	0	0	ms	168	0	0
Aug. 1	1.78	?		--	--	--		a	72	0	0	ms	175	0	0
2	1.76	?		--	--	--	t		130	0	0	ms	317	0	0
3	1.73	?		--	--	--	t		89	0	0	ms	218	0	0
4	1.70	?		--	--	--	t		79	0	0	ms	193	0	0
5	1.67	?		--	--	--	t		60	0	0	ms	146	0	0
6	1.67	?		--	--	--	t		30	0	0	ms	73	0	0
7	1.64	?		--	--	--		a	44	0	0	ms	107	0	0
8	1.61	?		--	--	--		a	44	0	0	ms	107	0	0
9	1.56	?		--	--	--		a	44	0	0	ms	107	0	0
10	1.56	?		--	--	--		a	44	0	0	ms	107	0	0
11	1.56	?		--	--	--		a	44	0	0	ms	107	0	0
12	1.56	?		--	--	--		a	44	0	0	ms	107	0	0
13	1.56	?		--	--	--		a	44	0	0	ms	107	0	0
14	1.56	?		--	--	--		a	44	0	0	ms	107	0	0
15	1.56	?		--	--	--		a	44	0	0	ms	107	0	0
16	1.53	?		--	--	--	t		20	0	0	ms	49	0	0
17	1.50	?		--	--	--	t		20	0	0	ms	49	0	0
18	1.47	?		--	--	--	t		0	0	0	ms	0	0	0
19	1.44	?		--	--	--	t		10	0	0	ms	24	0	0
20	1.42	?		--	--	--	t		0	0	0	ms	0	0	0
21	1.39	?		--	--	--	t		10	0	0	ms	24	0	0
22	1.36	?		--	--	--		a	5	0	0	ms	12	0	0
23	1.30	?		--	--	--		a	5	0	0	ms	12	0	0
24	1.27	?		--	--	--		a	5	0	0	ms	12	0	0
25	1.25	?		--	--	--		a	5	0	0	ms	12	0	0
26	1.22	?		--	--	--		a	5	0	0	ms	12	0	0
27	1.22	?		--	--	--		a	5	0	0	ms	12	0	0
28	1.19	?		--	--	--		a	5	0	0	ms	12	0	0
29	1.19	?		--	--	--	t		0	0	0	ms	0	0	0
30	1.16	?		--	--	--		a	0	0	0	ms	0	0	0
31	1.16	?		--	--	--		a	0	0	0	ms	0	0	0
Sep. 1	1.16	?		--	--	--	t		0	0	0	ms	0	0	0

Appendix Table 3.1 (continued).

Date 1988		Basin Flow (m^3/s)	Steamboat Creek: Data code Te	Sb	Emigrant class P	I	S	Canton Creek: Data code Te	Sb	Emigrant class P	I	S	Basin total: Summary codes	Emigrant class P	I	S
Sep.	2	1.13	?		--	--	--	t		0	0	0	ms	0	0	0
	3	1.10	?		--	--	--		a	0	0	0	ms	0	0	0
	4	1.08	?		--	--	--		a	0	0	0	ms	0	0	0
	5	1.08	?		--	--	--		a	0	0	0	ms	0	0	0
	6	1.08	?		--	--	--		a	0	0	0	ms	0	0	0
	7	1.08	?		--	--	--		a	0	0	0	ms	0	0	0
	8	1.08	?		--	--	--	t		0	0	0	ms	0	0	0
	9	1.05	?		--	--	--		a	0	0	0	ms	0	0	0
	10	1.05	?		--	--	--		a	0	0	0	ms	0	0	0
	11	1.02	?		--	--	--		a	0	0	0	ms	0	0	0
	12	1.02	?		--	--	--	t		0	0	0	ms	0	0	0
	13	0.99	?		--	--	--		a	5	0	0	ms	12	0	0
	14	0.99	?		--	--	--		a	5	0	0	ms	12	0	0
	15	0.99	?		--	--	--		a	5	0	0	ms	12	0	0
	16	0.99	?		--	--	--		a	5	0	0	ms	12	0	0
	17	0.99	?		--	--	--		a	5	0	0	ms	12	0	0
	18	0.99	?		--	--	--		a	5	0	0	ms	12	0	0
	19	1.56	?		--	--	--		a	5	0	0	ms	12	0	0
	20	2.10	?		--	--	--		a	5	0	0	ms	12	0	0
	21	1.59	?		--	--	--		a	5	0	0	ms	12	0	0
	22	1.36	?		--	--	--		a	5	0	0	ms	12	0	0
	23	1.25	?		--	--	--		a	5	0	0	ms	12	0	0
	24	1.19	?		--	--	--		a	5	0	0	ms	12	0	0
	25	1.16	?		--	--	--		a	5	0	0	ms	12	0	0
	26	1.19	?		--	--	--	t		10	0	0	ms	24	0	0
	27	2.46	?		--	--	--		a	6	0	0	ms	16	0	0
	28	2.18	?		--	--	--		a	6	0	0	ms	15	0	0
	29	1.56	?		--	--	--	t		0	0	0	ms	0	0	0
	30	1.33	?		--	--	--	t		9	0	0	ms	23	0	0
Oct.	1	1.25	?		--	--	--	t		0	0	0	ms	0	0	0
	2	1.19	?		--	--	--		a	2	0	0	ms	4	0	0
	3	1.13	?		--	--	--		a	2	0	0	ms	4	0	0
	4	1.16	?		--	--	--	t		0	0	0	ms	0	0	0
	5	1.33	?		--	--	--		a	0	0	0	ms	0	0	0
	6	1.27	?		--	--	--	t		0	0	0	ms	0	0	0
	7	1.22	?		--	--	--	t		0	0	0	ms	0	0	0
	8	1.16	?		--	--	--		a	5	0	0	ms	11	0	0
	9	1.13	?		--	--	--		a	5	0	0	ms	11	0	0
	10	1.10	?		--	--	--		a	5	0	0	ms	11	0	0
	11	1.08	?		--	--	--	t		9	0	0	ms	23	0	0
	12	1.08	?		--	--	--		a	5	0	0	ms	13	0	0
	13	1.05	?		--	--	--	t		0	0	0	ms	0	0	0
	14	1.05	?		--	--	--	t		0	0	0	ms	0	0	0
	15	1.05	?		--	--	--	t		0	0	0	ms	0	0	0
	16	1.02	?		--	--	--	t		0	0	0	ms	0	0	0
	17	1.02	?		--	--	--		a	0	0	0	ms	0	0	0
	18	1.02	?		--	--	--		a	0	0	0	ms	0	0	0
	19	1.02	?		--	--	--		a	0	0	0	ms	0	0	0
	20	0.99	?		--	--	--		a	0	0	0	ms	0	0	0
	21	0.99	?		--	--	--		a	0	0	0	ms	0	0	0
	22	0.99	?		--	--	--	t		0	0	0	ms	0	0	0
	23	0.99	?		--	--	--	t		0	0	0	ms	0	0	0
	24	0.96	?		--	--	--	t		0	0	0	ms	0	0	0
	25	0.96	?		--	--	--	t		0	0	0	ms	0	0	0

Appendix Table 3.1 (continued).

Date 1988	Basin Flow (m^3/s)	Steamboat Creek Data code Te	Sb	Emigrant class P	I	S	Canton Creek Data code Te	Sb	Emigrant class P	I	S	Basin total Summary codes	Emigrant class P	I	S
Oct. 26	0.96	?		--	--	--		a	0	0	0	ms	0	0	0
27	0.96	?		--	--	--		a	0	0	0	ms	0	0	0
28	0.96	?		--	--	--	t		0	0	0	ms	0	0	0
29	0.93	?		--	--	--	t		0	0	0	ms	0	0	0
30	0.93	?		--	--	--	t		0	0	0	ms	0	0	0
31	0.93	?		--	--	--	t		0	0	0	ms	0	0	0
Nov. 1	0.93	?		--	--	--		a	0	0	0	ms	0	0	0
2	1.50	?		--	--	--		a	0	0	0	ms	0	0	0
3	7.39	?		--	--	--		a	0	0	0	ms	0	0	0
4	6.51	e		795	0	0	?		--	--	--	mc	1347	0	0
5	3.65	e		129	0	0	?		--	--	--	mc	218	0	0
6	11.9		a	491	0	0	?		--	--	--	mc	832	0	0
7	6.71	e		1464	0	0	?		--	--	--	mc	2481	0	0
8	4.59	e		97	0	0	?		--	--	--	mc	164	0	0
9	3.79	e		0	0	0	?		--	--	--	mc	0	0	0
10	12.7		a	286	0	0	?		--	--	--	mc	485	0	0
11	14.8		a	286	0	0	?		--	--	--	mc	485	0	0
12	15.5	e		62	0	0	?		--	--	--	mc	104	0	0
13	14.8	e		73	0	0	?		--	--	--	mc	123	0	0
14	12.4	e		23	0	0	?		--	--	--	mc	39	0	0
15	14.9		a	44	0	0	?		--	--	--	mc	75	0	0
16	27.0	e		35	0	0	?		--	--	--	mc	60	0	0
17	38.5		a	32	0	0	?		--	--	--	mc	54	0	0
18	20.5		a	32	0	0	?		--	--	--	mc	54	0	0
19	13.0		a	32	0	0	?		--	--	--	mc, as	54	0	8
20	29.4	e		23	0	0	?		--	--	--	mc	39	0	0
21	68.8	e		37	0	0	?		--	--	--	mc	63	0	0
22	205			--	--	--			--	--	--		--	--	--
23	117			--	--	--			--	--	--		--	--	--
24	47.5			--	--	--			--	--	--		--	--	--
25	33.7			--	--	--			--	--	--		--	--	--
26	35.6			--	--	--			--	--	--		--	--	--
27	38.5			--	--	--			--	--	--		--	--	--
28	102			--	--	--			--	--	--		--	--	--
29	50.4			--	--	--			--	--	--		--	--	--
30	31.4			--	--	--			--	--	--		--	--	--
Dec. 1	29.1			--	--	--			--	--	--	as	0	0	0
2	29.4			--	--	--			--	--	--		--	--	--
3	25.3			--	--	--			--	--	--		--	--	--
4	22.1			--	--	--			--	--	--		--	--	--
5	18.7			--	--	--			--	--	--		--	--	--
6	23.5			--	--	--			--	--	--		--	--	--
7	22.3			--	--	--			--	--	--		--	--	--
8	17.5			--	--	--			--	--	--		--	--	--
9	15.6			--	--	--			--	--	--	as	9	0	0
10	16.0			--	--	--			--	--	--	as	0	0	0
11	14.5			--	--	--			--	--	--	as	3	0	0
12	12.6			--	--	--			--	--	--	as	0	0	0
13	11.6			--	--	--			--	--	--	as	0	0	0
14	10.4			--	--	--			--	--	--	as	0	0	0
15	9.01			--	--	--			--	--	--	as	0	0	0
16	7.90			--	--	--			--	--	--	as	0	0	0
17	7.11			--	--	--			--	--	--	as	0	0	0
18	6.49			--	--	--			--	--	--	as	0	0	0
19	6.91			--	--	--			--	--	--	as	0	0	0

Appendix Table 3.1B. Subtotaled estimates of age >1 juvenile steelhead classed as parr (P), intermediate smolts (I), and smolts (S), emigrating from Steamboat and Canton Creek. Data and summary codes denote different techniques used to calculate estimates. Data codes for different methods of calculating trap efficiency: e, calculations using fish length and flow dependent trap efficiency; and t, those using time averaged efficiencies; ?, denotes times when traps were deployed, but data were not used because efficiencies were not known. Data codes used for substitution of data for days of no trapping: f, estimates derived from relationships of flow and emigration; a, estimates derived from average of adjacent days when trapping occurred; and x, for days when no substitution of data was made. Codes for calculation of total basin emigration: s, summed daily estimates from Steamboat and Canton Creek; ms and mc, proportional multipliers used to expand total estimates in time periods when only one trap was in use, for Steamboat and Canton Creek, respectively. Multipliers based upon the proportion of fish emigrating from Steamboat and Canton Creek before June 28. Parr from Steamboat and Canton Creek were 59% and 41%, and smolts and intermediate smolts were 80% and 20%, respectively (parr ms=1.44, mc=0.69; smolts and intermediate smolts ms=4.0). Total basin estimate from Archimedean-screw trap: as. Small discrepancies in totals are due to rounding.

Subtotal by data codes, with number of days used in "( )"	Steamboat Creek				Canton Creek				Basin total		
	Emigrant class				Emigrant class				Emigrant class		
	P	I	S		P	I	S		P	I	S
e	25954	1033	1512	(69)	12326	113	278	(44)	38279	1146	1790
t	0	0	0	(0)	1631	46	31	(50)	1631	46	31
?*	5179	224	212	(128)	2738	0	0	(18)	7916	224	212
a	1203	0	0	(7)	1968	10	18	(78)	3171	10	18
f	3524	145	210	(12)	5812	134	110	(26)	9335	279	320
x	597	21	35	(9)	483	5	11	(9)	1080	25	46
as (13)									15	0	8
Total[z]	36456	1423	1969	(225)	24957	308	449	(225)	61428	1731	2426

* total fish added by proportional multiplication (using ms and mc) to basin total, but not shown in daily estimates.

z trapping operations from April 11 to December 19, 1988 totalled 254 days.

Appendix Table 3.2. Estimated number of age 0 emigrants from Steamboat and Canton Creek, April 11 to December 19, 1988.

Two-week interval	Steamboat Creek			Canton Creek			Total basin
	Ca[a]	Dy[b]	estimate[c]	Ca[a]	Dy[b]	estimate[c]	estimate
Apr. 11-24	0	14	0	0	6	0	0
Apr. 25-May 8	0	9	0	50	9	594	594
May 9-22	11	11	99	196	9	2327	2427
May 23-June 5	48	7	681	188	7	2870	3551
June 6-19	1428	12	11816	34	5	727	12542
June 20-July 3	1344	10	13345	109	13	896	14241
July 4-17	--	--	--	242	7	3695	16626[d]
July 18-31	--	--	--	146	3	5201	23405[d]
Aug. 1-14	--	--	--	244	5	5215	23469[d]
Aug. 15-28	--	--	--	149	6	2654	11943[d]
Aug. 29-Sep. 11	--	--	--	1	4	27	120[d]
Sep. 12-25	--	--	--	0	1	0	0[d]
Sep. 26-Oct. 9	--	--	--	17	7	260	1168[d]
Oct. 10-23	1	7	14	9	8	120	134
Oct. 24-Nov. 6	192	8	2383	153	8	2044	4427
Nov. 7-20	295	9	3255	10	2	534	3789
Nov. 21-Dec. 4	18	1	1787	--	--	--	2321[e]
Dec. 5-18 & 19	--	--	--	--	--	--	966[f]
Total (253 days)	3337	88	33379	1548	100	27164	120756

[a] total fish captured in time interval.

[b] total number of days Humphreys fish trap successfully operated in time interval.

[c] estimates calculated using a trap efficiency (eff.) of 0.141 for Steamboat Creek, and 0.131 for Canton Creek, by:

$$estimate = \frac{\frac{Ca}{Dy}}{eff.} \times 14\ days\ .$$

[d] Canton Creek estimates multiplied by 3.50 and added to basin total to represent Steamboat Creek when no trapping occurred. From Apr. 11 to July 3, Steamboat Creek had 77.8% and Canton had 22.2% of total age 0 emigrants (3.50=77.8/22.2).

[e] Steamboat Creek estimates multiplied by (0.285) and added to basin total to represent Canton Creek when no trapping occurred (see [d] above).

[f] Archimedean screw trap used with an efficiency of 0.095 based on 4 recaptured age 0 fish from 42 fish marked and released upstream of trap. Estimate made by equation in [c] above.

Appendix Table 3.3. Length-frequency distribution of age >1 steelhead emigrants classed as parr, smolts, and intermediate smolts. From Steamboat Creek (A, B, and C respectively), and Canton Creek (D, E, and F respectively), from the spring through the fall of 1988. Shown are estimated number of emigrants expanded by length and flow dependent efficiencies or Humphreys trap data.

A. Steamboat Creek, steelhead parr

Fork length in mm	Apr. 11-24	Apr. 25-May 8	May 9-22	May 23-June 5	June 6-19	June 20-July 3	Nov. 7-20	Total
61-65	17	0	0	0	0	0	0	17
70	61	0	0	0	12	7	0	81
75	190	44	57	52	41	0	0	383
80	502	112	152	425	177	15	0	1384
85	875	198	296	677	365	59	0	2470
90	877	325	561	1094	508	44	0	3411
95	795*	251*	332*	862	508	74	0	2821
100	653	376	470	1100*	707*	22*	0	3328
105	439	102	316	704	613	109	95	2378*
110	718	292	537	1986	1881	32	647	6094
115	459	152	318	940	796	32	348	3044
120	305	68	203	585	426	0	286	1872
125	11	15	33	215	369	0	223	866
130	0	0	69	228	203	32	398	930
135	0	0	49	61	67	32	238*	447
140	0	0	13	0	33	0	395	441
145	0	0	0	0	0	0	351	351
150	0	0	0	0	0	0	191	191
155	0	0	0	0	0	0	0	0
160	0	0	0	0	0	0	208	208
165	0	0	0	0	0	0	95	95
170	0	0	0	0	0	0	95	95
175	0	0	0	0	0	0	0	0
180	0	0	0	0	0	0	48	48
185	0	0	0	0	0	0	48	48
190	0	0	0	0	0	0	0	0
195	0	0	0	0	0	0	0	0
200	0	0	0	0	0	0	48	48
205	0	0	0	0	0	0	143	143
210	0	0	0	0	0	0	0	0
215	0	0	0	0	0	0	48	48
220	0	0	0	0	0	0	0	0
Total	5903	1934	3405	8929	6706	460	3903	31240

* mean length class

Appendix Table 3.3 (continued).

B. Steamboat Creek, steelhead smolts

Fork length in mm	Apr. 11-24	Apr. 25-May 8	May 9-22	May 23-June 5	June 6-19	June 20-July 3	Nov. 7-20	Total
61-65	0	0	0	0	0	0	0	0
70	0	0	0	0	0	0	0	0
75	0	0	0	0	0	0	0	0
80	0	0	0	0	0	0	0	0
85	0	0	0	0	0	0	0	0
90	0	0	0	0	0	0	0	0
95	0	0	0	9	0	0	0	9
100	0	0	0	9	6	0	0	15
105	0	0	0	9	19	0	0	28
110	0	0	0	59	113	0	0	172
115	0	0	0	0	79	0	0	79
120	0	0	0	59	125*	32*	0	216
125	0	0	0	164*	10	0	0	174
130	0	0	0	14	70	0	0	84
135	0	0	0	14	90	0	0	103
140	90	0	0	92	0	0	0	181*
145	45	0	0	46	0	0	0	91
150	50	42	0	0	47	0	0	138
155	23	12	0	0	0	0	0	34
160	14*	15	0	0	0	0	0	29
165	0	45*	0	0	0	0	0	45
170	47	45	0	14	0	0	0	105
175	23	15	14	0	0	0	0	52
180	0	30	0	16	0	0	0	47
185	10	0	0*	0	0	0	0	10
190	24	12	16	0	0	0	0	52
195	12	0	0	0	0	0	0	12
200	12	30	14	0	0	0	0	56
205	0	0	0	0	0	0	0	0
210	10	0	0	0	0	0	0	10
215	0	0	0	0	0	0	0	0
220	12	0	0	0	0	0	0	12
Total	372	246	44	503	559	32	0	1756

* mean length class

Appendix Table 3.3 (continiued).

C. Steamboat Creek, steelhead intermediate smolts

Fork length in mm	Apr. 11-24	Apr. 25-May 8	May 9-22	May 23-June 5	June 6-19	June 20-July 3	Nov. 7-20	Total
61-65	0	0	0	0	0	0	0	0
70	0	0	0	0	0	0	0	0
75	0	0	0	0	0	0	0	0
80	0	0	0	0	0	0	0	0
85	0	0	0	0	0	0	0	0
90	0	0	0	0	0	0	0	0
95	0	0	0	9	0	0	0	9
100	0	0	0	9	0	0	0	9
105	0	0	0	0	23	0	0	23
110	0	0	0	73	0*	97*	0	169
115	0	0	0	14	34	0	0	48
120	101	25	0	46	10	32	0	214
125	113*	51*	0	0*	0	0	0	164*
130	166	14	16	0	0	0	0	196
135	21	28	16*	0	0	0	0	66
140	42	28	32	49	0	0	0	152
145	10	11	16	33	0	0	0	70
150	0	0	15	33	0	0	0	48
155	0	0	0	0	0	0	0	0
160	0	0	0	16	0	0	0	16
165	0	0	0	0	0	0	0	0
170	0	0	0	16	0	0	0	16
175	0	0	0	0	0	0	0	0
180	0	0	0	0	0	0	0	0
185	0	0	0	0	0	0	0	0
190	0	0	0	0	0	0	0	0
195	0	0	0	0	0	0	0	0
200	0	0	0	0	0	0	0	0
205	0	0	0	0	0	0	0	0
210	0	0	0	0	0	0	0	0
215	0	0	0	0	0	0	0	0
220	0	0	0	0	0	0	0	0
Total	454	158	94	297	67	129	0	1199

* mean length class

Appendix Table 3.3 (continued).

D. Canton Creek, steelhead parr

Fork length in mm	Apr. 11-24	Apr. 25-May 8	May 9-22	May 23-June 5	June 6-19	June 20-July 3	July 4-17	July 18-31	Aug. 1-14	Aug. 15-28	Aug. 29-Nov. 6	Total
61-65	75	9	19	10	0	0	0	0	0	0	0	114
70	234	29	79	85	58	24	15	0	0	0	0	524
75	324	71	123	187	242	99	63	0	0	0	0	1109
80	673*	189	405	642	126	249	49	88	0	0	0	2420
85	306	186	399	871	458	448	237	178	37	0	0	3121
90	274	286*	521*	1170*	205*	439*	265*	139	97	0	0	3397*
95	96	311	327	794	214	352	186	100*	61	45	0	2485
100	400	238	279	1105	524	328	213	104	213*	24	0	3428
105	263	145	213	616	157	172	41	160	134	25*	66	1990
110	55	152	224	678	248	124	85	115	24	0	23	1729
115	0	73	148	302	87	60	90	0	149	27	0	937
120	0	28	38	164	56	23	15	0	16	0	0*	341
125	24	0	28	122	56	15	0	78	0	0	0	324
130	0	9	9	47	56	0	0	0	16	0	0	138
135	0	0	9	38	0	0	0	0	0	0	13	60
140	0	0	0	0	0	0	0	0	16	0	0	16
145	0	0	0	0	0	0	0	0	33	17	0	50
150	0	0	0	0	0	0	0	0	16	0	0	16
155	0	0	0	0	0	0	0	0	0	0	0	0
160	0	0	0	0	0	0	0	0	0	0	0	0
165	0	0	0	0	0	0	0	0	0	0	12	12
170	0	0	0	0	0	0	0	0	0	0	0	0
175	0	0	0	0	0	0	0	0	0	0	0	0
180	0	0	0	0	0	0	0	0	0	0	0	0
185	0	0	0	0	0	0	0	0	0	0	0	0
190	0	0	0	0	0	0	0	0	0	0	0	0
195	0	0	0	0	0	0	0	0	0	0	0	0
200	0	0	0	0	0	0	0	0	0	0	0	0
205	0	0	0	0	0	0	0	0	0	0	12	12
210	0	0	0	0	0	0	0	0	0	0	0	0
215	0	0	0	0	0	0	0	0	0	0	0	0
220	0	0	0	0	0	0	0	0	0	0	0	0
Total	2723	1727	2820	6832	2489	2332	1260	963	810	138	126	22220

* mean length class

Appendix Table 3.3 (continued).

E. Canton Creek, steelhead smolts

Fork length in mm	Apr. 11-24	Apr. 25-May 8	May 9-22	May 23-June 5	June 6-19	June 20-July 3	July 4-17	July 18-31	Aug. 1-14	Aug. 15-28	Aug. 29-Nov. 6	Total
61-65	0	0	0	0	0	0	0	0	0	0	0	0
70	0	0	0	0	0	0	0	0	0	0	0	0
75	0	0	0	0	0	0	0	0	0	0	0	0
80	0	0	0	0	0	0	0	0	0	0	0	0
85	0	0	0	0	0	0	0	0	0	0	0	0
90	0	0	0	0	0	0	0	0	0	0	0	0
95	0	0	0	0	0	0	0	0	0	0	0	0
100	0	0	0	0	0	0	0	0	0	0	0	0
105	0	0	0	0	0	0	0	0	0	0	0	0
110	0	0	0	28	0	11	0	0	0	0	0	39
115	0	0	0	15	0	12	0	0	0	0	0	27
120	0	0	0	10	0	8	0	0	0	0	0	17
125	0	0	0	19	0	8*	0	0	0	0	0	27
130	0	0	0	10	45	0	14*	0	0	0	0	69
135	0	0	0	10*	0*	8	14	0	0	0	0	31*
140	0	0	0*	38	23	31	0	0	0	0	0	92
145	0	0	20	19	0	0	14	0	0	0	0	52
150	0	0	0	10	23	7	0	0	0	0	0	40
155	0	9*	0	0	0	0	0	0	0	0	0	9
160	0	0	0	10	0	0	0	0	0	0	0	10
165	0	9	0	10	0	0	0	0	0	0	0	18
170	0	0	0	0	0	0	0	0	0	0	0	0
175	0	0	0	10	0	0	0	0	0	0	0	10
180	0	0	0	0	0	0	0	0	0	0	0	0
185	0	0	0	9	0	0	0	0	0	0	0	9
190	0	0	0	0	0	0	0	0	0	0	0	0
195	0	0	0	0	0	0	0	0	0	0	0	0
200	0	0	0	0	0	0	0	0	0	0	0	0
205	0	0	0	0	0	0	0	0	0	0	0	0
210	0	0	0	0	0	0	0	0	0	0	0	0
215	0	0	0	0	0	0	0	0	0	0	0	0
220	0	0	0	0	0	0	0	0	0	0	0	0
Total	0	17	20	195	91	84	41	0	0	0	0	449

* mean length class

Appendix Table 3.3 (continued).

F. Canton Creek, steelhead intermediate smolts

Fork length in mm	Apr. 11-24	Apr. 25-May 8	May 9-22	May 23-June 5	June 6-19	June 20-July 3	July 4-17	July 18-31	Aug. 1-14	Aug. 15-28	Aug. 29-Nov. 6	Total
61-65	0	0	0	0	0	0	0	0	0	0	0	0
70	0	0	0	0	0	0	0	0	0	0	0	0
75	0	0	0	0	0	0	0	0	0	0	0	0
80	0	0	0	0	0	0	0	0	0	0	0	0
85	0	0	0	0	0	0	0	0	0	0	0	0
90	0	0	0	0	0	0	0	0	0	0	0	0
95	0	0	0	0	0	0	0	0	0	0	0	0
100	0	0	0	0	0	0	0	0	0	0	0	0
105	0	0	0	0	0	0	0	0	0	0	0	0
110	0	0	0	0	0	22	0	0	0	0	0	22
115	0	0	0	0	0	24*	0	0	0	0	0	24
120	0	8	0	0	0	23	0	0	0	0	0	31
125	48	42*	0	0	0	8	0	0	0	0	0	97
130	0	25	20*	0	23*	0	17*	0	0	0	0	86*
135	0*	0	0	0	0	0	0	0	0	0	0	0
140	48	0	0	0	0	0	0	0	0	0	0	48
145	0	0	0	0	0	0	0	0	0	0	0	0
150	0	0	0	0	0	0	0	0	0	0	0	0
155	0	0	0	0	0	0	0	0	0	0	0	0
160	0	0	0	0	0	0	0	0	0	0	0	0
165	0	0	0	0	0	0	0	0	0	0	0	0
170	0	0	0	0	0	0	0	0	0	0	0	0
175	0	0	0	0	0	0	0	0	0	0	0	0
180	0	0	0	0	0	0	0	0	0	0	0	0
185	0	0	0	0	0	0	0	0	0	0	0	0
190	0	0	0	0	0	0	0	0	0	0	0	0
195	0	0	0	0	0	0	0	0	0	0	0	0
200	0	0	0	0	0	0	0	0	0	0	0	0
205	0	0	0	0	0	0	0	0	0	0	0	0
210	0	0	0	0	0	0	0	0	0	0	0	0
215	0	0	0	0	0	0	0	0	0	0	0	0
220	0	0	0	0	0	0	0	0	0	0	0	0
Total	95	76	20	0	23	77	17	0	0	0	0	308

* mean length class