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AN EVALUATION OF HABITAT ENHANCEMENT AND WILD FRY SUPPLEMENTATION AS A MEANS OF INCREASING COHO SALMON PRODUCTION OF THE CLEARWATER RIVER, WASHINGTON

by

Roger Joseph Peters

A dissertation submitted in partial fulfillment
of the requirements for the degree of

Doctor of Philosophy

University of Washington

1996

Approved by Gilbert B. Pauley
(Chairperson of Supervisory Committee)

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to Offer Degree School of Fisheries

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Doctoral Dissertation

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Abstract

An Evaluation of Habitat Enhancement and Wild Fry Supplementation as a Means of Increasing Coho Salmon Production of the Clearwater River, Washington

by Roger Joseph Peters

Chairperson of the Supervisory Committee: Professor Gilbert Pauley
School of Fisheries

I examined mainstem habitat enhancement and coho fry supplementation as methods for increasing coho salmon (*Oncorhynchus kisutch*) production in the Clearwater River Basin. I also measured macro- and microhabitat use and behavioral patterns of summer rearing coho salmon in the mainstem. Overall, fry supplementation did not significantly increase wild coho fry or cutthroat trout (*O. clarki*) emigration. However, a strong ($r=0.94$) positive relationship observed in control streams between early summer coho salmon rearing densities and numbers of emigrants was altered in supplemented streams. At low rearing densities, more coho fry emigrated from supplemented than control streams. Emigration rates of wild coho salmon, cutthroat, and steelhead (*O. mykiss*) were significantly altered in supplemented streams during one year but not the other. Although not statistically significant, coho fry densities (fish/m^2 pool area) were greater (18-89%) in supplemented than control streams. Wild coho salmon and cutthroat trout densities were not reduced by supplementation. Wild coho fry in supplemented streams were smaller than those in control streams, apparently due to reduced spring and early summer (May to late June) growth.

Summer rearing densities (fish/km) of juvenile coho salmon in the mainstem were increased by introducing woody debris bundles and were positively related to debris densities (#/km). However, woody debris introductions did not result in increased migration of coho salmon into overwintering habitats. Coho salmon abundance was greatest in pool habitats containing the largest, most complex woody debris accumulations. Two distinct foraging groups, 'foragers' and 'resters', were observed using mainstem woody debris accumulations. Foragers selected focal positions with faster current velocities and deeper water, and generally were deeper in the water column and farther from woody debris cover than resting individuals. Foraging individuals foraged and displayed aggressive behavior more frequently than resting individuals.

Based on the coho salmon mainstem rearing densities and numbers coho salmon emigrating from streams, coho salmon production in the Clearwater River Basin appears to be limited more frequently by insufficient numbers of juveniles to fully seed available habitat than by habitat availability. However, mainstem rearing likely limits coho salmon production during years with adequate escapement in this system.

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Adult coho salmon capture, spawning, incubation, and rearing of fry for the supplementation

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CHAPTER I

General Introduction

Wild coho salmon (*Oncorhynchus kisutch*) stocks in the Pacific Northwest have declined over the last decade, some to critically low levels (Nehlsen et al. 1991). Reduced populations have resulted in reduced or restricted fisheries and genetic variability is threatened (Helle 1984). These reductions have lead to petitions to list coho salmon stocks for protection under the Endangered Species Act (Weikamp et al. 1995). The determination of coho salmon status was focused on "natural" fish, which were defined as progeny of naturally spawning fish (Waples 1991). As a result, many management entities are examining restoration techniques with potential for increasing natural coho salmon production.

Two distinct strategies have been considered for the Clearwater River, which is located on the north coast of Washington State (Figure 1.1). One focuses on stocking hatchery-reared coho salmon fry (supplementation) produced by a broodstock developed from native wild stocks, while the other focuses on restoration of mainstem summer rearing habitat through woody debris introductions.

Coho salmon production in the Clearwater Basin is believed to be limited at times by insufficient numbers of spawners to fully seed the system or by summer rearing habitat in the mainstem (Cederholm and Reid 1987). Juvenile coho salmon rearing in the mainstem Clearwater River during the summer are the primary source of fall immigrants into off-channel ponds (Cederholm and Scarlett 1982). Off-channel ponds connected to the mainstem by wall-base channels provide important over-wintering habitat for juvenile coho salmon in the Clearwater Basin and have been the focus of earlier restoration efforts (Cederholm et al. 1988; Cederholm and Scarlett 1991). Although 25% to 65% of coho salmon in the Clearwater Basin over-winter in off-channel ponds (Dave King, Washington Department of Fish and Wildlife, personal communication), these habitats appear to be underseeded (Peterson and Reid 1984). A majority of coho salmon spawning in the Clearwater River basin occurs in mainstem tributaries. Thus, reduced escapement would result in underseeding of mainstem habitat, which relies on colonization by coho fry emigrating from tributaries, and would result in underseeding of off-channel ponds. During years with sufficient spawning to seed the mainstem, insufficient mainstem habitats may result in underseeding of off-channel pond habitats.

The Clearwater River has suffered from reduced coho salmon escapement during the past two decades (Quinault Indian Nation 1994a). A significant proportion of Clearwater River coho salmon are intercepted in Canadian fisheries. Harvest in this fishery occasionally exceeds the total harvestable surplus of this stock (Quinault Indian Nation 1994a). Poor ocean survival in recent years has further exacerbated poor escapements in the Clearwater (Queets) system, which has exceeded the lower end of the escapement goal in only 5 of the last 18 years (Quinault Indian Nation 1994a). Reduced escapements decrease the ability of stocks to absorb losses from habitat perturbations such as extreme freshets, droughts, and landslides, because the system lacks surplus fish (Cederholm and Reid 1987). This may result in too few juveniles to fully seed the available habitat in the basin. Mainstem and wall-base channel habitats might be underutilized in this case, since most spawning in this system occurs in tributary streams. This problem may be addressed by reducing fisheries or producing more juveniles from available spawners.

More progeny can be produced per spawner by removing adults from the river during their upstream migration, artificially spawning them, and rearing their progeny in a hatchery. Fry produced from these adults can then be transplanted back into streams throughout the basin (fry supplementation). However, supplementation is an unproven tool for increasing production and the genetic and ecological characteristics of native stocks may be affected if non-native stocks are used as a brood source (Steward and Bjornn 1990; Wunderlich and Pantaleo 1995). Fry supplementation using hatchery-reared coho salmon has produced mixed results. Nickelson et al. (1986) observed a 41% increase in overall juvenile coho salmon densities following stocking of hatchery coho salmon presmolts. However, hatchery coho salmon replaced 44% of wild juvenile coho salmon. Adults produced by these planted fry produced significantly lower juvenile coho salmon densities, apparently due to the early spawning time of hatchery fish (Nickelson et al. 1986).

To reduce the problems associated with using non-native brood sources (see review by Steward and Bjornn 1990), the Quinault Indian Nation, Washington Department of Fisheries, and the U.S. Fish and Wildlife Service developed a native broodstock for supplementation activities in the Clearwater basin (Quinault Indian Nation 1992). This broodstock was developed by taking adult coho salmon from the Clearwater River and rearing their progeny in a hatchery to the smolt stage. These smolts were released from a collection facility on Shale Creek (Figure 1.1) for subsequent collection of adults upon their return. The returning adults were spawned at this facility to produce progeny for the supplementation program. Wild coho salmon taken from the mainstem Clearwater River and its tributaries have been incorporated back into this broodstock each year to help maintain genetic integrity (Quinault Indian Nation 1992).

The use of local broodstocks should reduce potential alteration of genetic characteristics of native stock. However, this does not assure the success of supplementation programs or that wild salmonids will not be replaced by hatchery-reared salmonids. Stocked hatchery-reared native coho fry may emigrate from streams as a result of prior residence of native coho salmon and/or trout, or increase emigration of wild salmonids. Either of these results would influence the success of a supplementation program. Therefore, it is important that fry supplementation programs using fry produced from native broodstocks be evaluated.

Restoration of summer rearing habitat in the mainstem may increase immigration of juvenile coho salmon into wall-base channel ponds during the fall, ultimately increasing coho salmon production in the Clearwater River Basin. Juvenile coho salmon overwintering in wall-base channel ponds normally experience exceptional survival (up to 78%) and growth (49-94% increase) (Peterson 1982a) and generally are larger as smolts than those rearing in free-running tributaries (Quinault Indian Nation 1994a). Increased immigration of coho salmon into wall-base channel ponds would increase the production of these large smolts. Larger coho salmon smolts have experienced better marine survival than smaller coho smolts, especially when marine conditions have been poor (Holtby et al. 1990). Thus, increased smolt production from wall-base channels could lead to larger numbers of smolts experiencing improved marine survival, thereby resulting in increased adult returns to the basin.

The Clearwater Basin is managed intensively for timber production by both state and private entities, which can reduce a watershed's ability to provide large woody debris to streams and rivers (Bisson et al. 1987). This may have greater effects in larger mainstem rivers, which generally possess lower woody debris densities than smaller streams (Bilby and Ward 1989). Reductions of woody debris in streams has resulted in decreased salmonid biomass (Bryant 1982; Dolloff 1986; Elliott 1986), while summer carrying capacities of salmon and trout streams have been increased by adding stable woody debris (Ward and Slaney 1979; Anderson 1982; House and Boehne 1985, 1986; Nickelson et al. 1992b). This technique is viewed as a tool for restoring wild coho salmon summer rearing habitat in the mainstem Clearwater River. However, most examples of habitat enhancement using woody debris introductions have occurred in streams smaller (1st-3rd order) than the Clearwater River.

The habitat requirements at all stages of the early life history of stream fish must be considered if habitat restoration projects are to be successful (Moore and Gregory 1988; Nickelson et al. 1992b). Data on habitat requirements and selection by summer rearing juvenile coho salmon comes predominately from small streams (e.g., Bisson et al. 1982, 1988; Bugert et al. 1991; Nickelson et al. 1992a; Nielsen 1992), with habitat preference of summer rearing coho salmon in large rivers represented by a single study (Lister and Genoe 1970). Changes in channel size (Baltz and Moyle 1984), fish communities (Fausch and White 1981; Baltz et al. 1982; Schlosser 1987; Beecher et al. 1988; Bugert and Bjornn 1991), and temperature (Baltz et al. 1982; Baltz et al. 1987; Reeves et al. 1987) associated with larger rivers can influence salmonid habitat use and distribution.

Behavior of juvenile salmonids may differ between different habitat types, which could alter the importance of woody debris as a component of coho salmon rearing habitat (Swain and Holtby 1989). A recent study indicated that pool depth was nearly as important as the presence of woody debris in determining coho salmon distribution and survival in a small stream channel (Lonzarich and Quinn 1995). The mainstem Clearwater River possesses many large pools with very low current velocities. If woody debris does not influence coho salmon distribution in the mainstem Clearwater River, its introduction may be an ineffective habitat restoration technique. For this reason, I measured the summer habitat selection and behavior of juvenile coho salmon in the mainstem Clearwater River as well as the effectiveness of woody debris as a restoration technique in this system.

Although the influences of habitat restoration and supplementation have been examined, the interaction of these two different restoration techniques has not been evaluated. The effectiveness of these techniques may be altered by the simultaneous implementation of the other. There is also little information regarding the effects of mainstem habitat restoration or supplementation using progeny obtained from a native broodstock.

The objectives of this research were to determine: (1) whether juvenile coho salmon production in the mainstem Clearwater River and subsequent immigration into wall-base channels could be increased through introductions of woody debris bundles, (2) whether woody debris is an important physical factor determining the distribution of summer rearing juvenile coho salmon in the mainstem Clearwater River, (3) whether stocking hatchery-reared coho salmon in tributaries of the Clearwater River would increase total summer coho salmon densities in these tributaries, (4) whether stocking hatchery-reared coho fry reduces wild coho salmon densities and growth in stocked streams, and (5) whether the lack of mainstem summer rearing habitat and/or reduced escapement levels limit coho salmon production in the Clearwater River basin.

Study Area

This study was completed in the Clearwater River basin located on the north coast of Washington State (Figure 1.1). The Clearwater River originates from the west slope of the Olympic Mountains, flows west to southwest for 58 km to its confluence with the Queets River (Winter 1992). The river's drainage area of approximately 350 km^2 (Cederholm and Scarlett 1982) receives over 350 cm of rain annually (Cederholm and Scarlett 1991). The river is fed primarily by surface runoff and ground water (Winter 1992). Median discharge near the town of Clearwater for the years 1932 and 1938-1949 ranged from about 3.7 m^3/s to 9.3 m^3/s from June to September; a peak flood of 1,059 m^3/s was recorded 3 November 1955 (Amerman and Orsborn 1987). The river gradient is low to moderate and the river is composed primarily of pools with relatively short riffles (Phinney and Bucknell 1975). A majority of the coho production occurs in tributary streams, with the mainstem serving as juvenile summer rearing habitat (Phinney and Bucknell 1975). The study area extended from Bull Creek (river kilometer (Rkm) 30) downstream to Morrison Pond (Rkm 4.8).

Mainstem habitat restoration and habitat selection research was completed in a study reach from Bull Creek (Rkm 30) to a creek described as 0031 Creek (Rkm 10) (Phinney and Bucknell 1975). Six wall-base channel ponds monitored during the fall for immigrating juvenile coho salmon included: Coppermine Bottom Pond, Pond 2, Paradise Pond, Swamp Creek Beaded Channel, Airport Pond, and Morrison Pond. Coho salmon smolts emigrating from these ponds have been trapped annually by the Quinault Indian Nation and the Washington State Department of Natural Resources (Quinault Indian

Nation 1992, 1993, 1994) to determine smolt production. The ponds are typical wall-base channel ponds in differing stages of succession (Peterson and Reid 1984).

Six tributaries were selected for the supplementation experiment based on recommendations from Quinault Indian Nation fisheries personnel and personal examination. Bull, Prairie, Peterson, 0042, Elkhorn, and Hunt Creeks were selected based on their size and low escapements in recent years. Bull, Peterson, Elkhorn, and Hunt Creeks drain directly into the mainstem Clearwater River, while 0042 is a tributary to Shale Creek, and Prairie Creek is a tributary to Deception Creek, both of which drain directly into the mainstem (Figure 1.1).

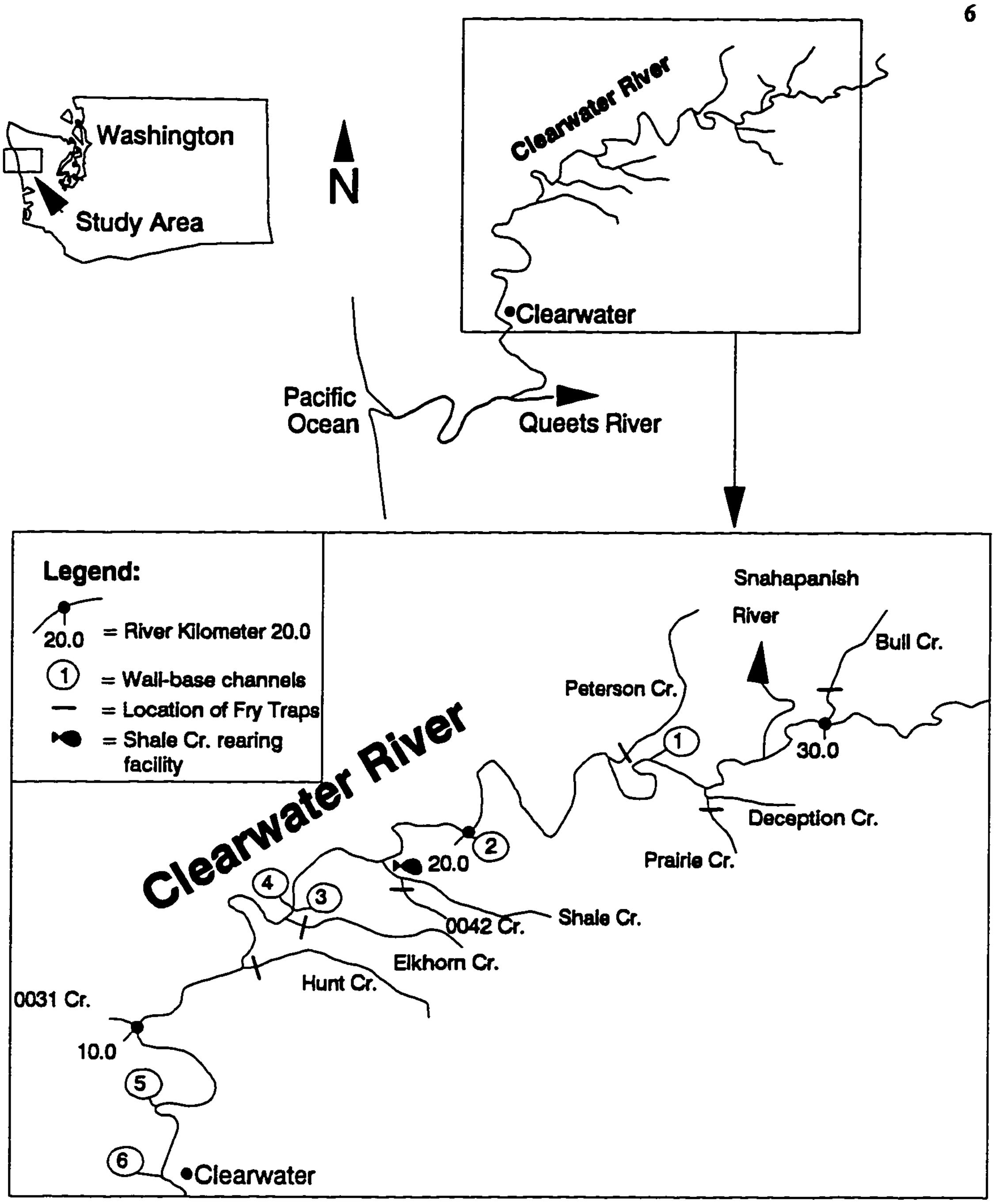

Figure 1.1. Study area locations in the Clearwater River basin. Mainstem habitat enhancement research was completed in a study reach which extended from Bull Creek (Rkm 30.0) to 0031 Creek (Rkm 10.0). Wall-base channels sampled for immigrating coho salmon during the fall include: (1) Coppermine Bottom Pond, (2) Pond 2, (3) Paradise Pond, (4) Swamp Creek Beaded Channel, (5) Airport Pond, and (6) Morrison Pond. Supplementation using hatchery-reared coho salmon fry obtained from a native broodstock was evaluated in Bull, Prairie, Peterson, 0042, Elkhorn and Hunt Creeks.

CHAPTER II

The Effects of Fry Supplementation on the Migration of Salmonids

INTRODUCTION

The effect of stocking hatchery-reared coho salmon fry (*Oncorhynchus kisutch*) obtained from a native broodstock on the emigration of native juvenile coho salmon and trout is examined in this study. Few detailed studies evaluating supplementation exist (Steward and Bjornn 1990; Wunderlich and Pantaleo 1995). There is concern that supplementation using non-native hatchery stocks could negatively affect genetic and ecological characteristics of native stocks as well as reduce their productivity (Steward and Bjornn 1990). Genetic and ecological effects stem largely from transfer of genetic characteristics from hatchery stocks to wild stocks potentially resulting in maladapted behavior. Progeny of hatchery fish and those produced by wild and hatchery matings often display reduced survival compared to wild progeny (Reisenbichler and McIntyre 1977; Chilcote et al. 1986; Nickelson et al. 1986; Leider et al. 1990). Maladaptive traits which negatively influence survival of hatchery fish and hatchery:wild offspring include early run timing (Nickelson et al. 1986), reduced disease resistance (Buchanan et al. 1983; Hemmingsen et al. 1986), altered behavior (Fenderson et al. 1968; Swain and Riddell 1990), and reduced foraging efficiency (Sosiak et al. 1979; Bachman 1984; Irvine and Bailey 1992). To avoid the problems associated with using non-native hatchery stocks, the Quinault Indian Nation, Washington Department of Fisheries, and the U.S. Fish and Wildlife Service developed a native broodstock for supplementation activities in the Clearwater basin (Quinault Indian Nation 1992).

Although use of a native broodstock for fry in a supplementation program reduces the potential for altered genetic characteristics, it does not eliminate the potential for failure of these programs. Stocked fry may emigrate from the stream and/or increase emigration of the stock they are intended to supplement. Fry supplementation can reduce native stock productivity at the time of planting mainly through competition for food and space resulting in emigration and/or mortality of native salmonids (Steward and Bjornn 1990). Hatchery coho salmon fry stocked in Oregon coastal streams replaced 44% of wild coho salmon, apparently as a result of the competitive advantage resulting from the larger size of hatchery fish at stocking (Nickelson et al. 1986). The mode of replacement, mortality or emigration, was not determined. Introductions of hatchery-reared coho salmon resulted in shifts in microhabitat use and foraging behavior and caused a greater rate of downstream movement in wild coho salmon (Nielsen 1994). Hatchery coho salmon in Nielsen's (1994) study originated from both hatchery and wild broodstocks.

Studies examining the effect of stocked hatchery salmonids on the displacement or emigration of wild salmonids have given mixed results. Stocking catchable sized rainbow trout (*O. mykiss*) did not affect wild rainbow or cutthroat trout (*O. clarki*) except at the highest stocking rates, when effects were limited (Petrosky and Bjornn 1988). Stocked catchable rainbow trout used different habitat than wild steelhead trout (< 200 mm) and no aggressive interactions were observed between the two groups (Hillman and Chapman 1989). Stocked catchable size brown trout (*Salmo trutta*) displaced wild brown trout but then failed to return to foraging sites after aggressive interactions or foraging forays (Bachman 1984). Catchable size rainbow trout stocked into streams have displaced juvenile steelhead trout, assumed their foraging stations (Pollard and Bjornn 1973), and caused accelerated movements of 2-year-old and older wild brown trout (Vincent 1987).

Studies evaluating the effect of stocking zero age salmonids on the emigration of wild salmonids have also given mixed results. Stocked age 0+ Atlantic salmon (*S. salar*) used different habitat than resident rainbow trout fry and did not affect their movements (Hearn and Kynard 1986). Juvenile chinook salmon (*O. tshawytscha*) occupied different habitats following stocking of hatchery coho salmon; however, emigration of juvenile chinook and steelhead was not noticeably increased (Spaulding et al. 1989). "Thinning" releases (releases designed to decrease densities in hatchery ponds) of hatchery steelhead (age 0) did not cause wild chinook or steelhead to emigrate (Hillman and Mullan 1989). In contrast, "thinning" releases of hatchery chinook salmon caused 38-78% of wild chinook salmon and 15-45% of wild steelhead to emigrate (Hillman and Mullan 1989). Hillman and Mullan (1989) speculated that the migration pattern of the hatchery chinook salmon, rather than competition, caused the emigration of wild chinook salmon and steelhead. Released chinook salmon migrated downstream, taking up temporary feeding stations.

The main objective of this study was to evaluate the effect of stocking small streams with hatchery-reared coho salmon fry (obtained from a native broodstock) on the emigration of wild coho fry and native trout. Specifically, I wanted to determine whether stocking hatchery-reared, wild coho fry increased the rate or magnitude of emigration by wild coho fry and native trout. I also wished to determine whether wild and hatchery-reared coho fry exhibited different emigration timing. Finally, the fate of emigrating wild and hatchery-reared coho salmon fry was examined to determine whether emigrating wild coho fry were more likely to take up residence in habitats downstream.

Study Area

This study was conducted in six small tributaries of the Clearwater River, Washington (Figure 1.1). These streams were selected based on personal examination and on recommendations from Quinault Indian Nation fisheries personnel. The primary selection criteria were that wild coho salmon were known to use the stream and that stream size was amenable to the installation and operation of weir style fry traps. Bull, Prairie, Peterson, 0042, Elkhorn, and Hunt creeks were selected based on these criteria (Table 2.1). Mainstem and wall-base channel habitats sampled during the summer and winter to determine the fate and distribution of emigrating wild and hatchery coho fry have been described elsewhere (Chapters I and IV).

Table 2.1. Summary of stream conditions.

Stream	Length (km)	Stream Order	Discharge (cfs)[a]	Gradient (%)	Approx. Basin Area (km^2)	Canopy
Bull	4.0	2	1.00	1-2	6[b]	Alder, Spruce, Salmon berry
Prairie	2.4	2	0.60	4-6	3	Salmon berry, Hemlock, Alder, Spruce
Peterson	3.7	1	0.08	1-2	3[c]	Salmon berry, Alder, Spruce, Hemlock
0042	1.0	2	0.30	2-4	3	Alder, Salmon berry, Hemlock
Elkhorn	3.1	1	0.30	2-5	3[c]	Alder, Salmon berry, Hemlock
Hunt	3.7	2-3	0.35	3-5	5	Alder, Salmon berry, Hemlock

[a] Quinault Indian Nation, Department of Natural Resources (Unpublished data), low flow data
[b] Winter and Wampler (1980)
[c] Cederholm and Scarlett (1982)

MATERIALS AND METHODS

The effect of fry supplementation on the emigration of native salmonids was evaluated in six tributaries of the Clearwater River over a 3-year period. Three randomly selected streams were stocked (Bull, 0042, Hunt) during the spring of 1991 with hatchery-reared coho salmon fry obtained from a native broodstock (Quinault Indian Nation 1992). The three remaining streams were not stocked and served as controls (Peterson, Prairie, Elkhorn) for 1991. Treatments and controls were reversed during the spring of 1992, with streams stocked in 1991 serving as controls during 1992, while 1991 control streams were stocked in 1992. Emigration data also were collected from all six streams during 1993 when no stocking occurred (controls). Fry traps were installed in each stream prior to stocking to monitor downstream movement of hatchery-reared and wild coho fry, coho smolts, and native trout.

Coho salmon fry used to stock supplemented streams were obtained from a native broodstock developed by the Quinault Indian Nation, Washington Department of Fisheries, and U.S. Fish and

Wildlife Service (Quinault Indian Nation 1992). The broodstock was developed by capturing wild coho salmon from the Clearwater River, beginning in 1984, and rearing their progeny to smolts before release (Quinault Indian Nation 1992). The release site of smolts and the location of most adult collection is the Washington Department of Fish and Wildlife Shale Creek Hatchery located within the Clearwater River basin (Figure 1.1). Wild spawners from the mainstem and its tributaries have been collected each year and infused back into the broodstock population to maintain genetic characteristics.

Broodstock collection for the spring 1991 fry stocking occurred during the fall of 1990. One hundred Shale Creek females and 46 wild Clearwater females were spawned with Shale Creek males (Quinault Indian Nation 1992). The progeny were reared at the Quinault Tribe's Lake Quinault Hatchery until May when they were released (Table 2.2). Nearly all hatchery-reared fry were adipose fin clipped and coded wire tagged with a unique code for each stream (Table 2.2).

No Shale Creek broodstock was available during the 1991 brood year due to a 1990 Viral Hemorrhagic Septicemia Virus (VHSV) outbreak at the Soleduck Hatchery, the original incubation site for the Clearwater River eggs (Quinault Indian Nation 1992). This resulted in the loss of nearly all the 1988 broodyear release from Shale Creek and all of the progeny from the 1989 brood year. Thus, only wild coho salmon from the Clearwater River were used for the broodstock during 1991. Fry were the progeny of 37 males and 31 females. VHSV was isolated in the ovarian fluid of one of these females. Fortunately, eggs were incubated in five-fish lots, each with a separate water source, allowing the VHSV-positive lot to be culled to prevent contamination of other lots. The remaining egg take was isolated during incubation and early rearing and the effluent treated. Routine testing of the remaining eggs showed no other VHSV contamination. Tagging was completed at the Shale Creek facility within the Clearwater River Watershed. Net pens were constructed to keep the different tag groups (by stream) of fry separate during the tagging procedure. However, the mesh size was too large and fry escaped and intermingled, eliminating the ability to identify the hatchery-reared fry stocked into the different supplemented streams following emigration and distribution throughout the basin (Quinault Indian Nation 1993).

Fry (0.6-1.1 g) were stocked in early May during both 1991 and 1992 (Table 2.2). A tanker truck was used to transport fry to the stream vicinity. Fry were then transferred to buckets containing plastic bags, which were filled with oxygen and tied shut to provide oxygen during transportation. The buckets were carried upstream and fry released into each pool at an approximate density of 3 fry/m^2 pool area until all fry had been released (Table 2.2).

Table 2.2. Total number of hatchery-reared coho salmon fry released into test streams during 1991-1992 (adapted from Quinault Indian Nation 1992, 1993).

Stream	Release Date	Nominal Release	Actual Release	Ad. Marked (%)	Tagged (%)	Actual Density (fry/m^2)^a	Size at Release (g)
			1991				
Bull	3 May 1991	10,000	9,701	99	81.2	2.2	1.1
Hunt	2 May 1991	10,000	9,360	98	74.5	2.4	1.0
0042	2 May 1991	3,600	3,897	97	78.0	3.0	1.1
			1992				
Prairie	2 May 1992	2,200	1,709	94	56.9	2.3	0.6
Peterson	2 May 1992	3,600	3,423	94	56.9	2.8	0.6
Elkhorn	1 May 1992	2,000	1,259	94	56.9	1.9	0.6

[a] based on habitat measurements taken at summer low flow the year before planting.

Downstream migrant traps were installed in each stream (Figure 1.1) prior to stocking of hatchery-reared coho salmon fry to monitor the downstream migration of hatchery-reared and wild coho salmon fry, coho smolts, and native trout. Traps were installed as soon as the water level dropped to a workable level in early spring (March-April) and were operated through mid to late August (Appendix A). The traps were v-weirs constructed with wood-framed wings which supported 0.64-cm hardware cloth. The wings forced the fish to the center of the 'v' where a 10-cm plastic pipe entered the weir and extended downstream to a wood-framed live box. Mid-stream wings had framed "pop-outs" which could be removed during periods of high flow to protect the trap from damage. Traps were checked daily during periods of intensive migration and every other day during periods of less intense migration. All species were enumerated with a sample of each salmonid species weighed (nearest g) and measured for fork length (nearest mm). In 1991 wild and hatchery-reared coho salmon fry were marked using carbon dioxide freeze branding (Bryant and Walkotten 1980) with a brand unique to that stream to allow for identification later in the summer. Once all data had been recorded, fish were released downstream of the trap to continue their migration.

Total emigration of wild and hatchery-reared coho salmon fry was estimated by summing the total number trapped, the estimated number eaten by coho smolts, cutthroat trout, and steelhead trout while in the live box, and the estimated number of fish migrating past the trap while it was not fishing. Some coho salmon fry were consumed in the live box even though screens were installed to keep fry separate from larger salmonids. Coho smolts, cutthroat trout, and steelhead trout removed from the live box were given a fullness index of "full" or "not full", based on the protrusion of their stomachs. Coho salmon fry were extracted from a sample of coho smolts, cutthroat trout, and steelhead trout of different lengths using pulsed gastric irrigation (Foster 1977). It was assumed that all coho fry which appeared to be little digested were consumed in the live box. This information was used to develop a regression equation relating numbers of fry consumed by length of predator, to fish of both fullness indices, to estimate the number of coho salmon fry eaten by the unsampled portion of each species (Appendix B). All predator species were combined to develop this regression equation, since sample sizes were insufficient to obtain meaningful results for each predator species individually. The numbers of wild and hatchery-reared coho salmon fry consumed were calculated based on the proportion of each type of fry in that day's catch. This calculation assumes that wild and hatchery-reared coho salmon fry were equally susceptible to predation in the live box. The number of salmonids migrating each day the trap was not fishing was estimated by averaging the catch during the last day the trap fished properly and the first catch after the trap resumed fishing. Estimates of total emigration of coho smolts, cutthroat, and steelhead were obtained using these same methods, with the exception that no estimate of consumption in the trap was developed. None of these species were observed in stomach samples of predatory fish.

Effect of Coho Fry Supplementation on Total Coho Fry and Cutthroat Emigration

The effect of fry supplementation on the total number of wild coho salmon and cutthroat trout emigrating from streams was examined by comparing the estimated number of emigrants of each species from control and supplemented streams. An ANCOVA was used to compare the mean numbers of emigrants and the relationship between total numbers of emigrants and observed rearing densities (fish/m^2 pool) of each species in supplemented and control streams during June. The ANCOVA for coho salmon was completed using both wild coho fry densities only and combined wild and hatchery coho fry densities as the covariate.

Effect of Coho Fry Supplementation on Salmonid Emigration Rates

The effect of stocking hatchery-reared coho salmon fry on the emigration rate of wild coho salmon fry, cutthroat trout, steelhead trout, and wild coho salmon smolts was evaluated among supplemented and control streams using a Kolmogorov-Smirnov goodness of fit test for continuous data (KS test). The migration rates of hatchery and wild coho salmon (fry and smolts) from supplemented streams also were compared using a KS test. These tests were completed for data collected during

1991 and 1992 separately and combined, (1992 and 1993 for hatchery and wild smolts), using emigration data obtained from the time hatchery fry were stocked to the end of the trapping season. One exception was for the evaluation of hatchery and wild coho smolts emigration rates, which was completed using data for the entire trapping season (included data collected prior to stocking hatchery fry).

Daily catch data (numbers of emigrants) for each species were transformed to percent of total emigration (daily) by dividing the number of emigrants caught each day by the total number of fish of each species estimated to have emigrated from the stream (see above section). Cumulative percent emigration for each species was then calculated for each trapping day by adding the daily percents from each successive day to the cumulative percent up to that day. The mean cumulative percent for control and supplemented streams (overall effect of supplementation on emigration) and hatchery and wild coho fry and smolts from supplemented streams (comparison of hatchery and wild emigration rates) were calculated and compared using a KS test (Zar 1984). This procedure was used to compare emigration rates of each salmonid species (coho fry (wild and hatchery), coho smolts (wild and hatchery), cutthroat, steelhead) sampled while trapping.

Effect of Coho Fry Supplementation on Lengths of Emigrating Salmonids

The effect of stocking hatchery-reared coho salmon on the length of emigrating wild coho salmon fry was examined using two different methods. First, the average length of wild coho salmon emigrating the day prior to stocking hatchery-reared coho salmon in supplemented streams was compared to the average length of wild coho salmon emigrating the day following stocking in these streams using a standard t-test. Second, the lengths of wild coho fry emigrating from control versus supplemented streams, from the time hatchery-reared coho fry were stocked until trapping was terminated was compared using an ANCOVA. The date when lengths were recorded was included in the ANCOVA as the covariate. The ANCOVA was used to determine whether the average lengths of emigrating wild coho fry were significantly different in control and supplemented streams and whether lengths of emigrating wild coho fry changed differently over time in supplemented than in control streams. Only data from 1991 were used for this comparison because insufficient data were available for statistical analysis during 1992.

The lengths of wild and hatchery coho fry emigrating from within each supplemented streams during 1991 and 1992 also were compared using an ANCOVA. This analysis included only data from the date when hatchery fry were stocked through the last day when both hatchery and wild coho fry were represented in the catch. This eliminated the potential bias from different growing periods available to emigrating fry, which would occur if one group ceased emigrating before the other.

A two-way ANOVA was used to compare the length of wild coho salmon smolts emigrating from supplemented and control streams the year following stocking (e.g., stocked 1991, comparison of smolt size in 1992). It was assumed that growth of coho smolts during the emigration period would be negligible. Therefore, comparisons of wild coho smolt lengths were completed using data collected during the entire smolt emigration period without controlling for timing (date). Treatment (control and supplemented) and year (1992 and 1993) were included as the two factors in the two-way ANOVA and the interaction between these two factors was examined. Lengths of wild and hatchery coho smolts emigrating from each supplemented stream during 1992 and 1993 were compared using a standard t-test.

Fate of Emigrating Coho Salmon

An effort was made to determine the subsequent fate of emigrating coho salmon fry freeze branded prior to release from the traps in 1991. We sampled downstream of the fry traps in Bull Creek, Peterson Creek, 0042 Creek, and Elkhorn Creek to their confluence with the mainstem during mid-summer, using electrofishing. Since 0042 is a tributary to Shale Creek, we also sampled Shale Creek to its confluence with the mainstem Clearwater River. We did not sample downstream of the traps in Hunt Creek because there is little distance between the trap and the confluence with the mainstem, and in Prairie Creek (too few fry were branded there). We also sampled areas in the mainstem downstream of each study stream's confluence during July and September. Beach and purse seines were used to catch coho salmon near woody debris accumulation in the mainstem (Chapter IV). We also examined fry as they moved into wall-base channels during the fall (Chapter IV). All fry were anesthetized, examined for brands with a sub-sample being weighed (g) and measured for fork length (mm) as described above and released into the habitat from which they had been taken.

RESULTS

Effects of Coho Fry Supplementation on Coho Fry and Cutthroat Emigration

Total emigration of hatchery-reared coho salmon stocked into supplemented streams was quite variable (Table 2.3). Between 9.3% and 46.9% of hatchery-reared coho fry emigrated from supplemented streams. The percent of hatchery fry stocked into supplemented streams emigrating from that stream was greater (t-test: $P=0.0139$) in 1991 (mean = 34.6%) than 1992 (mean = 14.8%). Estimated densities that emigrating hatchery-reared coho fry would have produced in upstream habitat during late August ranged from 0.56 to 3.07 fry/ m^2 pool area. Daily emigration patterns of hatchery-reared coho fry are displayed in Figures C.1-C.2 in Appendix C.

Total numbers of wild coho fry actually caught and estimated to have emigrated from control and supplemented streams varied between streams and years (Table 2.4). Actual and estimated emigration was greatest during 1991 and declined during the next three years. Daily emigration patterns of wild coho fry are displayed graphically in Figures C.1-C.3 in Appendix C.

Table 2.3. Total number of hatchery-reared coho salmon fry caught in fry traps, estimates of total migration, and the percent of stocked hatchery-reared coho salmon emigrating during 1991-1992.

	Actual catch		Estimated migrants		Percent emigration	
Stream	1991	1992	1991	1992	1991	1992
Bull	3,691	—	4,549	—	46.9	—
Prairie	—	156	—	193	—	11.3
Peterson	—	766	—	815	—	23.8
0042	1,473	—	1,594	—	40.9	—
Elkhorn	—	98	—	117	—	9.29
Hunt	1,287	—	1,507	—	16.1	—

Table 2.4. Total number of wild coho fry caught in fry traps and estimates of total emigration during 1991-1993.

	Actual catch			Estimated migrants		
Stream	1991	1992	1993	1991	1992	1993
Bull	1,652	773	72	2,167	1,352	321
Prairie	64	18	0	86	147	0
Peterson	3,174	402	4	3,559	839	5
0042	3,290	2	98	3,795	2	129
Elkhorn	3,049	167	753	3,187	307	892
Hunt	1,404	31	127	1,507	485	287

Mean total emigration of wild coho salmon was not increased in supplemented streams as compared to control streams during 1991 and 1992 (Table 2.5). However, the relationship between the number of emigrating coho salmon and June rearing densities (fish/m^2 pool area) was different in supplemented and control streams (Figure 2.1), although the difference was not statistically significant (Table 2.5). The estimated number of emigrants in control streams was low when observed densities were low and increased as observed densities increased. In contrast, estimated numbers of emigrants were high when observed densities were low and decreased as observed densities increased. The relationship was the same whether only wild coho or combined wild and hatchery-reared coho fry densities were used (Figure 2.1).

Actual and estimated numbers of emigrating cutthroat trout were relatively consistent among streams and years (Table 2.6) compared to coho fry emigration (Table 2.4). Daily emigration patterns of cutthroat trout are displayed graphically in Appendix Figures C.4-C.6.

Mean total emigration of cutthroat trout was not increased in supplemented streams as compared to control streams during 1991 and 1992 (Table 2.5). However, the relationship between estimated numbers of emigrants and observed rearing densities (fish/m^2 pool) during June was different in control and supplemented streams (Figure 2.2), although the difference was not statistically significant (Table 2.5). Estimated numbers of cutthroat emigrants did not change with increasing cutthroat densities in control streams (Figure 2.2). In contrast, the estimated number of cutthroat emigrants increased with increasing cutthroat densities in supplemented streams (Figure 2.2).

Table 2.5. Mean estimated emigration of wild coho fry and cutthroat trout in supplemented and control streams and results of the ANCOVA comparing these means among control and supplemented streams and the relationship of estimated numbers of emigrants with observed densities during June in control and supplemented streams during 1991 and 1992.

	Mean (SD) number of emigrants		Results (*P*) of ANCOVA comparison	
Species	Control	Supplemented	Means	Relationship (emigrants vs. density)
Coho	1445.2 (1572.5)	1460.3 (1370.6)	0.1485[a]/ 0.2122[b]	0.1332[a]/ 0.1245[b]
Cutthroat	166.7 (70.2)	210.8 (73.6)	0.8605	0.4113

[a] Results calculated using observed densities of wild coho salmon only

[b] Results calculated using observed combined wild and hatchery-reared coho fry densities

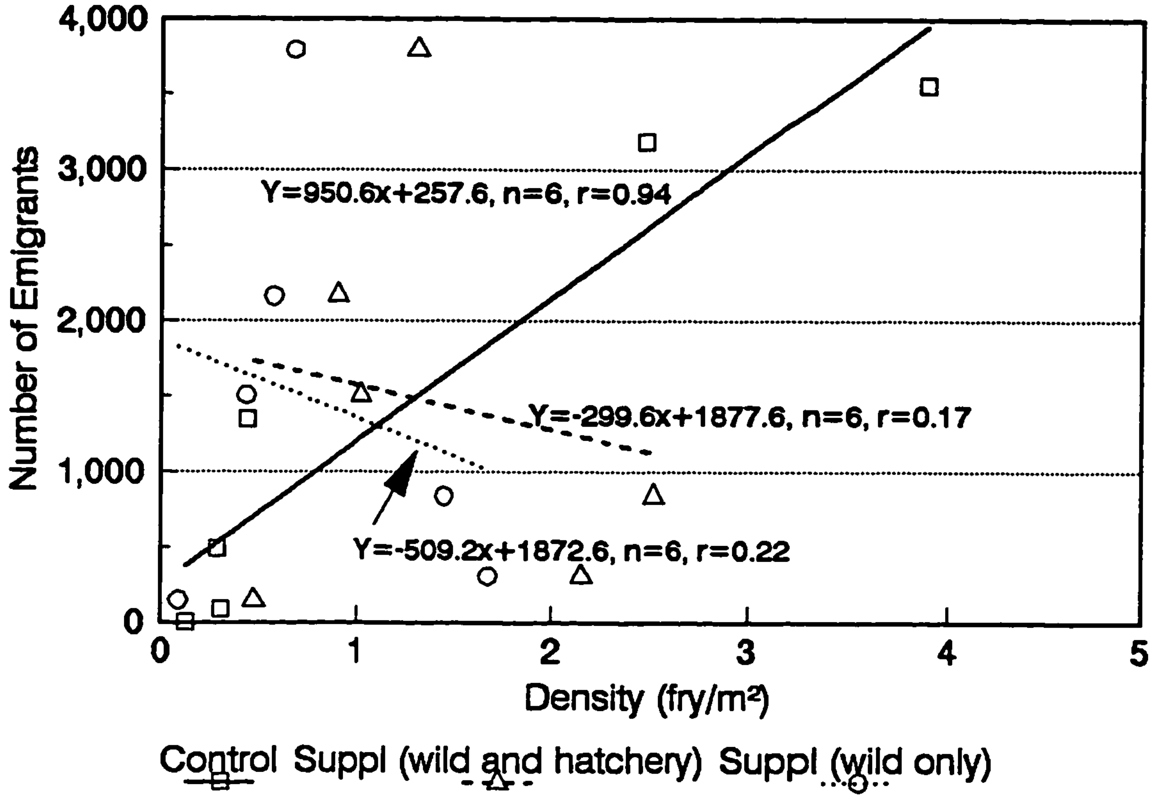

Figure 2.1. Relationship between coho salmon fry rearing densities (fish/m² pool area) during June (Chapter III) in supplemented (wild only and wild and hatchery combined) and control streams (wild only) and estimated numbers of emigrating wild coho fry during 1991-1992.

Table 2.6. Total number of cutthroat trout caught in fry traps and estimated total emigration during 1991-1993.

	Actual catch			Estimated migrants		
Stream	1991	1992	1993	1991	1992	1993
Bull	217	146	155	244	270	211
Prairie	115	307	133	122	334	141
Peterson	127	97	104	127	126	119
0042	143	120	30	152	136	40
Elkhorn	104	187	115	104	210	126
Hunt	185	193	113	199	241	179

Actual catch and estimated numbers of emigrating wild and hatchery coho smolts varied between streams (Table 2.7). Variability in the numbers of wild coho smolts emigrating from study streams was relatively small between years, with the exception of Peterson and 0042 Creeks. These two streams produced many more wild coho smolts during 1992 than during either 1991 or 1993. Estimates of wild smolt emigration ranged from 0 in Prairie Creek (1991 and 1993) to 558 in Bull Creek (1993). The number of hatchery coho smolts emigrating from streams the year following supplementation was much lower than that of wild coho smolts emigrating, with the exception of Hunt Creek during 1992. Hatchery coho fry stocked during 1991 smolted from 1991 control streams located downstream, evidently as a result of winter redistributions. Daily emigration patterns of wild and hatchery coho smolts are listed in Figures C.7-C.12 in Appendix C.

Actual catch and estimated emigration of steelhead showed moderate variability between streams and years when compared to other emigrating salmonids (Table 2.8). Estimated emigration ranged from 4 to 207 steelhead. Emigration of zero age trout was much greater during 1991 than 1992 and 1993, when no zero age trout were caught (Table 2.9). Nearly all zero age trout caught during this study were from 0042 Creek. Daily emigration patterns of steelhead and zero age trout are displayed graphically in Figures C.12-C.14 in Appendix C.

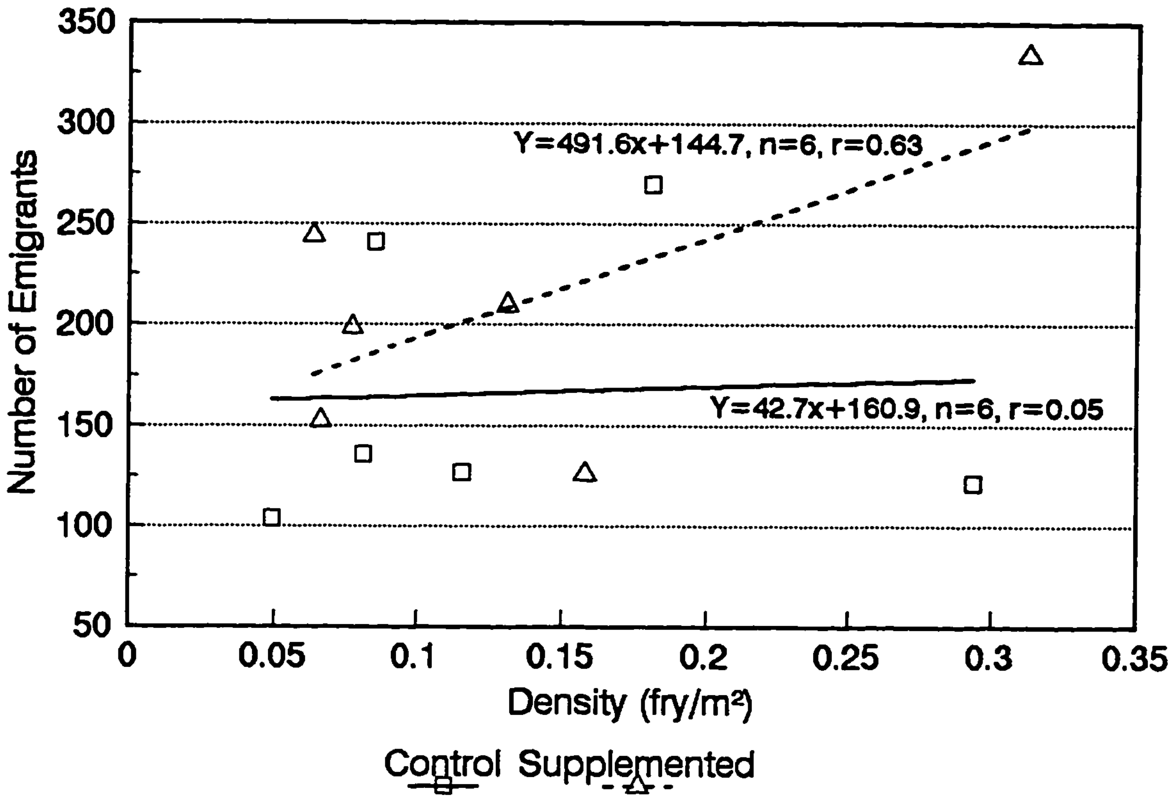

Figure 2.2. **Relationship between observed densities (fish/m² pool area) of cutthroat trout in supplemented and control streams during June (Chapter III) and estimated numbers of cutthroat trout emigrating from these streams during 1991-1992.**

Table 2.7. Total number of wild coho smolts caught in fry traps and estimates of total emigration during 1991-1993.

	Actual Catch					Estimated Migrants				
Stream	1991[a]	1992		1993		1991[a]	1992		1993	
		Wild	Hatchery	Wild	Hatchery	Wild	Wild	Hatchery	Wild	Hatchery
Bull	432	287	15	458	0	501	378	20	558	0
Prairie	0	6	0	0	5	0	6	0	0	5
Peterson	23	510	2	68	20	23	610	2	79	21
0042	24	162	34	22	0	26	168	36	21	0
Elkhorn	244	386	6	74	5	244	411	6	91	5
Hunt	307	430	265	311	0	335	464	285	338	0

[a] Only wild coho smolts were present during 1991

Table 2.8. Total number of steelhead trout caught in fry traps and estimates of total emigration during 1991-1993.

	Actual catch			Estimated migrants		
Stream	1991	1992	1993	1991	1992	1993
Bull	193	25	122	205	41	136
Prairie	18	35	24	19	37	25
Peterson	207	125	53	207	126	55
0042	19	30	4	20	33	4
Elkhorn	75	85	16	75	88	16
Hunt	62	69	22	66	74	22

Table 2.9. Total number of zero age trout caught in fry traps and estimates of total emigration during 1991-1993.

	Total Catch			Estimated Migrants		
Stream	1991	1992	1993	1991	1992	1993
Bull	0	0	0	0	0	0
Prairie	9	0	0	11	0	0
Peterson	0	0	0	0	0	0
0042	49	0	0	50	0	0
Elkhorn	0	0	0	1	0	0
Hunt	1	0	0	1	0	0

Effect of Coho Fry Supplementation on Salmonid Emigration Rates

Contradictory results were obtained regarding the influence of coho salmon fry supplementation on the emigration rate of wild coho fry (Figure 2.3). Wild coho fry in supplemented streams emigrated earlier than those in control streams during 1991 (Figure 2.3). In contrast, overall emigration of wild coho salmon occurred earlier in control streams than in supplemented streams during 1992, although initial emigration was earlier in supplemented streams (Figure 2.3). When data from both years were combined, the results indicated that wild coho fry in supplemented streams emigrated earlier than those in control streams.

The emigration rate of cutthroat trout generally was unaffected by coho salmon fry supplementation (Figure 2.4). Cutthroat trout emigration in control streams was significantly later than in supplemented streams during 1992. However, no significant differences in cutthroat trout emigration rates were observed during 1991, or when data from 1991 and 1992 were combined. Emigration rates of wild coho smolts were unaffected by coho fry supplementation (Figure 2.5). No significant differences in wild coho smolt emigration rates were detected between control and supplemented streams during 1991 and 1992. Nor were differences detected when data from the two years were combined.

Emigration rates of steelhead trout appeared to be increased by coho salmon fry supplementation (Figure 2.6), although the results were inconsistent. No significant difference was observed in the emigration rates of steelhead in supplemented and control streams during 1991. However, steelhead trout in supplemented streams emigrated significantly faster than those in control streams during 1992. This difference was maintained when data from 1991 and 1992 were combined (Figure 2.6).

Wild and hatchery coho salmon fry and smolts each displayed significantly different rates of emigration from supplemented streams (Figure 2.7-2.8). Hatchery coho fry emigrated from supplemented streams much faster than wild coho fry during both 1991 and 1992 (Figure 2.7). This difference was maintained when data from 1991 and 1992 were combined. In contrast, hatchery coho smolts emigrated from supplemented streams significantly slower than wild coho smolts (Figure 2.8). This difference existed during both 1991 and 1992 as well as when data from both years were combined.

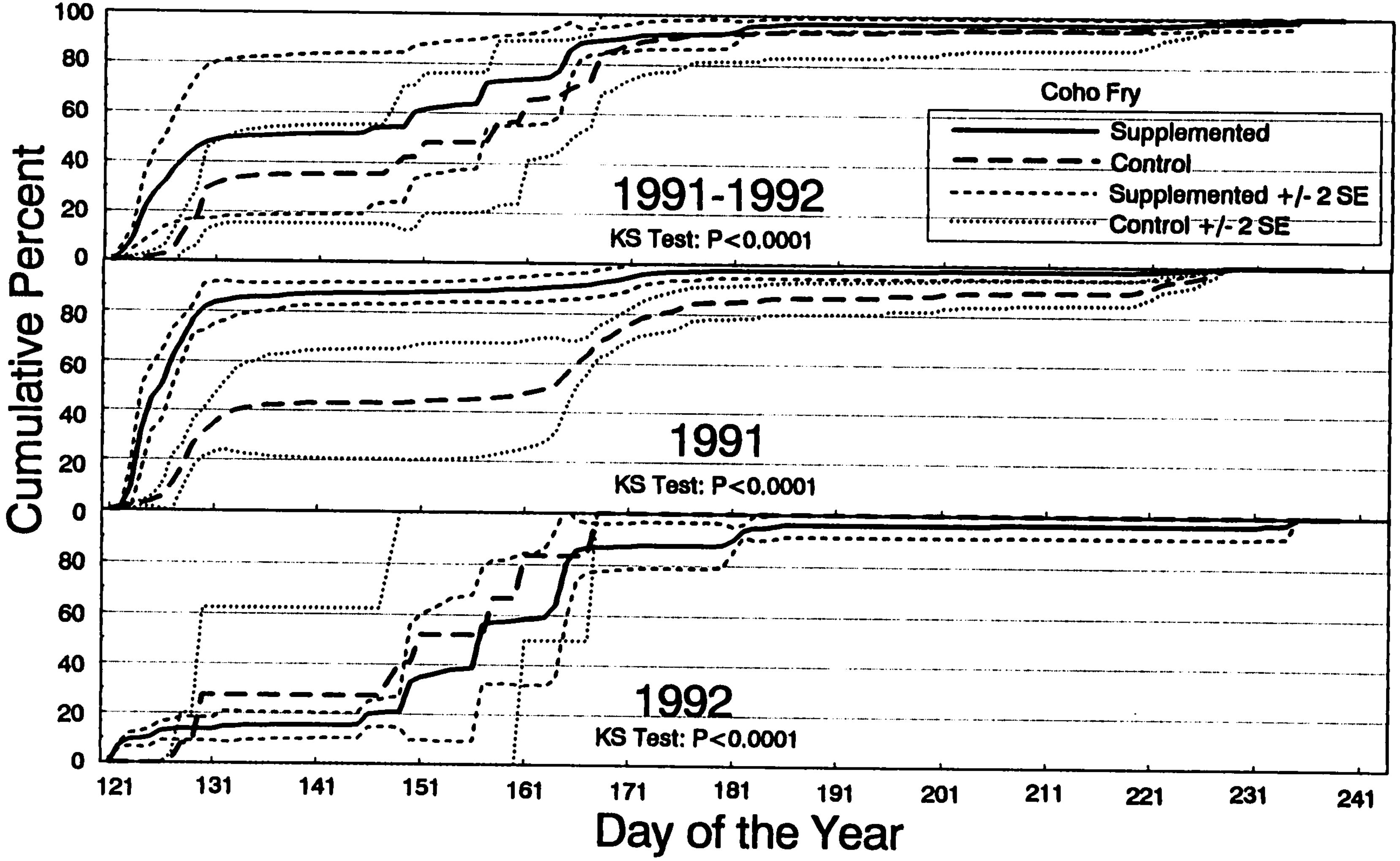

Figure 2.3. Cumulative percent emigration of wild coho salmon fry from supplemented and control streams during 1991-1992. Fine dashed and dotted lines represent the range (+/- 2 SE) for control and supplemented streams, respectively.

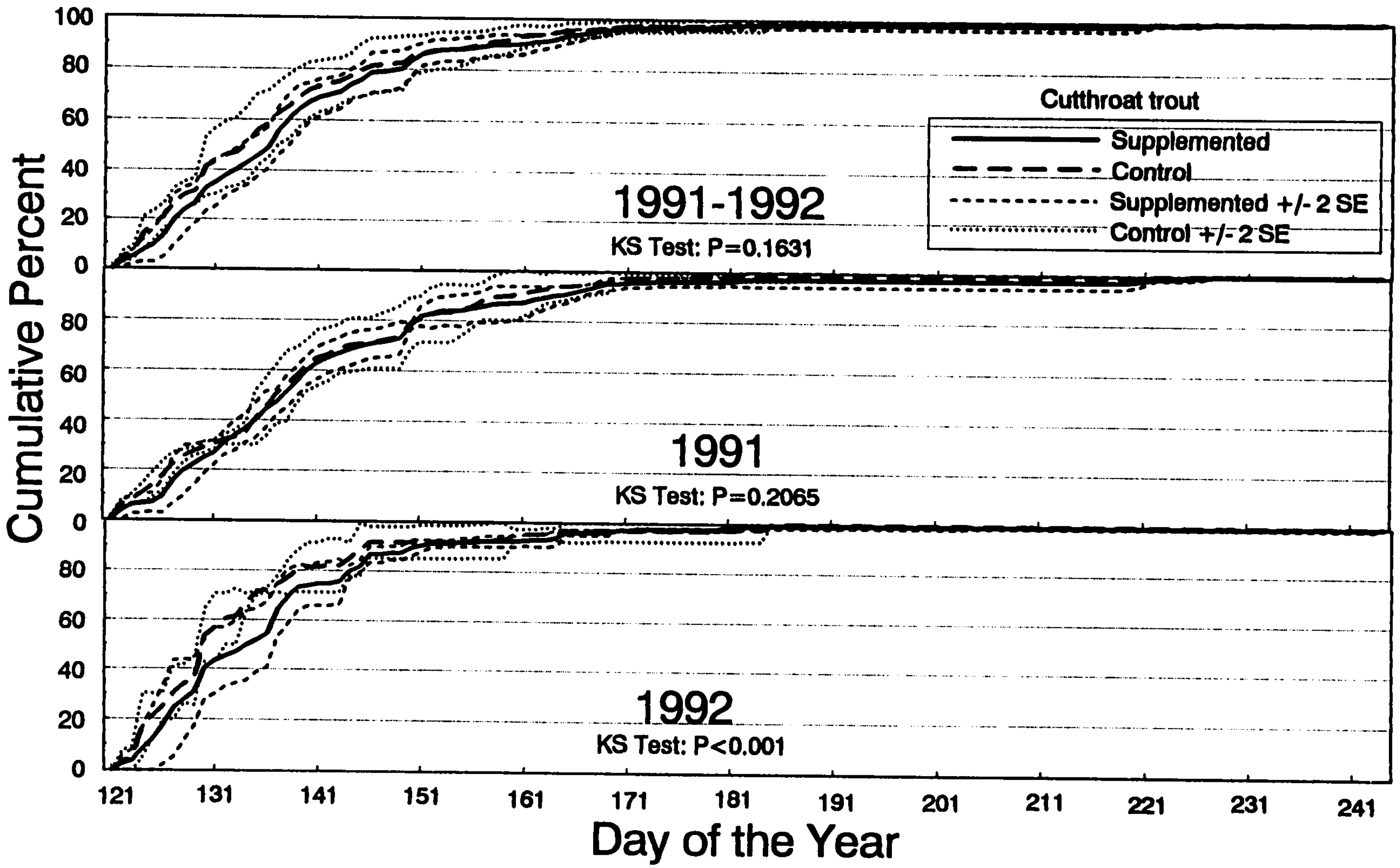

Figure 2.4. Cumulative percent emigration of cutthroat trout from supplemented and control streams during 1991-1992. Fine dashed and dotted lines represent the range (+/- 2 SE) for control and supplemented streams, respectively.

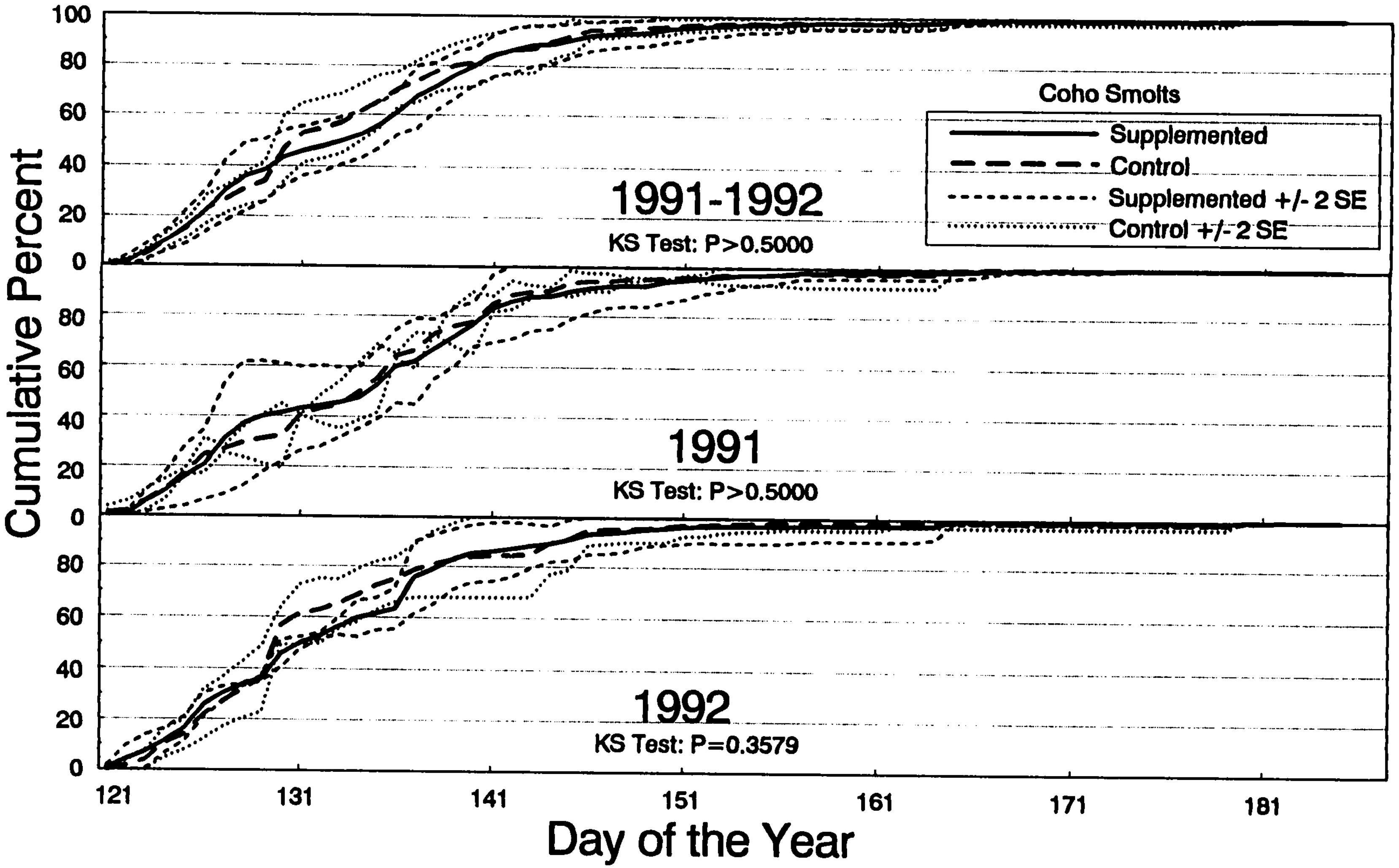

Figure 2.5. Cumulative percent emigration of wild coho smolts from supplemented and control streams during 1991-1992. Fine dashed and dotted lines represent the range (+/- 2 SE) for control and supplemented streams, respectively.

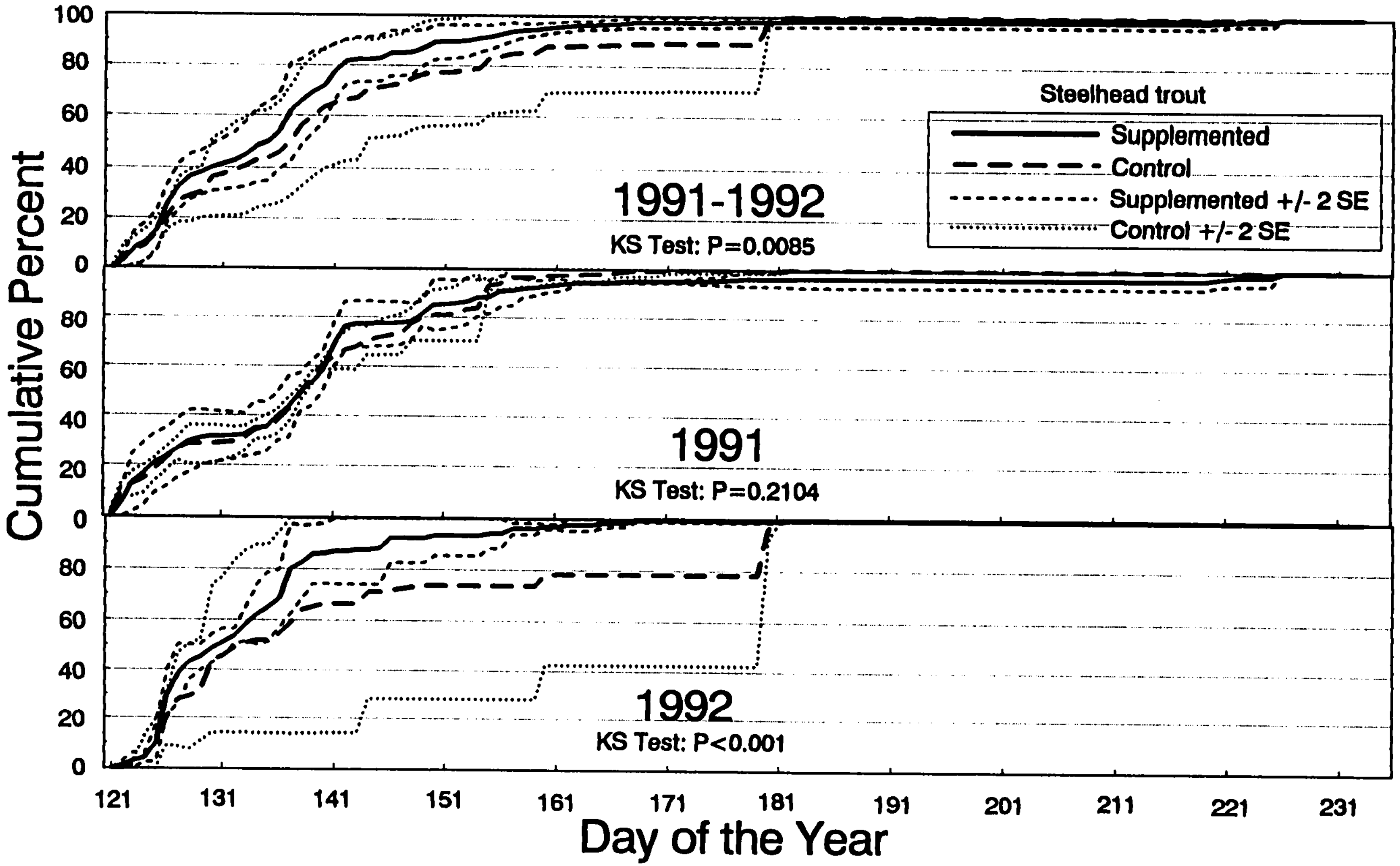

Figure 2.6. Cumulative percent emigration of steelhead from supplemented and control streams during 1991-1992. Fine dashed and dotted lines represent the range (+/- 2 SE) for control and supplemented streams, respectively.

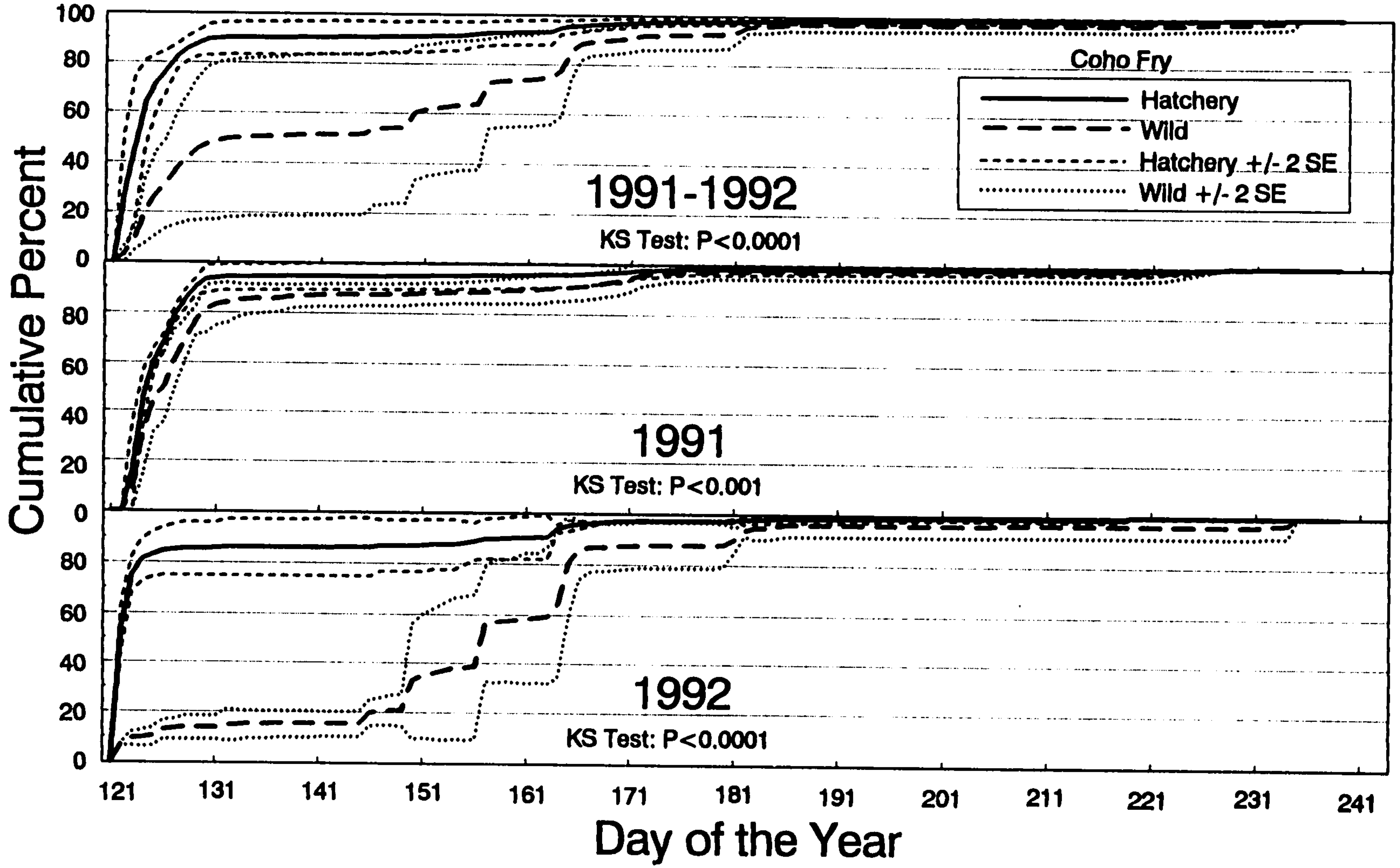

Figure 2.7. Cumulative percent emigration of wild and hatchery coho salmon fry from supplemented streams during 1991-1992. Fine dashed and dotted lines represent the range (+/- 2 SE) for hatchery and wild fish, respectively.

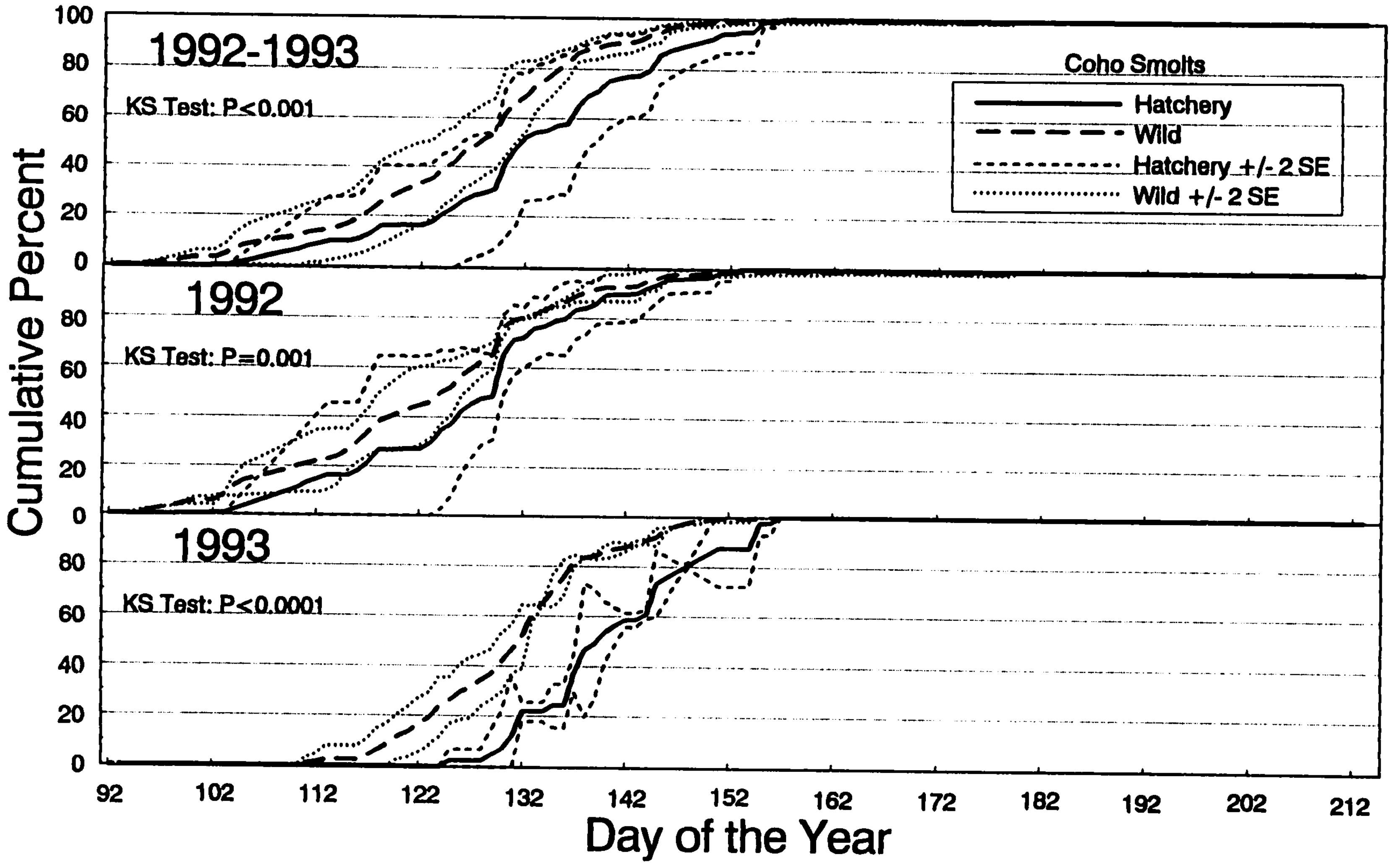

Figure 2.8. Cumulative percent emigration of wild and hatchery coho salmon smolts from supplemented streams during 1992-1993. Fine dashed and dotted lines represent the range (+/- 2 SE) for hatchery and wild fish, respectively.

Effects of Coho Fry Supplementation on Lengths of Emigrating Salmonids

No consistent difference in the length of wild coho fry emigrating from supplemented and control streams was observed before or after stocking hatchery-reared coho fry (Figure 2.9). Wild coho salmon fry emigrating prior to stocking hatchery-reared coho salmon fry were larger than those migrating after stocking in 0042 Creek during 1991 (t-test: $P=0.0001$). However, wild coho salmon fry emigrating prior to stocking were smaller than those migrating after stocking in Hunt Creek during 1991 (t-test: $P=0.0001$). No difference was observed in Bull Creek (1991) (t-test: $P=0.6571$) or Elkhorn Creek (1992) (t-test: $P=0.4074$). No test was possible for either Prairie Creek or Peterson Creek because too few fish emigrated before and after stocking.

Average length of wild coho fry emigrating from supplemented streams appeared to be negatively influenced by coho fry supplementation during 1991. Wild coho salmon emigrating from supplemented streams were smaller than those emigrating from control streams (ANCOVA: $P=0.0001$). The size of emigrating wild coho salmon in control streams increased during the trapping period at a greater (ANCOVA: $P=0.001$) rate (slope) than in supplemented streams (Figure 2.9). Insufficient numbers of emigrating wild coho fry were observed in supplemented and control streams during 1992 for meaningful statistical comparisons.

Emigrating hatchery coho salmon fry were generally larger than wild coho fry in supplemented streams during 1991, however the opposite was true during 1992 (Figures 2.10-14). Hatchery coho fry emigrating from 0042 (ANCOVA: $P=0.0046$) and Hunt Creek (ANCOVA: $P=0.0001$) were larger than wild coho salmon fry during 1991 (Figures 2.10-2.11). No difference (ANCOVA: $P=0.3008$) was detected between the fork lengths of wild and hatchery coho fry emigrating from Bull Creek during 1991 (Figure 2.12). The change in the fork length of emigrating wild and hatchery coho salmon fry during the trapping season was not different in 0042 (ANCOVA: $P=0.4523$) or Bull Creek (ANCOVA: $P=0.2103$) during 1991. However, lengths of emigrating wild coho fry increased more (ANCOVA: $P=0.0001$) during the trapping season than that of hatchery coho salmon in Hunt Creek (Figure 2.13).

No difference was detected in the lengths of wild and hatchery coho fry emigrating from Elkhorn Creek during 1992 (ANCOVA: $P=0.7866$). In contrast, wild coho salmon in Peterson Creek were larger than emigrating hatchery fry during 1992 (ANOVA: $P=0.0001$). The length of wild and hatchery coho salmon emigrating from Elkhorn Creek during 1992 did not change differently (ANCOVA: $P=0.7981$) during the trapping season (Figure 2.14). However, the lengths of emigrating wild coho salmon in Peterson Creek increased more (ANCOVA: $P=0.0001$) during trapping than the lengths of hatchery coho fry (Figure 2.15). Insufficient data existed for meaningful comparisons in Prairie Creek.

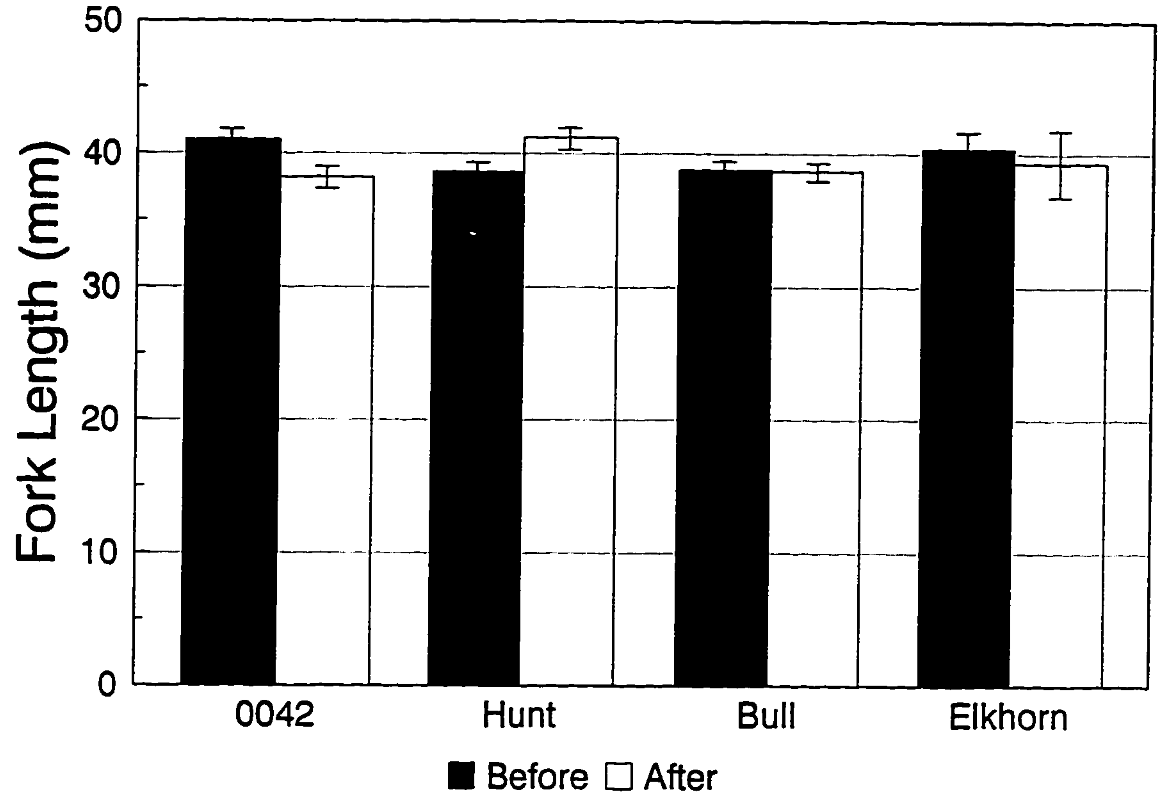

Figure 2.9. Mean fork length (+/- 2 SE) of wild coho salmon fry emigrating from supplemented streams the day before and the day after stocking with hatchery-reared coho salmon fry during 1991 (0042, Hunt, Bull) and 1992 (Elkhorn).

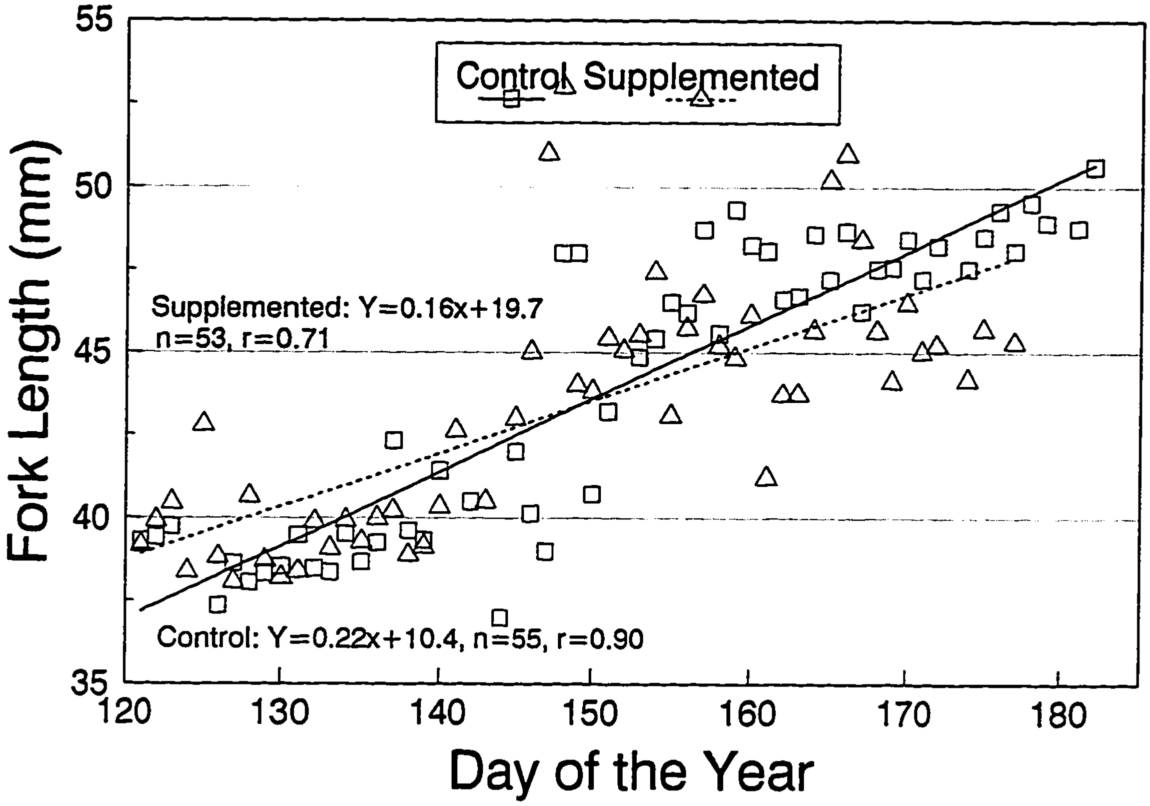

Figure 2.10. **Changes in fork length of wild coho fry emigrating from supplemented and control streams during 1991. Data included date from when hatchery coho fry were stocked to the last day when both wild and hatchery coho fry were caught emigrating from the stream.**

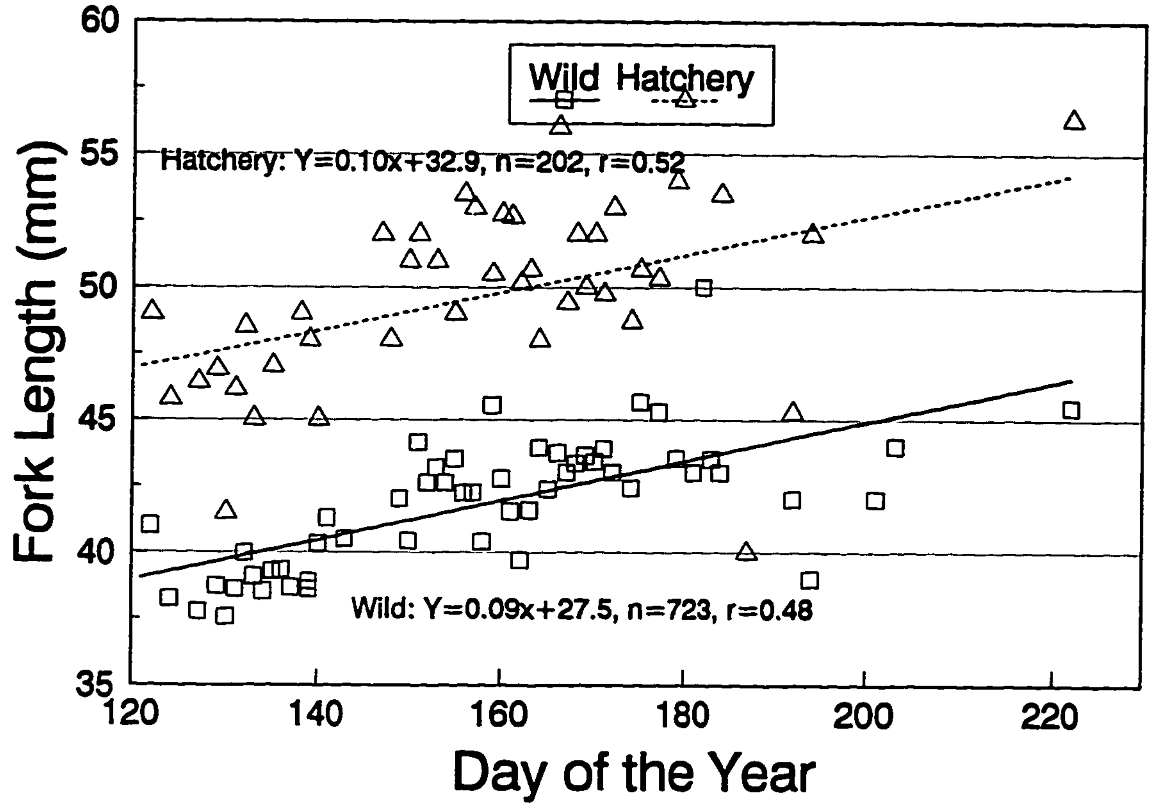

Figure 2.11. Changes in mean fork lengths of wild and hatchery-reared coho fry emigrating from 0042 Creek during 1991. Data includes dates from when hatchery coho fry were stocked to the last day when both wild and hatchery coho fry were caught emigrating from the stream.

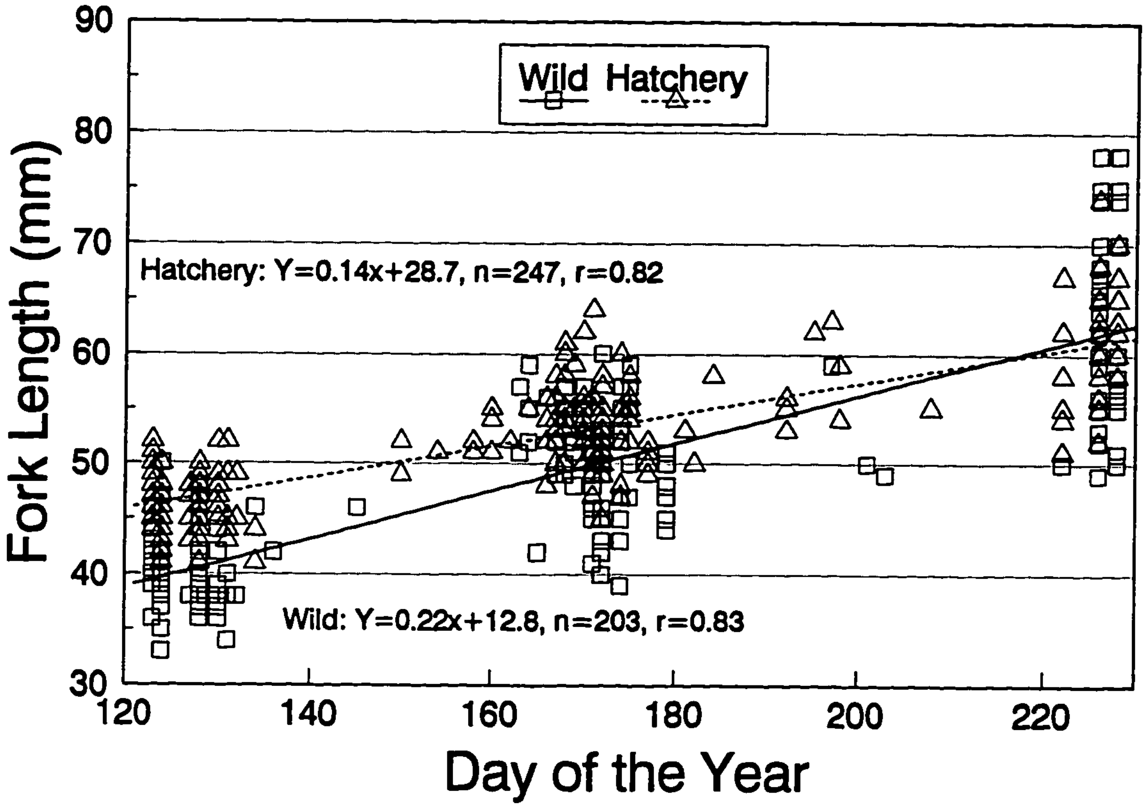

Figure 2.12. Changes in mean fork lengths of wild and hatchery-reared coho fry emigrating from Hunt Creek during 1991. Data includes dates from when hatchery coho fry were stocked to the last day when both wild and hatchery coho fry were caught emigrating from the stream.

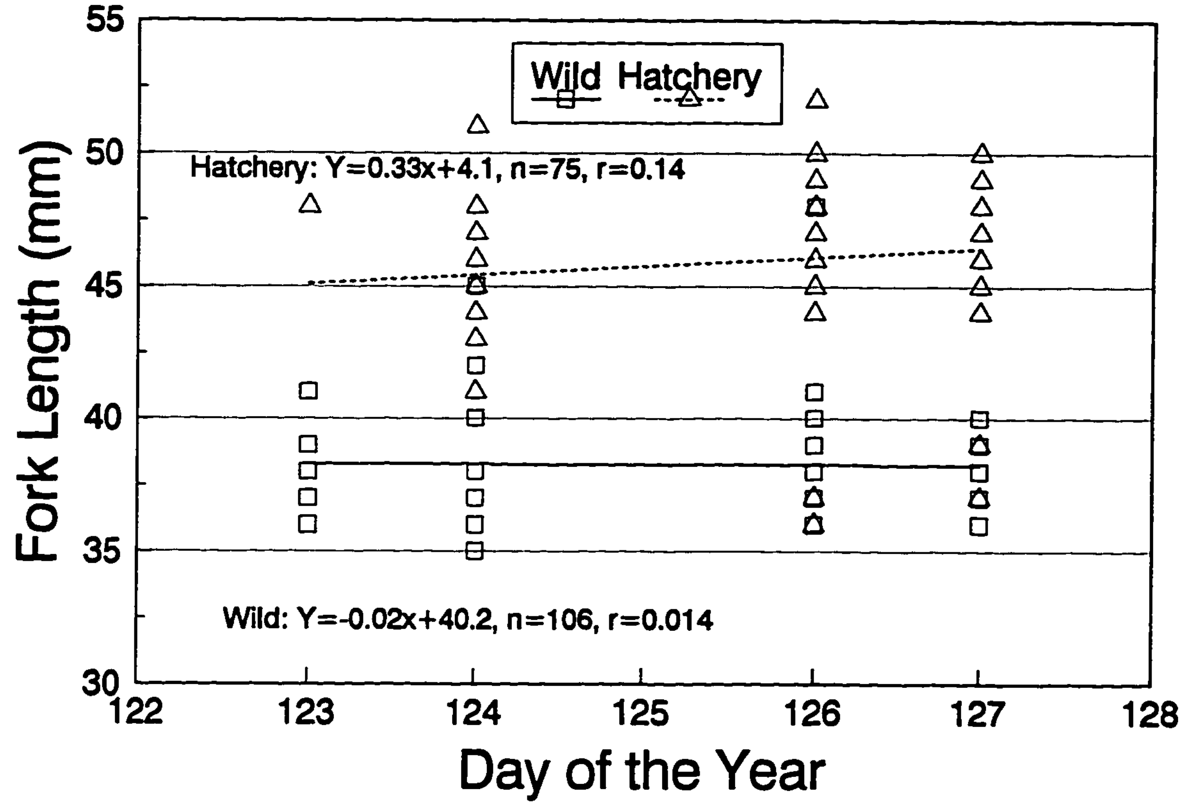

Figure 2.13. Changes in mean fork lengths of wild and hatchery-reared coho fry emigrating from Bull Creek during 1991. Data includes dates from when hatchery coho fry were stocked to the last day when both wild and hatchery coho fry were caught emigrating from the stream.

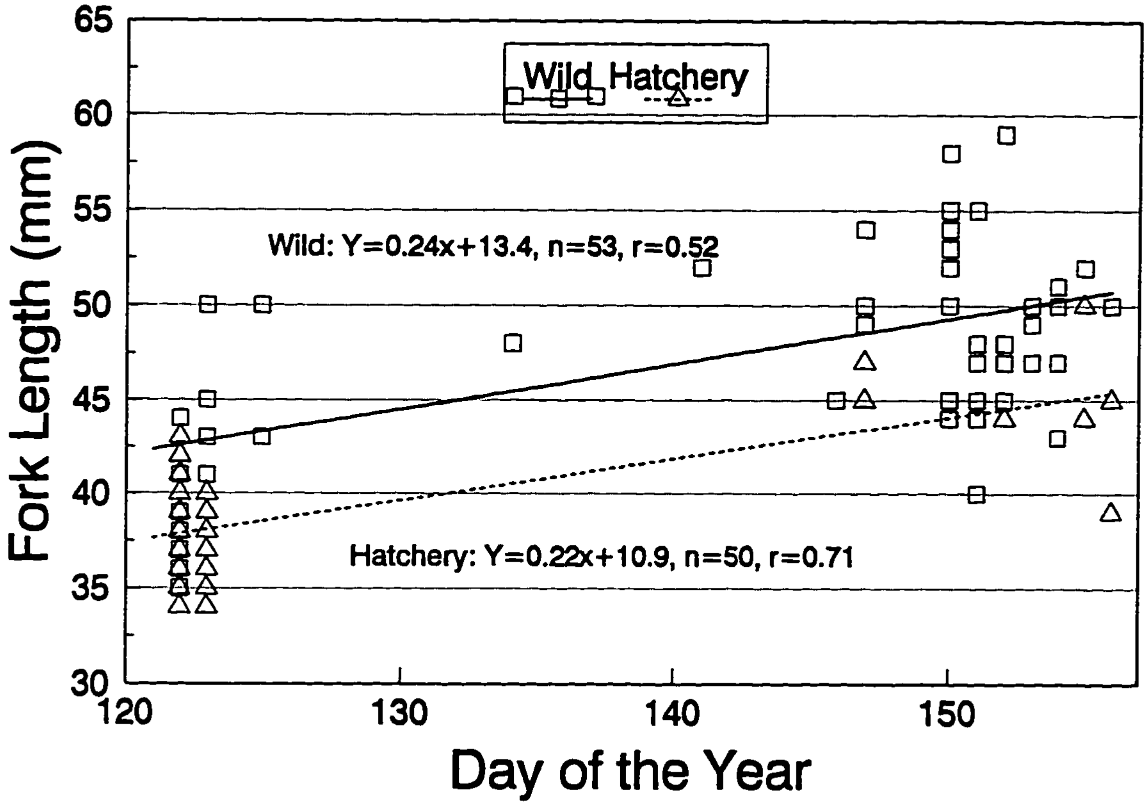

Figure 2.14. Changes in mean fork lengths of wild and hatchery-reared coho fry emigrating from Elkhorn Creek during 1992. Data includes dates from when hatchery coho fry were stocked to the last day when both wild and hatchery coho fry were caught emigrating from the stream.

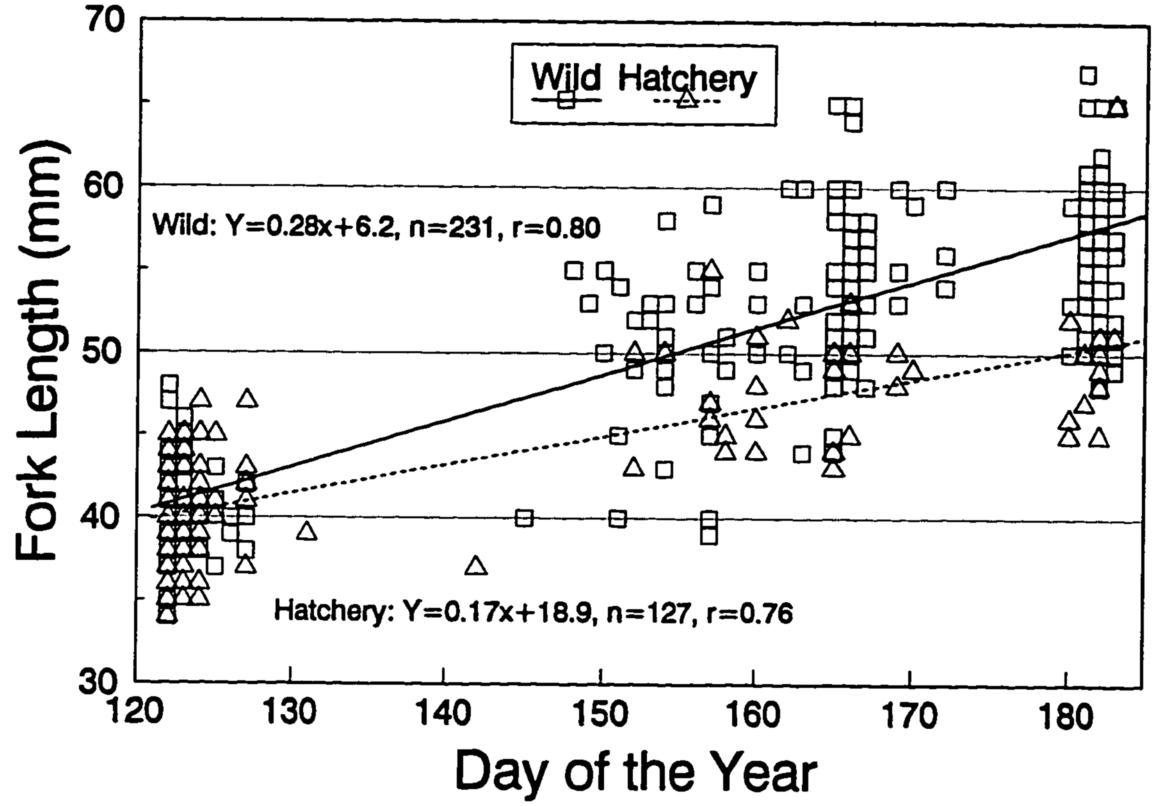

Figure 2.15. Changes in mean fork lengths of wild and hatchery-reared coho fry emigrating from Peterson Creek during 1992. Data includes dates from when hatchery coho fry were stocked to the last day both wild and hatchery coho fry were caught emigrating from the stream.

Significant differences in the fork length of wild coho salmon smolts existed between years and treatments (control vs. supplemented). Wild coho smolts were larger in 1993 (Mean = 103.2, SD = 8.98) than in 1992 (Mean = 98.3, SD = 9.30) (two-way ANOVA: P=0.0001) and in supplemented streams (Mean = 100.4, SD = 10.27) than in control streams (Mean = 99.8, SD = 10.86) (two-way ANOVA: P=0.0001). No interaction was detected between the factors treatment and year (two-way ANOVA: P=0.9894).

No consistent trend existed between wild and hatchery-reared coho smolt lengths in supplemented streams (Figure 2.16). Wild and hatchery coho smolt lengths were not different in 0042 Creek (t-test: 1992: P=0.1384, Power < 0.30), Bull Creek (t-test: 1992: P=0.5448; Power <0.30); or Elkhorn Creek (t-test: P=0.1558; Power < 0.30); however, the power of these tests was low. Hatchery coho smolts were larger than wild coho salmon smolts in Hunt Creek during 1992 (t-test: P=0.0001). In contrast, wild coho salmon smolts were larger than hatchery coho smolts in Peterson Creek during 1993 (t-test: P=0.0001). No comparison was possible for Prairie Creek due to too few emigrants.

Fate of Emigrating Coho Salmon

Emigrating wild and hatchery-reared coho salmon fry freeze branded and released below fry traps took up residency in habitats downstream of the traps. From limited electroshocking observations it appears that wild coho salmon fry emigrating past our traps may have been more likely to reside in downstream habitats than hatchery-reared coho salmon fry (Table 2.10). The recovery rate of branded wild fry below the Bull Creek trap was 3.25% compared to 0.66% for hatchery-reared coho salmon. However, a large number (136) of unbranded hatchery-reared coho fry were observed below this trap. Unbranded hatchery-reared coho salmon either migrated while the trap was not fishing or the brands faded. An estimated 426 wild and 810 hatchery-reared coho salmon fry emigrated past the trap without being branded during brief periods while the trap was not fishing from the beginning of trapping and the 29 July 1991 survey. The recovery rate of hatchery-reared coho salmon fry below the trap, based on the total number of hatchery-reared coho salmon fry (branded and unbranded) recovered, was 3.28% which is similar to the recovery rate of wild coho fry. However, it is likely that some of the unbranded wild coho salmon observed below the trap had also migrated while the trap was not fishing. This would result in an increased recovery rate for wild fish as well. Recoveries of both wild and hatchery-reared coho salmon fry were less in Shale Creek than Bull Creek.

Wild and hatchery coho salmon in the mainstem Clearwater River were sampled with beach and purse seines from 16 July through 29 July and examined for brands. Juvenile coho salmon from 52 debris accumulations in the mainstem Clearwater River were sampled and examined for brands

(Table 2.11). Branded wild and/or hatchery-reared coho fry or unbranded hatchery coho fry were recovered at 22 of the 52 stations during the July sampling. Wild coho salmon branded in Bull, Peterson, 0042, and Elkhorn creeks were recovered (Table 2.12). Recoveries of branded hatchery coho salmon were all from Bull Creek. Wild coho salmon had migrated from 0 to 10 km downstream once they entered the mainstem (Figure 2.17). However, two marked fish from Elkhorn Creek had moved upstream approximately 300 m from the mouth of Elkhorn Creek. Both marked hatchery-reared coho salmon originated from Bull Creek and had moved downstream (0-2 km).

A second survey of the mainstem Clearwater River was completed from 9 September to 16 September (Table 2.11). Eleven mainstem debris accumulations were sampled during this survey, with branded wild coho fry or unbranded hatchery-reared coho fry being recovered at six of these accumulations (Figure 2.17). However only two branded wild coho fry and no hatchery-reared coho fry were recovered during this survey. Marked wild coho salmon originated from Bull Creek and Peterson Creek and had traveled 10 km and 4 km, respectively.

Immigrant fry traps were operated on six wall-base channel outlet streams from 5 September 1991 to 7 January 1992. During this period 7,008 wild and 151 hatchery-reared juvenile coho salmon were caught immigrating into wall-base channels. Seven wild coho fry had been branded at the tributary fry traps, while none of the hatchery-reared coho fry had been branded (Table 2.12). One of the fry originating from 0042 Creek had migrated upstream approximately 2.4 km, while the other two had migrated 2.4 km downstream. The one marked wild coho salmon from Elkhorn Creek had migrated upstream approximately 300 m from this tributary to immigrate into Paradise Pond (Figure 2.17). All other migrations were downstream (Peterson Creek: 16 km; Prairie Creek: 22.5 km; Hunt Creek: 7.5 km).

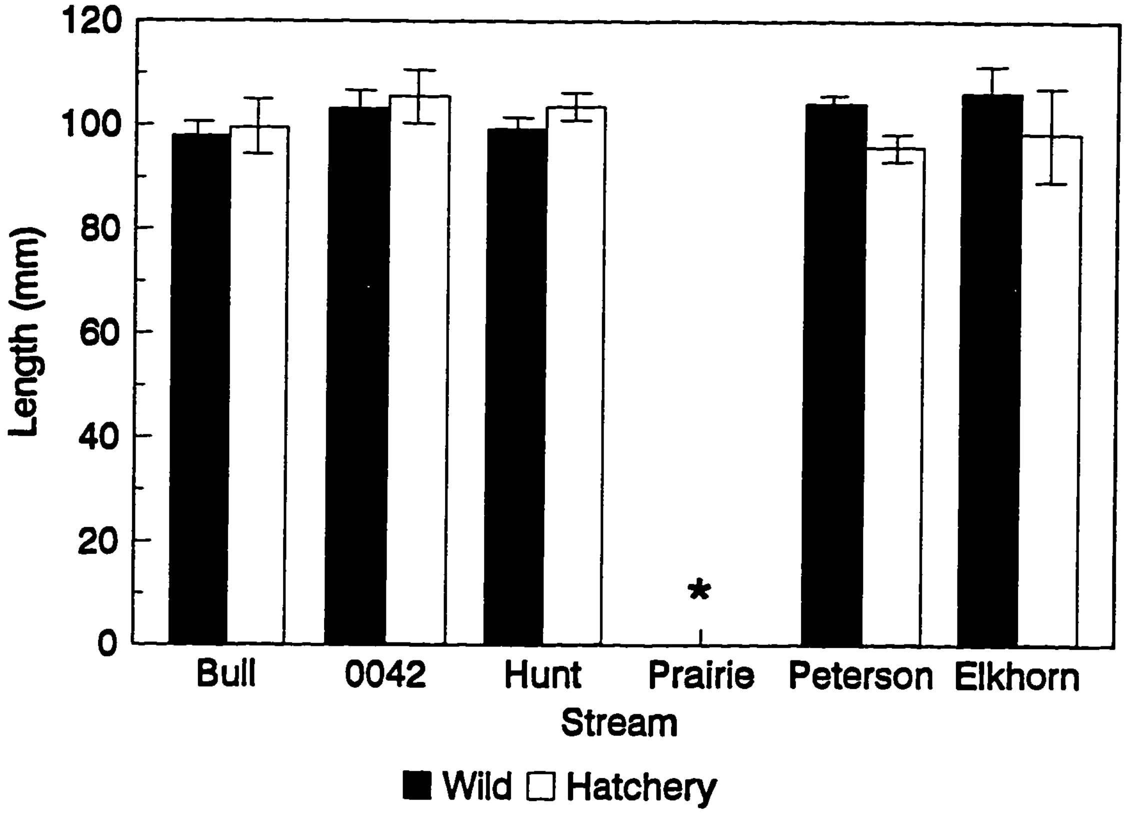

Figure 2.16. Mean fork length of wild and hatchery coho smolts emigrating from 0042, Bull, Hunt, Peterson, and Elkhorn creeks the year following supplementation. (* indicates no comparison possible in Prairie Creek.

Table 2.10. Number of wild and hatchery-reared coho salmon fry (marked and unmarked) captured during electrofishing surveys below tributary traps during 1991.

Stream	Date	Wild Coho Fry				Hatchery-Reared Coho Fry					
		Marked	Total	Number Branded	Percent Recovered	Marked	Total	Number Branded	Percent Recovered	Estimated Migration	Percent Recovered[b]
Peterson	26 June	80	367	2,952	2.71%						
Elkhorn	2 July	65	135	2,442	2.66%						
Bull	29 July	32	402	984	3.25%	13	149	1,975	0.66%	4547	3.28%
Shale	30-31 July	28	403	2,713[a]	1.03%	1	1	1,090	0.09%	1578	0.06%
Peterson	21 August	58	385	3,098	1.87%						
Elkhorn	26 August	47	134	2,614	1.80%						

[a] Branded in 0042 Creek, which is a tributary to Shale Creek.

[b] Number of Hatchery fish + number of hatchery fish branded.

Table 2.11. The number of wild and hatchery-reared coho fry examined for brands and the number having brands in the mainstem Clearwater River (July and September 1991) and wall-base channels (September 1991 and January 1992).

Recovery Location	Date	Wild		Hatchery	
		Number Examined	Number with Brands	Number Examined	Number with Brands
Mainstem	16 July - 30 July	3,606	36	64	2
Mainstem	9 Sept. - 16 Sept.	603	2	12	0
Wall-base Channels	5 Sept. 1991 - 7 January 1992	7,008	7	151	0

Table 2.12. Number and location (Noted in Figure 2.19) (number at that location) of wild and hatchery-reared coho salmon from each tributary recovered in the mainstem Clearwater River and six wall-base channels. Recoveries of hatchery coho salmon include branded fish and unbranded fish which were sacrificed for CWT recovery.

Origin	Number Recovered	Location (#)	Number Recovered	Location (#)
		Mainstem Recoveries (16 July - 30 July 1991)		
Bull	6	a(1); f(1); h(1)	9	a(3); c(3); g(1); k(1); n(1)
Prairie	0		0	
Peterson	11	i(5); j(2); k(1); m(2); n(1)	0	
0042	1	o	0	
Elkhorn	17	p(3); q(5); r(1); s(4); t(4)	0	
Hunt	0		1	v
		Mainstem Recoveries (9 September - 16 September 1991)		
Bull	1	D	0	
Prairie	0		0	
Peterson	1	D	0	
0042	0		0	
Elkhorn	0		0	
Hunt	0		0	
		Wall-Base Channel Recoveries (5 September 1991 - 7 January 1992)		
Bull	0			
Prairie	1	6	0	
Peterson	1	5	0	
0042	3	2(1); 3(1); 4(1)	0	
Elkhorn	1	3	0	
Hunt	1	6	0	

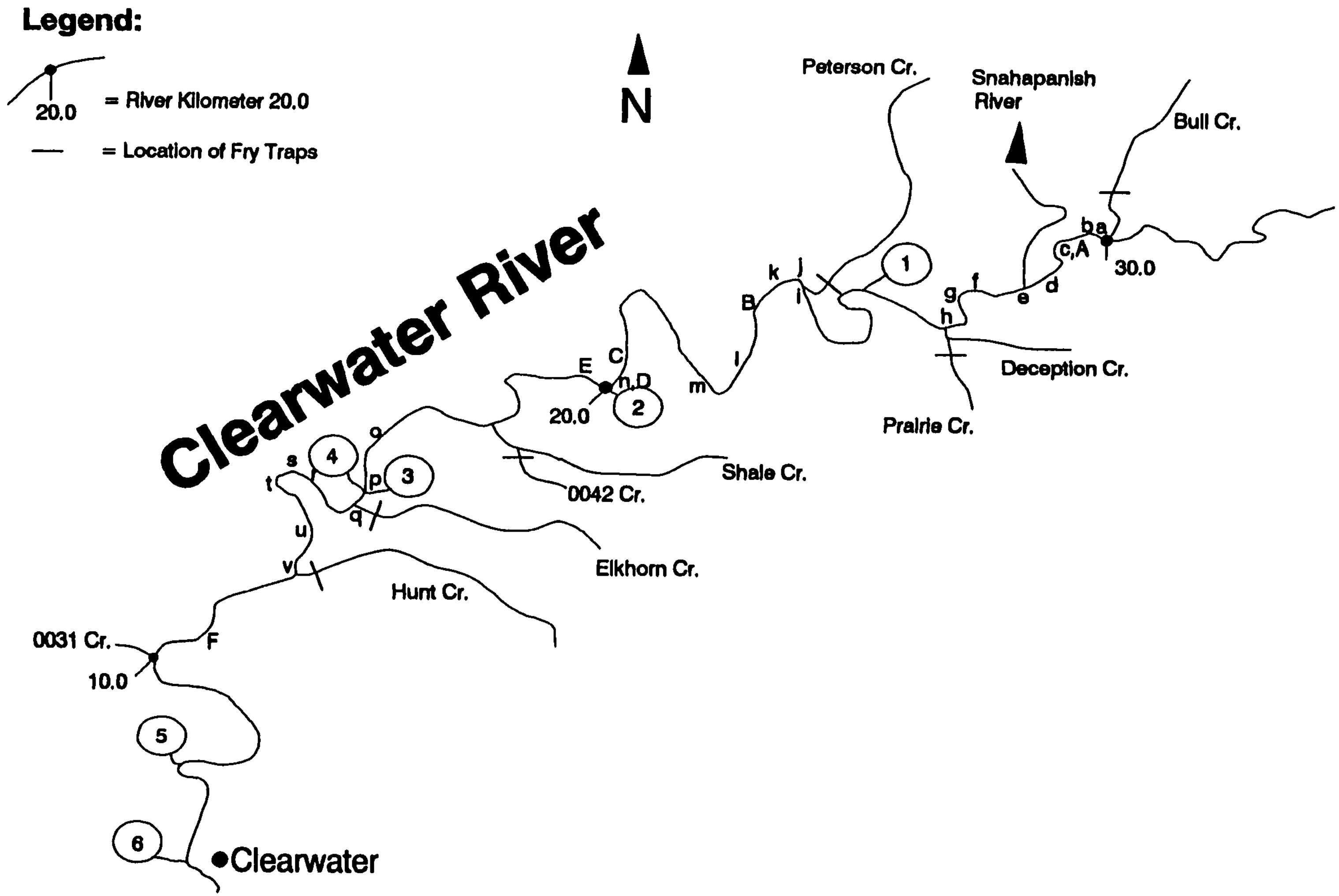

Figure 2.17. Location where coho salmon fry marked at tributary traps were recovered in the mainstem and wall-base channels during 1991. Letters correspond to those listed in Table 2.12.

DISCUSSION

Total emigration of wild coho fry and cutthroat trout was not increased by stocking tributaries of the Clearwater River with hatchery-reared coho fry obtained from a native broodstock. However, the relationship between total emigration of wild coho fry and cutthroat trout and June rearing densities of these species were different in supplemented and control streams. Wild coho fry emigrated earlier in supplemented streams than those in control streams. The emigration timing of cutthroat trout appeared to be delayed by coho fry supplementation. Total emigration of hatchery-reared coho fry varied between 9.3% and 46.9%. Hatchery-reared coho salmon emigrated earlier than wild coho salmon and were less likely to take up residency than wild coho fry in habitats downstream of emigration traps. The magnitude and rate of hatchery-reared coho fry emigration and potential increases in wild coho fry emigration could reduce the ability of supplementation programs to successfully increase total coho salmon densities in streams.

This study failed to demonstrate that supplementing small streams with hatchery-reared coho salmon produced from a native broodstock increased total numbers of wild coho fry and cutthroat trout emigrating from streams. However, there was evidence that the wild coho fry and cutthroat trout emigration was disrupted by coho fry supplementation. A strong relationship existed between the estimated number of wild coho fry emigrating from control streams and rearing densities observed during June. Total estimated emigration of wild coho fry was low when June rearing densities were low and high when June rearing densities were high. In contrast, there was little relationship between the number of cutthroat trout emigrating from the streams and early summer rearing densities in control streams. However, cutthroat trout emigration increased as rearing densities increased in supplemented streams.

Competition for food and space regulates coho salmon populations in small streams (Chapman 1966) apparently by causing increased emigration of 'surplus' fish (Chapman 1962). Thus, the observation of increased wild coho fry emigration with increased early summer rearing densities is the expected result. The disruption of this relationship in control streams is an indication that coho fry supplementation negatively impacted wild coho fry in these streams. Although differences were not statistically different, visual examination of the differences in these relationships suggests significant biological implications. However, the early summer wild coho fry rearing densities did not appear to be reduced by coho fry supplementation (Chapter III). The disruption of cutthroat trout emigration was not as clear as that for wild coho fry. This may have been due to differences in intra- and interspecific competition between wild coho fry and cutthroat trout, with stocked hatchery-reared coho fry. Although the relationship between cutthroat emigration and early summer rearing densities was disrupted this did not result in reduced early summer rearing densities of cutthroat trout (Chapter III).

Competition for food and space should be greatest for species exhibiting the greatest degree of spatial and niche overlap. Although hatchery-rearing may alter habitat selection (Dickson and MacCrimmon 1982), hatchery-reared coho salmon would be expected to occupied habitats similar to that of wild coho salmon and cutthroat trout underyearling (Glova 1987). Most of the cutthroat trout emigrating from the study streams we sampled appeared to be yearlings based on size. It seems unlikely that yearling cutthroat trout and stocked hatchery-reared coho fry would compete for the same habitat. It seems more likely that hatchery-reared coho fry would be preyed upon by yearling cutthroat trout. Therefore, competition may have influenced emigration of wild coho salmon, while food abundance may have influenced emigration of cutthroat trout. Published literature supports the hypothesis that native salmonids expected to occupy microhabitats similar to that of the stocked salmonids are generally more likely to be negatively impacted by stocking than those occupying less similar habitats. However, some conflicting evidence also is available.

Stocking hatchery-reared salmonids generally has not increased emigration of native salmonids which occupy different microhabitats than stocked salmonids. Stocked age 0+ Atlantic salmon selected different habitat than wild age 0+ wild rainbow trout and did not affect the timing of movement (Hearn and Kynard 1986). Stocking hatchery-reared coho salmon in side-channels of the Wenatchee River, Washington, resulted in a habitat shift by chinook salmon, but did increase emigration of chinook salmon or steelhead (Spaulding et al. 1989). Hatchery "thinning" releases of age zero steelhead did not result in increased emigration of wild chinook salmon (Hillman and Mullan 1989). In contrast, "thinning" releases of chinook salmon resulted in increased emigration of steelhead trout. However, competition between chinook and steelhead was not apparent. Wild steelhead appeared to be "pulled" downstream by emigrating hatchery chinook salmon (Hillman and Mullan 1989).

Stocking hatchery-reared salmonids has generally increased the emigration of native salmonids expected to occupy microhabitats similar to those of stocked fish. Hatchery-reared coho salmon, originating from both hatchery and native stocks, affected microhabitat use and foraging behavior, and caused a greater rate of downstream movement in wild coho salmon (Nielsen 1994). This increased emigration reduced production in two of four wild coho salmon foraging phenotypes, but did not significantly reduce overall production in the study streams (Nielsen 1994). Hatchery "thinning" releases of chinook salmon increased emigration of wild chinook salmon (Hillman and Mullan 1989). However, this appeared to be the result of wild chinook being "pulled" by emigrating hatchery chinook rather than competition between the two groups. In contrast, hatchery "thinning" releases of steelhead (age 0) did not increase emigration of wild steelhead (Hillman and Mullan 1989). However, this evaluation lasted only 24 hours. Hatchery steelhead dispersed very little during this time, originally moving to the bottom where they displayed little activity. This behavior would increase densities in localized areas, but may not have increase competition within the 24 hour evaluation period. Potential impacts may have occurred following the 24-hour evaluation period, when hatchery steelhead began displaying more natural behavior.

This study did not provide conclusive evidence that the emigration rates of wild coho salmon and other native salmonids were significantly altered by coho fry supplementation. Although several studies have examined the influence of stocking hatchery-reared salmonids on total emigration or habitat shifts in native salmonids, I could find no published information discussing the impacts of stocking on the emigration rates of native salmonids.

The effect of coho fry supplementation on the emigration rates of wild coho salmon may have been density dependent, size related, or related to the physical nature of the study streams. Emigration rates of wild coho salmon were increased during 1991 when the greatest densities were observed. However, hatchery-reared coho fry also were larger than wild coho fry during 1991, which would be expected to provide hatchery-reared coho fry a competitive advantage. Emigration of wild coho fry occurred earlier in Bull, Hunt, and 0042 creeks whether they were supplemented or not. However, emigration rates were much earlier during 1991, when they were supplemented, than in 1992, when they were not. Emigration of wild coho fry initially occurred earlier in supplemented streams (Elkhorn, Prairie, Peterson) during 1992 even though hatchery-reared coho fry were smaller during this year. However, overall wild coho fry emigration occurred earlier in control streams (Bull, Hunt, 0042) during 1992. Thus, it appears that the differences in emigration timing in the different study streams may have masked the effect of stocking hatchery-reared coho fry on wild coho fry emigration.

Coho fry supplementation did not appear to significantly increase the emigration rate of cutthroat trout. When emigration timing was influenced it was delayed. It's possible that cutthroat trout remained in supplemented streams to feed on hatchery-reared coho salmon. However, if coho fry were such an important food source to alter cutthroat trout emigration behavior, one would expect the delayed emigration to have occurred during 1991, when coho salmon densities were greatest, rather than 1992.

Coho fry supplementation increased the emigration rate of steelhead during one year but not the other. The effect of densities as a causative mechanism increasing the emigration rates of steelhead trout could not be assessed with available data. Emigration rates of steelhead were slower during 1991 when coho salmon densities were greatest. However, steelhead densities were not measured and could have influenced emigration rates of steelhead trout.

Poor survival of hatchery-reared salmonids following stocking is thought to be a major factor leading to the failure of many supplementation programs (Sosiak et al. 1979; Dickson and MacCrimmon 1982; Irvine and Baily 1992). Data from this study suggest that emigration of hatchery-reared coho salmon may be a significant factor resulting in apparent mortality of stocked hatchery-reared coho fry. In two of six cases, over 40% of stocked hatchery-reared coho salmon emigrated from the stream into which they were planted. Hatchery coho fry stocked in streams lacking native coho salmon populations also showed significant total emigration (37-69%) (Bilby and Bisson 1987). Hatchery-reared coho salmon also emigrated much earlier than wild coho fry and were less likely to take up residency in habitats downstream of emigration traps following their release. Emigration patterns of hatchery coho fry observed in the present study were similar to those of hatchery coho fry stocked into streams lacking native coho salmon populations (Bilby and Bisson 1987). The early emigration of hatchery-reared juvenile coho salmon could result in reduced survival by exposing these fish to high flow conditions in the mainstem. This is supported by the few emigrants observed in habitats downstream of the emigration traps. Since emigrating wild and hatchery-reared coho salmon were not differentially marked over time, it is impossible to determine if differences in likelihood to take up residency in downstream habitat were related to emigration timing.

This study did not provide conclusive evidence regarding the impacts of coho fry supplementation on the emigration rate and magnitude of wild coho salmon. However, potential negative impacts of coho fry supplementation on wild coho salmon emigration, and for increased emigration of stocked hatchery-reared coho salmon, appeared to be density related. Stocking densities used in the present study (3 fry/m^2 pool) may be too high for effective supplementation of natural coho salmon stocks. Additional evaluation of the effects of supplementation on native coho salmon populations should be completed using much lower stocking densities. This would reduce competition between wild and hatchery-reared coho salmon, which may reduce impacts to total emigration and emigration rates of both wild and hatchery-reared coho salmon. The early emigration timing could be a significant factor contributing to past failures of coho fry supplementation programs.

CHAPTER III

The Effects of Coho Salmon Fry Supplementation on Salmonid Densities, Survival, and Growth

INTRODUCTION

This chapter describes the effects of stocking hatchery-reared coho salmon (*Oncorhynchus kisutch*) fry obtained from a native broodstock on densities and growth of wild juvenile coho salmon and native trout (primarily cutthroat trout (*O. clarki*)). Although fry supplementation has been advocated as a tool for increasing salmonid production in areas with depressed stocks, it is as yet unproven, and there are few positive examples of increased production (Steward and Bjornn 1990; Wunderlich and Pantaleo 1995). Supplementation programs may even result in reduced production of wild salmonids (Nickelson et al. 1986; Steward and Bjornn 1990). Stocking non-native hatchery coho presmolts into Oregon coastal streams resulted in a 41% increase in overall juvenile coho salmon densities (Nickelson et al. 1986). However, 44% of wild juvenile coho salmon were replaced by hatchery presmolts, apparently because hatchery presmolts were 29 mm larger than native fry (Nickelson et al. 1986).

The native broodstock described in Chapter II was developed to eliminate potential problems associated with non-native hatchery stocks. Preliminary results indicate that stocking streams with hatchery-reared coho salmon fry derived from this native broodstock did not negatively impact the growth and survival of wild coho salmon (Wampler et al. 1990). However, there were some violations of basic study design assumptions that make their results somewhat suspect (Wampler et al. 1990). The authors also did not report whether coho salmon rearing densities were increased.

Gross level evaluations of coho fry supplementation using this native broodstock (Quinault Indian Nation 1992, 1993; Lestelle et al. 1993) suggested that stocked hatchery-reared coho fry survival during the summer was similar to that of wild coho fry. However, total coho fry densities in supplemented streams did not appear to be increased compared to wild coho salmon densities in unsupplemented streams (Quinault Indian Nation 1993). Overall smolt yield in the Clearwater River Basin was not increased as a result of this supplementation program (Lestelle et al. 1993).

Most successful supplementation programs have occurred in areas barren of the species being stocked (Wunderlich and Pantaleo 1995). Coho salmon escapement was increased by stocking hatchery-reared coho fry above natural barriers in British Columbia streams (Hurst 1993). However, survival was significantly higher when wild or wild hybrid stocks were used than when hatchery stocks were used (Hurst 1993). Survival (26-68%) of coho salmon fry stocked in Alaskan lakes above migratory barriers also was greater than observed in the Clearwater Basin (Heard 1978).

The relative success of coho fry supplementation programs in areas devoid of naturally spawning populations suggests that competition between hatchery-reared and wild coho salmon may be an important factor determining the success/failure of coho fry supplementation programs. This competition could result in reduced densities and growth of wild coho fry in supplemented streams, thus offsetting potential benefits of stocking hatchery-reared coho salmon.

The objectives of this study were to determine whether supplementing native coho fry in small streams with hatchery-reared coho fry obtained from a native broodstock would result in increased late-summer rearing densities or reduce densities and growth of wild coho fry and native trout.

Study Area

This study was conducted in the six small streams of the Clearwater River described in Chapters I and II (Figure 1.1, Table 2.1). Study reaches usually began at a location just upstream of the high water influence (≈ 100 m) of the mainstem Clearwater River (or above the stream to which they were tributaries for 0042 and Prairie Creeks). Bull Creek was an exception, since the lower reaches of this stream are braided from approximately stream kilometer 0.5 to its confluence with the mainstem Clearwater River. One channel has intermittent flow during the summer low flow period, while the second contains several large pools with silted substrates which would have prevented efficient sampling. For this reason, the study section in Bull Creek began at approximately stream kilometer 0.5. With the exception of Prairie Creek, study reaches terminated downstream of the upper limit of coho salmon access.

MATERIALS AND METHODS

Study Design

Six tributaries of the Clearwater River were selected for this study. Background information of juvenile coho salmon densities was collected on four of the six study tributaries during the summer of 1990. It was concluded from this information that four study streams would be insufficient; therefore, two additional study streams were added for the 1991-1993 field seasons. During the spring of 1991, three randomly selected streams (Bull, 0042, Hunt) were stocked with hatchery-reared coho fry originating from the native broodstock described in Chapter II (Quinault Indian Nation 1992). The remaining three streams (Peterson, Prairie, Elkhorn) were not stocked to serve as controls. Treatments were reversed during the spring of 1992, with 1991 control streams stocked during 1992 and 1991 stocked streams serving as controls during 1992 (Table 3.1). Additional background information was collected in all six streams during 1993 when no stocking occurred.

Study reaches in each stream consisted of seven sections. Study sections were defined as an area containing five pools. Coho salmon and native trout densities (fish/m^2 pool area) were estimated twice during the summer (June and August) during 1991 and 1992, but only once (August) during 1990 and 1993. Densities were estimated in four (randomly selected) of the seven study sections of each stream during June. All seven sections were surveyed during August. Mean coho salmon and cutthroat trout densities in supplemented and control streams were compared to determine if fry supplementation had increased total coho salmon rearing densities or reduced wild coho salmon and/or native trout densities and growth. Samples of coho salmon and native trout were weighed during each survey.

Table 3.1. Treatments (supplemented or control) applied to the six study streams, 1990-1993.

	Year			
Stream	1990	1991	1992	1993
Bull	NS[1]	Supplemented	Control	Control
0042	NS[1]	Supplemented	Control	Control
Hunt	Control	Supplemented	Control	Control
Peterson	Control	Control	Supplemented	Control
Elkhorn	Control	Control	Supplemented	Control
Prairie	Control	Control	Supplemented	Control

[1] Not surveyed this year

Population Estimates

Wild and hatchery coho salmon and native trout populations were estimated using Chapman's modified Peterson-mark-recapture methods (Ricker 1975). Each study section was blocked by a small seine to create a "closed" population. A Smith-Root Model XII back pack shocker was used to capture fish during both the marking and recapture survey. Mark and recapture surveys were each completed in one pass, which consisted of a sweep from the downstream to the upstream end of the section and back again. All salmonids captured during sampling were anesthetized with tricaine methanesulfonate (MS-222) and 25 fish of each fish species were weighed (g) and measured for fork length (mm). Fish caught during the marking survey were marked by clipping a small portion of the upper or lower lobe of the caudal fin with scissors. The fish were returned to their approximate capture locations. Recapture surveys were completed a minimum of one hour post-release. All salmonids were again anesthetized and examined for marks, with the number of marked and unmarked fish of each species recorded. Population and variance estimates for each study section of each stream were calculated as:

$$N_{ij} = ((M+1)*(C+1))/(R+1) \quad \text{(Equation 3.1) (Ricker 1975)}$$

$$\mathrm{Var}\ N_{ij} = (N_{ij}^{2}*(C-R))/((C+1)*(R+2))$$ (Equation 3.2) (Ricker 1975)

Where N_{ij} = Population estimate of section j in stream i

$\mathrm{Var}\ N_{ij}$ = Variance of population estimate in section j of stream i

M = Number of fish (each species) marked during the marking survey

C = Number of fish (each species) caught during the recapture survey

R = Number of fish marked during the marking survey, recaptured during the recapture survey

Habitat Measurements

Habitat measurements were taken once population estimates were completed for each section of the study stream. Stream habitats were designated as pools or riffles following Bisson et al. (1982). Pool surface area was calculated by measuring pool length and three widths measured at equal distances along the length of the pool (Figure 3.1). Pool surface area was calculated by multiplying the pool length by the average width.

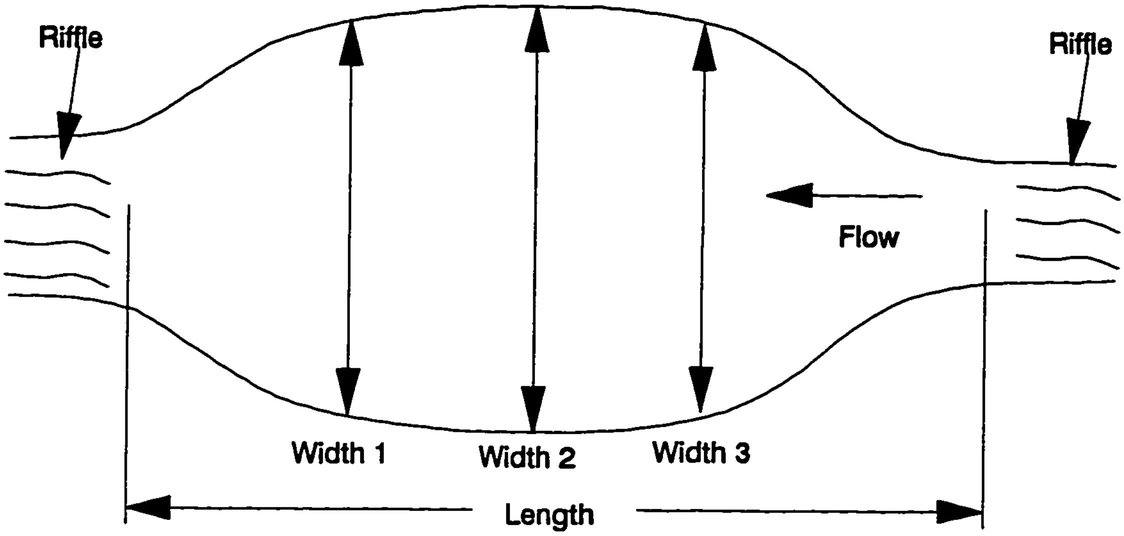

Figure 3.1. Methods used to measure pool surface area.

Effects of Coho Fry Supplementation on Salmonid Densities

Densities (fish/m^2 pool area) of coho salmon (wild, hatchery-reared, and combined), cutthroat trout, steelhead trout, zero age trout (cutthroat and steelhead combined), and combined trout were computed for each section of each stream by dividing population estimates for the section by the section's pool area. Weighted mean densities (fish/m^2 pool area) were calculated for each stream as:

$$D_i = (N_{i,j}+N_{i,j+1}\ldots+N_{i,j+7})/A_i \qquad \text{(Equation 3.3)}$$

where D_i = Weighted mean density of stream i, with i=1 to 6

A_i = Total pool area (m^2) of stream i, with i=1 to 6

$N_{i,j}$ = Population estimates of section j of stream i, with i=1 to 6 and j=1 to 7. (Calculated in equation 3.1)

Weighted population variances were computed as:

$$\text{Var } D_i = 1/(A_i^{2} * (\text{Var } N_{i,j} + \text{Var } N_{i,j+1} \ldots \text{Var } N_{i,j}) \quad \text{(Equation 3.4)}$$

Where: $\text{Var } D_i$ = Weighted variance of the mean density in stream i, with $i=1$ to 6

A_i = Total pool area (m^2) of stream i, with $i=1$ to 6

$\text{Var } N_{ij}$ = Variance observed in the population estimates of section j in stream i, with $i=1$ to 6 and $j=1$ to 7. (Calculated in equation 3.2)

A two-way analysis of variance (two-way ANOVA) was used to compare juvenile coho salmon (combined and wild only) and cutthroat trout densities (fish/m^2 pool area) in supplemented and control streams during June and August 1991 and 1992. The effect of the interaction between treatment (supplemented, control) and year (1991, 1992) was examined and considered significant at an alpha level of 0.10. A significant interaction renders the individual tests for the two factors meaningless (Zar 1984). Therefore, salmonid densities in supplemented and control streams were compared separately for each year using a Standard t-test if the interaction between treatment and year was significant.

The comparison of juvenile coho salmon densities in supplemented and control streams during August 1991 and 1992 was compromised by the fact that a major freshet occurred prior to the completion of population estimates in all six study streams during August 1991. Just over half (Bull, Prairie, Peterson, and 2 sections of Elkhorn and 0042) the study streams had been sampled and further sampling was prohibited by increased turbidity and high flow. Therefore, Elkhorn, 0042, and Hunt creeks were sampled following the storm. Pool surface area in Bull, Prairie, and Peterson creeks were measured again following the storm to account for differences before and after the storm. All densities in 1991 were calculated using habitat measurements completed after the storm. However, the original study design was seriously compromised by the storm since extensive redistribution of salmonids likely occurred (Cederholm and Scarlett 1982). Therefore, three sections of Peterson Creek, which had been completely sampled before the storm, were sampled after the storm to determine the effect of the storm on salmonid densities in those sections. If densities were significantly different following the storm, coho salmon densities (combined wild and hatchery and wild only) in streams supplemented during 1992 (Elkhorn, Peterson, and Prairie) were compared to wild coho fry densities in these same streams during 1990 and 1993 (control years) using a t-test. No estimates of trout densities were calculated for 1990. Thus, cutthroat trout densities from 1992 supplemented streams could only be compared to these streams in 1993.

Effect of Coho Fry Supplementation on Salmonid Size

The weights of wild coho salmon caught during population surveys in supplemented and control streams during June and August 1991 and 1992 were compared using a two-way ANOVA. The two factors examined in the two-way ANOVA were treatment (supplemented and control) and year (1991 and 1992). The interaction between these two factors was significant at an alpha level of 0.10. The data for supplemented and control streams were compared separately for each year using a t-test if the interaction was significant. This procedure was also used to compare native trout weights in supplemented and control streams during 1991 and 1992. Comparisons for native trout weights were completed separately for each species.

The weights of wild and hatchery coho salmon in supplemented streams during June and August 1991 and 1992 were compared individually for each supplemented stream using a t-test. Weights of hatchery coho salmon in supplemented streams during 1991 and 1992 were also compared using a t-test.

Effect of Coho Fry Supplementation on Salmonid Growth

Relative population growth rates were calculated for wild and hatchery-reared coho salmon and cutthroat trout as:

$$\text{Relative rate of increase} = (W_2 - W_1)/W_1 \qquad \text{(Equation 3.5) (Ricker 1975)}$$

where W_1 is the initial mean population weight (June) and W_2 is the final mean population weight (August). Analysis of covariance (ANCOVA) was used to compare the relative growth rate of wild coho salmon and cutthroat trout in supplemented and controls streams while controlling for rearing densities (total wild and hatchery-reared for the coho analysis, and total trout for cutthroat). The influences (slopes) of density on the relative growth rates of wild coho fry and cutthroat trout in supplemented and control streams were compared using ANCOVA. Relative growth rates of wild and hatchery-reared coho salmon in supplemented streams were also compared using this method.

RESULTS

Effect of Coho Fry Supplementation on Salmonid Densities

Stocking tributaries of the Clearwater River with hatchery-reared coho salmon fry did not significantly increase total coho salmon densities during June (Figure 3.2). Combined wild and hatchery coho fry densities in supplemented streams were not significantly different than wild coho fry densities in control streams during either 1991 (t-test: $P=0.3884$; Power <0.30) or 1992 (t-test: $P=0.1493$; Power <0.30) (Figure 3.2). There was a significant (two-way ANOVA: $P=0.0690$) interaction between treatment (supplementation and control) and year during June 1991-1992. Mean coho salmon densities in Peterson, Elkhorn, and Prairie creeks were greater than those in Bull, Hunt, and 0042, regardless of whether or not they were supplemented (Figure 3.2). This required that coho fry densities in supplemented and control streams be compared separately for each year.

Stocking streams with hatchery-reared coho salmon did not appear to reduce wild coho salmon fry densities during June (Figure 3.2). No difference was detected in wild coho salmon densities in supplemented and control streams during either 1991 (t-test: $P=0.2501$; Power <0.30) or 1992 (t-test: $P=0.1930$; Power <0.30) (Figure 3.2). There again was a significant interaction between treatment (supplemented and control) and year (two-way ANOVA: $P=0.0667$). Mean wild coho salmon densities in Peterson, Prairie, and Elkhorn creeks were greater than Bull, Hunt, and 0042 during both years (Figure 3.2). This required that wild coho fry densities in supplemented and control streams be compared separately for each year.

Coho salmon, combined trout (steelhead, cutthroat, and zero age), and cutthroat trout densities in the three sections of Peterson Creek sampled after the August 1991 storm were different than before the storm; however, in most cases these differences were not statistically significant (Figure 3.3). Coho salmon densities before the storm were nearly twice those after the storm (t-test: $P=0.2464$, Power <0.3). In contrast, combined trout densities were greater following the storm (t-test: $P=0.0124$). The increase in combined trout densities appeared to result from the immigration of zero-aged trout. No zero-age trout were observed in the three sections of Peterson Creek before the storm, however, following the storm zero-age trout densities in the three sections averaged 0.32 trout/m^2 pool area. Cutthroat trout densities before and after the storm were not different (t-test: $P=0.3724$). There was little change in the steelhead population in the stream before and after the storm, as no steelhead were observed in the stream prior to the storm and only two steelhead were caught following the storm.

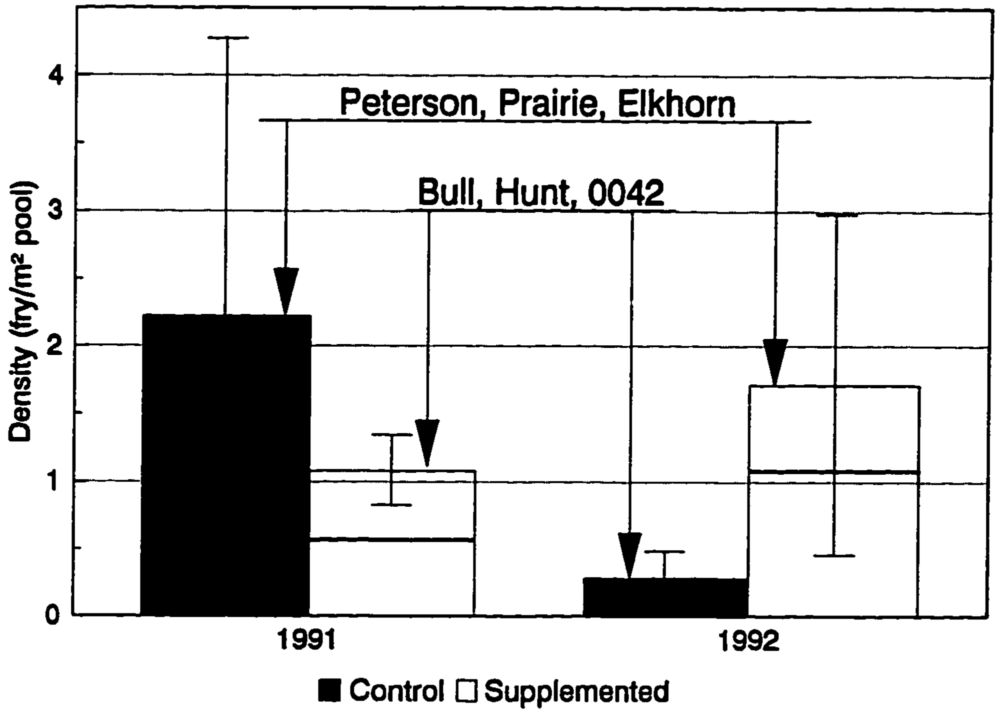

Figure 3.2. Mean (+/- 2 SE) densities (fish/m^2 pool area) of wild and hatchery-reared coho salmon in control and supplemented streams during June 1991 and 1992. The bar representing supplemented streams is divided into wild coho salmon fry (below horizontal line) and hatchery-reared coho salmon fry (above horizontal line).

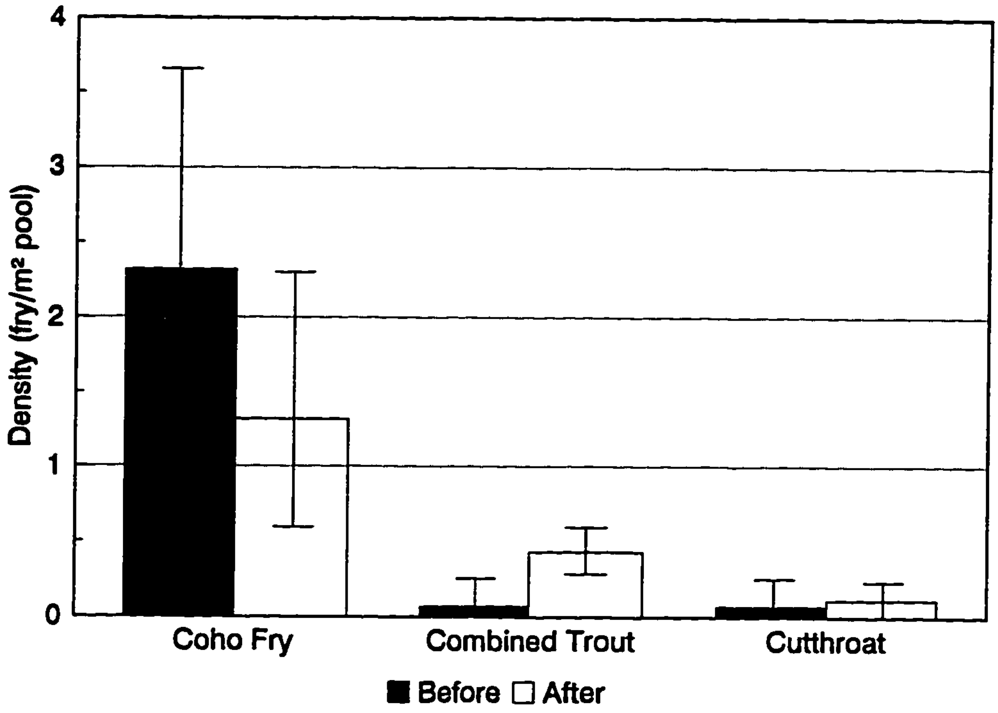

Figure 3.3. Mean (+/- 2 SE) wild coho fry, combined trout (steelhead, cutthroat, and zero-age), and cutthroat trout densities (fish/m^2 pool area) in three sections of Peterson Creek before and after the 1991 August storm.

Although most changes in population densities were not statistically different, statistical power of these tests was low, increasing the likelihood of concluding that there were no differences, when differences actually existed. The observed changes of approximately 45% reduction (coho) and 37% increase (cutthroat trout) could significantly influence the outcome of planned comparisons. Therefore, the planned comparisons using a two-way ANOVA was not completed. Instead, coho salmon densities in streams supplemented during 1992 (no storm) and these same streams during 1990 and 1993, when they were not supplemented were compared using a t-test. Cutthroat densities in Peterson, Prairie, and Elkhorn creeks during 1992, when they were supplemented, also were compared using a t-test to these same streams during 1993 when they were not. Trout densities were not determined in 1990 eliminating this potential comparison.

Total (wild and hatchery) coho fry densities in Elkhorn, Prairie and Peterson creeks when supplemented (1992) were 19% (1990) and 89% (1993) greater than those observed during 1990 and 1993 when these streams were not (Figure 3.4). However, these differences were not statistically significant (t-test: 1990: $P=0.7374$; 1993: $P=0.3763$; Power <0.3 in both cases) . Total juvenile coho salmon densities also were 3% greater in Bull, 0042, and Hunt creeks following supplementation in 1991 (storm influenced) as compared to 1993 when they were controls. Again these differences were not significant (t-test: $P=0.1475$; Power <0.3). Results from the Bull, 0042, and Hunt comparison are interesting since densities in 1991 were likely underestimated, since 0042 and Hunt creeks were sampled following the storm which reduced rearing densities in Peterson Creek (Figure 3.3).

Stocking hatchery-reared coho salmon did not significantly reduce densities of wild juvenile coho salmon in Peterson, Prairie, and Elkhorn creeks during August 1992, when the streams were supplemented compared to either August 1990 or 1993 when they were not (Figure 3.4). Wild coho salmon densities in these streams were 28% lower in August 1992 than August 1990 (t-test: $P=0.5679$; Power <0.3), but were 13% greater than those observed during August 1993 (t-test: $P=0.8757$; Power <0.3). No difference was observed in wild juvenile coho salmon densities in Bull, 0042, and Hunt creeks during August 1991 (supplemented and storm influenced) and 1993 (control) (t-test: $P=1.000$; Power <0.3).

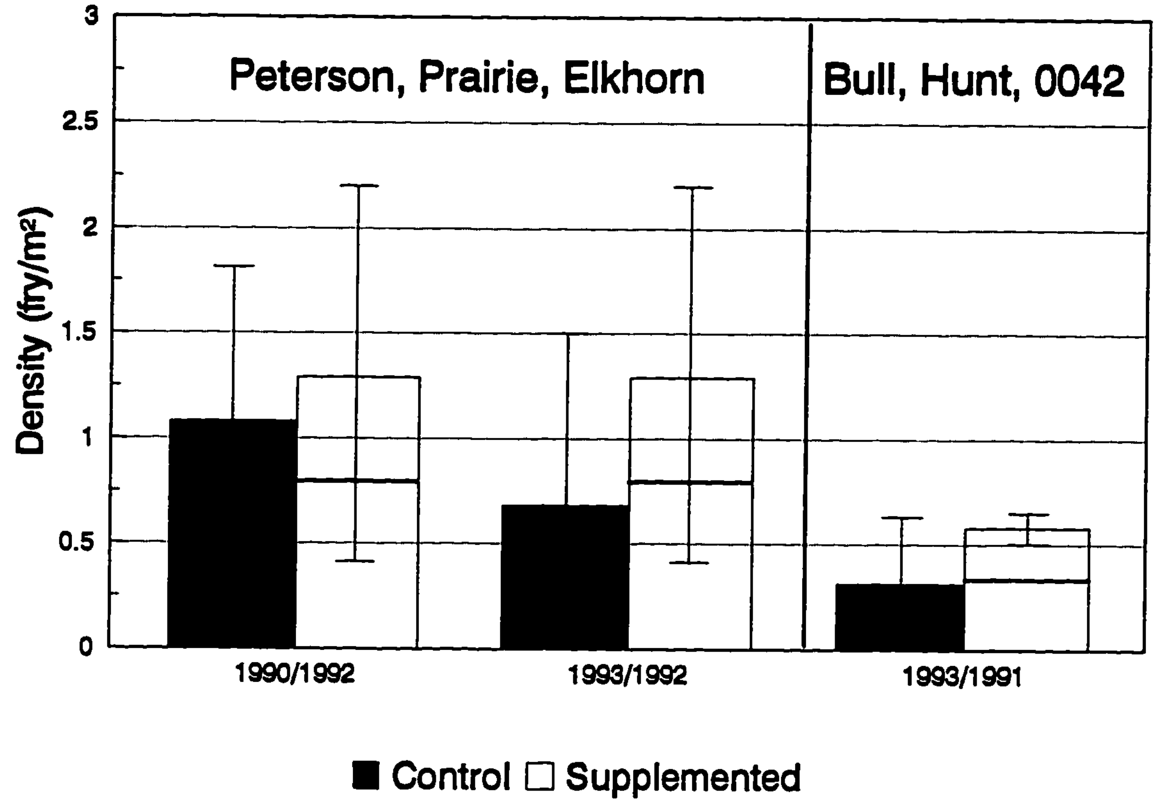

Figure 3.4. Mean (+/- 2 SE) combined (full bar), wild (below horizontal line), and hatchery (above horizontal line) juvenile coho salmon densities (fish/m^2 pool) in Peterson, Elkhorn, and Prairie creeks when they were supplemented (1992) and when they served as controls (1990 and 1993) and Bull, Hunt, and 0042 creeks when they were supplemented (1991-storm influenced) and when they served as controls (1993).

Cutthroat densities (fish/m^2 pool area) in June did not appear to be reduced by stocking hatchery-reared coho fry. No difference existed between cutthroat densities in supplemented and control streams during June 1991 (t-test: P=0.2934). However, cutthroat densities were significantly greater in supplemented streams during 1992 (t-test: P=0.0310). A significant (two-way ANOVA: P=0.0433) interaction existed between treatment and year for cutthroat trout densities during June 1991-1992, requiring separate comparisons of cutthroat densities in supplemented and control streams for each year. Cutthroat densities were higher in Peterson, Elkhorn, and Prairie creeks during both 1991 and 1992 (Figure 3.5).

In contrast, August cutthroat trout densities appeared to be reduced by coho fry supplementation. Cutthroat densities in Peterson, Prairie, and Elkhorn creeks during 1992, when they were supplemented, were less than 50% of the densities observed during 1993 when they were not (Figure 3.5). However, this difference was not statistically significant (t-test: P=0.2270).

Effect of Supplementation on Salmonid Size

Wild coho salmon size appeared to be negatively influenced by stocking hatchery-reared coho salmon (Figure 3.6). Wild coho salmon in control streams were larger (t-test: Both: P=0.0001) than those in supplemented streams during both June 1991 and 1992 (Figure 3.6). These comparisons were completed separately for each year because a significant (two-way ANOVA: P=0.0016) interaction existed between treatment (supplemented and control) and year (1991 and 1992).

Size comparisons of salmonids in supplemented and control streams during August were compromised due to the August 1991 storm and subsequent migration of fish discussed above. To determine the impact of the storm on the average weight of wild coho salmon in the study streams, wild coho salmon weights in three sections of Peterson Creek after the storm were compared to the weights observed prior to the storm. Wild coho salmon in Peterson Creek were larger after (Mean = 3.0, SD = 1.53) the storm than before (Mean = 2.5, SD = 0.98) the storm (t-test: P=0.0146).

These results suggest that comparisons of wild coho salmon weights could be compromised by immigration of coho salmon from the mainstem. All tests were completed as originally designed; however, interpretations of results of wild coho salmon weight comparisons will require considerable caution. Wild coho salmon weighed more in control streams than supplemented streams during August 1992 (t-test: P=0.0001) but not August 1991 (t-test: P=0.0976) (Figure 3.6). A significant interaction existed between treatment (supplemented and control) and year (1991 and 1992). This required the comparison of wild coho salmon weights in supplemented and control streams be completed separately for each year.

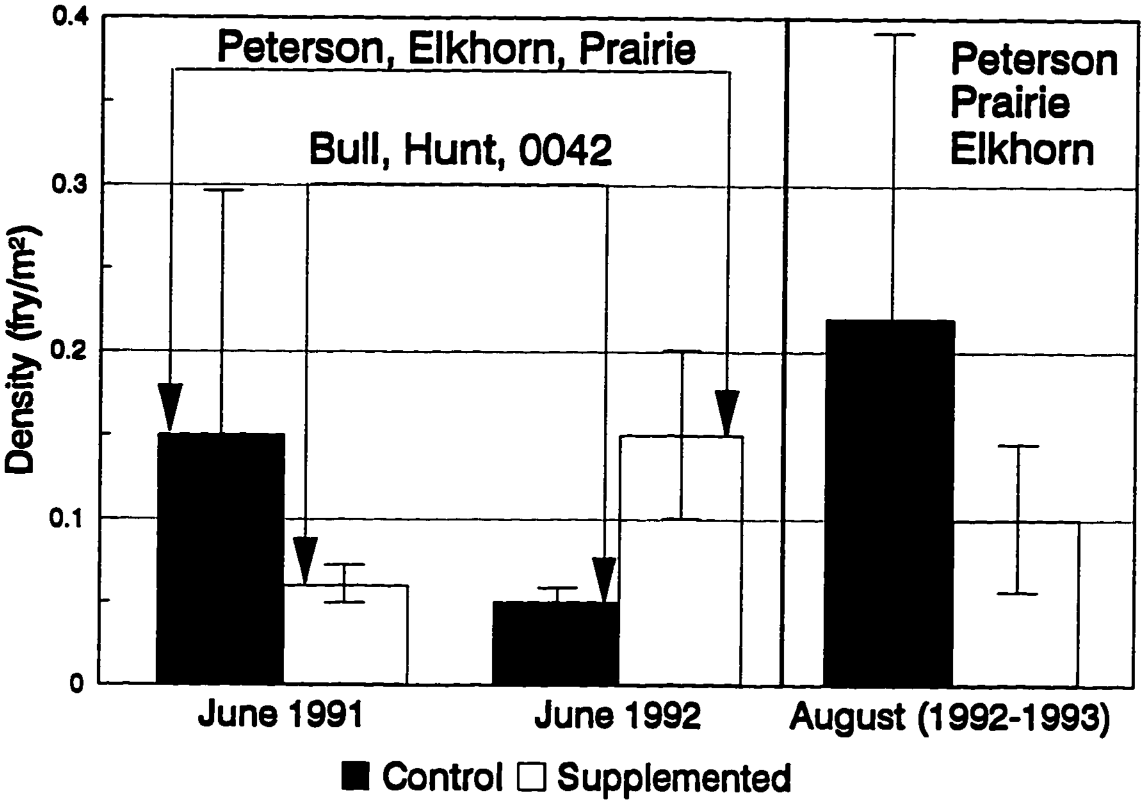

Figure 3.5. Mean (+/- 2 SE) cutthroat trout densities in supplemented and control streams during June 1991 and 1992 and in Peterson, Prairie, and Elkhorn creeks during August 1992 (supplemented) and 1993 (control).

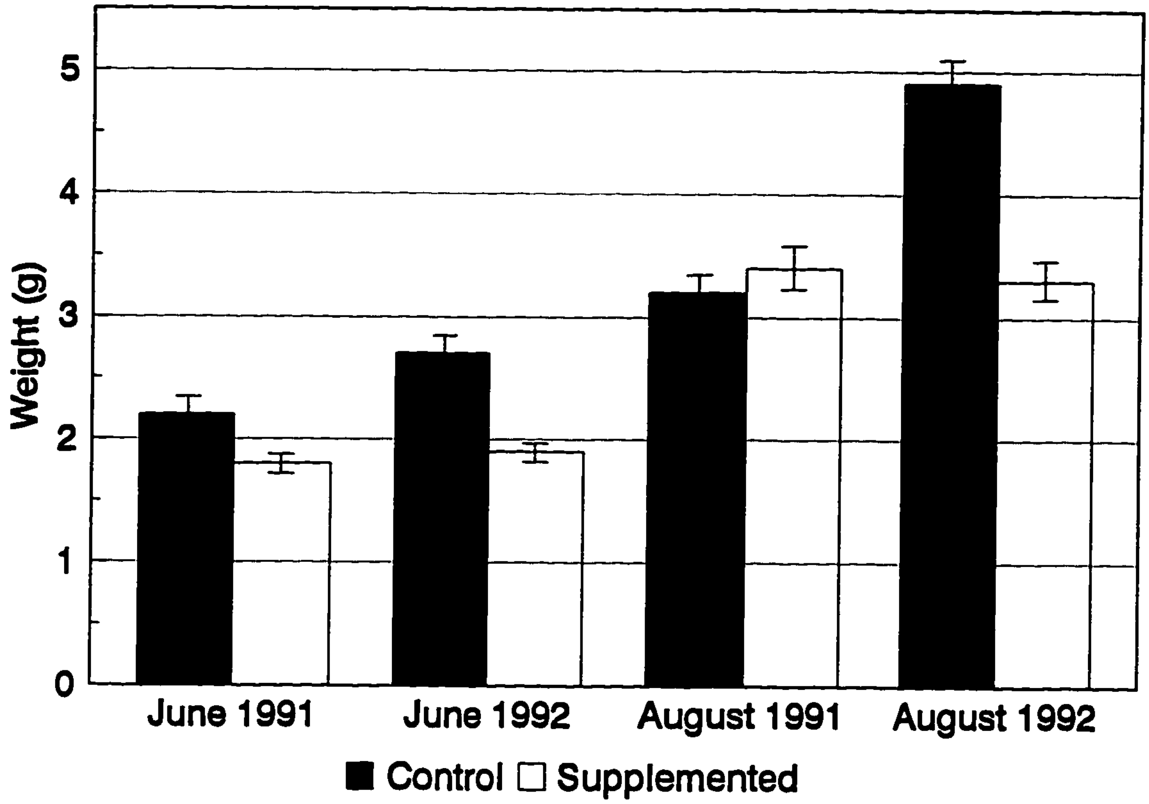

Figure 3.6. Mean (+/- 2 SE) weight of wild coho salmon in supplemented and control streams during June and August, 1991 and 1992.

No clear trend was observed between wild and hatchery-reared coho salmon weights in supplemented streams. Hatchery-reared coho salmon generally weighed more than wild coho salmon during 1991; however, the opposite was true during 1992 (Figure 3.7). Hatchery-reared coho fry weighed more than wild coho fry in both Bull (t-test: June $P=0.0001$; August $P=0.0090$) and 0042 (t-test: Both: $P=0.0001$) creeks during June and August 1991. However, no difference in wild and hatchery coho salmon weights were detected in Hunt Creek during June (t-test: $P=0.1148$) or August 1991 (t-test: $P=0.0830$). Wild coho salmon weighed more than hatchery coho salmon in Elkhorn and Peterson creeks during June and August 1992 (t-test: All: $P=0.0001$). No difference in wild and hatchery coho fry weights were detected in Prairie Creek during June 1992 (t-test: $P=0.8552$). However, wild coho salmon in Prairie Creek weighed more than hatchery coho salmon during August 1992 (t-test: $P=0.0001$).

Cutthroat trout weights did not appear to be influenced by coho fry supplementation (Figure 3.8). Cutthroat trout weighed more (t-test: $P=0.0010$) in supplemented than control streams during 1991, but no difference was observed during 1992 (t-test: $P=0.0559$). A significant (two-way ANOVA: $P=0.0016$) interaction existed between treatment (supplemented and control) and year (1991 and 1992) during June, requiring that the comparison of cutthroat trout weights in supplemented and control streams be completed separately for 1991 and 1992. Cutthroat trout weights appeared to be influenced more by the groups of streams than by supplementation. Cutthroat trout weighed more in Bull, Hunt, and 0042 creeks than in Peterson, Prairie, and Elkhorn creeks regardless of treatment (Figure 3.8). Insufficient numbers of steelhead and zero-age trout were caught for statistical comparisons with these species.

Cutthroat trout weights in Peterson Creek before (Mean = 16.9, SD = 13.25) and after (Mean = 18.6, SD = 16.0) the August 1991 storm were not significantly different (t-test: $P=0.7636$). Therefore, tests comparing weights of cutthroat trout were likely unaffected by the storm and were completed as originally planned. Cutthroat trout in control streams weighed less (t-test: $P=0.0001$) than those in supplemented streams during August 1991 and more (t-test: $P=0.0001$) during August 1992 (Figure 3.8). A significant (two-way ANOVA: $P=0.0001$) interaction existed between treatment (supplemented and control) and year (1991 and 1992) in the analysis of cutthroat trout weights during August 1991 and 1992. This required cutthroat trout weights in supplemented and control streams to be compared separately for each year. Again cutthroat trout weighed more in Bull, Hunt, and 0042 creeks than Peterson, Prairie, and Elkhorn creeks.

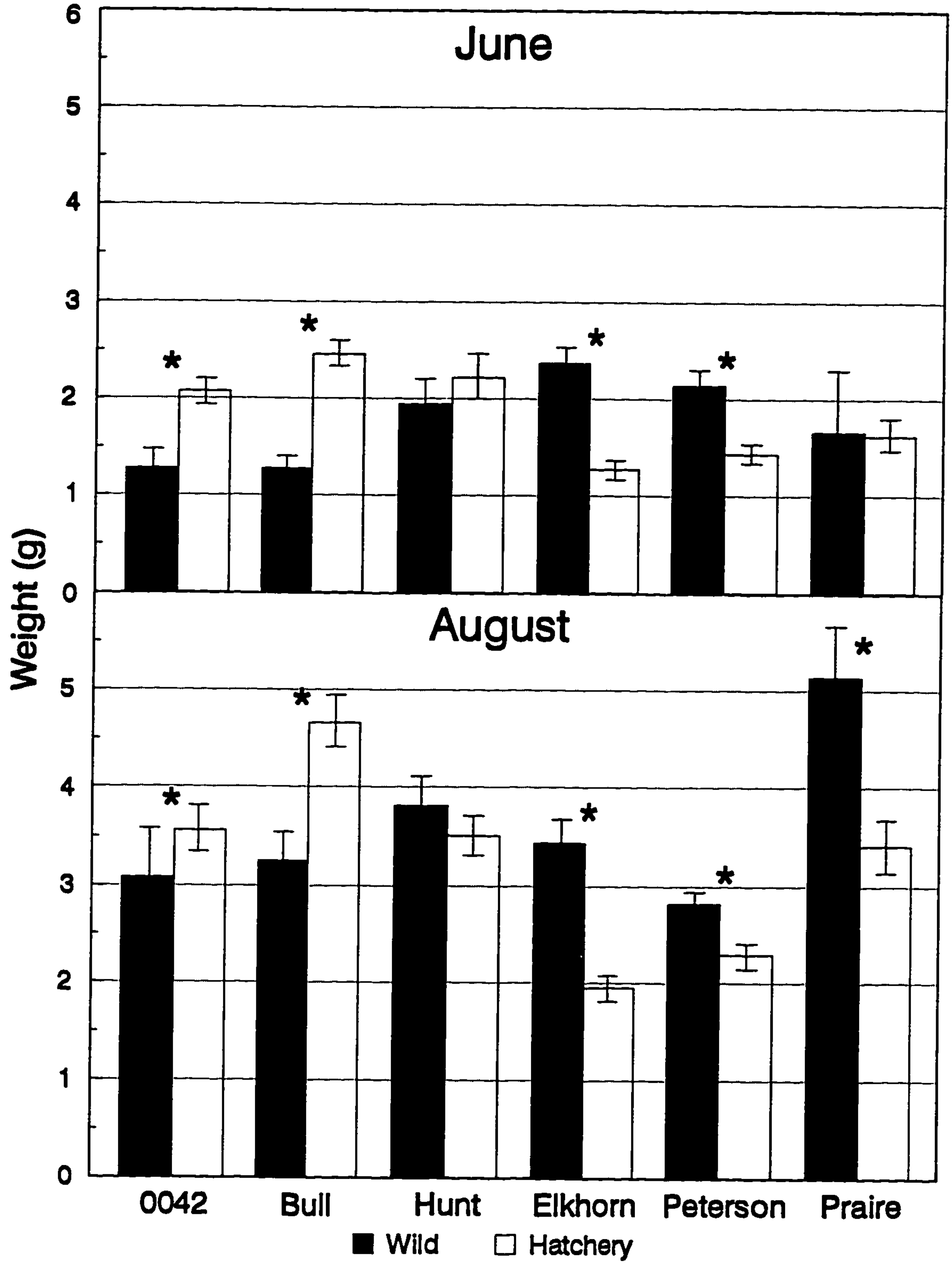

Figure 3.7. Mean (+/- 2 SE) weights of wild and hatchery coho salmon in supplemented streams during June and August, 1991 and 1992. An asterisk (*) indicates significant differences (t-test: $P<0.05$).

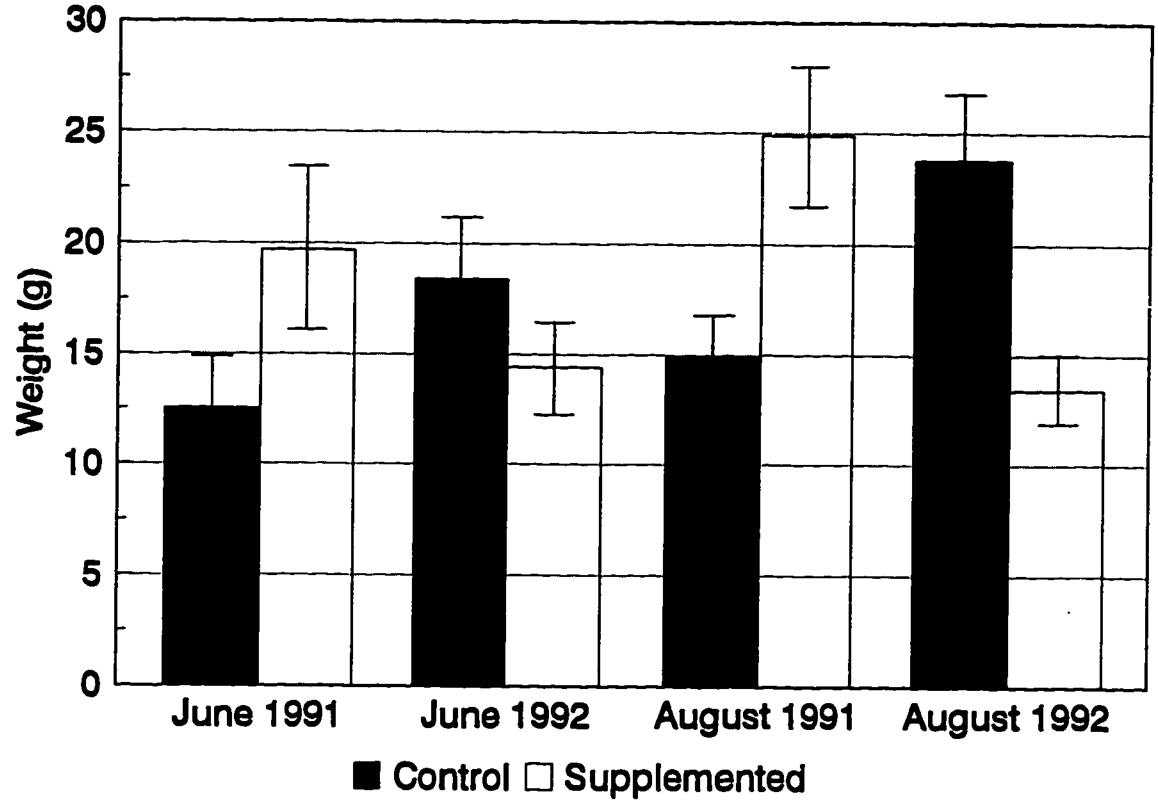

Figure 3.8. Mean (+/- 2 SE) weights of cutthroat trout in supplemented and control streams during June and August, 1991 and 1992.

Effect of Coho Fry Supplementation on Salmonid Growth

Coho fry supplementation did not negatively influence the relative growth rate of wild coho fry (Figure 3.9), although relative growth rates of wild coho salmon were influenced by coho salmon rearing densities (Figure 3.10). Wild coho salmon in supplemented streams nearly doubled in weight between June and August, while those in control streams increased less than 50% (two-way ANCOVA: $P=0.0312$). Relative growth rates were negatively (two-way ANCOVA: $P=0.0096$) influenced by increasing coho salmon rearing densities (measured in August) (Figure 3.10). However, the influence (slope) of coho salmon rearing densities on relative growth rates of wild coho salmon were not different between supplemented and control streams (two-way ANCOVA: $P=0.2499$) or between 1991 and 1992 (two-way ANCOVA: $P=0.7088$). No differences in relative growth rates of wild coho salmon were detected between 1991 and 1992 (two-way ANCOVA: $P=0.8107$).

Relative growth rates of wild coho salmon were greater than hatchery-reared coho salmon in supplemented streams and were reduced to a greater degree as coho salmon rearing densities increased (Figure 3.11-3.12). Wild coho salmon in supplemented streams nearly doubled in weight, while hatchery-reared coho fry increased approximately 60% (two-way ANCOVA: $P=0.0095$) (Figure 3.11). No difference in the relative growth rates of wild and hatchery-reared coho salmon was detected between 1991 and 1992 (two-way ANCOVA: $P=0.3367$). Relative growth rates of wild and hatchery coho salmon were not significantly influenced by density (two-way ANCOVA: $P=0.9634$). However, increasing coho salmon rearing densities reduced the relative growth rates of wild coho salmon more than that of hatchery-reared coho salmon (two-way ANCOVA: $P=0.0313$). Growth of wild coho was greater than that of hatchery-reared coho at rearing densities of 0.5 fish/m^2 pool area, but less at rearing densities near 2 fish/m^2 pool area (Figure 3.12).

Coho salmon fry supplementation did not reduce the relative growth rates of cutthroat trout (Figure 3.13). A significant (two-way ANCOVA: $P=0.0701$) interaction existed between the factors treatment (supplemented and control) and year (1991 and 1992). This required separate statistical comparisons of the relative growth rates of cutthroat trout in supplemented and control streams for each year. Cutthroat trout weights in supplemented streams increased by approximately 30%, while those in control streams increased about 10% during 1991 (ANCOVA: $P=0.6418$). Cutthroat trout weights increased by nearly 20% in control streams during 1992, while those in supplemented streams actually lost weight (ANCOVA: $P=0.4254$) (Figure 3.13). Cutthroat trout rearing densities (measured in August) did not influence the relative growth rates of cutthroat trout during 1991 (ANCOVA: $P=0.2157$) or 1992 (ANCOVA: $P=0.5442$) and was not different in supplemented and control streams during either 1991 (ANCOVA: $P=0.3851$) or 1992 (ANCOVA: $P=0.5486$).

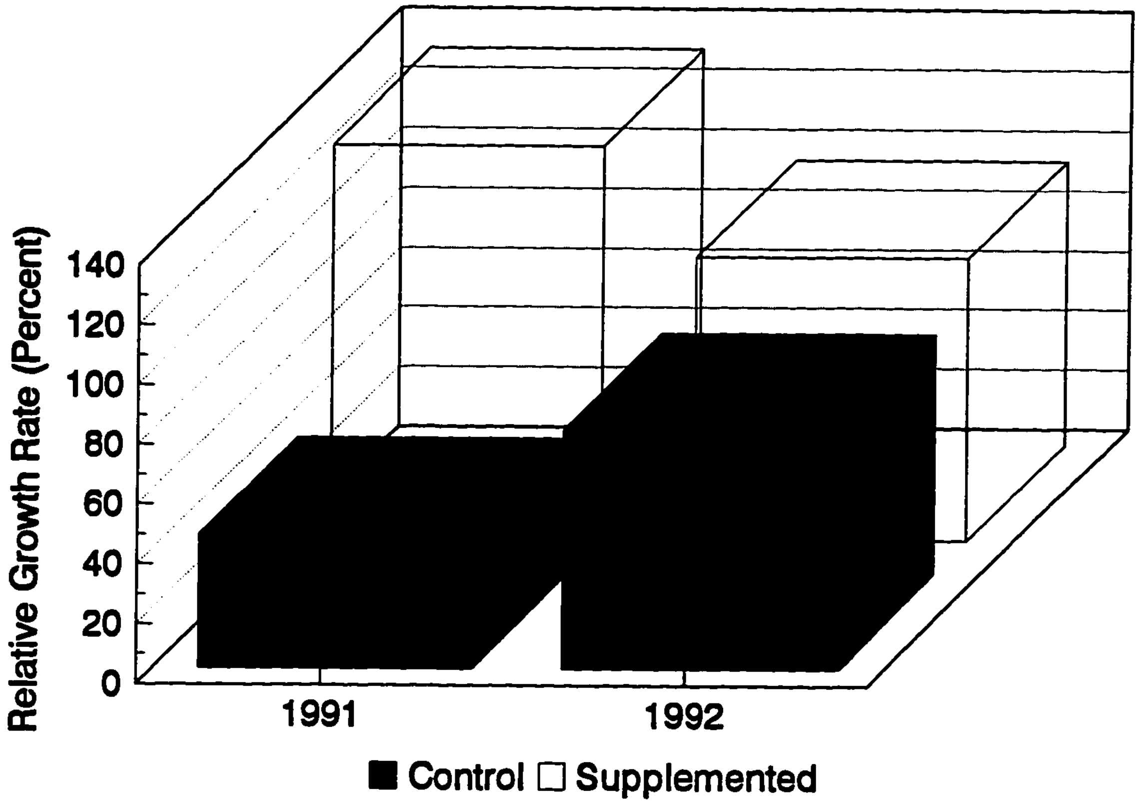

Figure 3.9. Relative growth rates of wild coho salmon between June and August in supplemented and control streams during 1991 and 1992.

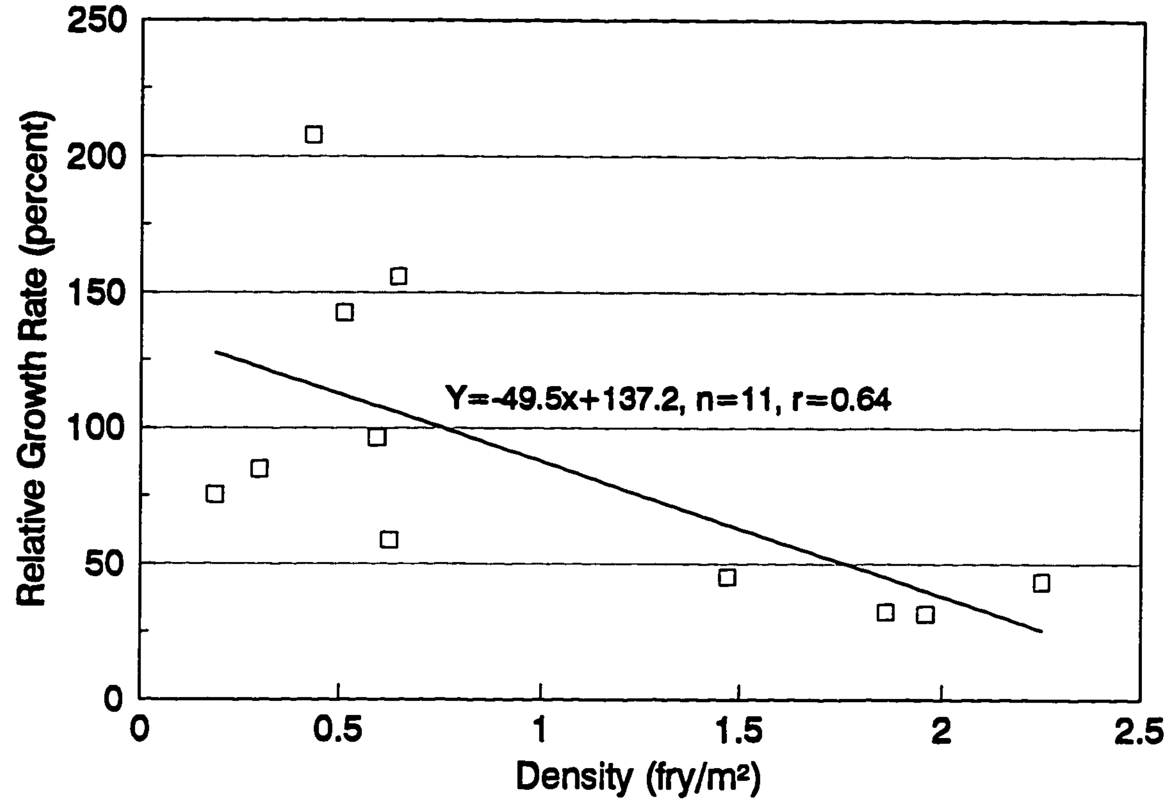

Figure 3.10. Relationship between the relative growth rate of wild coho salmon between June and August and combined coho salmon densities (as measured in August) in supplemented and control streams during 1991 and 1992.

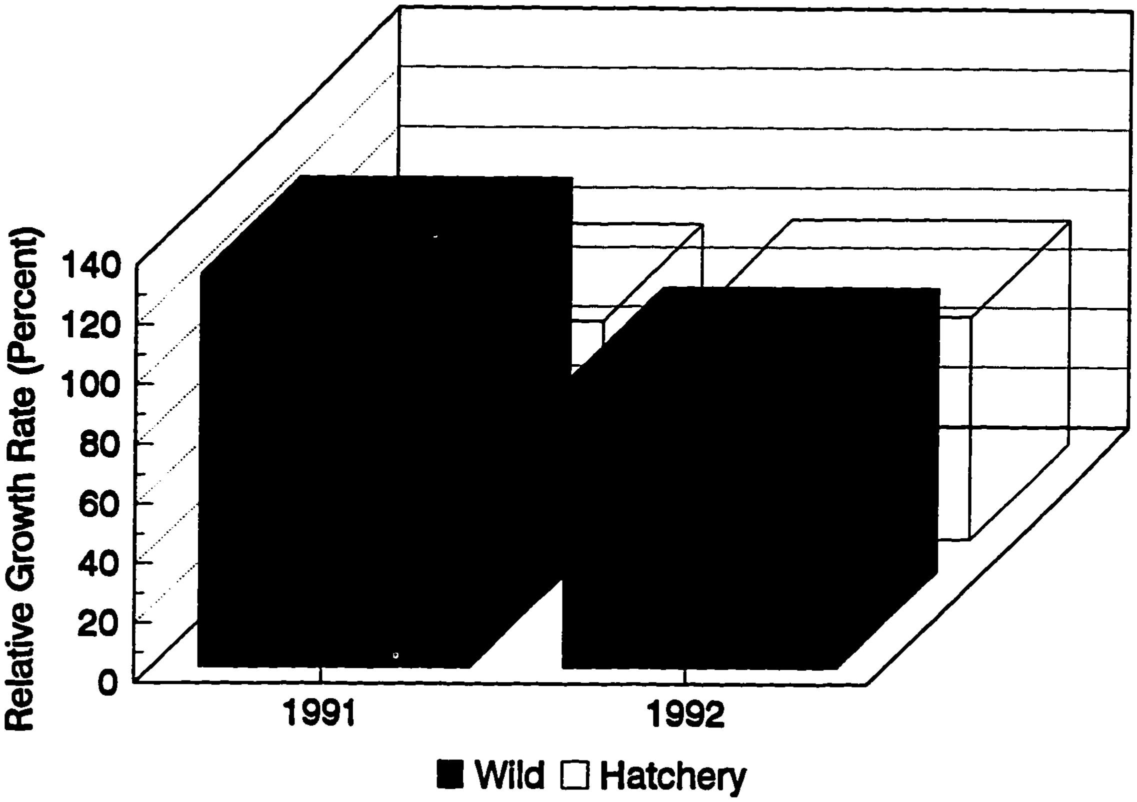

Figure 3.11. Relative growth rates of wild and hatchery-reared coho salmon between June and August in supplemented streams during 1991 and 1992.

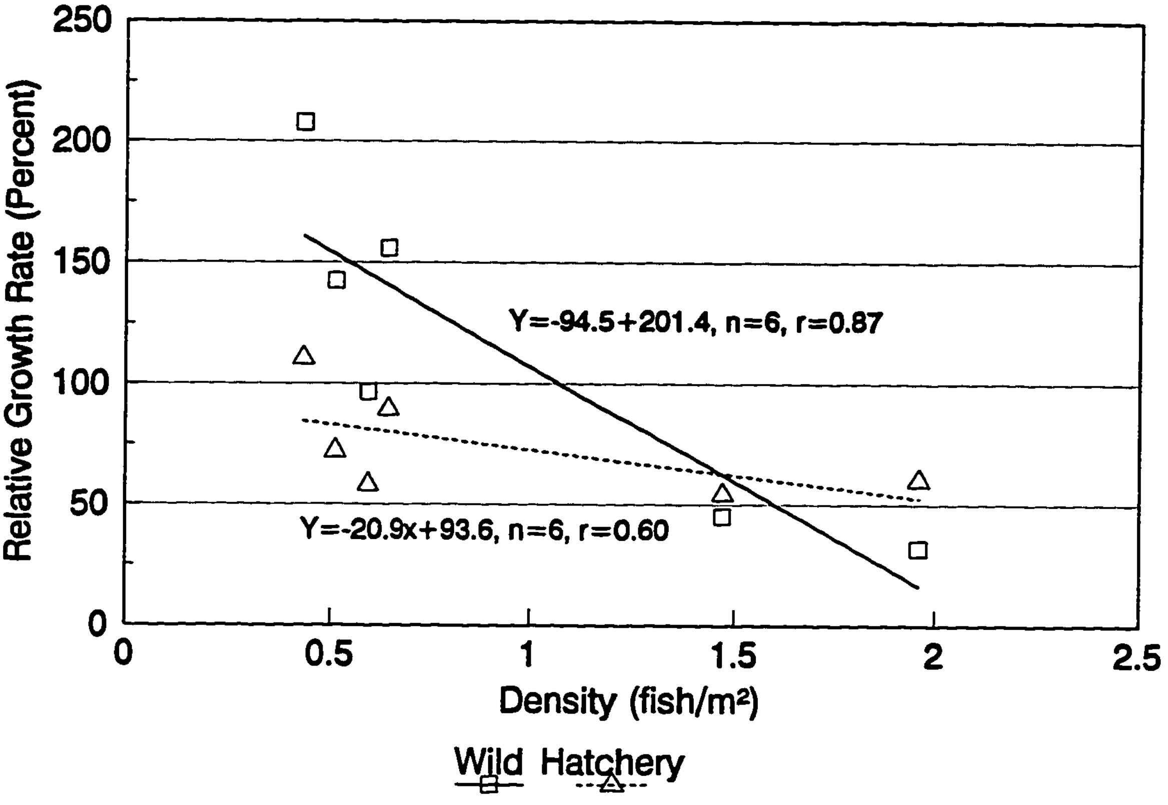

Figure 3.12. Relationship between the relative growth rate of wild and hatchery-reared coho salmon between June and August in supplemented steams and combined coho salmon rearing densities (as measured in August).

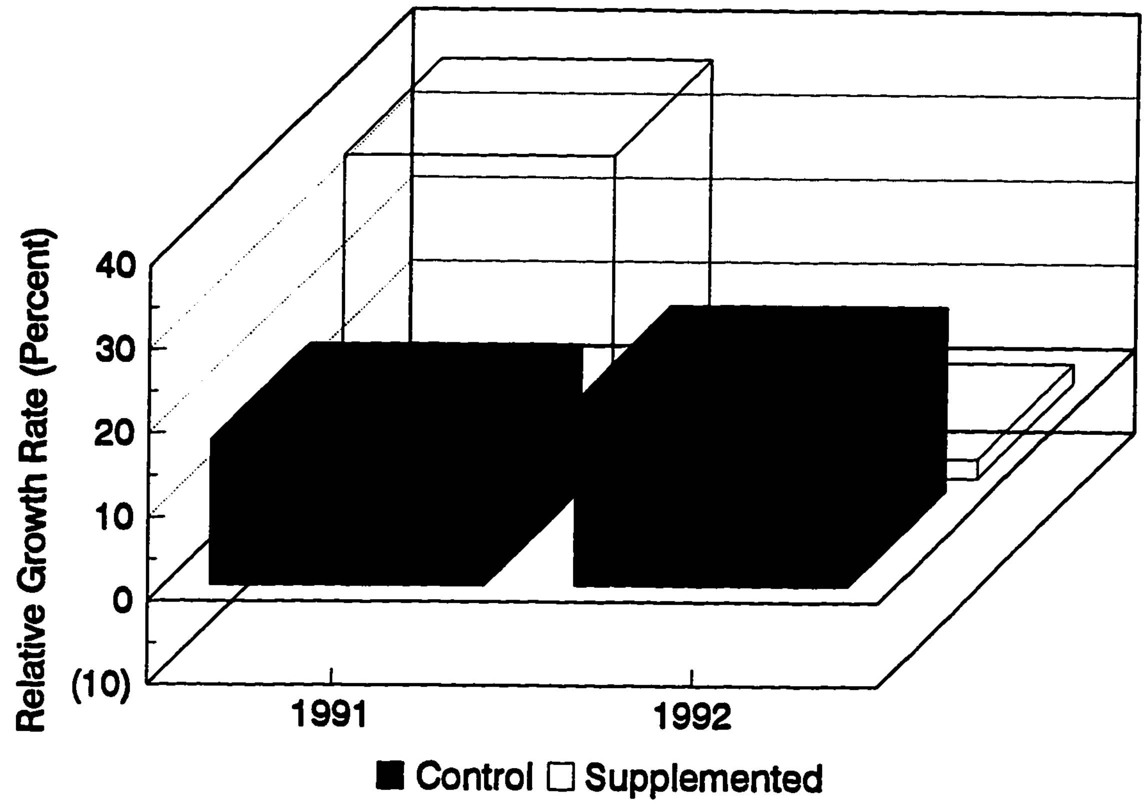

Figure 3.13. Relative growth rates of cutthroat trout between June and August in supplemented and control streams during 1991 and 1992.

DISCUSSION

Results reported in this manuscript are less rigorous than originally intended due inherent differences in wild coho salmon densities in streams receiving different treatments and the major freshet during August 1991. Coho salmon densities were always greater in one group of streams regardless of treatment. This altered the intended analysis, which reduced sample size and power for June comparisons. A major freshet occurred prior to the completion of late summer population estimates during the first year streams were supplemented (1991). The extensive redistribution of wild salmonids in the Clearwater Basin normally associated with freshets (Cederholm and Scarlett 1982) would have biased the results between supplemented and control streams during August 1991 and 1992. Therefore, the August 1991 data was not used in the analysis which reduced sample size and power of the analysis. This low statistical power increases the likelihood of not rejecting a false null hypothesis that coho salmon densities in control and supplemented streams were not different.

Stocking small Washington coastal streams with hatchery-reared coho fry produced by a native broodstock increased coho salmon rearing densities by 19% and 89% in Peterson, Elkhorn, and Prairie creeks during August. These plants did not appear to reduce wild coho salmon or cutthroat trout densities. Coho fry supplementation was associated with decreased size of wild coho fry during summer. However, the relative growth rates of wild coho fry between June and August were greater in supplemented than control streams. Wild coho salmon grew faster than hatchery coho salmon in supplemented streams but were influenced to a greater degree by increasing coho salmon rearing densities than hatchery coho fry. Growth of cutthroat trout was not affected by coho fry supplementation.

Results from this study suggest that fry supplementation did not result in statistically significant increased coho salmon densities in tributaries of the Clearwater River. However, the power of statistical tests was extremely low (<0.3). Coho salmon densities in Peterson, Prairie, and Elkhorn creeks when supplemented would have had to increase two- to three-fold for statistically significant differences to be detected ($\alpha=0.05$) 75% of the time. Coho fry densities in these three streams were 19% (1990) and 89% (1993) greater when supplemented (1992) than when they were not supplemented (1990 and 1993). These increases were observed in streams with wild coho fry densities above 0.7 fish/m^2. These densities are not substantially depressed based on carrying capacity estimates of pool habitats in Oregon streams (Nickelson et al. 1992a). In a much larger study, 41% increases in total coho fry densities were considered significant (Nickelson et al. 1986). The increases observed in the present study exceeded this level during 1993. This is an indication that stocking coho fry from a native broodstock during the spring may increase total coho fry rearing densities at summer low flow, especially in streams with natural seeding lower than that observed in this study (i.e., <0.7 fry/m2).

There are few examples (e.g., Nickelson et al. 1986) of fry supplementation for salmonids already present in a stream resulting in increased production of that species (Steward and Bjornn 1990; Wunderlich and Pantaleo 1995). This indicates that supplementing coho salmon streams with non-native hatchery stocks could have a substantial impact on the gene pool of native fish resulting in reduced stock productivity (Steward and Bjornn 1990). Stocking tributaries of the Clearwater River with coho salmon fry obtained from a native broodstock did not result in significant increases in smolt production from this system (Lestelle et al. 1993). In contrast, stocking coho salmon in areas lacking native coho salmon has resulted in significant smolt and adult production (Heard 1978; Hurst 1993).

This suggests that competition between wild and hatchery-reared coho salmon may be an important factor contributing to the failure of supplementation programs. Competition could result in increased emigration mortality of wild and hatchery-reared coho salmon. Supplementing streams with hatchery-reared coho salmon obtained from a native broodstock did not result in statistically significant decreases in wild coho salmon densities as compared to control streams. However, the low power of the statistical tests completed as a result of the interaction and the August storm, required wild coho salmon to be completely eradicated from supplemented streams before statically significant ($\alpha=0.05$) results would have been obtained. Empirical examination of the data does not suggest that wild coho salmon densities were reduced in supplemented streams; since densities were lower (28%) in one year, but greater (13%) the next.

Total emigration of hatchery-reared coho salmon from supplemented streams varied between 9 and 47% (Chapter II). Emigrating hatchery-reared coho fry were less likely to reside downstream than were wild coho salmon (Chapter II). However, this emigration rate was not greater than that observed for coho fry obtained from a hatchery stock planted in areas devoid of naturally produced coho salmon (37-69%) (Bilby and Bisson 1987). The effect of stocking hatchery-reared coho fry on the total emigration of wild coho fry was unclear, although the relationship between emigration and early summer rearing densities was altered by the stocking hatchery-reared coho salmon (Chapter II). Thus, conclusive data suggesting that competition increases total emigration of wild or hatchery-reared coho salmon is lacking.

Survival of wild and hatchery coho salmon could not be accurately measured in the present study because the study reaches did not extend to the upper limit of coho salmon production or to locations where hatchery-reared coho fry were stocked. Immigration of unknown proportions of wild and hatchery coho salmon into the study reaches of the streams would confound any attempts to measure survival. However, survival of hatchery-reared coho salmon fry obtained from the native broodstock used in the present study was similar to that of wild coho salmon (Quinault Indian Nation

1992). Wampler et al. (1990) also did not observe significant decreases in wild coho salmon survival as a result of stocking hatchery-reared coho fry obtained from native broodstocks. However, that study also did not account for immigration of wild and hatchery coho salmon from outside the study sections. Thus, there is presently inadequate data to accurately determine if reduced survival of hatchery-reared coho fry or wild coho salmon occurred in the present study.

Cutthroat trout densities were lower in Peterson, Elkhorn, and Prairie creeks when they were supplemented than when they were not. Again these differences were not statistically significant due to the small sample size, resulting from the altered experimental design. However, cutthroat trout emigration was not increased in supplemented streams compared to control streams (Chapter II). Tripp and McCarty (1983) observed reduced survival, growth, and production of allopatric populations of cutthroat trout as a result of stocking hatchery coho salmon fry above anadromous barriers.

Wild coho salmon in supplemented streams were smaller than wild coho fry in control streams during the June survey. This difference was apparently the result of reduced growth of wild coho in supplemented streams between early May, when hatchery-reared coho fry were stocked, and the first population survey in late June. Emigrating wild coho salmon in control and supplemented streams were the same size following stocking, but the size of wild coho fry in supplemented streams did not increase at the same rate as those in control streams (Chapter II).

The relative growth rate of wild coho salmon was greater in supplemented streams than control streams between June and August. The redistribution of coho salmon following the August 1991 storm may have influenced these results. Coho salmon in the Clearwater Basin both leave and enter free-running tributaries of the Clearwater River during freshets, with immigrating coho salmon generally larger than those originally present in these tributaries (Cederholm and Scarlett 1982). This would result in overestimation of the mean size and relative growth rates of wild coho salmon in two of the three supplemented streams during 1991.

Late summer size and mid summer growth of cutthroat trout did not appear to be negatively affected by coho fry supplementation. By contrast, Tripp and McCarty (1983) observed reduced survival and growth in allopatric cutthroat trout populations following the stocking of hatchery coho above anadromous barriers. However, cutthroat trout in the streams stocked in this study have evolved in sympatry with coho salmon populations and might be influenced to a lesser degree by the presence of coho salmon than allopatric populations of cutthroat trout. Glova (1987) and Sabo (1995) determined that allopatric populations of cutthroat trout defended habitat in pools more vigorously than sympatric populations. This would result in increased competition between stocked coho fry and allopatric cutthroat trout which would likely result in reduced growth in allopatric cutthroat populations. This could explain the reduced growth in cutthroat trout observed by Tripp and McCarty (1983) and the lack of significant reductions reported here.

Fry supplementation may be a viable tool for increasing summer densities of coho salmon in Washington State coastal streams already inhabited by native coho salmon. However, supplementation reduced the size of wild coho salmon in supplemented streams by late June, which may reduce summer and winter survival of wild coho salmon. Given this potential negative impact of fry supplementation on wild coho salmon, proposed supplementation programs should be critically scrutinized. Results reported here were obtained from streams with relatively good natural seeding. Thus, supplementation programs focusing on streams devoid of coho spawners or with very low spawner densities may be more successful. These benefits should be weighed against potential impacts to native cutthroat trout. The results of Glova (1987), Tripp and McCarty (1983), and Sabo (1995) suggest that stocking above anadromous barriers should not occur if native resident cutthroat trout exist in those areas.

CHAPTER IV

The Effects of Introduced Woody Debris on Juvenile Coho Salmon Densities in the Mainstem Clearwater River

INTRODUCTION

During summer 1990, the Washington Cooperative Fish and Wildlife Research Unit, U.S. Fish and Wildlife Service, and Washington Department of Natural Resources began evaluating the potential to increase juvenile coho salmon (*Oncorhynchus kisutch*) summer rearing habitat in the mainstem Clearwater River by introducing woody debris bundles. Woody debris is an important component of salmonid habitat, serving two primary functions, pool formation and providing protective cover (Bisson et al. 1987). Woody debris provides two forms of protection: cover from predators (Everest and Chapman 1972; Grant and Noakes 1987) and reduction of current velocities (McMahon and Hartman 1989; Shirvell 1990; Fausch 1993). As an example, young-of-the-year brook trout have a shorter reactive distance to predators in areas with concentrated cover, increasing their foraging opportunities (Grant and Noakes 1987). Woody debris also prevents the displacement of juvenile salmonids from rearing areas (McMahon and Hartman 1989). Areas containing woody debris are often the preferred habitat of juvenile coho salmon during the summer (Lister and Genoe 1970; Bisson et al. 1982) and winter (Bustard and Narver 1975a, 1975b). Numbers of salmonids are often positively related to debris density (House and Boehne 1986; McMahon and Holtby 1992) and salmonid biomass decreases after the removal of woody debris (Bryant 1982; Dolloff 1986; Elliott 1986).

Hall and Baker (1982) recommend that the rehabilitation of salmonid rearing areas be emphasized and Sedell and Luchessa (1982) encourage the restoration of habitat complexity to mainstem channels of 4th- to 7th-order streams. Summer carrying capacity of salmon and trout streams has been increased with the addition of woody debris (Ward and Slaney 1981; Anderson 1982; House and Boehne 1985, 1986; Nickelson et al. 1992b). However, most examples of habitat enhancement have occurred in relatively small streams (1st-3rd order). Common techniques of enhancement involve the addition of stable debris to provide resting areas, overhead cover, and new pools (Bisson et al. 1987). Sedell et al. (1985) predicted that salmon production in debris-impoverished streams could be increased by increasing the debris load. Hall and Baker (1982) also suggested that these measures would enhance existing wild stocks and maintain their genetic variability.

If mainstem restoration through woody debris introductions is successful, the potential limitation to coho salmon production in the Clearwater Basin (Cederholm and Reid 1987) may be eliminated and immigration of coho salmon into wall-base channel ponds during the fall may increase, thereby increasing production in this system (Chapter I). The specific objectives of this study were to determine whether juvenile coho salmon summer rearing densities in the mainstem Clearwater River could be increased by introducing woody debris and whether this would increase juvenile coho salmon immigrations into wall-base channel ponds during the fall.

Study Area

This study was conducted on the mainstem Clearwater River and six of its riverine ponds (Figure 1.1). The study area, described in more detail in Chapter I, extends from Bull Creek (Rkm 30) downstream to a creek described as 0031 Creek (rkm 10). Juvenile coho salmon immigration was monitored at six riverine ponds (Figure 1.1, Table 4.1). Coppermine Bottom, Pond 2, Paradise and Swamp Creek Beaded Channel have been described previously (Peterson 1982a; Cederholm et al 1988; Cederholm and Scarlett 1991). Paradise Pond and Swamp Creek Beaded Channel were the subjects of earlier enhancement projects (Cederholm et al. 1988; Cederholm and Scarlett 1982) and are located on opposite sides of the river at approximately rkm 15.3. Morrison Pond is a relatively small pond bordered by an extensive sedge swamp, whereas Airport Pond is actually two adjacent ponds with a single outlet.

Table 4.1. Summary of the physical features of the six wall-base channel ponds where juvenile coho salmon were sampled. (Source: Peterson 1982a; Cederholm et al. 1988; Cederholm and Scarlett 1991; Dave King, Washington Department of Fish and Wildlife, unpublished data).

Pond	Surface area (ha)	Outlet length (m)	River kilometer
Coppermine Bottom	0.9	350	27.4
Pond 2	1.3	350	20.0
Paradise	0.5	350	15.3
Swamp Creek	0.3	220	15.3
Airport	1.4/2.1	150	7.2
Morrison	1.0	150	4.8

MATERIALS AND METHODS

Comparison of Enhanced and Unenhanced Reaches

A 2-year study design was used to evaluate the effect of habitat enhancement on juvenile coho salmon summer rearing densities. Following preliminary observations during 1990, seven adjacent study reaches were established in the mainstem Clearwater River (Table 4.2). One reach, approximately 2.1 km in length, was unaltered during both years (1992 and 1993) to serve as a year-to-year control. Of the six remaining reaches, four were approximately 2.4 km long and two were approximately 4.0 km long (Table 4.2). During the first year (1992), the habitat in three randomly selected reaches (two 2.4-km and one 4.0-km reaches) were enhanced by introducing 10-20 woody debris bundles to each (enhanced reaches). The three remaining reaches were unaltered (control reaches) (Table 4.2). Treatments were reversed during 1993. The three control reaches from 1992 were enhanced during 1993 by introducing 10-20 woody debris bundles. The three enhanced reaches from 1992 were returned to their natural state during early spring 1993 by removing introduced woody debris bundles remaining after the winter so they could serve as control reaches (Table 4.2).

Woody debris bundles were installed by a 10-person crew during early May at predetermined stations within each reach. Two or three sitka spruce (*Picea sitchensis*) or western hemlock (*Tsuga heterophylla*) trees, averaging 10-20 cm diameter at the base, were removed from the adjacent riparian zone and carried to the river's edge, where they were laid parallel and joined at their butt ends with rope or a large metal spike. The bundle of trees was then rolled into the river and then floated to the desired position, where it was lashed in a submerged position to an existing tree or rock.

Juvenile coho salmon abundances were estimated for each study reach, during early (June/July) and late summer (August/September). Abundance estimates were made in each reach by summing snorkel-count estimates of coho salmon abundance at three types of stations (natural, introduced, or no debris) within each reach (two station types in control reaches without introduced debris). Stations composed of only naturally occurring woody debris were classified as natural and were present in both enhanced and control reaches. Stations where woody debris was introduced were classified as introduced and were only present in enhanced reaches. Control stations were areas that were similar to natural and introduced debris stations, except the area lacked woody debris. Control stations were present in both enhanced and control reaches. Two snorkelers entered the river upstream of the survey station and proceeded downstream, counting juvenile coho salmon as they passed the station. Once downstream of the station, the snorkelers proceeded upstream, again counting juvenile coho salmon as they passed the station. The snorkelers then discussed their individual estimates and came to a consensus, which became the abundance estimate for that station.

Table 4.2. **Treatments and lengths of study reaches during 1991-1993. Number in parenthesis represents the number of introduced woody debris stations in enhanced reaches.**

	Treatment			
Reach name[1]	1991	1992	1993	Approx. length (km)
Bull	Enhanced(8)	Control	Enhanced(7)	2.4
Deception	Control	Enhanced(9)	Control	4.0
Peterson	Enhanced(20)	Control	Enhanced(14)	4.0
Gross	Control[2]	Control[2]	Control[2]	2.1
Shale	Control	Enhanced(10)	Control	2.4
Elkhorn	Enhanced(10)	Control	Enhanced(7)	2.4
Hunt	Control	Enhanced(12)	Control	2.4

[1] Reach names were selected based on tributary (or bridge) at the upstream end of the reach (i.e., The reach running from Bull Creek to Deception Creek = Bull Reach, Figure 1.1)

[2] Year-to-year control

The sum of the abundance estimates at all the stations surveyed in each reach was considered a minimum estimate for that reach. Estimates were considered minimum coho salmon abundance in the reach because stations rather than the entire reach were surveyed and snorkel estimates generally underestimate true abundances (Slaney and Martin 1987). Although no quantitative estimate is available, the author believes that greater than 90% of juvenile coho salmon within a reach were seen using the above methodology and snorkel estimates represented approximately 67% of actual coho salmon abundance at stations (Appendix E). Minimum juvenile coho salmon densities were calculated by dividing the minimum abundance estimates for the reach by the reach length (coho salmon/km). A sign rank test was used to compare coho salmon rearing densities in enhanced and control reaches during June 1991-1992, June 1992-1993, and August 1992-1993.

The influence of woody debris on estimated coho salmon densities in each study reach was examined using linear regression with estimated coho salmon densities as the dependent variable and the total number of natural and introduced woody debris accumulations present in the reach as the independent variable. Separate analyses were completed for the early summer and late summer survey data.

The study was originally planned for 1991 and 1992, following preliminary observations collected during 1990. However, an unusual storm in mid August 1991 brought 15 cm of rain during a 4-day period. This storm occurred after the early summer (1991) survey but before the late summer survey. Many of the introduced woody debris bundles were removed by the storm, thereby eliminating the treatment. For this reason, late summer survey data from 1991 does not appear in the results. The treatments for 1991 were replicated in 1993 in order to complete the 2-year study design.

Effect of Enhancement on Wall-base Channel Immigration

The effect of habitat enhancement on the number of juvenile coho salmon moving into wall-base channel ponds during fall and winter was evaluated. Following the late summer surveys in 1990 and 1992-1993, coho salmon were captured and marked at a number of natural and introduced debris stations within each reach. Because of the large number of stations, long stretch of river, and time constraints, attempts to capture juvenile coho salmon for marking were made only at stations with relatively large estimated populations (50 or more). Juvenile coho salmon were captured by beach or purse seining, anesthetized with tricaine methanesulfonate (MS-222), measured to fork length (mm), and weighed (g). Coho salmon were then marked using freeze branding (Bryant and Walkotten 1980) in 1990 and 1992, and by injecting acrylic paint into the caudal fin (Lotrich and Meredith 1974; Thresher and Gronell 1978) in 1993. After recovering from the anesthetic, fish were released into the debris station from which they had been captured. In 1992 and 1993 attempts were made to mark equal numbers of coho salmon from enhanced and control reaches, as well as from stations with natural and introduced woody debris to allow comparisons of the contribution of coho salmon rearing in these areas during the summer to immigration into wall base channel ponds during the fall. To accomplish this, a majority of coho salmon marked from enhanced reaches were from stations with introduced woody debris stations, although some coho salmon from stations with natural woody debris were also marked.

Coho salmon were captured and checked for marks as they migrated into wall-base channel ponds. Six wall-base channel ponds were monitored in 1992 and 1993 (Figure 1.1) while only four (Coppermine Bottom, Pond 2, Paradise, and Swamp Creek) were monitored during 1990 (Figure 1.1). Coho salmon were captured as they migrated into these ponds from the first fall freshet through the end of December using upstream weirs and wood framed live-box traps. Fish were removed from traps, anesthetized, and checked for marks. A random sample of up to 25 coho salmon (marked and unmarked) were weighed (g) and measured to fork length (mm) each time the trap was checked. After recovery, the fish were released upstream of the trap.

A t-test, using arc sine transformed data (Zar 1984), was used to compare the recovery rates (percent marked fish recovered) at: 1) enhanced and control reaches of the mainstem, 2) introduced and natural debris stations, and 3) debris stations located in pools and glides. These analyses were completed with data from all three years separately and combined.

The number of coho salmon moving into wall base channel ponds from summer rearing areas located in control and enhanced reaches was estimated using the recovery rate and the estimated population size in each reach type. Estimated coho salmon abundance in control and enhanced reaches was multiplied by the percent of marked fish from each reach type recovered migrating into wall-base channel ponds to calculate the estimated number of coho salmon from each reach migrating into this habitat.

Coho Salmon Size Comparison

A number of comparisons of coho salmon fork lengths were completed using either a Student's t-test or a one-way ANOVA and Tukey multiple comparisons. A t-test was used to compare the fork length of juvenile coho salmon captured from enhanced and control reaches and those from introduced and natural debris stations during August (marking survey). ANOVA and Tukeys multiple comparisons were used to compare coho salmon lengths: (1) those captured from debris located in different riverine habitat (pools, riffles, and glides); and (2) those migrating into wall-base channels during the fall. A Student's t-test was used to compare the fork length of juvenile coho salmon captured from enhanced and control reaches and those from introduced and natural debris stations during August (marking survey).

RESULTS

Comparison of Enhanced and Unenhanced Reaches

Although coho salmon densities in mainstem study reaches varied between reaches and years, woody debris introductions appear to be an effective tool for increasing coho salmon late summer rearing densities in the mainstem Clearwater River. Coho salmon densities (fish/km) were generally higher in enhanced reaches than control reaches (Figures 4.1-4.3) and were positively related to woody debris densities (Figure 4.4). Coho salmon rearing densities were significantly higher in enhanced and control reaches during June 1991-1992 (Figure 4.1) and August 1992-1993 (Figure 4.3), but not during June 1992-1993 (Figure 4.2). Coho salmon densities were significantly and positively influence by increasing woody debris densities (introduced and natural woody debris accumulations/km) (Figure 4.4).

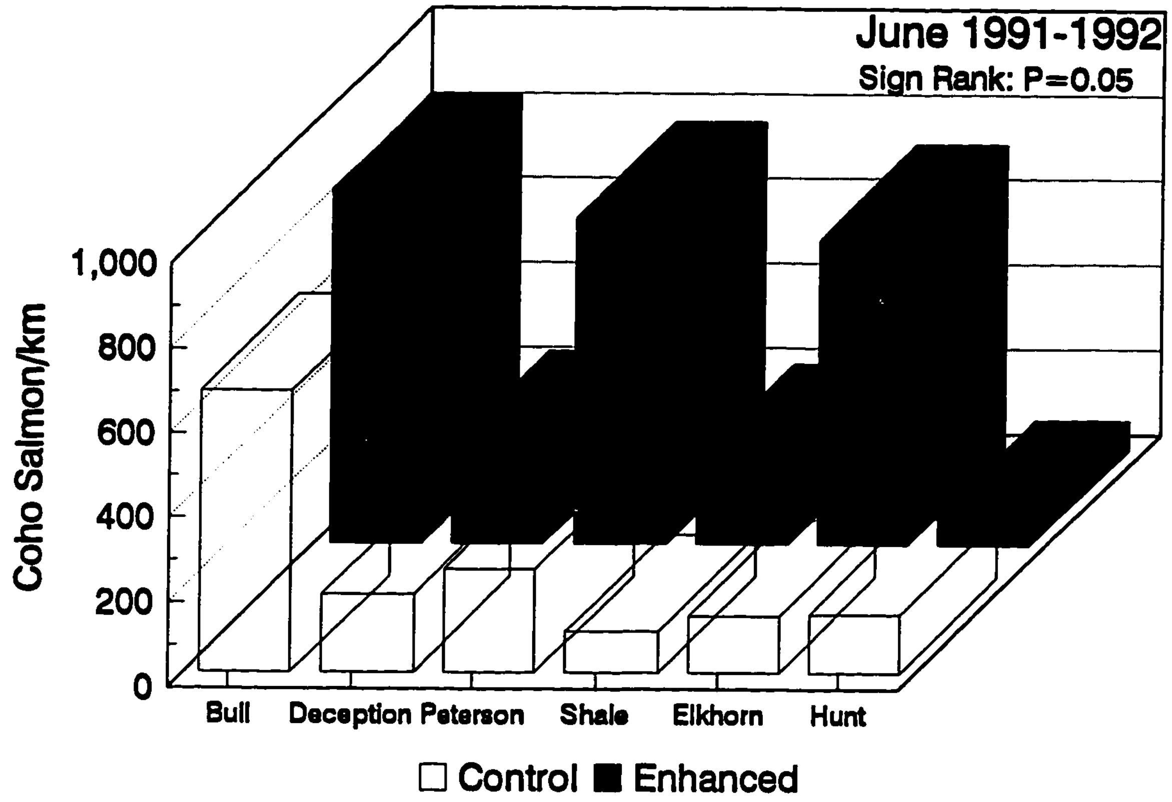

Figure 4.1. Estimated coho salmon densities (coho/km) in the six study reaches when they were enhanced and when they were controls during June 1991-1992. Result of the sign rank test used to compare rearing densities in enhanced and control reaches is included.

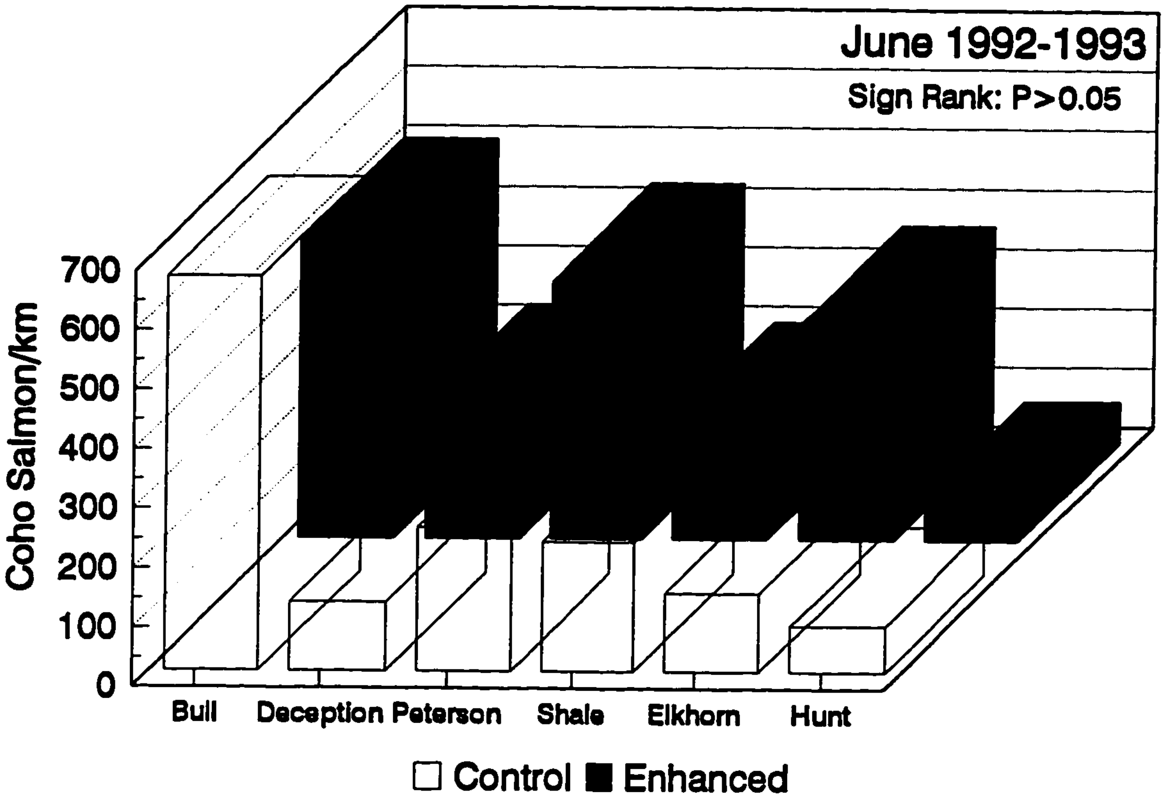

Figure 4.2. Estimated coho salmon densities (coho/km) in the six study reaches when they were enhanced and when they were controls during June 1992-1993. Result of the sign rank test used to compare rearing densities in enhanced and control reaches is included.

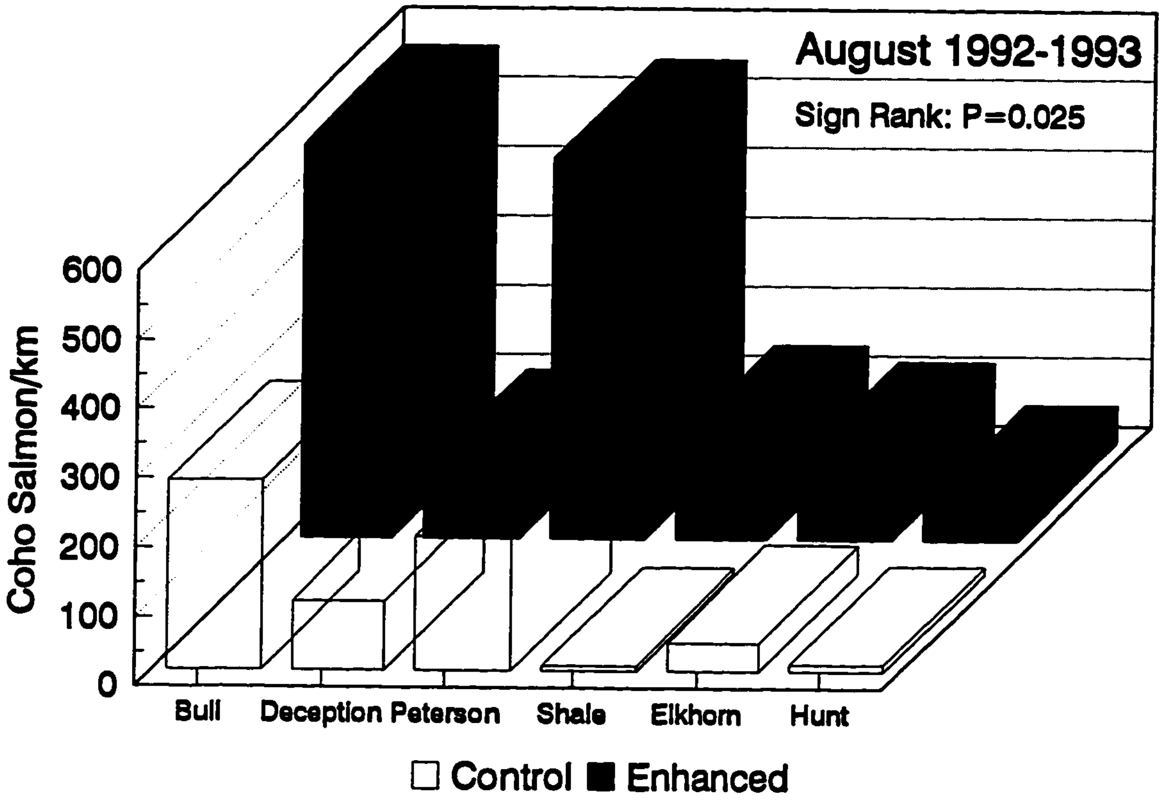

Figure 4.3. Estimated coho salmon densities (coho/km) in the six study reaches when they were enhanced and when they were controls during August 1992-1993. Result of the sign rank test used to compare rearing densities in enhanced and control reaches is included.

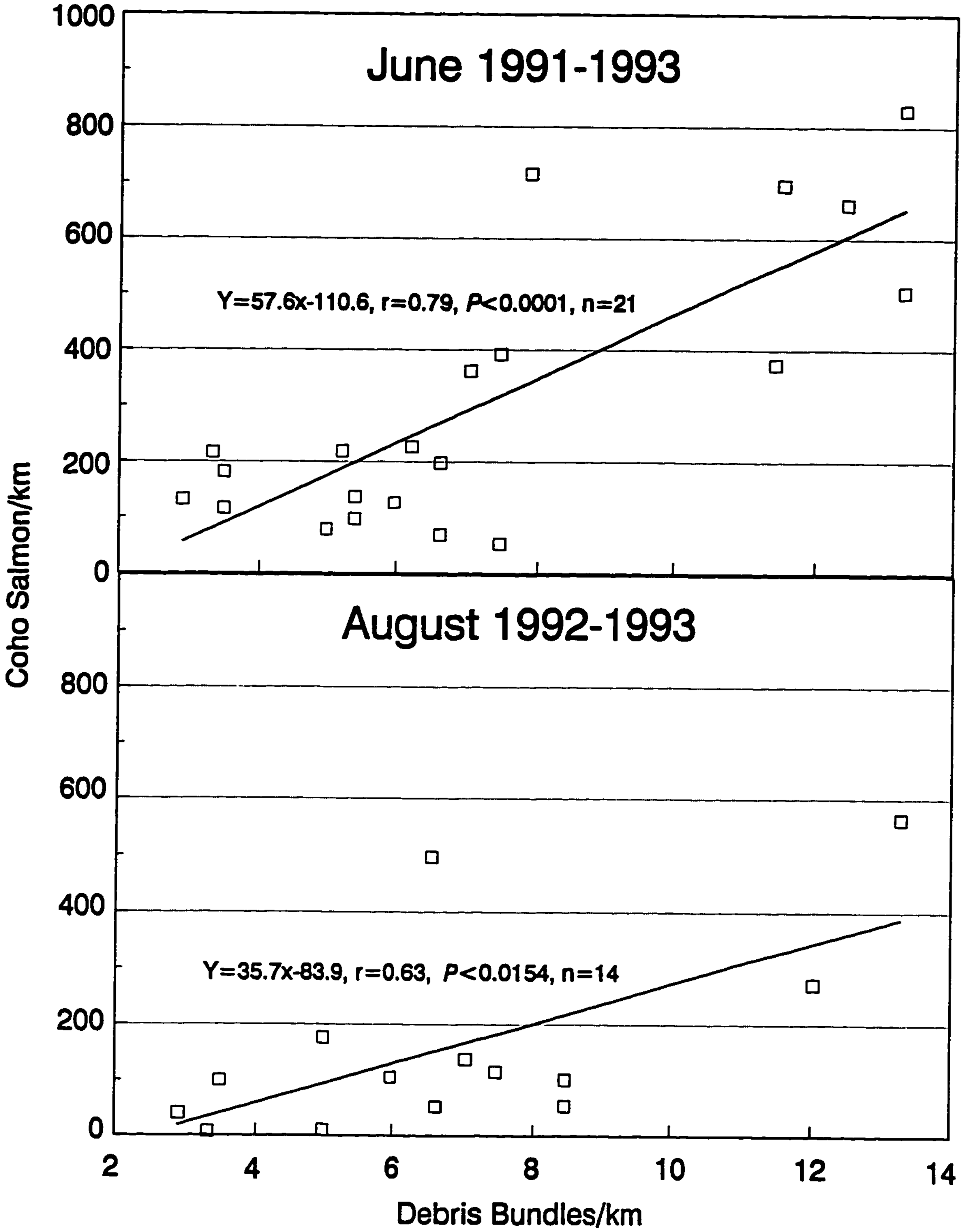

Figure 4.4. Relationship between estimated coho salmon population densities per kilometer of river and the number of debris stations per kilometer of river (June/July 1991-1993 and August 1992-1993).

Effect of Enhancement on Wall-base Channel Immigration

Immigration of coho salmon into wall-base channel ponds varied between years and between ponds (Appendix D). Between 531 and 1939 coho salmon were caught entering each of these ponds during the four years they were sampled. Recoveries of coho salmon marked at individual mainstem woody debris accumulation sites ranged from 0 to 11 individuals per site. Totals of 37, 41, and 23 marked coho salmon were recovered during 1991, 1992, and 1993, respectively. Marked coho salmon generally moved downstream prior to moving into a wall-base channel pond. Of the 101 marked fish recovered, all but one had moved downstream. Marked fish had migrated between 0 and 27.5 km (ave. 9.3) prior to being captured at wall-base channel ponds. The one fish recovered at a pond upstream of the station where it was marked had traveled 7.2 km.

Introducing woody debris bundles into study reaches of the mainstem Clearwater River did not increase the percentage of marked fish recovered (Table 4.3) or the estimated number (Table 4.4) of coho salmon moving into wall-base channel ponds. Recovery rates of coho salmon marked at debris accumulations in enhanced and control reaches were not statistically different. Results were the same whether the data from 1992-1993 were combined for analysis (t-test: $P=0.4321$) or when it was analyzed separately (t-test: 1992: $P=0.7107$; 1993: $P=0.2451$; Power < 0.30 all tests) (Table 4.3). Numbers of coho salmon migrating into wall-base channels appeared to be influenced more by the groups of study reaches than by the introduction of woody debris (Table 4.4). More coho salmon were estimated to have migrated into wall-base channels from the Bull, Peterson, and Elkhorn reaches than the Deception, Shale, and Hunt reaches, whether they were enhanced by introducing woody debris (1993) or not (1992). In contrast, coho salmon rearing in the Deception, Shale, and Hunt reaches were recovered at higher percentages than those from the Bull, Peterson, and Elkhorn reaches, whether the habitat was enhanced (1992) or not (1993). More coho salmon from the Bull, Peterson, and Elkhorn reaches were estimated to have moved into wall-base channel ponds during both 1992 and 1993 even though the recovery rates were lower (Table 4.4). This was due to the higher estimated coho salmon populations in these reaches (Table 4.4).

The percent of coho salmon marked at introduced and natural woody debris accumulation sites recovered immigrating into wall-base channels were not significantly different when the data was combined for analysis (t-test: $P=0.1687$) or when data from 1992 (t-test: $P=0.8800$) and 1993 (t-test: $P=0.6171$) were analyzed separately (Table 4.5). However, coho salmon marked at natural debris stations were recovered more frequently (t-test: $P=0.0163$) than those marked at introduced debris stations during 1990 (Table 4.5), although coho salmon were marked at only two natural debris stations compared to 10 introduced debris stations during that year.

The river habitat (pool, riffle, glide) in which coho salmon were marked did not effect the percent recovered at wall-base channel ponds (All years: $P=0.5753$; 1990: $P=0.5926$; 1992: $P=0.6087$; 1993: $P=0.9270$). Although not significant, recovery rates of coho salmon marked at introduced debris accumulations in pools (3.3%) appeared greater than those from introduced debris accumulations located in glides (1.6%). The opposite may have been true for natural debris accumulations, with numerically more coho salmon marked at natural debris accumulations in glides (6.1%) being recovered than that observed in pools (4.7%).

Coho Salmon Size Comparison

No significant differences in coho salmon lengths were observed between enhanced and control reaches during 1992 (t-test: $P=0.1205$) or 1993 (t-test: $P=0.3682$) or between introduced and natural debris stations during 1990 and 1992-1993 (t-test: 1990, $P=0.0568$; 1992, $P=0.2252$; 1993, $P=0.9799$). Coho salmon from pools were significantly (ANOVA: $P=0.0356$) longer than those from glides (Tukey: $P=0.0268$) during 1990 but not 1992 (t-test: $P=0.3582$) or 1993 (t-test: $P=0.8184$) (Figure 4.5). No significant difference existed in coho salmon length between pool and riffles or glides and riffles for 1990. No riffles were sampled during 1992 or 1993.

There were significant (ANOVA: $P<0.0001$ in all years) differences in the fork length of coho salmon migrating into the wall-base channel ponds sampled during 1990 and 1992-1993 (Figure 4.6). Juvenile coho salmon migrating into Swamp Creek Beaded Channel were significantly smaller than those migrating into the other ponds during all years. Juvenile coho salmon migrating into Airport and Morrison ponds during 1992 and 1993 were longer than those migrating into any other pond. There was no significant difference in the fork length of juvenile coho salmon migrating into these two ponds. No other significant differences existed.

Table 4.3. Number of juvenile coho salmon marked in enhanced and control reaches along with the number and percentage of marked fish recovered migrating into wall-base channel ponds.

Treatment	1992			1993			Total		
	Number Marked	Number Recovered	Percent Recovered	Number Marked	Number Recovered	Percent Recovered	Number Marked	Number Recovered	Percent Recovered
Enhanced	293	17	5.8	561	8	1.4	854	25	2.9
Control	327	16	4.9	152	10	6.6	479	26	5.4
Total	620	33	5.3	713	18	2.5	1,333	41	3.1

Table 4.4. Estimated coho salmon abundance in enhanced and control reaches during August 1992-1993 and the estimated number of these fish migrating into the wall-base channel ponds sampled during this study. The estimated number of fish from enhanced and control reaches migrating into wall-base channel ponds was calculated by multiplying the percent of marks recovered (Table 4.3) by the estimate of coho salmon abundance in each reach type. The Deception, Shale, and Hunt reaches wee enhanced during 1992 and controls during 1993, while Bull, Peterson, and Elkhorn reaches were controls in 1992 and enhanced in 1993.

Treatment	1992		1993		Total	
	Estimated abundance	Est. no. migrating into ponds	Estimated abundance	Est. no. migrating into ponds	Estimated abundance	Est. no. migrating into ponds
Enhanced	863	50	3,387	53	4,250	106
Control	1,744	85	551	36	2,295	124

Table 4.5. Number of juvenile coho salmon marked at introduced and natural debris stations along with the number and percentage of marked coho salmon recovered migrating into wall-base channel ponds. Included are the number of stations where marking occurred and the number and percentage of stations from which marks were recovered.

Debris type	1990			1992			1993			Total		
	Number Marked	Number Recovered	Percent Recovered	Number Marked	Number Recovered	Percent Recovered	Number Marked	Number Recovered	Percent Recovered	Number Marked	Number Recovered	Percent Recovered
Number of coho salmon marked and recovered												
Introduced	680	7	1.0	224	14	6.3	515	8	1.6	1,419	29	2.0
Natural	229	14	6.1	396	19	4.8	198	10	5.1	823	43	5.2
Total	909	21	2.3	620	33	5.3	713	18	2.5	2,214	72	3.2
Number of Stations Where Marking occurred and from which recoveries were made												
Introduced	10	6	60.0	7	6	85.7	6	3	50.0	23	15	65.2
Natural	2	2	100.0	11	10	90.9	7	2	28.6	20	14	70.0
Total	12	8	66.7	18	16	88.9	13	5	38.5	43	29	67.4

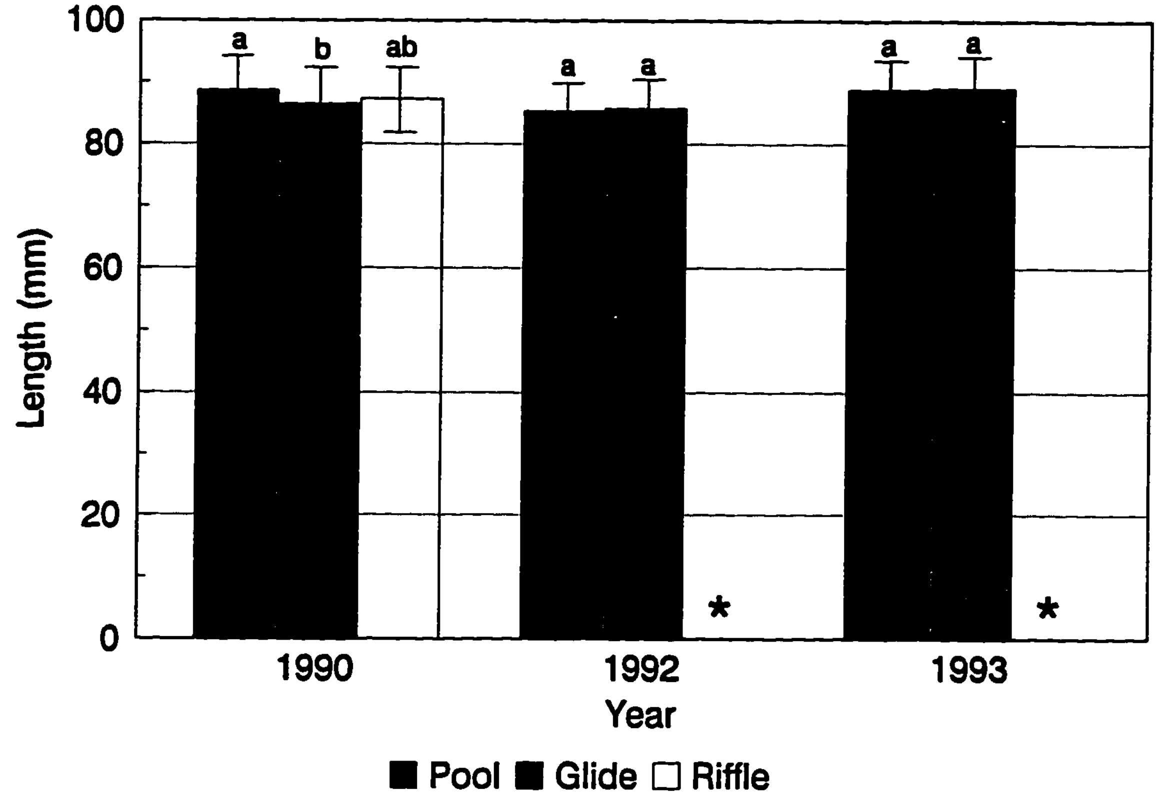

Figure 4.5. Mean (+/- 2 SE) fork length of coho salmon from different riverine habitats, 1990, 1992-1993. Groups of bars with different letters are significantly different (ANOVA and Tukey: $P<0.05$). (* = not sampled).

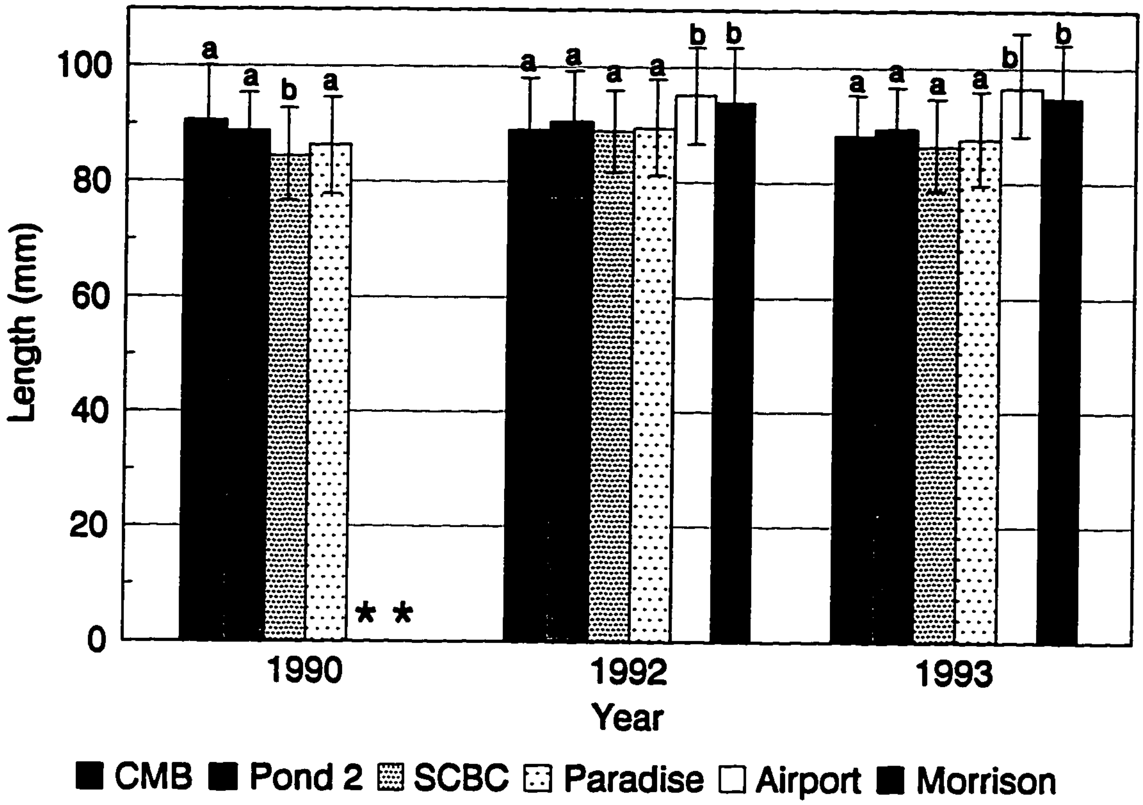

Figure 4.6. Mean (+/- 2 SE) fork length of coho salmon immigrating into wall-base channels during 1990, 1992-1993. Groups of bars with different letters are significantly different (ANOVA and Tukey: $P<0.05$). (CMB=Coppermine Bottom Pond, SCBC=Swamp Creek Beaded Channel, *=not sampled).

DISCUSSION

Introducing woody debris bundles into the mainstem Clearwater River increased coho salmon summer rearing densities (fish/km). Coho salmon summer rearing densities were positively related to woody debris densities (no. pieces of wood/km). The percent of coho salmon marked during late summer in mainstem study reaches recovered migrating into wall-base channel ponds during the fall were not increased by introducing woody debris bundles. Recovery of coho salmon marked in the mainstem appeared to be influenced more by the groups of study reaches receiving different treatments than by introductions of woody debris. Although summer rearing densities were increased in enhanced reaches, estimated numbers of coho salmon moving into wall-base channel ponds during the fall was not increased in enhanced reaches.

Woody debris introductions appear to be a useful technique for increasing coho salmon summer rearing densities in the mainstem Clearwater River. Summer rearing densities were higher in reaches enhanced by introducing woody debris bundles than control reaches and were positively influenced by increasing woody debris densities. Results of this study support that premise that habitat restoration in large mainstem rivers may increase salmonid production of these systems (Sedell and Luchessa 1982). Although summer populations of salmon and trout have been increased through woody debris introductions, most examples come from relatively small streams (Ward and Slaney 1981; Anderson 1982; House and Boehne 1985, 1986; Nickelson et al. 1992b). This is also true for examples of increasing salmonid rearing densities with increasing densities of woody debris (e.g. House and Boehne 1986; McMahon and Holtby 1992). Results reported in this study support conclusions of related studies which determined that the presence of woody debris was a primary factor determining coho salmon distribution in this river and that abundance was influenced by the size and density of woody debris accumulations (Chapter V).

Although results presented in this study demonstrate that summer rearing densities may be increased through woody debris introductions, it did not address question of whether stable woody debris which could withstand winter flows could be introduced into this relatively large channel. The woody debris bundles introduced in this study were meant to be temporary which allowed the treatments of the reaches to be switched each year. Therefore, the fact that many of the introduced woody debris structures were washed out during the August 1991 flood (and winter floods of 1992 and 1993) should not be misconstrued to mean that stable woody debris cannot be introduced into this system. The persistence of most natural woody debris accumulations sampled during this study (1990-1993) suggests that stable woody debris could be introduced to this system. However, these introductions would likely be limited to pool habitats and to locations on the point bar side of glide habitats just downstream of river bends. Although this eliminates a number of the locations where woody debris bundles were introduced in the present study, it also focuses woody debris introductions on the areas with the greatest potential benefits to coho salmon rearing habitat. Coho salmon abundance was greatest at large, dense debris accumulations located in pools (Chapter V).

A second question is whether the cost of introducing woody debris into mainstem rivers is justifiable. The Clearwater River has approximately 56.6 km of mainstem habitat available for anadromous salmonids (Phinney and Bucknell 1975). By extrapolating average annual observed coho salmon rearing densities in control and enhanced reaches (Table 4.6), it appears that enhancement could result in a 48-158% increase in the number of coho salmon rearing in this habitat. This extrapolation assumes that enhancement would have similar effects throughout the entire mainstem river and that food does not limit production. Based on the large size of coho salmon observed in the mainstem (80-90 mm) compared to those in tributaries of the mainstem (70-80 mm, Peters, unpublished data), the assumption that food does not limit production in the mainstem seems accurate. These extrapolations were calculated by summing corrected snorkel estimates of coho salmon abundance at all stations snorkeled for each study reach. I corrected the snorkel estimates because salmonid abundance estimates using this technique has been found to underestimate actual abundance (Slaney and Martin 1987). Snorkel estimates in the present study were found to represent approximately 67% of the actual population (Appendix E). Corrected snorkel estimates were calculated by applying the regression equation developed in Figure E.1 (Appendix E) to snorkel estimates for each woody debris accumulations where snorkel estimates were completed.

Table 4.6. Corrected annual estimates of juvenile coho salmon densities (coho/km) observed in enhanced and control reaches and extrapolated population estimate for the entire mainstem.

	Coho salmon density (coho/km)		Estimated population entire mainstem	
Date	Control	Enhanced	Control	Enhanced
June 1991/1992	332.0	678.1	18,791	38,380
June 1992/1993	288.8	426.5	16,346	24,140
August 1992/1993	197.0	507.7	11,150	28,736

Although enhancement apparently increased mainstem juvenile coho salmon densities, it did not increase the number of coho salmon migrating into wall-base channel ponds. Recovery rates from control reaches and natural debris stations were nearly twice those of enhanced reaches and introduced debris accumulations. Although these differences were not statistically significant, the power of the statistical test was less than 0.30. Thus, the difference in my opinion should be considered biologically meaningful. The apparent better contribution to wall-base channel immigration from control than from enhanced reaches may be an artifact of the apparently poor contribution of coho salmon from introduced than from natural debris stations. Most coho salmon marked in enhanced reaches were marked at introduced debris accumulations, while all fish marked in control reaches were at natural debris accumulations. Thus, observed differences between introduced and natural debris accumulations would be reflected in the comparison of enhanced and control reaches.

The introduced debris accumulations used in this study may have provided poorer quality habitat during high flows associated with fall freshets. Introduced woody debris accumulations were constructed using relatively small trees and lashed to existing debris using rope so they would wash out during winter flows to allow the treatments in different reaches to be switched each year. McMahon and Hartman (1989) found that juvenile coho salmon remained near debris during daylight and migrated at night during simulated freshets in an outdoor stream channel. The introduced woody debris bundles used in this study may not have afforded fish this option. Instead of migrating at night, which may afford protection from predators (Mace 1983; Wood et al. 1993), juvenile coho salmon residing at introduced debris stations may have had to migrate whenever the station failed. This may have resulted in increased mortality of coho salmon rearing at introduced debris accumulations during downstream migration. If so, enhancement with larger, more stable debris may increase the number of coho salmon moving into wall-base channels from enhancement sites.

When corrected snorkel estimates (as described above) as coho salmon abundance at natural and introduced woody debris accumulations (Table 4.7) were used to calculate immigration of coho salmon from woody debris accumulations in the mainstem, it was estimated that 23-55 coho salmon from introduced woody debris accumulations could have immigrated into wall-base channel ponds during 1990-1993 (Table 4.7). In contrast, coho salmon residing at natural woody debris accumulations during the summer were estimated to have contributed between 104 and 195 immigrants during this same period (Table 4.7). These calculations are based on the four (1990) to six (1992 and 1993) wall-base channel ponds monitored during this study. It is likely that coho salmon using introduced debris bundles moved into other wall-base channel ponds downstream from our enhanced reaches. The Washington Department of Fisheries (WDF) has described more than 30 such habitats in the Clearwater River Basin (Dave King, WDF, personal communication). Thus, our estimates take into account only 20% of available wall-base channel ponds. By extrapolating contribution rates to account for additional wall-base channel ponds, estimated contribution of coho salmon using introduced debris bundles to wall-base channel immigration would be approximately: 1990, 115; 1992, 275; and 1993, 200. This assumes that immigration rates are equal, which may not be the case. Nevertheless, mainstem habitat enhancement would have limited benefits to overall wall-base channel immigration. However, only a small portion of the mainstem was enhanced during this study (1990--14 km; 1992 & 1993--8.9 km), with un-enhanced reaches interspersed between the enhanced reaches. Enhancement of the entire mainstem should result in greater migration rates of coho salmon into wall-base channel ponds than were reported here.

The effectiveness of future enhancement activities in the mainstem Clearwater River could be increased with a better understanding of factors causing the initiation of fall migration of juvenile coho salmon to overwintering habitats. Peterson (1982b) observed peak migration of coho salmon into wall-base channel ponds during freshets, with the greatest immigration rates occurring during the first few fall freshets. Sampling in the mainstem following marking showed that some coho salmon were moving downstream prior to the first freshets (Peters et al. unpublished data), suggesting that fall migration is initiated prior to the first fall freshet. This could result in individuals migrating into free-running tributaries prior to the first freshet because wall-base channel ponds are generally inaccessible until the first major freshet. These fish could also continue migrating downstream where they use lower river wall-base channel ponds potentially affecting observed coho salmon migration rates into wall-base channel ponds. One would expect greater percentages of coho salmon to migrate into wall-base channel ponds during years with early fall freshets as compared to years with relatively dry falls. Therefore, modification of wall-base channel accessibility may have a greater effect on coho salmon immigration rates into wall-base channel ponds than introducing woody debris to the mainstem, especially during dry falls. However, the early initiation of coho salmon migration could also result in poorer survival of coho salmon in areas where woody debris accumulations are sparse because migrating salmon may not find adequate woody debris accumulations as they begin their migration. Thus, contribution rates reported here may have been higher if the entire mainstem had been enhanced.

The addition of woody debris may be an effective habitat enhancement method for increasing coho salmon summer rearing densities in the mainstem Clearwater River. However, this enhancement may have only limited effects on the fall migration rate of coho salmon into wall-base channel ponds. It is possible that larger, more stable debris, which is less likely to wash away, and affords fish more velocity refuge during high flows, or modification of wall-base channel pond outlets to make them more accessible during the fall could increase immigration into wall-base channel ponds. The synergy of these two techniques could improve coho salmon production in this river system. However, more information is needed regarding the initiation of coho salmon fall migration to wall-base channel ponds.

Table 4.7. Estimated numbers of coho salmon using introduced and natural woody debris stations during August 1990, 1992, and 1993 and their estimated contribution to wall-base channel immigration. Estimates are based on corrected estimates from the regression in appendix E.

	Estimated coho salmon abundance		Estimated coho salmon immigrants	
Year	Introduced	Natural	Introduced	Natural
1990[a]	2,232	1,709	23	104
1992	884	2,686	55	129
1993	2,569	3,860	40	195

[a] Recoveries from only 4 ponds

CHAPTER V

Macrohabitat Selection by Juvenile Coho Salmon in the Mainstem Clearwater River

INTRODUCTION

Restoration of salmonid habitat has received much attention in the past decade (Reeves et al. 1991). Sedell and Luchessa (1982) state that emphasis should be placed on restoring habitat complexity to mainstem channels of 4th- to 7th-order streams. These areas provide over 70 percent of productive stream length available to migrating fish and have, based on historical records, been significantly altered from their pristine state through removal of woody debris resulting in reduced habitat complexity. However, there are presently two factors limiting habitat restoration in large rivers. The first is the limited ability to introduce stable structures which can withstand the high flows within these channels (Frissel and Nawa 1992). The second is the limited knowledge of habitat use by salmonids in these large rivers. Prior to completing habitat enhancement for a particular fish, one must understand the habitat requirements of all its life stages (Moore and Gregory 1988; Nickelson et al. 1992b) and determine which life stages are limited by habitat availability (Nickelson et al. 1992b). Information regarding the summer habitat preferences of many salmonids, including juvenile coho salmon (*Oncorhynchus kisutch*), comes predominantly from experiences in small streams (e.g., Bisson et al. 1982, 1988; Bugert et al. 1991). In contrast, habitat preferences of summer rearing coho salmon in large rivers is represented by a single study (Lister and Genoe 1970).

Preferred habitats of juvenile coho salmon could differ between large and small streams. Microhabitat selection by rainbow trout (*O. mykiss*) has been related to channel size (Baltz and Moyle 1984). Changes in fish communities are often associated with varying stream size (Beecher et al. 1988) which may result in the presence of new, or the loss of old predators and competitors. Changes in fish communities can influence salmonid habitat use (Fausch and White 1981; Baltz et al. 1982; Schlosser 1987; Bugert and Bjornn 1991). Temperature differences associated with large streams may alter habitat use, either by changing preferred habitats (Baltz et al. 1987) or by altering the outcomes of competitive interactions (Baltz et al. 1982; Reeves et al. 1987). Thus, coho salmon in large river channels may select different habitats than those reported in the literature for small streams.

Woody debris is an important component of juvenile salmonid habitat in lotic systems (Bisson et al. 1987), providing protection from extreme current velocities (McMahon and Hartman 1989; Shirvell 1990; Fausch 1993) and predators (Everest and Chapman 1972; Grant and Noakes 1987). Coho salmon densities have been reduced following removal of woody debris (Bryant 1982; Dolloff 1982; Elliot 1986). However, coho salmon distribution and survival in a semi-artificial rearing channel was not consistently related to woody debris cover (Quinn et al. 1994; Spalding et al. 1995). This suggests that pools formed by woody debris may actually be more important than the cover provided by woody debris for summer rearing juvenile coho salmon. The combination of woody debris and deep pools may be ideal, as Lonzarich and Quinn (1995) observed greater coho salmon densities in pools with woody debris than in pools of equal depth lacking woody debris. Coho salmon densities were greatest in the deepest pools containing woody debris (Lonzarich and Quinn 1995).

Large mainstem rivers such as the Clearwater generally possess pools much deeper than those commonly found in smaller streams. It is unclear if the presence of woody debris in these large pools will influence the abundance of coho salmon or distribution within these large pools.. The greater abundance and diversity of the predator community likely to be observed in these larger rivers could increase the importance of woody debris cover compared to small streams. This is supported by the observation that juvenile coho salmon are less willing than other Pacific salmon to take risks during feeding (Abrahams and Healey 1993), which results in reduced attack distance to food following the presentation of model predators (Dill and Fraser 1984). The objectives of this study were to determine whether woody debris influences the distribution and abundance of coho salmon in the Clearwater River and the relative importance of other habitat variables singly and in combination in influencing habitat use by summer rearing juvenile coho salmon in this relatively large stream channel.

Study Area

The general study area was described in Chapter I. The present study was completed in the mainstem Clearwater River with the study reach extending downstream from Bull Creek (Rkm 30) to 0031 Creek (Rkm 10) (Phinney and Bucknell 1975) (Figure 1.1). The study reach was divided into seven sub reaches including: Bull Creek to Deception Creek, Deception Creek to Peterson Creek, Peterson Creek to Gross Bridge, Gross Bridge to Shale Creek, Shale Creek to Elkhorn Creek, and Elkhorn Creek to Hunt Creek (Figure 1.1).

MATERIALS AND METHODS

Habitat use by juvenile coho salmon was assessed by examining abundance at three types of woody debris sampling stations within the mainstem. The three debris types (stations) were areas with naturally occurring woody debris, areas containing introduced woody debris (See Chapter IV for procedures for introducing woody debris), and areas lacking woody debris (controls). Juvenile coho salmon abundances were estimated at several (n=4 to 100) of these three debris station types in early summer (June/July) and late summer (August/September). Two snorkelers entered the river upstream of the station to be surveyed and proceeded downstream, counting juvenile coho salmon as they moved past the station. Once well downstream of the station, the snorkelers moved upstream past the station again to make a second estimate. The snorkelers then discussed their individual estimates and came to a consensus, which became the estimate of coho salmon abundance at that station.

Juvenile coho salmon density (fish/m^2 debris surface area) and abundance at the three debris types (natural, introduced, control) were compared using a Kruskal-Wallis test and Dunn's multiple comparisons test (Zar 1984). The surface area of the debris stations was measured during late summer surveys in 1990 and 1992, and for both the early and late summer surveys in 1993 to compensate for differing surface areas of introduced and natural woody debris stations. The surface area of control stations was measured as the entire area snorkeled because no woody debris was present at these stations. Debris surface areas were not measured during early summer surveys of 1990 and 1992, which prevented the calculation of coho salmon densities during these surveys. Therefore, coho salmon abundance estimates rather than density were used for these comparisons. The distribution of coho salmon abundance estimates from early summer 1990 and 1992 was skewed towards samples with few fish (0-50) (skewed left) and thus was transformed using the square root transformation ($X' = (X+0.5)^{1/2}$) prior to statistical analysis.

The effects of several physical habitat variables on coho salmon abundance were evaluated at stations with woody debris (natural or introduced). Physical habitat variables (water depth, velocity, riverine habitat type, woody debris surface area, debris species, woody debris density, and substrate) were measured after the area had been snorkeled to estimate abundance. Water depth was measured to the nearest 3 cm at two locations, on the outer edge of the debris station and half-way from the outer edge of the station to the shore (Figure 5.1). Current velocity was measured to the nearest 3 cm/s with a Swoffer model 2100 current meter. Current velocities were measured at the two locations where water depth was measured and also just upstream and downstream of each debris station (Figure 5.1). All velocities were measured at approximately 60% of total depth. Woody debris length was measured on an axis from the upstream edge to the downstream edge of the woody debris accumulation. Woody debris width was calculated as the average distance the debris extended from the near-shore edge to the mid-stream edge of the debris accumulation. Woody debris length and width were used to calculate woody debris surface area. Riverine habitat was designated as pool, riffle, or glide, as defined by Bisson et al. (1982). Debris density was visually classified as dense, medium, or sparse and reflected the complexity of cover produced by the debris. Predominant debris plant species and underlying substrate were classified as described in Tables 5.1 and 5.2. Physical habitat variables were measured only after the late summer surveys during 1990 and 1992 and following both the early and late summer surveys in 1993.

Table 5.1. Classifications of debris species in accumulations used by coho salmon.

Species	Description
Alder	Debris accumulation composed of single or multiple alder trees, which had branches attached.
SWD	An accumulation of several small (< 10 cm diameter) logs and branches regardless of species.
LWD	An accumulation of several large logs (> 10 cm diameter and 2 m in length) regardless of species.
Rootwad	The rootwad of a tree which was for the most part intact and which made up a majority of the cover.
Spruce	One or more spruce trees.
Hemlock	One or more hemlock trees.
Spurce/Hemlock	Debris accumulation composed of both spruce and hemlock trees.

Table 5.2. Classification system used to designate the substrate below woody debris stations (Adapted and modified from Cummins 1962)

Substrate	Description/Particle Size Range (mm)
Silt	0.0039-0.0625
Sand	0.0625-2
Gravel	2-64
Cobble	64-256
Boulder	> 256
Bedrock	Exposed underlying rock not distinguishable as a boulder
Debris	Bottom covered with terrestrial debris such as leaf litter and/or small woody debris

The effects of the individual habitat variables and debris station type on estimated coho salmon abundance (transformed) were evaluated using two-way analysis of variance (ANOVA) or analysis of covariance (ANCOVA). The interaction between station type and the individual habitat variables also was examined. The effect of the environmental variable on coho salmon abundance was tested individually for each debris station type if a significant interaction existed. These individual tests were completed using a one-way ANOVA and Tukey multiple comparisons (categorical variables-habitat, density, etc.) or linear regression (continuous variables-depth, current velocity, etc.). General linear modelling was used to identify those variables which, in combination, were important in explaining variation in abundance estimates of juvenile coho salmon at introduced and natural debris stations. "Best" models were developed by beginning with the most significant single variable (based on individual variable analysis) and adding the next significant variable and the interaction between the two. Variables were kept in the model if they were significant at the 0.1 alpha level in the General Linear Model. Remaining variables were included in the model in the order of their probability of significance based on single variable analyses. Effects of habitat variables were evaluated for introduced and natural woody debris both individually and in combination.

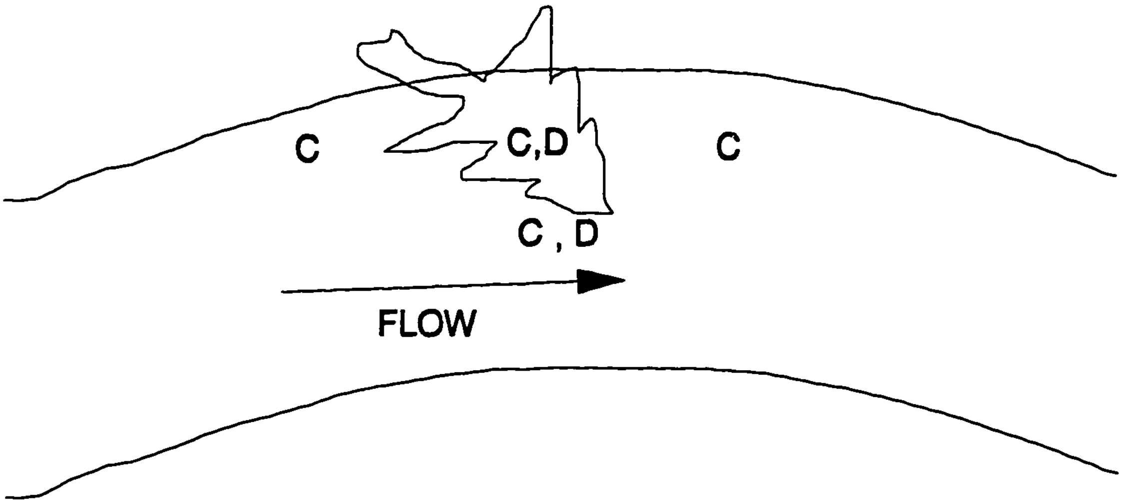

Figure 5.1. Locations where water depth (D) and current velocity (C) were measured.

RESULTS

Relative Abundance by Debris Type

Coho salmon occupied areas with woody debris more often than areas lacking woody debris (Table 5.3 and 5.4). When the data were analyzed using estimated coho salmon abundance (transformed), more coho salmon were observed at stations with natural or introduced woody debris than control stations (Table 5.3). Coho salmon abundance also was greater at introduced than natural debris stations during August 1991, June 1993, and August 1993. No difference in coho salmon abundance existed between introduced and natural debris stations during August and September 1990 or June 1991 and 1992.

Table 5.3. Mean coho salmon abundance estimates and Kruskal-Wallis and Dunn test results comparing estimated coho salmon abundance at introduced and natural debris and control stations during early and late summer 1990-1993.

		Station Type			Kruskal -Wallis	Dunn	
Year		Introduced	Natural	Control	*P*	Result	*P*
August 1990	Mean	43.65	45.79	0	0.0018	I=N	>0.5000
	SD	52.87	51.46	0		I>C	<0.0001
	n	48	38	4		N>C	<0.0001
Sept. 1990	Mean	35.33	36.47	0	0.0016	I=N	>0.5000
	SD	36.35	44.78	0		I>C	<0.0010
	n	46	34	4		N>C	<0.0010
June 1991	Mean	66.16	49.95	—	0.0224[a]	I>N	0.0224
	SD	65.66	69.63	—			
	n	38	127	0			
June 1992	Mean	33.0	34.80	0.59	0.0001	I=N	0.1085
	SD	51.49	67.68	2.06		I>C	<0.0001
	n	32	100	22		N>C	<0.0001
August 1992	Mean	19.47	18.81	0	0.0001	I>N	<0.0001
	SD	25.79	58.13	0		I>C	<0.0001
	n	32	100	19		N>C	<0.0001
July 1993	Mean	55.14	36.67	1.53	0.0001	I>N	0.0083
	SD	39.62	57.74	4.70		I>C	<0.0001
	n	29	99	19		N>C	<0.0001
August 1993	Mean	59.10	28.61	0	0.0001	I>N	<0.0001
	SD	49.62	64.86	0		I>C	<0.0001
	n	30	95	19		N>C	<0.0001

[a] Wilcoxon Sign Rank Test

The above analysis does not account for differences in the size of the debris accumulation. Debris surface area was measured during September 1990, August 1992, and June and August 1993, allowing the comparison of coho salmon densities (coho salmon/m^2 debris) at the three station types. Coho salmon densities at control stations were calculated using the surface area of the entire area snorkeled (areas were similar in size to introduced and natural debris stations). Coho salmon densities were greater at introduced and natural woody debris accumulations than at control areas during all years (Table 5.4). They were also greater at introduced than natural debris accumulations in all years except September 1990 (Table 5.4).

Table 5.4. Mean coho salmon densities (coho/m^2 debris) and Kruskal-Wallis and Dunn test results comparing mean densities at introduced and natural debris and control stations lacking woody debris during late summer 1990, 1992, and early and late summer 1993.

		Station Type			Kruskal-Wallis	Dunn	
Year		Introduced	Natural	Control	*P*	Result	*P*
Sept.	Mean	1.996	2.694	0	0.0033	I=N	>0.5000
1990	SD	2.331	3.769	0		I>C	0.0018
	n	46	34	4		N>C	<0.0001
August	Mean	0.691	0.314	0	0.0001	I>N	<0.0001
1992	SD	0.774	0.794	0		I>C	<0.0001
	n	32	100	20		N>C	<0.0001
July	Mean	3.521	1.706	0.085	0.0001	I>N	<0.0001
1993	SD	3.116	3.319	0.225		I>C	<0.0001
	n	29	99	19		N>C	<0.0001
August	Mean	4.092	0.728	0	0.0001	I>N	<0.0001
1993	SD	4.285	1.271	0		I>C	<0.0001
	n	30	95	19		N>C	<0.0001

Influence of Habitat Variables on Abundance

Coho salmon occupied the densest woody debris accumulations (Figure 5.2). More coho salmon were observed in dense than either medium or sparse debris accumulations during all years (Figure 5.2). More coho salmon were observed at medium debris than sparse debris accumulations during July and August 1993, but not during 1990 and 1992. A significant interaction (two-way ANOVA: $P=0.0167$) existed between debris density and station type during 1992, requiring the analysis of the effects of debris density on coho salmon abundance be completed separately for introduced and natural debris stations. More coho salmon were observed in dense natural debris accumulations than either medium or sparse during 1992. No difference in coho salmon abundance was observed between medium and sparse natural debris stations. No introduced stations were classified as sparse during 1992.

The riverine habitat (pool, glide, riffle) in which the woody debris was located influenced coho salmon abundance (Figure 5.3). More coho salmon were observed at introduced and natural debris accumulations located in pools than at glides or riffles in four of six comparisons. These differences were significant for introduced and natural debris accumulations during 1992 and natural debris accumulations during July and August 1993. In contrast, coho salmon abundance was greater at introduced debris accumulations located in glides than pools during July and August 1993, but was significant only during July 1993 (Figure 5.3). More coho salmon generally occupied debris accumulations located in glides than riffles; however, differences were statistically significant only during 1992 and August 1993 (natural debris accumulations). A significant interaction existed between station and habitat type during July (two-way ANOVA: $P=0.0010$) and August 1993 (two-way ANOVA: $P=0.0209$). Therefore, statistical testing for the effect of riverine habitat on coho salmon abundance was completed separately for each station type for data collected during July and August 1993.

The tree species which constituted a majority of the natural and introduced debris accumulations did not significantly influence coho salmon abundance (Figure 5.4). Station type did not significantly influence the analysis for the effect of tree species on coho salmon abundance (number of coho/debris accumulation) during any year (two-way ANOVA: $P=0.2283$-0.0.6578). No differences in coho salmon abundance were observed at introduced and natural debris accumulations composed of different tree/vegetation species during any year (two-way ANOVA: $P=0.0578$-0.6952).

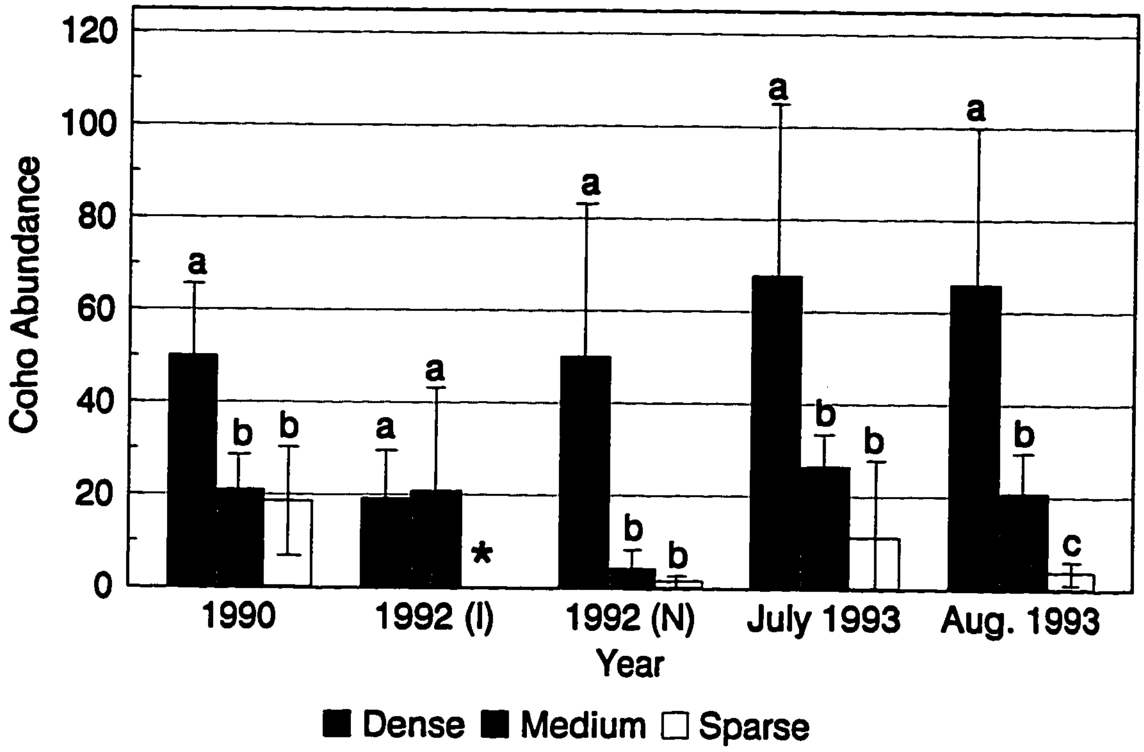

Figure 5.2. Mean (+/- 2 SE) coho salmon abundance (#/debris accumulation) at natural and introduced debris (combined) accumulations of different density during 1990, 1992, and August 1993 and natural (N) and introduced (I) (separate) debris accumulations during 1992. Data for 1992 were analyzed separately for debris of different densities because a significant interaction existed between the factors station type and density. For debris accumulations of different density, bars with different letters are significantly different (two-way ANOVA and Tukey test: $P<0.05$). (* = no stations classified as sparse).

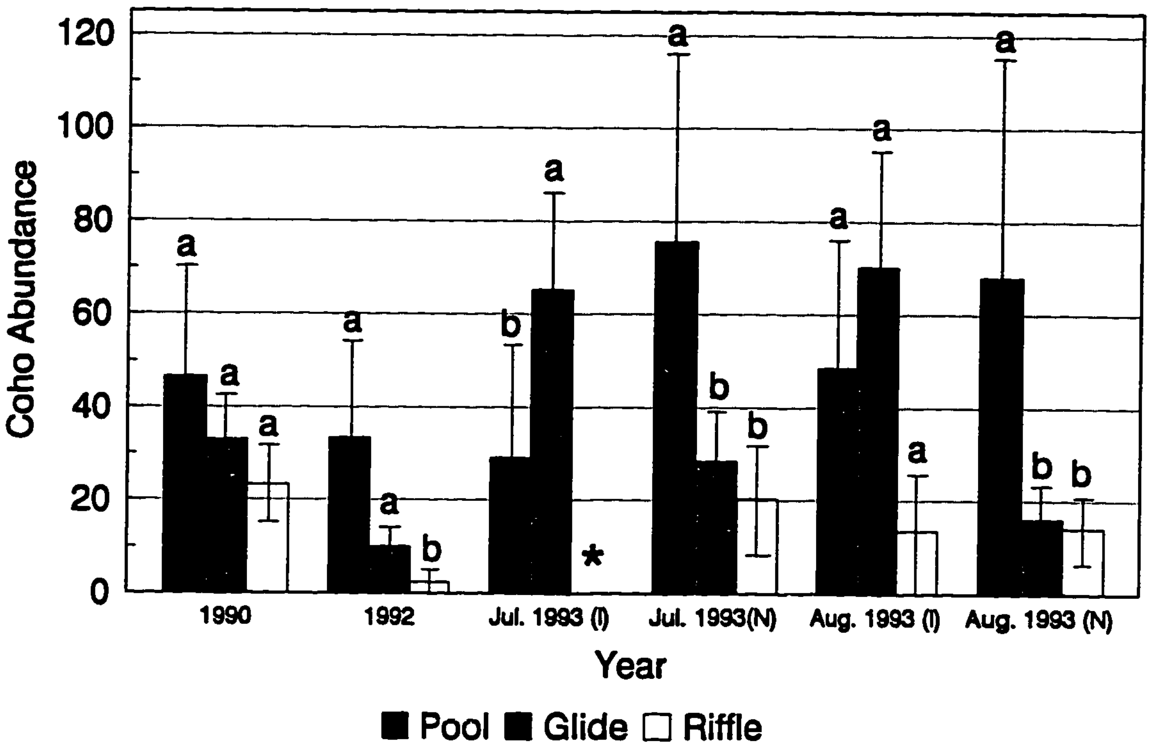

Figure 5.3. Mean (+/- 2 SE) coho salmon abundance (# coho/debris accumulation) at natural and introduced debris accumulations located in different riverine habitat, 1990, 1992-1993. Coho salmon abundance at debris accumulations located in different habitats were analyzed separately for introduced (I) and natural (N) debris accumulations during July and August 1993 because a significant interaction existed between the factors station type (I or N) and habitat. For debris accumulations in different habitats, bars with different letters are significantly different (two-way ANOVA and Tukey tests: $P<0.05$). (* = no stations located in riffles).

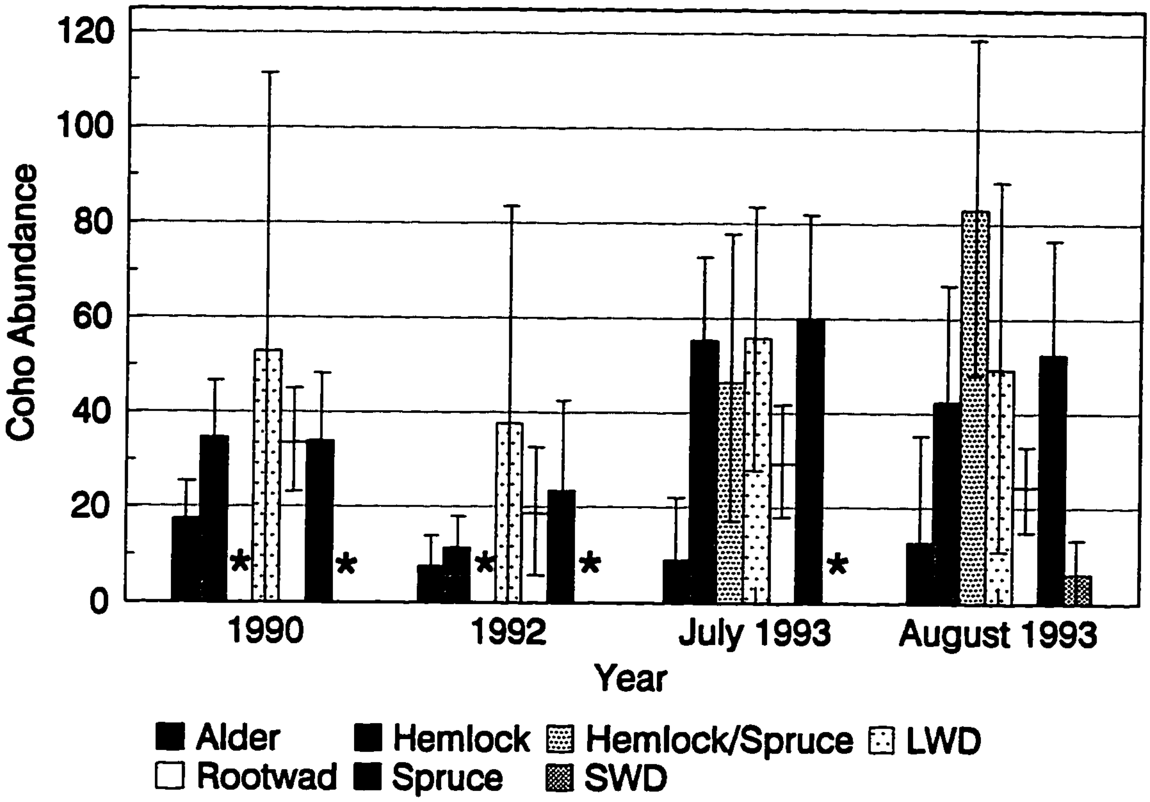

Figure 5.4. Mean (+/- 2 SE) coho salmon abundance (# coho/debris accumulation) at natural and introduced debris accumulations composed of different species of wood. (* = no debris stations classified as SWD or hemlock/spruce) (SWD = small woody debris, LWD = large woody debris).

The predominant substrate under the debris accumulation did not correlate with coho salmon abundance (Figure 5.5). Station type had a significant effect on the analysis for the effects of substrate on coho salmon abundance during July and August 1993 (two-way ANOVA: July 1993: $P=0.0152$; August 1993: $P=0.0001$) but not during 1990 or 1992 (two-way ANOVA: 1990: $P=0.8398$; 1992: $P=0.1159$). Thus, the analysis for the July and August 1993 data sets was completed separately for introduced and natural debris stations. Coho salmon abundance (number of coho/debris accumulation) was not influenced by the substrate under introduced and natural debris stations during 1990 and 1992 (two-way ANOVA: $P=0.1159$-0.5443). Substrate under introduced and natural debris stations also did not influence coho salmon abundance during July and August 1993 (ANOVA: Introduced: $P=0.5$-0.9470; Natural: $P=0.0833$-0.4799).

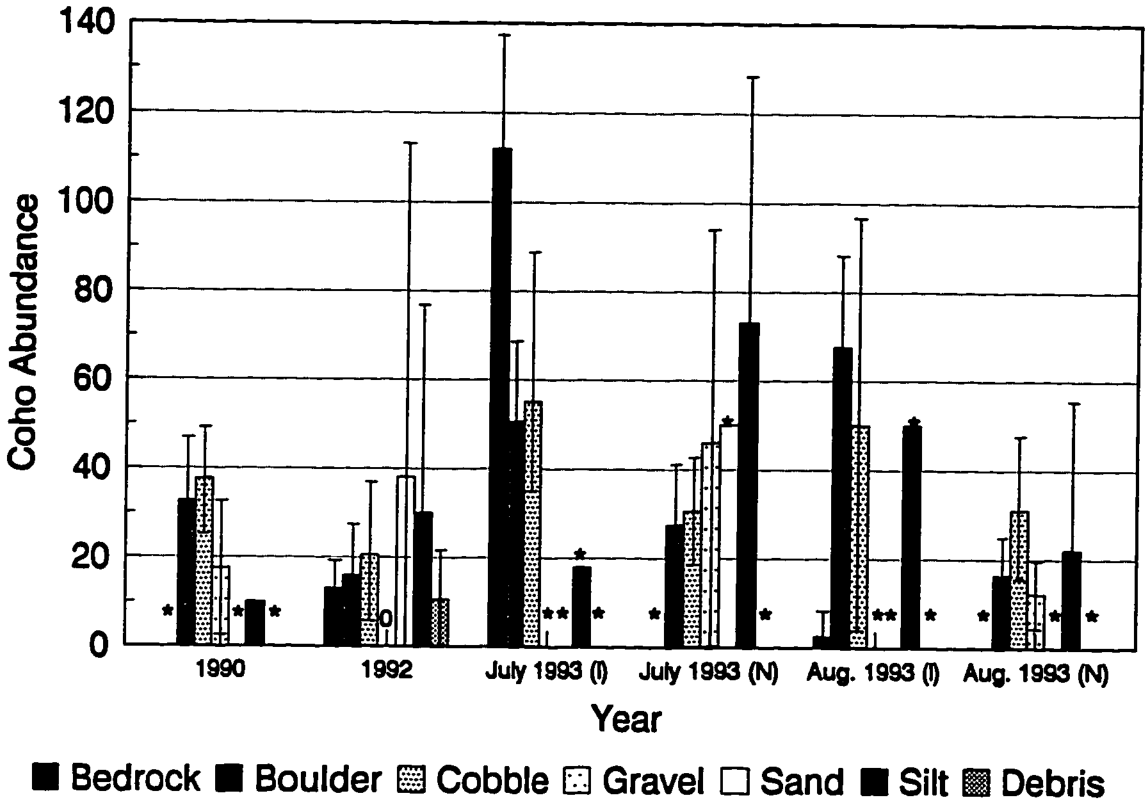

Figure 5.5. Mean (+/- 2 SE) coho salmon abundance (# coho/debris accumulation) in relation to the substrate below natural and introduced debris accumulations. (I)=introduced debris station, (N)=Natural debris station (* = n=0 or n=1, not included in statistical analysis).

The influence of the location of the debris station (i.e., whether or not it was located in a back eddy) was examined during 1993. Coho salmon abundances were not statistically greater (Sign Rank Test: July 1993: P=0.8008; August 1993: P=0.4335) greater at debris accumulations located in back eddies (July 1993: Mean=81.7, SD=142.3, n=7; August 1993: Mean=75.1, SD=160.2, n=9) then at those located elsewhere (July 1993: Mean=33.3, SD=45.7, n=92; August 1993: Mean=32.9, SD=45.3, n=116).

Coho salmon abundance was generally positively influenced by the size of woody debris accumulations (Figure 5.6). The effect of debris surface area on coho salmon abundance was different for introduced and natural debris accumulations for all surveys (ANCOVA: 1992: P=0.0036; July 1993 P=0.0001; August 1993: P=0.0001), except 1990 (ANCOVA: P=0.9594). These significant interactions require the analysis for the effect of debris surface areas on coho salmon abundance be completed separately for each station type. Coho salmon abundance increased significantly with increases in debris surface area in every case, except at introduced debris stations during July and August 1993 (Figure 5.6).

Depth on the outer edge of debris did not consistently influence coho salmon abundance (number of coho/debris accumulation) (Figure 5.7). Significant interactions between station types during July (ANCOVA: *P*=0.0170) and August 1993 (ANCOVA: *P*=0.0025) required that the analysis for the effects of depth on coho salmon abundance be completed separately for introduced and natural debris stations during these two surveys. Coho salmon abundance was positively influenced by increasing water depth at introduced and natural debris stations during 1992 and natural debris stations during July and August 1993. Although, coho salmon abundance was positively influenced by water depth on the outer edge of natural and introduced debris stations during 1990, the effect was not statistically significant (Figure 5.7). Coho salmon abundance was not significantly influenced by water depth on the outer edge of introduced debris accumulations during July and August 1993. Very little of the variability in coho salmon abundance was explained by depth on the outer edge of debris accumulations alone (Figure 5.7).

The depth halfway from shore to the outer edge of the debris station generally did not influence coho salmon abundance (number of coho/debris accumulation) (Figure 5.8). Station type significantly influenced the results of the analysis during July (ANCOVA: *P*=0.0127) and August 1993 (ANCOVA: *P*=0.0003), requiring the influence of depth halfway from shore to the outer edge of the debris on coho salmon abundance be analyzed separately for introduced and natural debris stations. Depth halfway from shore to the outer edge of the debris station did not influence coho salmon abundance (number coho/debris accumulation) at introduced and natural debris stations during 1990 or at natural or introduced debris stations tested independently during July and August 1993. However, coho salmon abundance was positively related to depth half way from shore to the outer edge of the debris station during 1992 (Figure 5.8).

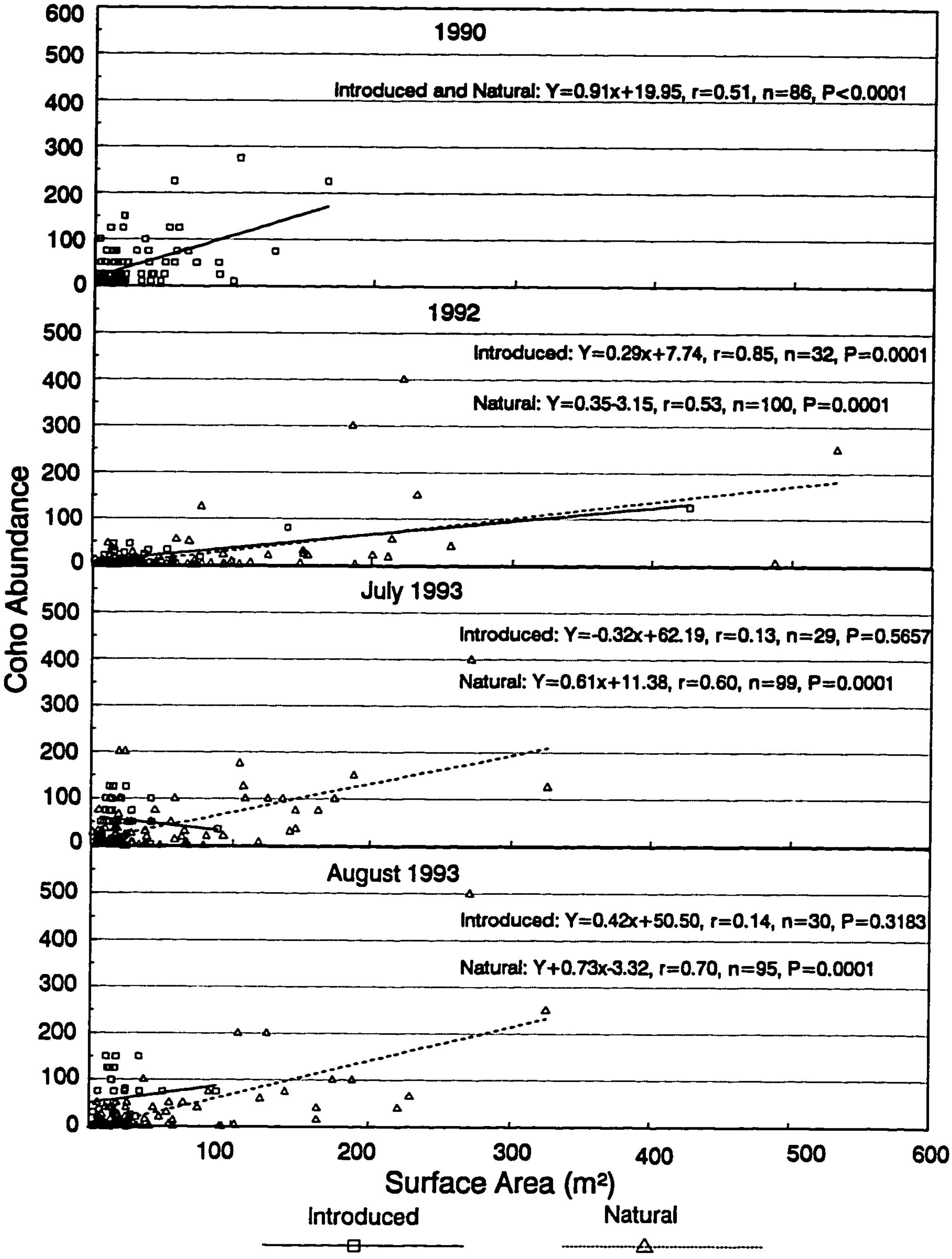

Figure 5.6. Relationship between coho salmon abundance (# coho/debris accumulation) and debris surface area of natural and introduced debris stations, 1990, 1992-1993.

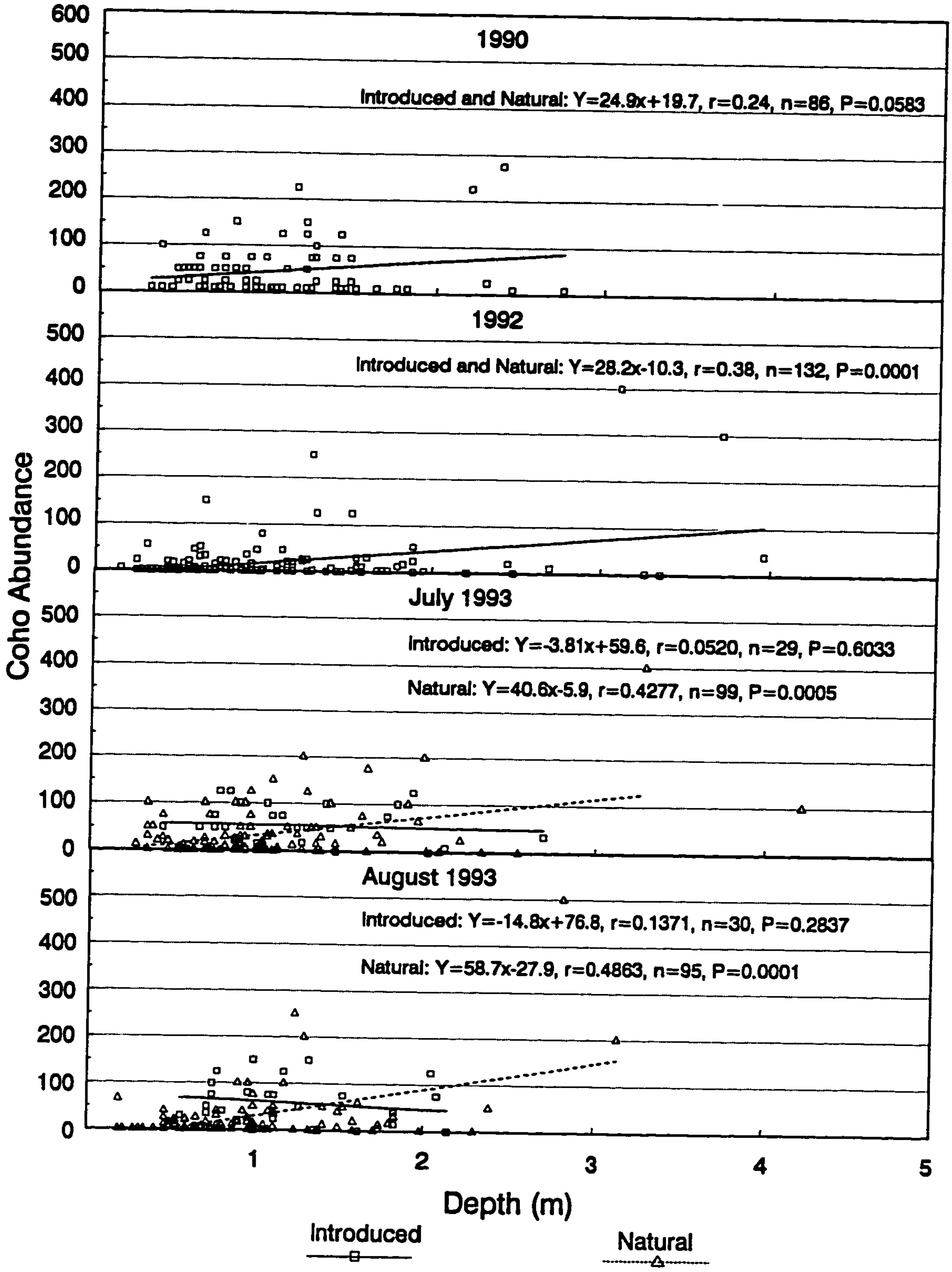

Figure 5.7. The relationship between coho salmon abundance (# coho/debris accumulation) and the depth on the outer edge of natural and introduced debris accumulations, 1990, 1992-1993.

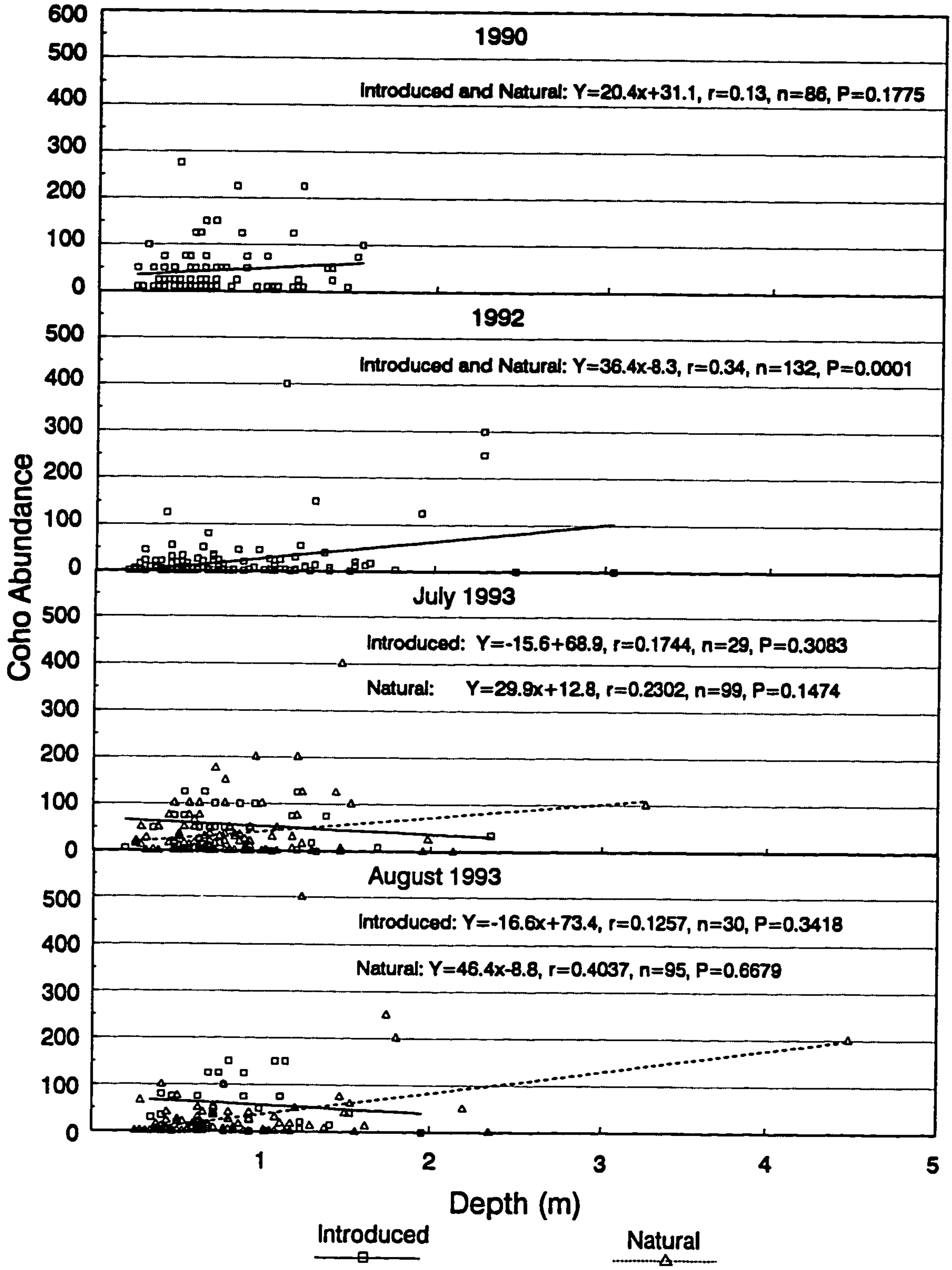

Figure 5.8. The relationship between coho salmon abundance (# coho/debris accumulation) and the depth half way from shore of natural and introduced debris accumulations, 1990, 1992-1993.

Current velocities measured upstream, downstream, on the outer edge, and in the center of debris stations were not correlated with coho salmon abundance (Table 5.5). Station type significantly (ANCOVA: $P=0.0004$-0.0383) influenced the analysis for the July and August 1993 data sets for all four locations where current velocities were measured. The influence of current velocities at all four locations on coho salmon abundance for these two data sets was analyzed separately for introduced and natural debris stations. Although the relationship was not significant, coho salmon abundance was generally negatively related to increasing current velocities, except at introduced debris accumulations during July 1993, when coho salmon abundance was positively related to current velocities upstream and downstream of the debris station (Table 5.5).

General Linear Models

Introduced and Natural Debris Combined

Coho salmon at introduced and natural debris accumulations were influenced most by the combination of debris surface area, debris density, and riverine habitat (Table 5.6). Debris surface area and debris density were significant variables in all general linear models for each survey. These two variables alone contributed to a majority of the variability explained by the strongest overall model (1990, 79%; 1992, 77%; July 1993, 91%; August 1993, 91%). An interactive term in which debris surface area was significantly related to riverine habitat type was also a significant variable in the strongest models in 1990, 1992 and August 1993. Increasing debris surface area in pools had a greater effect on coho salmon abundance (number of coho/debris accumulation) than increasing debris surface area in glides or riffles (Figure 5.9); however, this effect was significant only in 1992 (ANCOVA: 1990: $P=0.2281$; August 1993: $P=0.0691$; 1992: $P=0.0095$; Tukey: Pool>Glide: $P=0.0464$; Pool>Riffle: $P=0.0098$). Riverine habitat itself was not a significant term in these models but was included because the debris surface area-riverine habitat interactive term was statistically significant. During July 1993, either riverine habitat or current velocity on the outer edge of the debris accumulations could be combined with debris surface area and debris density to yield the strongest model (Table 5.6). During this survey, coho abundance was affected nearly equally in pool and glide habitat, with the fewest fish residing in debris accumulations located in riffles (Table 5.6). Increasing numbers of coho salmon were associated with decreasing current velocities on the outer edge of the debris accumulation (Table 5.6).

Table 5.5. Results of ANCOVA (combined) and linear regression (introduced and natural) analysis of the effects of current velocities on coho salmon abundance at introduced and natural debris accumulations during 1990, 1992, July 1993, and August 1993. Linear regression was used to analyze data for introduced and natural debris accumulations separately when station type significantly influenced the results. The analysis of introduced and natural debris was completed with combined (combined) data if no significant difference was observed between the two station types.

Date	Debris type	Regression equation	n	r	P
		Current Velocity on the Outer Edge			
1990	Combined	Y=-31.6x+51.6	78	0.10	0.5602
1992	Combined	Y=-13.1x+20.5	132	0.05	0.7959
July 1993	Introduced	Y=-52.6x+61.8	29	0.14	0.7724
July 1993	Natural	Y=-37.9x+46.0	99	0.20	0.0642
August 1993	Introduced	Y=-47.8x=63.2	30	0.08	0.8129
August 1993	Natural	Y=-26.3x+34.3	95	0.11	0.5890
		Current Velocity in the Center			
1990	Combined	Y=30.4x+44.1	80	0.07	0.8969
1992	Combined	Y=-149.3x+21.5	132	0.11	0.0974
July 1993	Introduced	Y=639.2x+59.2	29	0.24	0.3646
July 1993	Natural	Y=105.5x+42.3	99	0.16	0.0653
August 1993	Introduced	Y=-630.3x+61.6	30	0.17	0.6043
August 1993	Natural	Y=-28.5x+30.7	95	0.07	0.4314
		Current Velocity Upstream			
1990	Combined	Y=-3.1x+46.9	79	0.01	0.7842
1992	Combined	Y=-28.3x+21.1	132	0.08	0.3561
July 1993	Introduced	Y=11.8x+54.4	29	0.02	0.0711
July 1993	Natural	Y=-8.1x+36.2	98	0.10	0.6640
August 1993	Introduced	Y=-9.7x+59.6	30	0.02	0.6983
August 1993	Natural	Y=-6.0x+29.3	94	0.02	0.9791
		Current Velocity Downstream			
1990	Combined	Y=-10.8x+46.8	80	0.06	0.9446
1992	Combined	Y=-12.7x+20.1	132	0.04	0.6759
July 1993	Introduced	Y=281.3x+50.3	29	0.36	0.0905
July 1993	Natural	Y=-49.4x+41.6	99	0.14	0.1473
August 1993	Introduced	Y=-5.8x+59.8	29	0.004	0.9647
August 1993	Natural	Y=-27.9x+131.8	95	0.08	0.6679

Table 5.6. "Best" general linear models of coho salmon abundance (# coho/debris accumulation, transformed) with physical variables of natural and introduced debris accumulations combined. Sums of Squares (SS), significance level, correlation coefficients, and fitted models for different class variables are also listed.

Date	Type III SS Significance					P	R
1990		Area 0.0012	Density 0.0200	Habitat 0.4237	Area*Habitat 0.0436	0.0001	0.4300
Trans =	3.98	+ 0.003 Area	+ 1.05 Dense - 0.44 Medium - 0.62 Sparse	+ 0.69 Glide - 0.17 Pool - 0.52 Riffle	- 0.0020 Area*Glide + 0.0026 Area*Pool - 0.0007 Area*Riffle		
1992		Area 0.0021	Density 0.0001	Habitat 0.4566	Area*Habitat 0.0001	0.0001	0.7625
Trans =	1.71	+ 0.012 Area	+ 1.51 Dense - 0.48 Medium - 1.02 Sparse	+ 0.38 Glide - 0.21 Pool - 0.16 Riffle	- 0.009 Area*Glide + 0.017 Area*Pool - 0.009 Area*Riffle		
July 1993		Area 0.0001	Density 0.0001	Habitat 0.0140		0.0001	0.6786
Trans =	3.36	+ 0.028 Area	+ 2.26 Dense + 0.09 Medium - 2.36 Sparse	+ 0.70 Glide + 0.53 Pool - 1.22 Riffle			
		Area 0.0001	Density 0.0001	Outer Current 0.0019		0.0001	0.6753
Trans =	4.24	+ 0.029 Area	+ 2.23 Dense + 0.15 Medium - 2.38 Sparse	- 3.02 Outer Current			
August 1993		Area 0.0001	Density 0.0001	Habitat 0.3280	Area*Habitat 0.0196	0.0001	0.7682
Trans =	2.78	+ 0.029 Area	+ 2.48 Dense - 0.48 Medium - 2.01 Sparse	+ 0.53 Glide + 0.11 Pool - 0.64 Riffle	- 0.0091 Area*Glide + 0.016 Area*Pool - 0.007 Area*Riffle		

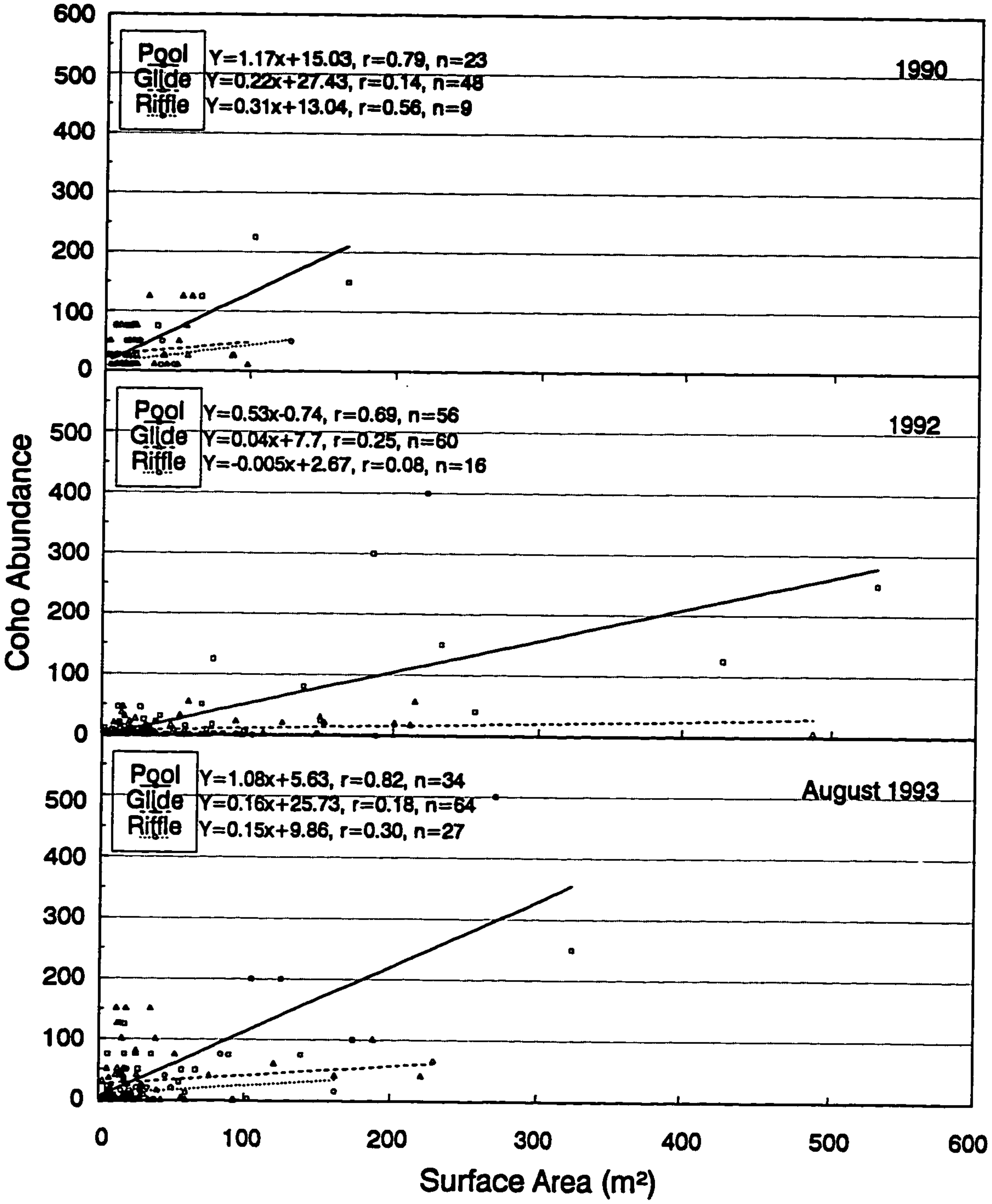

Figure 5.9. **Relation between debris surface area, riverine habitat and coho salmon abundance (# coho/debris accumulation) for the combined introduced and natural debris analysis 1990, 1992-1993.**

Natural Debris

The strongest models developed for natural debris accumulations contained the same variables as those for natural and introduced debris accumulations combined except for August 1993 (Table 5.7). Again, debris surface area and debris density were significant variables in all models and explained much of the overall variability explained by the strongest full model (1990: 49%; 1992: 86%; July 1993: 89%; August 1993: 84%). In contrast to the combined introduced and natural debris analysis, riverine habitat was a significant variable for the natural debris only analysis for 1990. As with the combined debris analysis, debris surface area was significantly related to riverine habitat type for 1990, 1992, and August 1993 (not in the best model for August 1993). In partial contrast to the combined debris analysis of 1990, increasing debris surface area had a positive effect on coho salmon abundance in pools and riffles for the natural debris analysis, but increasing debris surface area in glides did not affect coho salmon abundance (Figure 5.10). The effect of increasing debris surface on coho salmon abundance was significantly greater in pools than in glides and riffles during 1992 (ANCOVA: $P=0.0079$; Tukey: Pool>Glide: $P=0.0137$; Pool>Riffle: $P=0.0095$) and August 1993 (ANCOVA: $P=0.0086$; Tukey: Pool>Glide and Riffle: $P<0.0001$), but not in 1990 (ANCOVA: $P=0.5254$).

Two models, which explained nearly the same amount of variability in coho salmon abundance were developed for natural debris stations using August 1993 data (Table 5.7). These models differed from the strongest model for introduced and natural debris combined (Table 5.6). The model explaining the most variability in coho salmo abundance at natural debris accumulations during August 1993 contained the variables debris surface area, debris density, outer depth, and an interaction term between outer depth and debris surface area. Coho salmon abundance increased with increasing debris surface area and outer depth (Figure 5.11). Outer depth was not itself significant in this model but was included because the interactive term was significant. The second model developed for natural debris accumulations during August 1993 included the variables debris surface area, debris density, outer depth, and an interactive term between debris surface area and debris density. This model explained nearly as much variability as the first; however, all the terms in the second model were significant (Table 3.7). Increasing the surface area of dense debris accumulations had a significantly (ANCOVA: $P=0.0001$; Tukey Dense>Medium and Sparse: $P<0.0001$; Medium>Sparse: $P=0.0039$) greater impact on coho salmon abundance than increasing the debris surface area of medium or sparsely dense accumulations (Figure 5.12). More variation was explained by the natural debris model containing surface area, density, habitat and the interaction term between habitat and surface area for August 1993 (Table 5.7) than was explained by the same model in the combined analysis (Table 5.6).

Table 5.7. "Best" general linear models of coho salmon abundance (transformed) with physical variables of natural debris accumulations. Sums of Squares (SS), significance level, correlation coefficients, and fitted models for different class variable are also listed.

Date	Type III SS Significance						*P*	R
1990			Area 0.0201	Density 0.0470	Habitat 0.0023	Area*Habitat 0.0009	0.0001	0.7808
	Trans =	1.61	+ 0.014 Area	+ 1.05 Dense + 0.79 Medium - 1.85 Sparse	+ 3.43 Glide - 0.78 Pool - 2.64 Riffle	- 0.013 Area*Glide - 0.003 Area*Pool +0.016 Area*Riffle		
1992			Area 0.0018	Density 0.0001	Habitat 0.7380	Area*Habitat 0.0001	0.0001	0.7874
	Trans =	1.70	+ 0.013 Area	+ 1.73 Dense - 0.73 Medium - 0.99 Sparse	+ 0.26 Glide - 0.21 Pool - 0.06 Riffle	- 0.010 Area*Glide + 0.018 Area*Pool - 0.009 Area*Riffle		
July 1993			Area 0.0001	Density 0.0001	Habitat 0.0083		0.0001	0.7201
	Trans =	3.37	+ 0.029 Area	+ 1.84 Dense + 0.33 Medium - 2.17 Sparse	+ 1.22 Pool + 0.09 Glide -1.32 Riffle			
			Area 0.0001	Density 0.0001	Outer Current 0.0022		0.0001	0.7194
	Trans =	3.95	+ 0.032 Area	+ 1.85 Dense + 0.33 Medium + 2.18 Sparse	- 2.98 Outer Current			

Table 5.7. cont.

Date	Type III SS Significance					*P*	R
August 1993		Area 0.0161	Density 0.0001	Outer Depth 0.2181	Area*Outer Depth 0.0003	0.0001	0.8638
Trans =	1.64	+ 0.015 Area	+ 1.45 Dense - 1.42 Medium - 0.23 Sparse	- 0.67 Outer Depth	+ 0.017 Area*Outer Depth		
		Area 0.001	Density 0.0117	Outer Depth 0.0001	Area*Density 0.0082	0.0001	0.8585
Trans =	0.68	+ 0.024 Area	+ 1.15 Dense - 0.44 Medium - 0.72 Sparse	+ 1.92 Outer Depth	+ 0.018 Area*Dense + 0.006 Area*Medium - 0.024 Area*Sparse		
		Area 0.0001	Density 0.0001	Habitat 0.7677	Area*Habitat 0.0037	0.0001	0.8398
Trans=	2.41	+ 0.031 Area	+ 1.45 Dense + 0.05 Medium - 1.50 Sparse	- 0.25 Glide + 0.24 Pool + 0.02 Riffle	- 0.006 Area*Glide + 0.019 Area*Pool - 0.013 Area*Riffle		

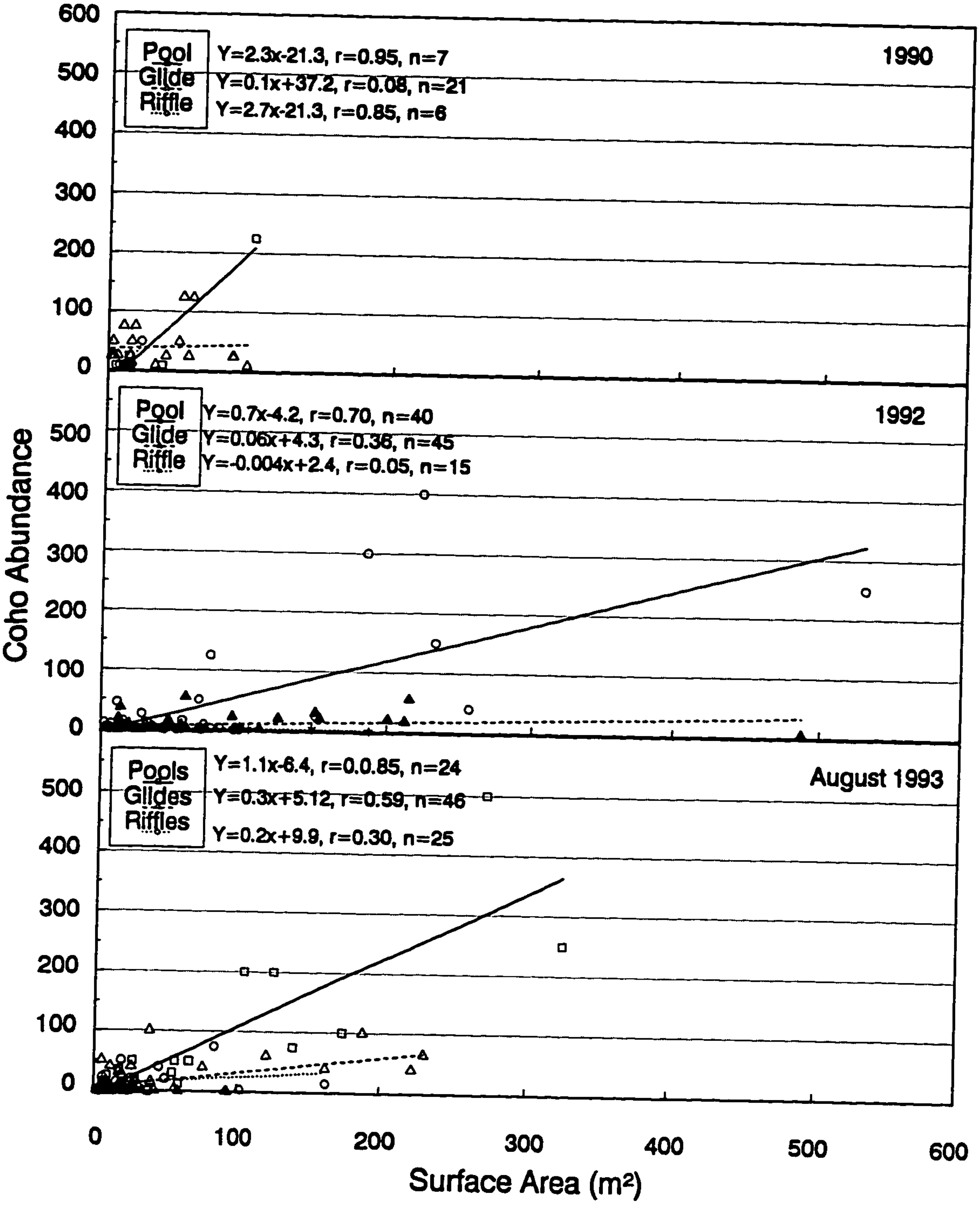

Figure 5.10. Relationship between debris surface area, riverine habitat and coho salmon abundance (# coho/debris accumulation) for natural debris accumulations 1990, 1992, and August 1993.

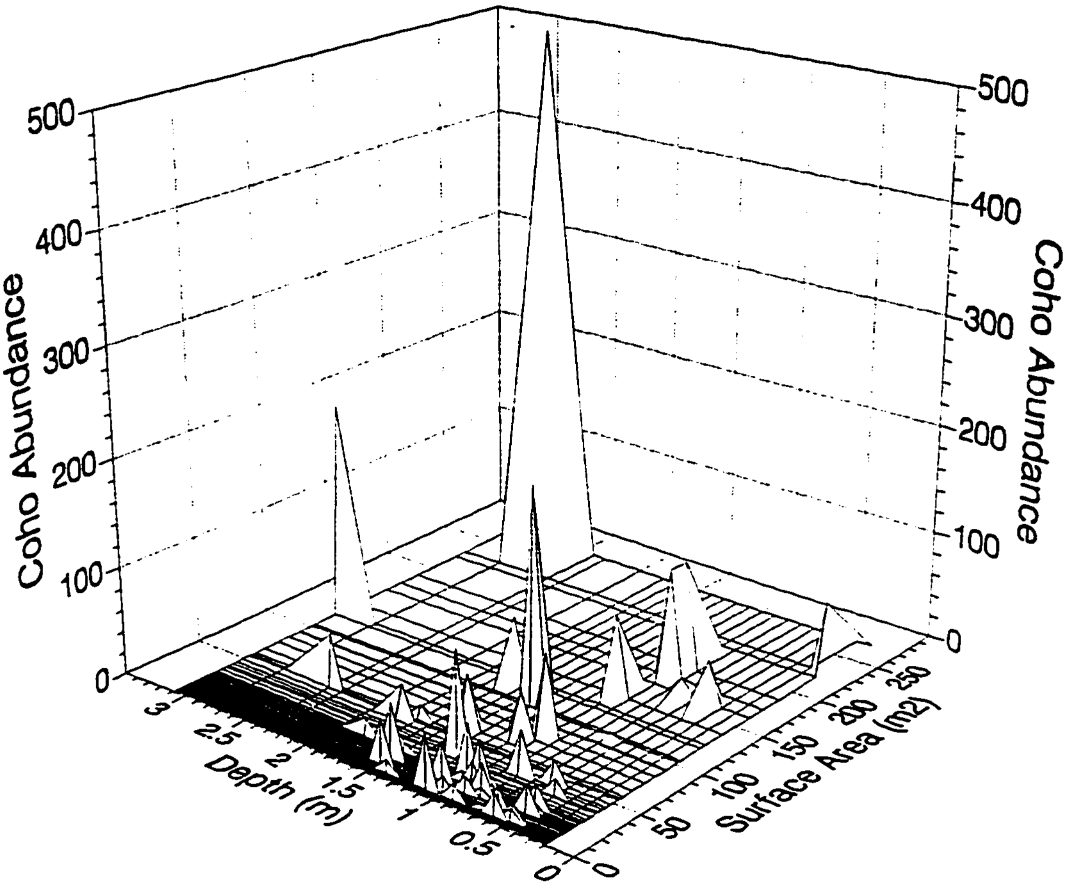

Figure 5.11. Relationship of the depth on the outer edge of the debris and debris surface area on coho salmon abundance (# coho/debris accumulation), August 1993.

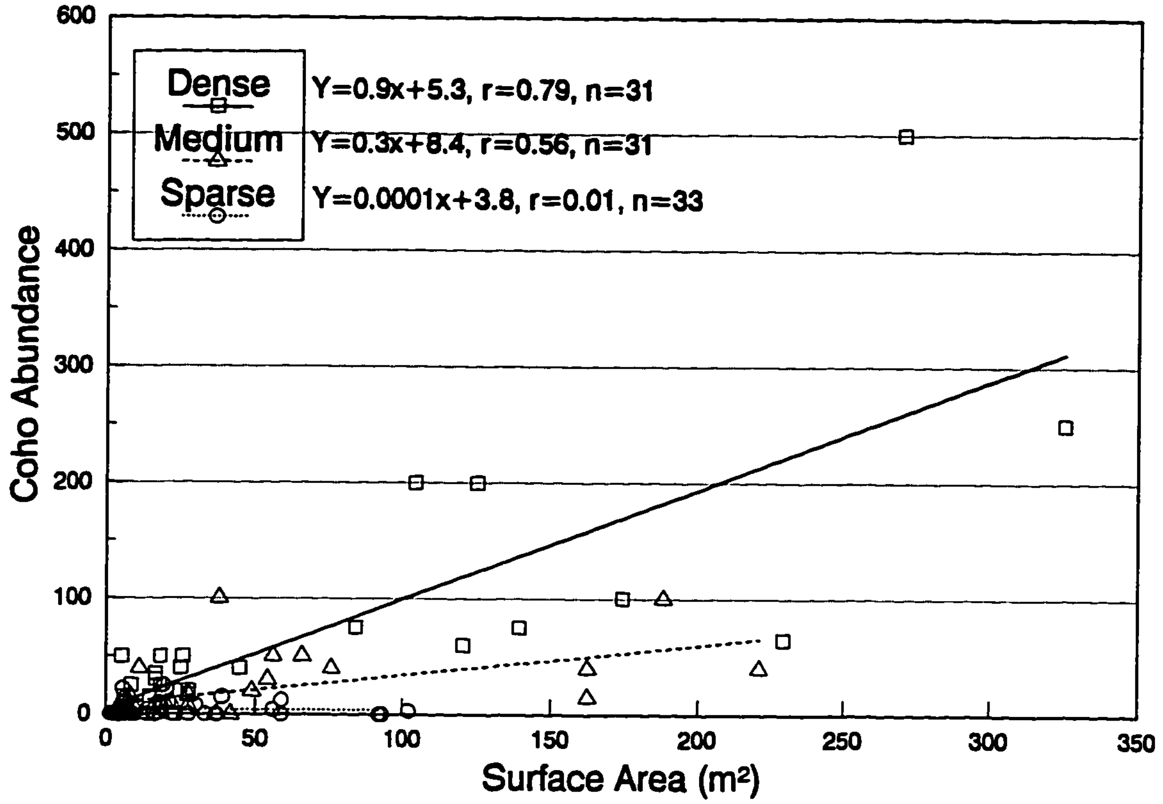

Figure 5.12. Relationship between coho salmon abundance (# coho/debris accumulation) and debris surface area at natural debris accumulations of different density, August 1993.

Introduced Debris

The strongest models developed for coho salmon abundance at introduced debris accumulations were somewhat different than those developed for natural debris accumulations (Table 5.8). Debris surface area and debris density were included in all models; however, debris density was not a significant variable in the model developed using the 1992 data. It was included in the model because of the significant interaction between debris surface area and debris density. Again, these two variables contributed to a majority of the variability explained by the strongest full model (1990--100%, 1992 area only 55%, and August 1993--52%). During 1990, debris density and debris surface area explained 36% of the variability in coho abundance (number coho/debris accumulation). Estimates from the equation show that dense accumulations attracted more coho salmon than either medium or sparse accumulations. Debris density and debris surface area were the only variables present in the strongest model. For 1992, debris density, although not significant, was included because of the significant interactive term between debris surface area and debris density. Increasing debris surface area may have had a greater effect on coho salmon abundance at debris accumulations of medium density than those with dense classifications (Figure 5.13), although, this difference was not statistically significant (ANCOVA: $P=0.9555$). No significant model could be developed for July 1993.

The strongest model for introduced debris developed using the August 1993 data included debris surface area, debris density, tree species, depth in the center of the debris, and the current velocity downstream of the debris (Table 5.8). Debris surface area and the current velocity downstream of the debris positively influenced coho abundance (number of coho/debris accumulation). Dense and sparse debris had a positive effect on coho salmon abundance, while medium accumulations had a negative effect. More coho salmon were associated with debris accumulations composed of a combination of hemlock and spruce trees, followed by those composed only of spruce and finally hemlock. Coho abundance was inversely associated with the depth in the center of the debris accumulation.

Table 5.8. "Best" general linear models of coho salmon abundance (transformed) with physical variables of introduced debris accumulations. Sums of Squares (SS), significance level, correlation coefficients, and fitted models for the different class variables are also listed.

Date	Type III SS Significance					*P*	R
1990		Area 0.0046	Density 0.0269			0.0001	0.6013
Trans =	4.34	+ 0.003 Area	+ 1.24 Dense - 0.96 Medium - 0.28 Sparse				
1992		Area 0.0001	Density 0.1405	Area*Density 0.0321		0.0001	0.7355
Trans =	2.24	+ 0.038 Area	+ 1.56 Dense - 1.56 Medium	- 0.037 Area*Dense +0.037 Area*Medium			
July 1993						No Significant Models	
August 1993	Area 0.0161	Density 0.0002	Species 0.0050	Mid Depth 0.0231	Back Current 0.0170	0.0011	0.8044
Trans =	5.11 + 0.091 Area	+ 3.99 Dense - 4.11 medium + 0.13 Sparse	+ 2.67 Hemlock/Spruce - 0.52 Spruce - 2.14 Hemlock	- 3.42 Mid Depth	+ 46.98 Back Current		
	Area 0.0129	Density 0.0004	Species 0.0127	Outer Depth 0.0572	Back Current 0.0404	0.0001	0.7871
Trans =	5.46 + 0.104 Area	+ 3.49 Dense - 4.56 Medium + 1.07 Sparse	+ 2.45 Hemlock/Spruce - 0.51 Spruce - 1.93 Hemlock	- 2.55 Outer Depth	+ 40.4 Back Current		

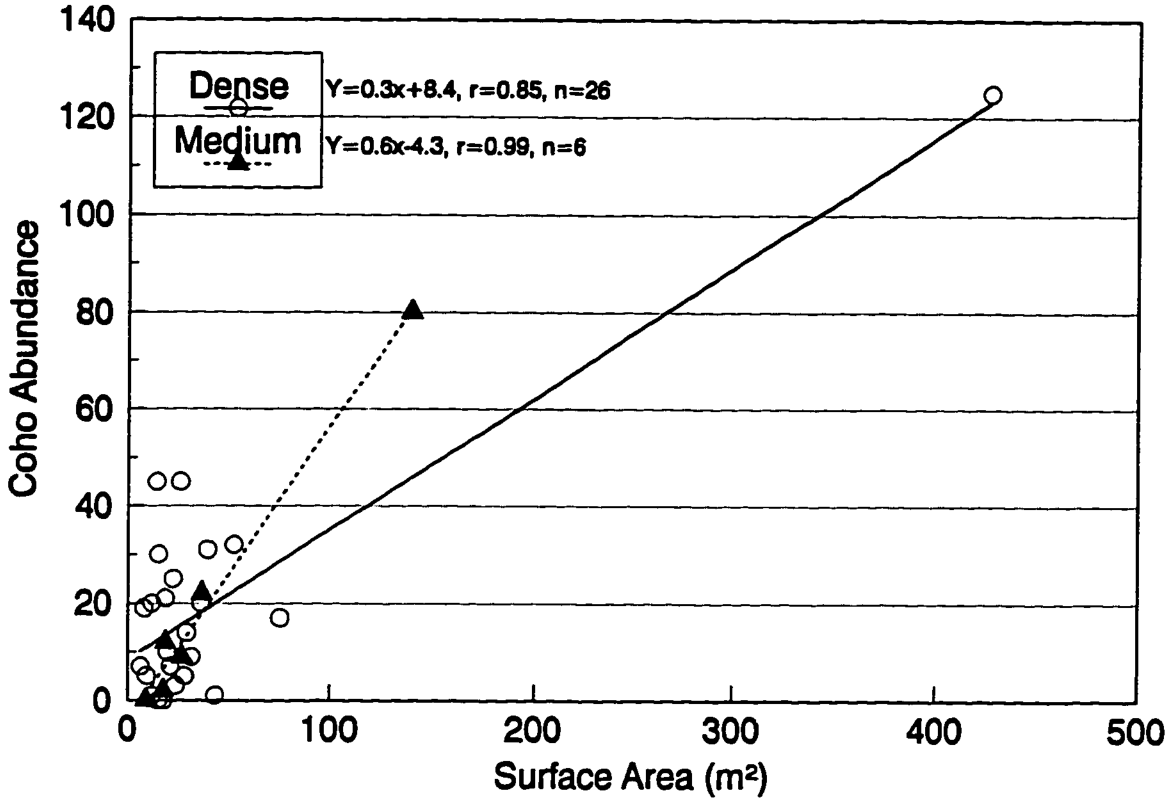

Figure 5.13. Relationship of coho salmon abundance (# coho/debris accumulation) with debris surface area at introduced debris accumulations of different density, 1992.

DISCUSSION

The presence of woody debris was the most important factor influencing the distribution of summer rearing juvenile coho salmon in the mainstem Clearwater River. More juvenile coho salmon were present at the largest, most dense debris accumulations. Increasing debris surface area in pools generally had a greater positive impact on coho salmon abundance than increasing debris surface area in glides and riffles.

Juvenile coho salmon in the mainstem Clearwater River were more abundant in areas containing woody debris. Woody debris is an important salmonid habitat component of streams, responsible for functions such as pool formation (Bisson et al. 1987), provision of cover from predators (Everest and Chapman 1972; Bisson et al. 1987; Grant and Noakes 1987), and protection from extreme current velocities (McMahon and Hartman 1989; Shirvell 1990; Fausch 1993). I hypothesize that woody debris in the mainstem Clearwater River primarily provides cover from predators, although, cover from high current velocities may be important during fall migration to wall-base channels. Coho salmon generally selected focal positions upstream of woody debris cover and were observed fleeing from otters (*Lutra canadensis*), cutthroat trout (*O. clarki clarki*), and common mergansers (*Mergus merganser*) during microhabitat observations (Chapter VI). Many debris accumulations were located in areas with current velocities well below those favored by coho salmon (10 cm/s: Murphy et al. 1989; 20 cm/s: Dolloff and Reeves 1990) and no relationship between coho salmon abundance and velocity was observed. Nevertheless, other studies have shown that protection from current velocities appears to be an important function of woody debris in riffles (Chapter VI). Although woody debris results in the formation of some pools in the mainstem Clearwater River, bedrock outcroppings and large boulders are the primary pool forming structures of this system. When present, woody debris is generally a secondary feature of these pools, having been deposited in slack water areas where it serves as cover habitat for juvenile coho salmon.

The mainstem Clearwater River has many potential predators of juvenile coho salmon, including the common merganser, great blue heron (*Ardea herodias*), belted kingfisher (*Ceryle alcyon*), river otter, and cutthroat trout. Wood (1987) showed that broods of common mergansers may consume large numbers of coho salmon fry during the summer. Merganser broods were seen along the study reach during most surveys. River otters also may consume large numbers of juvenile coho salmon (Dolloff 1993) and were observed in the study area. Dense cover associated with woody debris could prevent these predators from observing, pursuing, and capturing juvenile coho salmon, which might explain the greater abundance of coho salmon near dense debris accumulations. The distance at which young-of-the-year brook trout react to (flee from) an approaching predator is shorter in areas of high cover than low cover, which may increase foraging opportunities in these areas (Grant and Noakes

1987). Tabor and Wurtsbaugh (1991) showed that juvenile rainbow trout in reservoirs apparently selected inshore cover from predators even though more abundant food resources were located offshore. Juvenile coho salmon are relatively unwilling to expose themselves to predators when compared to other Pacific salmon (Abrahams and Healey 1993). The distance at which coho salmon will move to obtain food items is reduced in the presence of predators (Dill and Fraser 1984). Thus, the use of areas containing woody debris by juvenile coho salmon in the mainstem Clearwater River may be a result of balancing foraging opportunities while reducing risk of predation mortality.

The influence of woody debris on coho salmon distribution has received much attention recently and contradictory results have been presented. The distribution and density of coho salmon in a semi-natural stream channel were not directly associated with woody debris cover during summer months (Quinn et al. 1994; Spalding et al. 1995). However, coho salmon abundance was related to woody debris cover in another study completed in the same semi-natural stream channel, although water depth was an equally important factor influencing distribution (Lonzarich and Quinn 1995). The fewest coho salmon were observed in shallow areas lacking woody debris (Lonzarich and Quinn 1995). Experimental trials completed by Quinn et al. (1994) and Spalding et al. (1995) lacked aquatic predators which may influence salmonid distribution (e.g., Schlosser 1987; Bugert and Bjornn 1991). In contrast, potential predatory fish were included in the study completed by Lonzarich and Quinn (1995), which may have resulted in the observed differences in woody debris use by juvenile coho salmon in these experiments.

Juvenile coho salmon in the Big Qualicum River, Vancouver Island, B.C., were associated with bank cover early in the summer but shifted to midstream locations as they grew (Lister and Genoe 1970). In contrast, distance to cover decreased as coho salmon size increased in small streams of Prince of Wales Island, Alaska (Dolloff and Reeves 1990). In the present study, woody debris also appeared to be more important later in the summer when the fish were larger. Fausch (1993) determined that coho salmon rarely used artificial cover (plexiglass structures) in the Salmon River, B.C, and then only as refuge from current velocities rather than for overhead cover. However, the experimental units were located in runs with mean depths of 28-49 cm and the overhead cover was located only 10 cm above the substrate. This may have been too close to the substrate for coho salmon since they prefer mid-water focal positions (Dolloff and Reeves 1990, Bugert and Bjornn 1991, Bugert et al. 1991), which would have been approximately 14-24 cm above the bottom. A more likely cause of the discrepancy between Fausch (1993) and the present study is the scale at which habitat use was examined. Fausch (1993) discusses microhabitat selection while we measured macrohabitat use. Microhabitat refers to habitat variables measured at the focal position of individual fish, whereas macrohabitat describes larger scale distributions of fish (i.e., abundance in pool, riffle, glide). Focal positions (microhabitat use) of coho salmon in the mainstem Clearwater River were generally not directly associated with woody debris cover and were up to 10 m from woody debris cover (Chapter VI). However, coho salmon often fled to woody debris cover when threatened by predators (Chapter VI). It is possible that, when threatened, coho salmon in Fausch's (1993) experiment would have sought the cover provided. This point shows the importance of comparing habitat selection information using similar index scales as well as the benefits to be gained by using both micro and macro scales in habitat selection studies (Bozek and Rahel 1991).

Coho salmon abundance in small streams is highest in pools in small streams (Hartman 1965; Bisson et al. 1982, 1988; Nickelson et al. 1992a). Coho salmon abundance in the mainstem Clearwater River also was greatest at woody debris accumulations located in pools and was generally positively related to depth on the outer edge of the debris. Although pools were the preferred habitat, glides were often used by large numbers of juvenile coho salmon. Juvenile coho salmon prefer areas with slow current velocities in small streams (Bustard and Narver 1975; Murphy et al. 1989; Chapter VI). Murphy et al. (1989) (<10 cm/s) and Dolloff and Reeves (1990) (<20 cm/s) observed the highest densities of coho salmon in still or slow water. Bustard and Narver (1975) found that coho salmon preferred areas with current velocities below 15 cm/s during the winter. Coho salmon in the mainstem Clearwater River selected focal positions with current velocities less than 10 cm/s (Chapter VI). Although the relationship was not significant, coho salmon abundance was generally inversely related to increasing current velocities ranging from 0-116 cm/s at all locations where flow was measured in the present study. The lack of a significant relationship between current velocities and coho salmon abundance in the present study was likely caused by the large variability of coho salmon abundance estimates and the significance of other environmental variables (i.e. debris density and surface area). Based on this information, current velocities may not be an important variable to measure when determining macrohabitat use of salmonids. In contrast, this appears to be an important variable to measure when determining microhabitat use.

The species of woody debris affected coho salmon abundance during the final year of the study. This was likely due to the inherent differences in density of different types of debris. Debris accumulations composed of LWD, or introduced spruce or hemlock trees, were often denser than alder trees and SWD. No debris accumulations composed of SWD were classified as dense and the ratio of the three density classifications differed from an expected ratio (1/3:1/3:1/3) of dense:medium:sparse debris classifications (X^2: P=0.0144). Debris accumulations composed of spruce, hemlock and spruce/hemlock combinations did not conform to the expected ratio (X^2 spruce: P=0.0318; hemlock: P<0.0001; hemlock/spruce: P=0.0498), but these species had more dense accuiulations than expected. Debris accumulations composed of LWD, rootwads, and alder did not differ from the expected ratios.

Results from this study suggest that further enhancement in the mainstem Clearwater River should focus on placement of large, dense woody debris bundles in pools. Structures placed in pools also will have a greater probability of surviving high winter flows, a potential problem for enhancing the Clearwater River with woody debris structures. However, several large natural debris accumulations were present in pools during the entire study period, indicating that stable woody debris could be introduced into pools.

CHAPTER VI

Microhabitat Selection and Behavior of Summer Rearing Juvenile Coho Salmon in the Mainstem Clearwater River

INTRODUCTION

A number of studies have described the behavior and microhabitat distribution of juvenile coho salmon (*Oncorhynchus kisutch*) in small streams (for example, Chapman 1966; Chapman and Bjornn 1969; Nielsen 1992). In contrast, little is known about the microhabitat distribution and behavior of juvenile coho salmon in larger streams (4th order and larger). Significant differences in microhabitat distribution and behavior may occur as stream size increases.

Several factors associated with increasing stream size may influence habitat use by juvenile salmonids, including the increase in channel size (Baltz and Moyle 1984). The factors associated with increased channel size that could influence microhabitat use by salmonids include: differences in fish community structure (Beecher et al. 1988), predators and competitors (Fausch and White 1981; Baltz et al. 1982; Bugert and Bjornn 1991; Schlosser 1987; Tabor and Wurtsbaugh 1991), temperatures (Baltz et al. 1982; Reeves et al. 1987), food availability (Wilzbach 1985), fish size (Dolloff and Reeves 1990), and behavior (Nielsen 1992, 1994). Recent emphasis on rehabilitation of stream habitat, including that of larger rivers, requires a better understanding of habitat selection and behavior of salmonids in these larger systems.

Nielsen (1992, 1994) observed differential habitat use by juvenile coho salmon displaying distinct foraging behaviors in Washington and California streams and concluded that these foraging groups developed in response to environmental factors. Therefore, different foraging behaviors may occur in large rivers, which possess distinctly different physical environmental conditions from those of small streams. Swain and Holtby (1989) observed differences in agonistic behavior between juvenile coho salmon rearing in a lake and its inlet stream. Also, the body form of lake rearing coho salmon, more streamlined and smaller less colorful fins, appeared to be better suited for a schooling behavior in open water than for stream rearing. Juvenile coho salmon displaying the foraging behaviors described by Nielsen (1992, 1994) and those displaying schooling behaviors would likely use substantially different microhabitats. If these (or other) foraging behaviors are observed in juvenile coho salmon from large rivers, habitat enhancement measures should attempt to provide habitats important for fish displaying each behavior. Different foraging behaviors may segregate available resources and allow greater densities of the species to occur in available habitat. Therefore, the most successful habitat restoration programs should be those providing adequate rearing conditions for the greatest number of behavioral groups.

The purpose of this study was to evaluate microhabitat use and behavior of summer rearing juvenile coho salmon in a relatively large stream channel and determine if woody debris introductions are adequate to provide rearing habitat for different behavioral groups which may be observed. For the purpose of this study, microhabitat has been defined as the habitat characteristics associated with the focal position of individual fish.

Study Area

This study was completed in the mainstem Clearwater River. During 1992, four debris accumulations between Deception Creek and Peterson Creek were selected for microhabitat study (Figure 1.1). During 1993, 19 debris accumulations were selected. Six of these accumulations were located between Bull and Deception creeks, eleven were between Peterson Creek and Gross Bridge, and two were between Elkhorn and Hunt creeks (Figure 1.1). The Clearwater River and these study reaches have been described in more detail in Chapters IV and V.

MATERIALS AND METHODS

Habitat Use and Behavior

1992

Preliminary observations of microhabitat use and behavior were collected during 1992 near four woody debris accumulations of the mainstem Clearwater River. Three of these accumulations were introduced woody debris (see Chapter IV) and one was natural. Juvenile coho salmon at these debris accumulations were observed by snorkeling during four distinct periods (early and late August, late September, and early October). A snorkeler entered the water downstream (at least 10 meters) of the debris accumulation and proceeded upstream until a group of coho salmon was observed. A 5-min adjustment period, with the snorkeler waiting quietly in the water, proceeded collection of behavioral data. Following the acclimation period, the group was classified as either foraging or resting (Table 6.1) and the number of juvenile coho salmon in the group was estimated. A randomly selected individual fish was then observed and classified as either dominant, subdominant, or as a floater if it was in a foraging group (Table 6.1). Fish from the resting group were not further classified. The number of foraging attempts and behavioral displays (Table 6.2) made by the individual fish during a 2-min observation period were recorded underwater. Additional randomly selected juvenile coho salmon were observed until at least 20% of the fish in the group had been observed. The snorkeler then proceeded until another group was found, after which the process was repeated. Following the completion of all behavioral observations, microhabitat variables, including focal velocity, water depth, focal depth, distance from bottom, relative depth (calculated by dividing focal depth by water depth), and distance from woody debris were measured for each group observed (Table 6.3). Several measurements for each variable were taken over the entire area used by the group.

Table 6.1. **Definitions of terms used to classify behavioral groups and individual coho salmon rearing at debris accumulations in the mainstem Clearwater River. (Adapted and modified from Puckett and Dill (1985)).**

Behavior	Definition
Resting	A group of fish not actively feeding or displaying other activities (wandering, schooling, etc.).
Foraging	A group of fish actively pursuing food items.
Dominant	Individual fish at the most upstream position of a foraging hierarchy or aggregate.
Subdominant	Individual fish within a foraging hierarchy or aggregate but not at the most upstream position.
Floater	Individual fish foraging in a foraging arena, not associated with a foraging social hierarchy (Puckett and Dill 1985).

Table 6.2. Definitions of foraging and social behaviors recorded for individual juvenile coho salmon rearing at woody debris accumulations in the mainstem Clearwater River (Adapted from Kalleberg (1958)).

Behavior	Definition
Foraging	
Surface	Breaking the water surface to obtain a food item.
Mid-Water	Foraging on suspended food items within the water column.
Benthic	Making contact with the substrate while feeding.
Wandering	Continuous undirected swimming.
Aggressive	
Display	Flaring of fins and assumption of the tilted posture with the aggressor's head lowered toward the opponent.
Attack	Rapid swimming toward another fish without direct contact.
Nip	Biting movements by the aggressor towards another fish.
Chase	Chasing another individual as it flees from the attack.
Submissive	
Belly Display	Showing of the belly resulting in broken eye contact between the aggressor and submissive fish.
Flight	Fleeing from an attack.
Hiding	Using cover to evade an attack.

Table 6.3. Definitions of physical habitat variables measured to describe microhabitat selection of juvenile coho salmon in the mainstem Clearwater River.

Habitat Variable	Definition
Focal Velocity	Water velocity (m/s) at the fish's snout.
Depth	Perpendicular distance (m) from the substrate to the surface of the water measured at the snout of the fish.
Focal Depth	Perpendicular distance (m) from the fish's snout to the water surface.
Distance From Bottom	Perpendicular distance (m) from the fish's snout to the substrate.
Relative Depth	Focal Depth/Water Depth.
Distance to (from) woody debris	Horizontal distance (m) from the fish's snout to the nearest woody debris cover.

Habitat use and behavioral observation data were collected by two individuals during 1992. These individuals observed different groups of fish at different debris stations simultaneously to increase the number of fish which could be observed during the study. Habitat use and behavioral data collected by these two individuals were compared using separate t-tests for juvenile coho salmon from the foraging and resting behavior groups. If significant differences existed between observers, subsequent analysis of variables for which significant differences existed were completed separately for each observer.

Habitat use by juvenile coho salmon was compared between behavior groups (resting, foraging) during 1992 using a two-way ANOVA. The time period (early and late August, late September, and early October) during which observations were made was included in the two-way ANOVA as the second factor to determine whether habitat use changed during the survey period. The interaction between behavior group and sampling period also was examined. Statistical analysis of relative depth data was completed using arcsine transformed data ($X' = \arcsin (X)^{1/2}$). Foraging and behavioral data for 1992 were evaluated using a t-test to determine whether differences in these behaviors existed between juvenile coho salmon from the two behavior groups (foraging and resting).

1993

Nineteen stations were included in the evaluation during 1993. Eight were introduced debris accumulations and 11 were natural debris accumulations. Four of the eight introduced debris accumulations were located in pools and four in glides, four of the natural debris accumulations were in pools, four in glides, and three in riffles. Juvenile coho salmon were caught during 1993 with beach and purse seines at each woody debris accumulation. Ten coho salmon were randomly selected from the catch and marked (July 26-August 2, 1993) with non-toxic acrylic paint which was injected into the rays of the dorsal and/or caudal fin. At one station, fourteen coho salmon were marked because of the high abundance at this station (≈400) compared to the others (≈100). Different color combinations and mark locations were used for differential marking of individual fish (Lotrich and Meredith 1974; Thresher and Gronell 1978). Once marking was completed, the fish were released into the area from which they had been taken. Behavioral observations and habitat selection data were collected exclusively on these marked fish during two separate observation periods in 1993. The first set of observations were made between 5 August and 18 August, 1993 and the second between 13 September and 24 September, 1993.

As in 1992, behavioral and habitat selection observations were completed by snorkeling. A snorkeler would enter the water downstream of the debris accumulation to be surveyed, moving upstream until a marked fish was observed. Following a 10-min adjustment period, the group which the marked fish was a member was classified as foraging or resting (Table 6.1). Behavior activity (Table 6.2) of the marked fish was then recorded over a 10-min observation period. If the group contained more than one marked individual, behavioral observations for the remaining marked fish occurred following the 10-min observation of the previously observed fish unless the observer had to move to obtain adequate observations. In this case, an additional 10-min adjustment period occurred prior to making behavioral observations. Foraging and behavior data were defined as described above.

Physical habitat variables (same as in 1992) were measured following the observation of all marked fish at a debris station (Table 6.3). In contrast to 1992, habitat measurements were recorded for individual marked fish for which behavior data was collected rather than the group. Habitat measurements were measured as described for 1992.

A t-test was used to determine whether microhabitat use by juvenile coho salmon in the mainstem Clearwater River differed between August and September, 1993. If no significant differences were detected, data for the two sampling periods were combined for further analyses. However, if significant differences existed, data from each month were analyzed separately. All statistical analyses of relative depth data was completed with arcsine transformed data ($X' = \arcsin (X)^{1/2}$).

A two-way ANOVA was used to compare habitat use by individual marked juvenile coho salmon from the two behavior groups (foraging and resting) and by juvenile coho salmon rearing in different river habitats (pool, glide, riffle). If a significant interaction existed between the two variables, habitat use by juvenile coho salmon from the two behavior groups were compared separately for each type of habitat using a t-test. Statistical test for individual factors are meaningless if the interaction between the terms is significant, therefore, a conservative alpha level ($P=0.10$) was used to test the interaction (Zar 1984).

The effect of foraging position (dominant, subdominant, floater) and habitat type (pool, glide, riffle) on habitat use by juvenile coho salmon from the foraging group were evaluated using a two-way ANOVA. Because resting fish did not display dominant behavior, a one-way ANOVA was used to evaluate the effect of river habitat (pool, glide, riffle) on habitat use.

The effect of behavior group (foraging and resting) and sampling period (August and September) on the behavioral activity (e.g., forage, aggressive, submissive behavior) of juvenile coho salmon was evaluated using a two-way ANOVA. If a significant interaction was detected, behavioral activity between these two behavior groups was compared separately for each sampling period using a t-test. One-way ANOVAs were used to compare behavioral activity (e.g., foraging, aggressive, submissive behavior) of the individual classifications (dominant, subdominant, floater) of the foraging group.

The effect of debris type (introduced and natural) and river habitat (pool, glide, riffle) on the number of foraging (surface, midwater, bottom), aggressive (display, nip, attack, chase), submissive (display, flee, hide), and wandering behaviors were evaluated using two-way ANOVAs. Behavior data for foraging and resting groups were combined for analysis if no significant difference existed between these two behavioral groups for the variable in question. Otherwise the analysis was completed separately for each behavioral group.

A two-way ANOVA was used to compare the number of forage attempts made by foraging coho salmon at different locations (surface, midwater, bottom) and from different individual classes (dominant, subdominant, and floater). If a significant interaction was detected between these two factors, the mean number of foraging attempts at each foraging location was tested separately for foraging fish from individual classes using an ANOVA. This same approach was used to compare the type of aggressive (display, attack, nip, chase), and submissive (display, flee, hide) behaviors displayed by coho salmon from different individual classes. One-way ANOVAs were used to compare the number of forage attempts made at different foraging locations (surface, midwater, bottom) and the different types of aggressive (display, attack, nip, chase), and submissive (display, flee, hide) behaviors displayed by juvenile coho salmon from the resting group.

Size and Growth

Weights (g) of all juvenile coho salmon marked during 26 July and 2 August 1993 were recorded. Fifteen unmarked coho salmon from each station were also weighed. Following the last behavioral observations in September, attempts were made to capture coho salmon from each station using beach and purse seining. All marked fish captured, along with a sample of unmarked fish sufficient to bring the total sample size up to 25 individuals, were weighed. Weights of coho salmon captured at different types (introduced and natural) of woody debris accumulations and habitats during the marking survey were compared using a nested ANOVA (station nested). A nested ANOVA (stations nested) was used to compare the weights of juvenile coho salmon receiving marks and those not receiving marks because significant differences (ANOVA: $P=0.0001$) in coho salmon weights existed between stations.

Specific growth (% weight increase/day) rates of marked coho salmon recaptured in September were calculated as:

$$\text{Specific Growth Rate} = ((\log_e Y_2 - \text{Log}_e Y_1)/(t_2 - t_1))*100 \qquad \text{Equation 6.1 (Busacker et al. 1990)}$$

where: Y_1 = initial weight (g)

Y_2 = final weight (g)

t_1 = time initial weight was recorded

t_2 = time final weight was recorded

The specific growth rate of marked juvenile coho salmon re-captured at the end of the study from the station where they were marked, were compared between introduced and natural debris accumulations using a t-test. There were insufficient numbers of marked fish recaptured from different habitat type to complete a comparison of growth rates among habitat types.

Stomach samples were collected from marked coho salmon sampled following the September 1993 observations, using pulsed gastric lavage technique (Foster 1977) and preserved in 70% ethanol. In the laboratory, total weight of the sample and weight of individual taxa in the sample were determined. Average weights of stomach contents were pooled by behavioral groups for comparison.

RESULTS

Habitat Selection

1992

Habitat use data collected by the two observers were not significantly different and therefore were combined for statistical analysis (Appendix F). Groups of foraging coho salmon occupied focal position with greater current velocities and which were farther from woody debris cover than resting fish (Figure 6.1). Foraging and resting coho salmon selected focal positions with similar water depth, focal depth, distance from bottom, or relative depth (Figure 6.1). Microhabitat use by juvenile coho salmon from the two behavior groups was not different during the four sampling periods in 1992 (early and late August, late September, and early October) for any of the measured habitat selection variables (two-way ANOVA: P=0.3076 to 0.7863).

1993

No significant differences in microhabitat selection existed between August and September for coho salmon in either behavior group (foraging or resting) except that foraging groups were closer (t-test: P=0.0409) to the bottom during September than August (Appendix G). Since no significant differences in microhabitat use of juvenile coho salmon were observed in water depth, focal depth, relative depth, focal velocity, or distance to debris between months, the data for August and September were combined for additional statistical analysis. Distance to the bottom was analyzed separately for each month during which observations were recorded.

Juvenile coho salmon from the foraging group used focal positions with significantly greater velocities, depths, and relative depths than those from the resting group (Table 6.4). However, coho salmon from the two behavior groups selected focal positions at similar distances from the bottom during September. Focal depth of juvenile coho salmon rearing in pools was significantly deeper than those rearing in glides and riffles and was deeper in glides than riffles (Table 6.5). Juvenile coho salmon selected focal positions at greater relative depths in riffles than in pools (Table 6.5). Relative depths of focal positions were not different between riffles and glides or between pools and glides (Table 6.5). Focal positions in pools were significantly farther from the bottom than those rearing in riffles during September (Table 6.5). There were no differences in the distance focal positions were from the bottom for fish rearing in pools versus glides or glides versus riffles. Focal velocities selected by juvenile coho salmon rearing in different habitat types were not significantly different.

Foraging and resting coho salmon used focal positions different distances from woody debris and in different water depth (Table 6.6). The distance focal positions of foraging and resting fish were located from woody debris cover was dependent upon river habitat. Focal positions of foraging fish were farther from woody debris than resting fish in glides. In contrast, resting fish selected focal positions significantly further from woody debris in riffles. There was insufficient replication for comparison in pools. Foraging fish selected focal positions in significantly deeper water in glides and riffles than resting fish. There was insufficient replication for statistical comparisons of water depth used by foraging and resting fish in pools. Juvenile coho salmon selected focal positions at similar distances from the bottom during August (Table 6.6). Significant interactions existed between the factors behavior group and habitat type for the variable distance to bottom during August (two-way ANOVA: P=0.0015), water depth (two-way ANOVA: P=0.0002), and distance from debris (two-way ANOVA: P=0.0001). Thus, habitat use of resting and foraging groups were compared separately for each habitat type (Table 6.6).

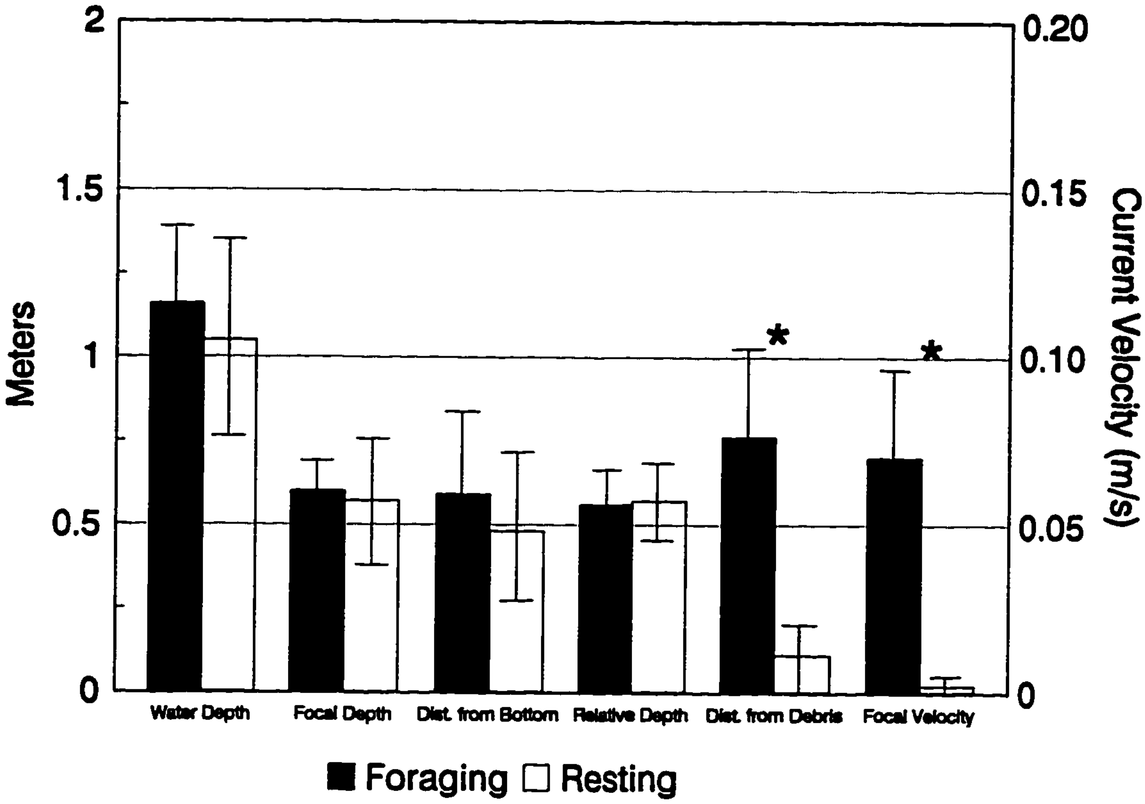

Figure 6.1. Mean (+/- 2 SE) water depth, focal depth, distance from bottom, distance from debris, relative depth, and focal current velocity selected by groups of foraging and resting juvenile coho salmon in the mainstem Clearwater River during 1992. All the variables except focal velocity refer to the Y-axis on the left. Focal velocities are list on the Y-axis on the right. Groups of bars for microhabitat variables marked with an asterisk (*) are significantly different (Two-way ANOVA: $P<0.05$).

Table 6.4 Mean focal velocity, focal depth, relative depth, and distance to bottom (September) used by juvenile coho salmon from foraging and resting groups in the mainstem Clearwater River during 1993. Results from the two-way ANOVA evaluating the effect of group (foraging and resting) and habitat (Table 6.5) on habitat selection variables are also included.

	Foraging Group (F)			Resting Group (R)				
Variable	n	Mean	SD	n	Mean	SD	Results	*P*
Focal Velocity (m/s)	55	0.0673	0.06124	20	0.0035	0.01349	F>R	0.0001
Focal Depth (m)	55	0.55	0.223	20	0.38	0.143	F>R	0.0138
Relative Depth	55	0.64	0.198	19	0.58	0.219	F>R	0.0031
Distance to Bottom (September)	19	0.27	0.238	6	0.24	0.092	F=R	0.5098

Table 6.5. Mean focal velocity, focal depth, relative depth, and distance to bottom (September) selected by juvenile coho salmon in different river habitat types during 1993. Results from the two-way ANOVA evaluating the effect of group (Table 6.4) and habitat (pool, glide, riffle) on habitat selection variables also is included.

	Pool (P)			Glide (G)			Riffle (R)						
Variable	n	Mean	SD	n	Mean	SD	n	Mean	SD	*P*	Tukey Results		
Focal Vel. (m/s)	19	0.048	0.0449	28	0.050	0.0665	28	0.052	0.0638	0.7810	—	—	—
Focal Depth (m)	19	0.67	0.226	28	0.53	0.215	28	0.37	0.106	0.0005	P>R <0.001	P>G 0.0154	G>R 0.0033
Relative Depth	19	0.51	0.215	28	0.60	0.209	27	0.72	0.143	0.0004	R>P 0.0027	R=G 0.0942	P=G 0.2374
Distance to Bottom (Sept.)	6	0.43	0.262	8	0.29	0.238	11	0.15	0.043	0.0319	P>R 0.0268	P=G 0.4101	G=R 0.3104

Table 6.6. Mean water depth, distance from bottom (August), and distance to debris selected by foraging (F) and resting (R) coho salmon rearing in pools, glides, and riffles during 1993.

		Foraging (F)			Resting (R)				
Variable	Habitat	n	Mean	SD	n	Mean	SD	Results	P^1
Water Depth (m)	Pool	16	1.36	0.678	3	2.28	0.075	N/A[2]	—
	Glide	21	0.98	0.284	7	0.72	0.133	F>R	0.0275
	Riffle	18	0.56	0.115	10	0.45	0.076	F>R	0.0133
Distance from Bottom (m) (August)	Pool	10	0.84	0.651	3	1.73	0.179	N/A[2]	—
	Glide	15	0.46	0.272	5	0.29	0.121	F=R	0.1905
	Riffle	11	0.15	0.119	6	0.14	0.036	F=R	0.8540
Distance from Debris (m)	Pool	15	0.73	0.856	3	0.41	0.352	N/A[2]	—
	Glide	21	1.51	1.393	7	0.18	0.256	F>R	0.0003
	Riffle	18	0.46	0.609	10	2.19	1.813	R>F	0.0147

[1] Results from t-test.

[2] Insufficient replications for statistical analysis.

Microhabitat use of resting coho salmon was influenced by river habitat type (Table 6.7). Focal positions used by resting in pools were located in deeper water than those in glides or riffles and in deeper water in glides than riffles (Table 6.7). Focal positions of resting coho salmon were farther from the bottom in pools than in glides or riffles. Resting fish selected focal positions farther from woody debris cover in riffles than in glides, but no difference was observed in pools versus glides or pools versus riffles. Resting coho salmon in riffles and glides selected greater relative depths (water depth/focal depth) than those in pools. Resting coho salmon in different habitats did not use significantly different focal velocities or focal depths (Table 6.7). However, the power of these tests was low (focal velocity: <0.20; focal depth: 0.35).

Foraging coho salmon displaying different individual behaviors (dominant, subdominant, and floater) used focal positions with similar microhabitat features (Table 6.8). No significant differences were observed in any of the microhabitat variables among dominant, subdominant, and floater foraging fish. Floaters were normally in deeper water and further from the bottom, however, these differences were not significant. There was insufficient replication to compare the distance from bottom selected by dominant (n=2), subdominant, and floater (n=1) fish. A significant interaction existed between the factors (individual class and habitat type) for the variable distance from bottom during August (two-way ANOVA: P=0.0182). This required that the comparisons of distance of focal positions from the bottom (August) for each habitat type be compared separately for each individual class. However, there were too few observations for this comparison.

Foraging coho salmon rearing in different habitats occupied focal positions which differed in several of the measured microhabitat variables (Table 6.9). Foraging coho salmon occupied deeper water in pools than in glides and riffles, and occupied deeper water in glides than in riffles (Table 6.9). Foraging coho salmon used focal positions twice as far from woody debris in glides than in pools and riffles. Focal positions occupied by foraging fish were deeper in pools than in glides and riffles, but the difference was only significant between pools and riffles. No difference was observed in the distance focal positions used by foraging fish were located from the bottom during September. The comparison of distance to the bottom selected by foraging coho salmon in different habitats during August was completed separately for each individual class, since the interaction between these two factors was significant (two-way ANOVA: P=0.0182). However, there was only sufficient data to complete this analysis for subdominant foraging fish. Subdominant foraging fish selected focal positions farther from the bottom in pools than riffles during August.

Table 6.7. Mean water depth, focal depth, distance from bottom, relative depth, distance from debris, and focal velocity selected by juvenile coho salmon by individuals from the resting group in different riverine habitats during 1993. Results from the ANOVA and tukey tests (only if the ANOVA was significant) are also presented. (For Tukey Results: P=Pool; G=Glide; R=Riffle).

Variable	Pool (P)			Glide (G)			Riffle (R)			*P*	Tukey Results		
	n	Mean	SD	n	Mean	SD	n	Mean	SD				
Water Depth (m)	3	2.28	0.075	7	0.721	0.133	7	0.46	0.084	0.0001	P>G <0.001	P>R <0.001	G>R 0.0012
Distance from Bottom (m)	3	1.73	0.179	7	0.30	0.107	7	0.16	0.045	0.0001	P>G <0.001	P>R <0.001	G=R 0.0530
Distance from Debris (m)	3	0.41	0.352	7	0.18	0.256	7	2.72	1.94	0.0058	R>G 0.0335	R=P 0.0518	P=G >0.50
Focal Velocity (m/s)	3	0	0	7	0.001	0.0038	7	0.009	0.0227	0.5997	—	—	—
Focal Depth (m)	3	0.55	0.104	7	0.42	0.147	7	0.33	0.108	0.0748	—	—	—
Relative Depth	3	0.24	0.055	7	0.57	0.141	7	0.73	0.209	0.0003^3	R>P <0.001	G>P 0.0015	R=G 0.5230

Table 6.8. Mean water depth, focal depth, distance from bottom, relative depth, distance from debris, and focal velocity of juvenile coho salmon from foraging groups in different individual classes (dominant, subdominant, floater) during 1993. Results of the two-way ANOVA evaluating the two factors (individual class of foraging group) and habitat type (Table 6.9) comparisons also are provided.

	Dominant			Subdominant			Floater			
Variable	n	Mean	SD	n	Mean	SD	n	Mean	SD	*P*
Water Depth (m)	7	0.71	0.294	38	0.98	0.499	7	1.08	0.701	0.7109
Distance from Bottom (m) (September)	2	0.12	0.042	14	0.29	0.263	1	0.49	—	N/A
Distance from Debris (m)	7	1.13	1.381	38	0.92	1.168	6	1.38	0.468	0.1230
Focal Velocity (m/s)	7	0.09	0.037	38	0.07	0.063	7	0.02	0.045	0.1068
Focal Depth (m)	7	0.51	0.188	38	0.56	0.243	7	0.58	0.114	0.9864
Relative Depth	7	0.74	0.133	38	0.62	0.215	7	0.63	0.177	0.7382

Table 6.9. Mean water depth, focal depth, distance from bottom, relative depth, distance from debris, and focal velocity of juvenile coho salmon from foraging groups rearing in different riverine habitat during 1993. Results from the two-way ANOVA using the two factors individual foraging group class (Table 6.8) and habitat type (pool, glide, riffle) are also included.

	Pool (P)			Glide (G)			Riffle (R)						
Variable	n	Mean	SD	n	Mean	SD	n	Mean	SD	*P*	Tukey Results		
Water Depth (m)	16	1.36	0.678	20	0.95	0.237	16	0.57	0.120	0.0015	P>G 0.0128	P>R <0.001	G>R 0.0226
Distance from Bottom (m) (Aug.)[1]	7	0.86	0.591	9	0.48	0.282	8	0.16	0.135	0.0055	P>R 0.0045	P=G 0.1310	G=R 0.2087
Distance from Bottom (m) (Sept.)	6	0.43	0.262	6	0.27	0.276	5	0.11	0.025	0.2615	—	—	—
Distance from Debris (m)	15	0.73	0.856	20	1.59	1.384	16	0.52	0.623	0.0109	G>P 0.0490	G>R 0.0097	P=R >0.500
Focal Velocity (m/s)	16	0.06	0.043	20	0.06	0.069	16	0.09	0.066	0.7878	—	—	—
Focal Depth (m)	16	0.69	0.237	20	0.56	0.223	16	0.42	0.093	0.0402	P>R 0.0030	P=G 0.1766	G=R 0.1320
Relative Depth	16	0.56	0.196	20	0.61	0.232	16	0.75	0.109	0.1310	—	—	—

[1] Subdominant fish only

Behavior

1992

Behavioral observations collected by the two observers during 1992 showed significant differences (Appendix F) for the variables surface forage attempts (t-test: $P=0.0154$), total forage attempts (t-test: $P=0.0196$), attacks (t-test: $P=0.0032$), and nips by fish in the foraging group (t-test: $P=0.0460$), wanders by fish from both the foraging (t-test: $P=0.0001$) and resting groups (t-test: $P=0.0289$), and chase behavior by resting fish (t-test: $P=0.0369$). Data for these variables were analyzed separately for each observer.

Juvenile coho salmon from foraging groups foraged more than those from resting groups during 1992 (Figure 6.2). Foraging fish made more surface, midwater, and total forage attempts than those resting fish, while no difference in the number of bottom foraging attempts was observed between the two groups. Although the two observers observed different numbers of surface and total forage attempts by foraging fish, results of the comparison between foraging and resting fish were consistent (i.e., foraging fish fed more).

Juvenile coho salmon in foraging groups displayed more aggressive behavior than those from resting groups during 1992, although results varied between the two observers (Figure 6.3). Observer 1 recorded significantly more chase and attack behavior in coho salmon from the foraging group than those from the resting group. Although observer 2 also recorded more chase behavior by foraging fish than resting fish the difference was not statistically significant. Observer 2 did not observe any attack behavior by either behavior group. Observer 2 recorded more nips from juvenile coho salmon in the foraging group than those in resting groups, whereas no difference was recorded by observer 1. Foraging fish made more aggressive displays and total aggressive behavior than those resting fish.

Although foraging fish were more aggressive than resting fish, they did not display more submissive behavior than resting fish (Figure 6.4). No difference was observed in the number of submissive displays, fleeing activities, hiding activities, or total submissive behaviors recorded for fish from the foraging and resting groups.

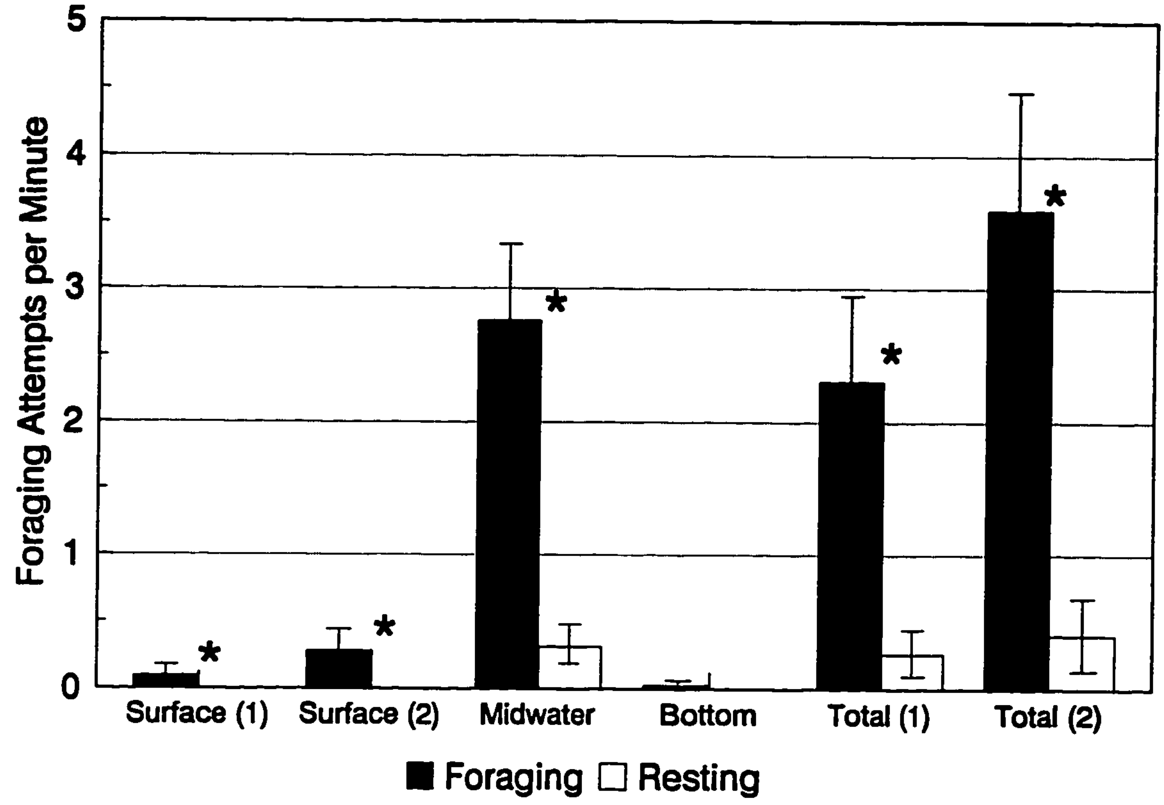

Figure 6.2. Mean (+/- 2 SE) number of surface, midwater, bottom and total forage attempts (attempts/min.) made by juvenile coho salmon from foraging and resting groups, during 1992. Results obtained by each observer (in parenthesis) are presented for the number of surface and total foraging attempts made, since significant differences existed in the data collected by the two observers. An asterisk (*) above groups of bars indicates significant differences (t-test: $P<0.05$).

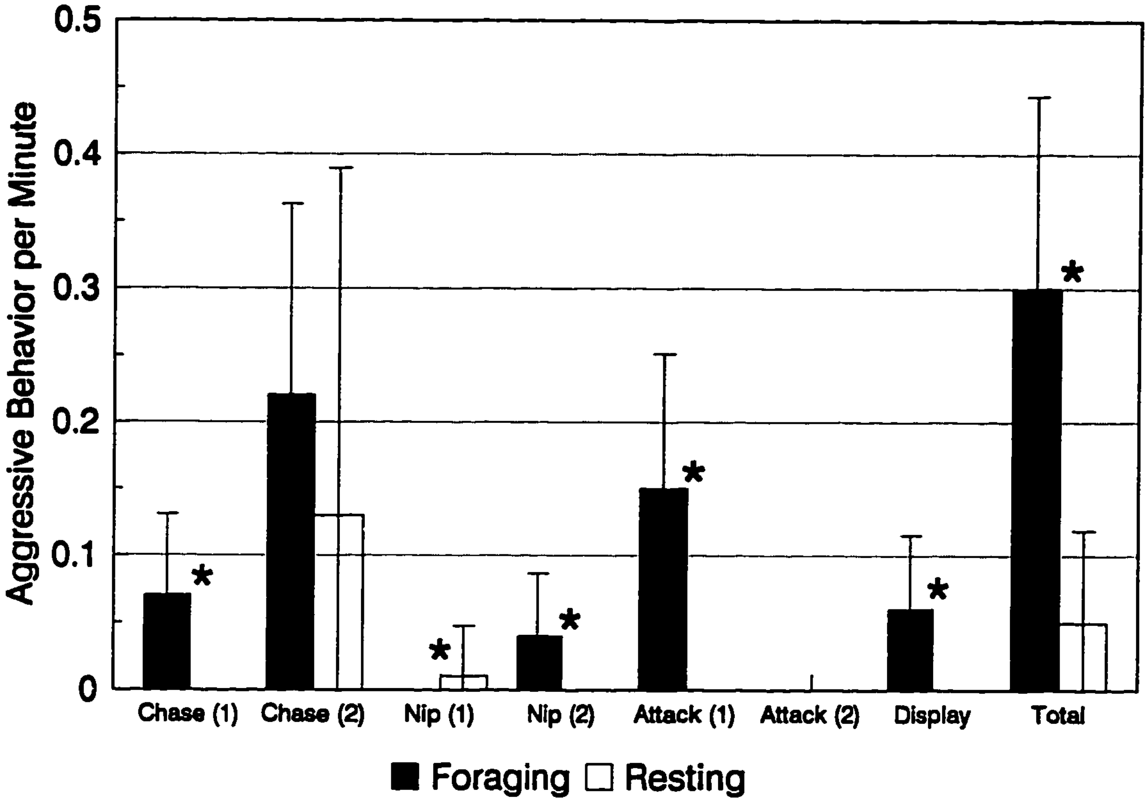

Figure 6.3. Mean (+/- 2 SE) number of aggressive displays, chases, nips, attacks, and total aggressive behavior per minute observed in juvenile coho salmon from foraging and resting groups during 1992. Mean number of chases, nips and attacks recorded by each observer (in parenthesis) are displayed because significant differences existed between the data collected by the two observers. An asterisk (*) above groups of bars indicates significant differences (t-test: $P < 0.05$).

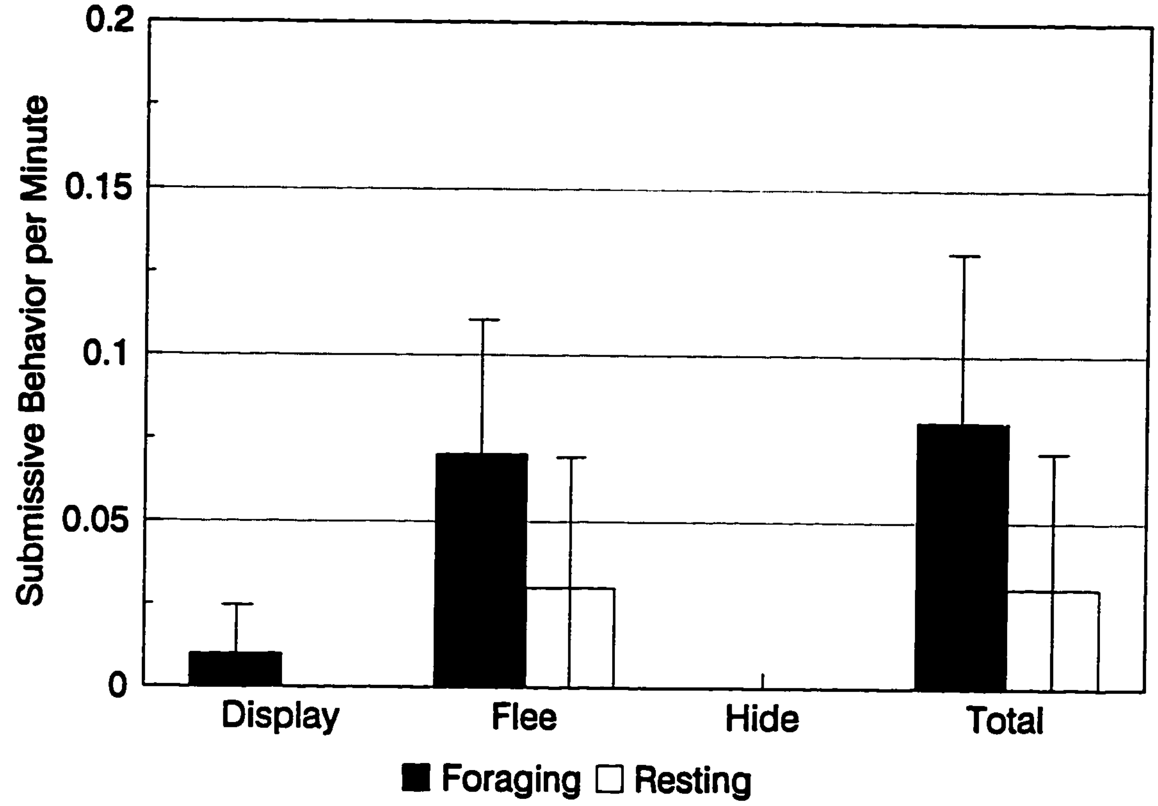

Figure 6.4. Mean (+/- 2 SE) number of submissive displays, flees, hiding and total submissive behavior per minute observed in juvenile coho salmon from foraging and resting groups during 1992.

No significant (t-test: Observer 1: *P*=0.8879; Observer 2: *P*=0.2762) differences in the number of wandering forays per minute were observed between juvenile coho salmon in foraging (Observer 1: Mean=0.31, SD=0.501; Observer 2: Mean=0.01; SD=0.071) and resting groups (Observer 1: Mean=0.30; SD=0.478; Observer 2: Mean=0.05, SD=0.154).

The proportion of coho salmon displaying foraging behavior varied between sampling dates. For example, during the first survey 11 groups of coho salmon totalling over 150 fish were classified as foraging and one group of 8 fish was classified as resting. During the second survey, 4 groups totalling 32 fish were foraging and 10 groups totalling nearly 200 fish were resting. During the third survey, coho salmon were more equally divided (foraging: 5 groups, 32 fish; resting: 2 groups, 47 fish). However, during the final survey, 11 groups totaling nearly 250 fish were foraging, while only 4 groups totalling 40 fish were resting. There were insufficient data to compare the number of coho salmon groups displaying foraging versus resting behavior in relation to time of day or weather conditions.

1993

As expected from their definition, foraging coho salmon foraged more than resting coho salmon (Table 6.10). However, these differences were significant only for midwater and total forage attempts. Coho salmon from the two behavior groups did not display different foraging intensities during August and September (two-way ANOVA: $P=0.2934$-0.8423).

Foraging coho salmon were more aggressive than resting fish, however, no difference was detected in the number of submissive behaviors displayed by the two behavior groups (Table 6.10). Foraging coho made significantly more aggressive displays and displayed more total aggressive behavior than resting individuals. No differences were detected in the frequency of attack, nip, or chase behavior of coho salmon from the two behavior groups. Aggressive behavior did not differ between August and September (two-way ANOVA: $P=0.0785$-0.9156). No differences were detected in submissive displays, flees, or hiding by coho salmon from the two foraging groups or in the number of submissive behaviors observed between August and September (two-way ANOVA: $P=0.2384$-7424) (Table 6.10). Coho salmon wandered more during August than September and those from resting groups wandered more than those from foraging groups (Table 6.10).

Foraging coho salmon displaying different individual behaviors (dominant, subdominant, floater) showed differences in foraging and aggressive behavior (Table 6.11). However, these differences were rarely statistically significant due to low replication which results in low statistical power (Table 6.11). Foraging coho salmon displaying the floater behavior foraged on the surface two to five times more than individuals displaying subdominant and dominant behavior. In contrast, dominant and subdominant foraging fish made twice as many midwater forage attempts and 50% more total forage attempts than floaters. Bottom foraging was similar among individuals displaying dominant, subdominant, and floater behaviors.

Dominant coho salmon displayed more aggressive behavior than those displaying subdominant and floater behaviors, however, these differences were only statistically significant for total aggressive behavior (dominant>subdominant: Tukey: $P=0.0173$; dominant>floaters: Tukey: $P=0.0270$). No difference in total aggressive behavior was detected between subdominant and floaters (Tukey: $P>0.5000$). Although dominant fish made several fold more aggressive displays and attacks than subdominant and floater individuals, these differences were not statistically significant. Subdominant fish were the only ones that displayed chase behavior and it was infrequent.

Submissive behavior was relatively infrequent in foraging coho salmon displaying dominant, subdominant, and floater characteristics (Table 6.11). Although, relatively large differences existed between these groups of foraging fish, these differences were not statistically significant (Table 6.11). Dominant fish reacted to aggression with more submissive displays than subdominant and floaters, while subdominant were more likely to flee than dominant and floater individuals. No hiding behavior was observed in foraging coho salmon. Floaters showed fewer total submissive behaviors than subdominant and dominant individuals (Table 6.11).

Wandering data was analyzed separately for August and September since significant differences in wandering activity existed between months. Floaters wandered more than dominant (Tukey: $P=0.0199$) and subdominant (Tukey: $P=0.0191$) coho salmon during August 1993. No difference was observed between dominans and subdominant (Tukey: $P>0.5000$). There was insufficient observations for statistical analysis for data collected during September 1993.

Table 6.10. Mean numbers of foraging, aggressive, submissive and wandering behavior displayed per minute by juvenile coho salmon during 1993 (August and September combined). Results of the two-way ANOVA examining the effect of foraging group (foraging and resting) and month (August and September - text) also are provided.

	Foraging group (F)			Resting group (R)				
Behavior	n	Mean	SD	n	Mean	SD	Results	*P*
FORAGING								
Surface	53	0.28	0.944	19	0.11	0.389	F=R	0.6043
Midwater	53	2.97	2.583	19	0.37	0.293	F>R	0.0001
Bottom	53	0.04	0.139	19	0.03	0.138	F=R	0.9197
Total	53	3.30	2.528	19	0.51	0.421	F>R	0.0001
AGGRESSIVE								
Display	53	0.08	0.152	19	0	0	F>R	0.0392
Attack	53	0.09	0.177	19	0.01	0.046	F=R	0.0717
Nip	53	0.004	0.020	19	0	0	F=R	0.2102
Chase	53	0.006	0.0305	19	0.016	0.0502	F=R	0.3454
Total	53	0.18	0.291	19	0.03	0.093	F>R	0.0363
SUBMISSIVE								
Display	53	0.02	0.070	19	0.005	0.023	F=R	0.3372
Flee	53	0.06	0.162	19	0.02	0.069	F=R	0.3843
Hide	53	0	0	19	0	0	F=R	N/A
Total	53	0.08	0.291	19	0.02	0.071	F=R	0.2480
WANDER	53	0.13	0.197	19	0.26	0.312	R>F	0.0325

Table 6.11. Mean (attempts/min.) foraging, aggressive, submissive, and wandering behavior displayed by dominant, subdominant, and floater coho salmon from the foraging group during 1993. Sample size (n = number of fish observed) and standard deviation for each group and results from the ANOVA are also provided.

	Dominant			Subdominant			Floater			
Behavior	n	Mean	SD	n	Mean	SD	n	Mean	SD	*P*
FORAGING										
Surface	7	0.08	0.186	38	0.27	0.992	7	0.54	1.224	0.6759
Midwater	7	3.57	1.778	38	3.14	2.742	7	1.44	2.232	0.2346
Bottom	7	0.01	0.038	38	0.05	0.157	7	0.04	0.113	0.8454
Total	7	3.66	1.822	38	3.46	2.700	7	2.02	2.238	0.3653
AGGRESSIVE										
Display	7	0.16	0.095	38	0.06	0.135	7	0.01	0.038	0.0724
Attack	7	0.20	0.242	38	0.05	0.116	7	0.06	0.151	0.0566
Nip	7	0.02	0.049	38	0.002	0.0114	7	0	0	0.1154
Chase	7	0	0	38	0.008	0.036	7	0	0	0.7219
Total	7	0.38	0.298	38	0.12	0.198	7	0.07	0.189	0.0123
SUBMISSIVE										
Display	7	0.07	0.095	38	0.01	0.068	7	0.01	0.038	0.1372
Flee	7	0.02	0.049	38	0.08	0.187	7	0	0	0.3809
Hide	7	0	0	38	0	0	7	0	0	1.0000
Total	7	0.09	0.131	38	0.09	0.204	7	0.01	0.038	0.5700
Wander (Aug.)	5	0.04	0.089	24	0.12	0.169	6	0.37	0.297	0.0104
Wander (Sept.)	2	0	0	14	0.03	0.058	1	0.67	—	N/A

Juvenile coho salmon from the two behavior groups generally made more forage attempts at introduced than natural woody debris accumulations (Table 6.12). Juvenile coho salmon rearing at introduced debris accumulations made more than twice as many surface foraging attempts than those at natural debris accumulations, however, these differences were not statistical significant. Foraging fish rearing at introduced debris accumulations made significantly more midwater and total forage attempts than those rearing at natural debris accumulations. In contrast, resting fish made similar numbers of midwater and total forage attempts at introduced and natural debris accumulations. Data for foraging and resting groups were analyzed separately for midwater and total forage attempts since significant differences were observed in foraging intensities among the two groups for these variables (Table 6.10). Foraging and resting fish made more bottom forage attempts at natural debris accumulations than those rearing at introduced debris accumulations. However, these differences were not significant (Table 6.12).

Juvenile coho salmon from foraging and resting groups displayed differing levels of foraging activity depending on riverine habitat (Table 6.13). Data for foraging and resting fish were analyzed separately for midwater and total forage attempts since significant differences were observed among these behavior groups for these foraging variables (Table 6.10). Foraging coho salmon made more midwater and total foraging attempts in pools and rifles than in glides. Results from the two-way ANOVA indicated significant differences existed among midwater and total forage attempts made by foraging fish in these different habitats (Table 6.13). However, post-test pair-wise comparisons using the Tukey test failed to detect significant differences (Table 6.13). Resting fish made more midwater forage attempts in glides than riffles. No significant differences in total foraging activity was observed in resting fish rearing in different river habitat types. Foraging and resting coho salmon foraged on the bottom more often in riffles than in glides and pools. No difference in surface foraging activity of foraging and resting fish was observed among different riverine habitat types (Table 6.13).

No significant differences in the levels of aggressive behavior for foraging and resting fish rearing at introduced and natural debris accumulations (Table 6.12) or rearing in different habitat types was observed (Table 6.13). Data for aggressive displays and total aggressive behavior were analyzed separately by behavior group (foraging and resting) because differences were observed between these two groups for these variables (Table 6.10). Total aggressive behavior for foraging fish also was analyzed separately for each individual class (dominant, subdominant, floater) because differences had been observed between these groups (Table 6.11). However there were insufficient sample sizes (n=7) to complete statistical analysis for dominant and floater classes. Therefore, only data for the subdominant class was used.

Juvenile coho salmon in riffles made more total submissive behavior displays than those in pools (Tukey: P=0.0387) or glides but no differences were observed between pools and glides (Table

6.13). However, no differences were observed in individual submissive behaviors (i.e., display, flee, etc.) displayed by juvenile coho salmon from different habitat types. No differences in submissive behavior were observed in juvenile coho salmon rearing at different types of woody debris accumulations (Table 6.12).

There was insufficient sample sizes to complete statistical testing of wandering behavior of coho salmon rearing at different types of debris accumulations and river habitats. Significant differences were detected in the mean number of wandering behaviors displayed by juvenile coho salmon between August and September so the data for each month were analyzed separately. Differences also existed between foraging and resting groups (Table 6.10) and between the individual classes within the foraging group (Table 6.11). This would require each of these comparisons be completed separately for each behavior group and individual class (foraging group). However, there were insufficient sample sizes in these groups to complete meaningful statistical tests. The data are for wandering behavior for each month is listed in Tables 6.12 and 6.13.

Foraging type and resting type coho salmon made more forage attempts at midwater locations than the surface or bottom locations (Figure 6.5). No difference was observed between surface and bottom foraging attempts for either foraging group. Foraging fish displaying dominant (Mean=1.22, SD=1.962, n=21), subdominant (Mean=1.15, SD=2.188, n=114), and floater (Mean=0.67, SD=1.517, n=21) strategies did not show significant differences (two-way ANOVA: $P=0.4182$) in foraging behavior.

Significant differences in the frequency of different types of aggressive behavior were observed in dominant and subdominant foraging coho salmon but not floaters (foraging group) or fish from the resting group (Figure 6.6). Dominant fish were more likely to attack opponents than chase them, while subdominant fish were more likely to display to an opponent than nip them. No other differences were observed between any combination of aggressive behaviors by dominant and subdominant coho salmon. The comparison of aggressive behavior displayed by foraging fish was completed separately for each individual class because a significant interaction (two-way ANOVA: $P=0.0896$) was detected between individual class and the type of aggressive behavior displayed.

No differences were detected in the type of submissive behavior displayed by juvenile coho salmon from either the foraging or resting group or from the different individual classes (dominant, subdominant, floater) of the foraging group (Figure 6.7).

Table 6.12. Mean number (attempts/min.) of foraging, aggressive, submissive, and wandering behavior displayed by juvenile coho salmon rearing at different types of woody debris accumulations during 1993. When significant differences existed between behavior groups, data for each is displayed, otherwise the data for the two foraging groups are combined. Results of the two-way ANOVA for the factor debris type (introduced and natural) are also given. Results for the second factor (habitat type) are given in Table 6.13.

	Introduced (I)			Natural (N)				
Behavior	n	Mean	SD	n	Mean	SD	Result	*P*
FORAGING BEHAVIOR								
Surface	23	0.44	1.258	50	0.14	0.519	I=N	0.3020
Midwater (foraging group)	19	3.25	3.549	34	2.82	1.892	I>N	0.0187
Midwater (resting group)	3	0.41	0.320	16	0.36	0.298	I=N	0.7372
Bottom	23	0.004	0.0209	50	0.05	0.163	I=N	0.1323
Total (foraging group)	19	3.79	3.444	34	3.02	1.839	I>N	0.0069
Total (resting group)	3	0.41	0.320	16	0.53	0.444	I=N	0.8582
AGGRESSIVE BEHAVIOR								
Display (foraging group)	19	0.06	0.165	34	0.09	0.145	I=N	0.5246
Display (resting group)	3	0	0	16	0	0	I=N	N/A
Attack	23	0.05	0.174	50	0.07	0.149	I=N	0.7595
Nip	23	0	0	50	0.004	0.0207	I=N	1.0000
Chase	23	0	0	50	0.01	0.044	I=N	1.0000
Total (foraging group) (subdominant)	13	0.04	0.084	25	0.17	0.227	I=N	0.0800
Total (resting group)	3	0	0	16	0.03	0.102	I=N	1.0000
SUBMISSIVE BEHAVIOR								
Display	23	0.01	0.042	50	0.02	0.068	I=N	0.9635
Flee	23	0	0	50	0.07	0.170	I=N	0.6084
Hide	23	0	0	50	0	0	I=N	N/A
Total	23	0.01	0.042	50	0.09	0.186	I=N	0.6527
WANDER BEHAVIOR								
August	13	0.13	0.173	34	0.23	0.288	N/A	N/A
September	10	0.12	0.205	16	0.06	0.119	N/A	N/A

Table 6.13. Mean number (attempts/min.) of foraging, aggressive, submissive, and wandering behavior displayed by juvenile coho salmon rearing at different river habitat types during 1993. When significant differences existed between behavior groups, data for each is displayed, otherwise the data for the two behavior groups are combined. Results of the two-way ANOVA for the factor habitat type (pool, glide, riffle) are also given. Results for the second factor (debris type) are given in table 6.12).

	Pool (P)			Glide (G)			Riffle (R)						
Behavior	n	Mean	SD	n	Mean	SD	n	Mean	SD	*P*	Tukey Results		
FORAGING BEHAVIOR													
Surface	20	0	0	27	0.40	1.163	26	0.24	0.708	0.2805			
Midwater (foraging group)	16	3.40	2.672	21	2.22	2.808	16	3.53	2.041	0.0251	R=P >0.50	R=G 0.2647	P=G 0.3453
Midwater (resting group)	4	0.31	0.331	5	0.69	0.175	10	0.24	0.211	0.0391	G>R 0.0108	G=P 0.0808	P=R >0.50
Bottom	20	0	0	27	0.004	0.0173	26	0.11	0.216	0.0193	R>G 0.0193	R>P 0.0246	G=P >0.50
Total (foraging group)	16	3.40	2.672	21	2.74	2.873	16	3.92	1.773	0.0253	R=P >0.50	R=G 0.3246	P=G >0.50
Total (resting group)	4	0.31	0.331	5	0.69	0.175	10	0.51	0.519	0.6583			
AGGRESSIVE BEHAVIOR													
Display (foraging group)	16	0.06	0.114	21	0.07	0.160	16	0.119	0.176	0.5700			
Display (resting group)	4	0	0	5	0	0	10	0	0	N/A			
Attack	20	0.06	0.115	27	0.06	0.172	26	0.08	0.170	0.9451			

Table 6.13. (cont.)

	Pool (P)			Glide (G)			Riffle (R)						
Behavior	n	Mean	SD	n	Mean	SD	n	Mean	SD	*P*	Tukey Results		
Nip	20	0	0	27	0	0	26	0.008	0.0285	0.2991			
Chase	20	0	0	27	0.007	0.039	26	0.02	0.046	0.2991			
Total (foraging group) (subdominant)	12	0.14	0.196	15	0.06	0.115	11	0.19	0.271	0.8543			
Total (resting group)	4	0	0	5	0	0	10	0.05	0.127	1.000			
SUBMISSIVE BEHAVIOR													
Display	20	0	0	27	0.01	0.042	26	0.04	0.091	0.1632			
Flee	20	0.03	0.114	27	0	0	26	0.11	0.207	0.0911			
Hide	20	0	0	27	0	0	26	0	0	N/A			
Total	20	0.03	0.114	27	0.01	0.042	26	0.15	0.227	0.0290	R>P 0.0387	R>G 0.0059	P=G >0.50
WANDERING BEHAVIOR													
Wander (Aug.)	12	0.17	0.326	18	0.22	0.236	17	0.21	0.257	N/A			
Wander (Sept.)	8	0.10	0.233	9	0.06	0.069	9	0.10	0.150	N/A			

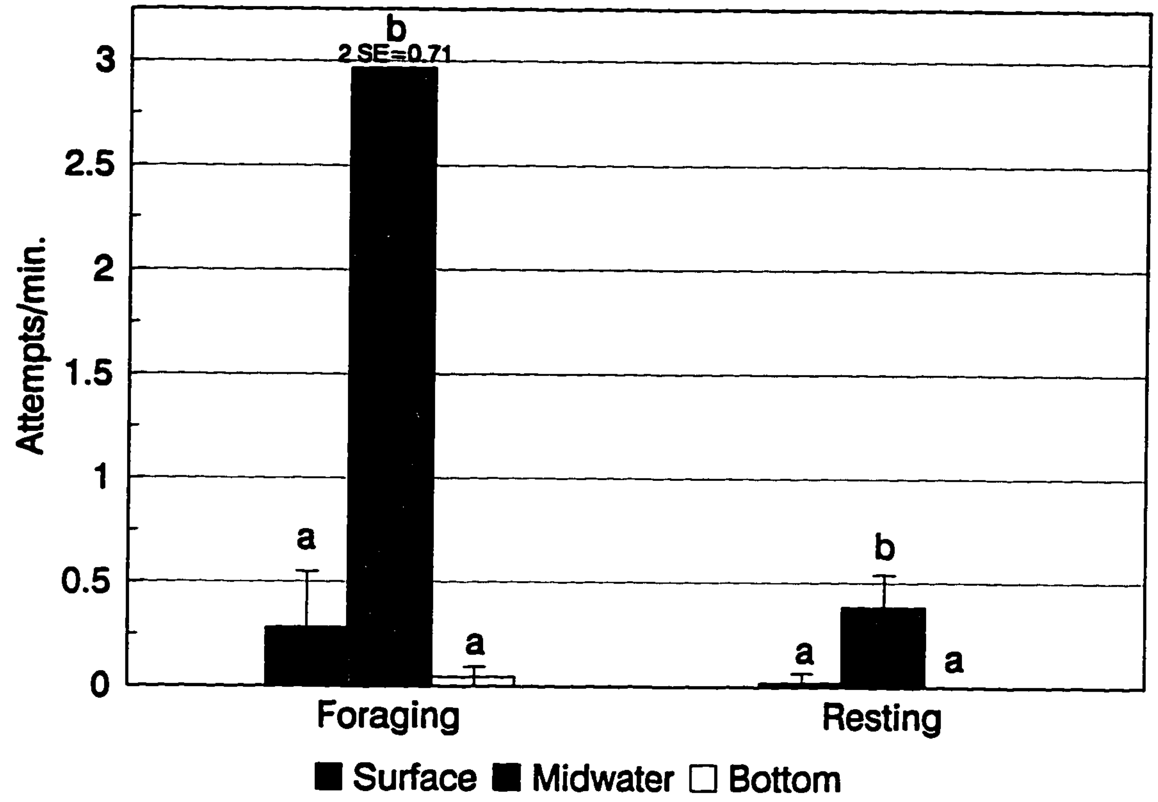

Figure 6.5. Mean (+/- 2 SE) surface, midwater, and bottom forage attempts (attempts/min.) by juvenile coho salmon from the foraging and resting group during 1993. For each group, bars with different letters are significantly different (Two-way ANOVA (foraging group), ANOVA (resting group), and Tukey: $P<0.05$).

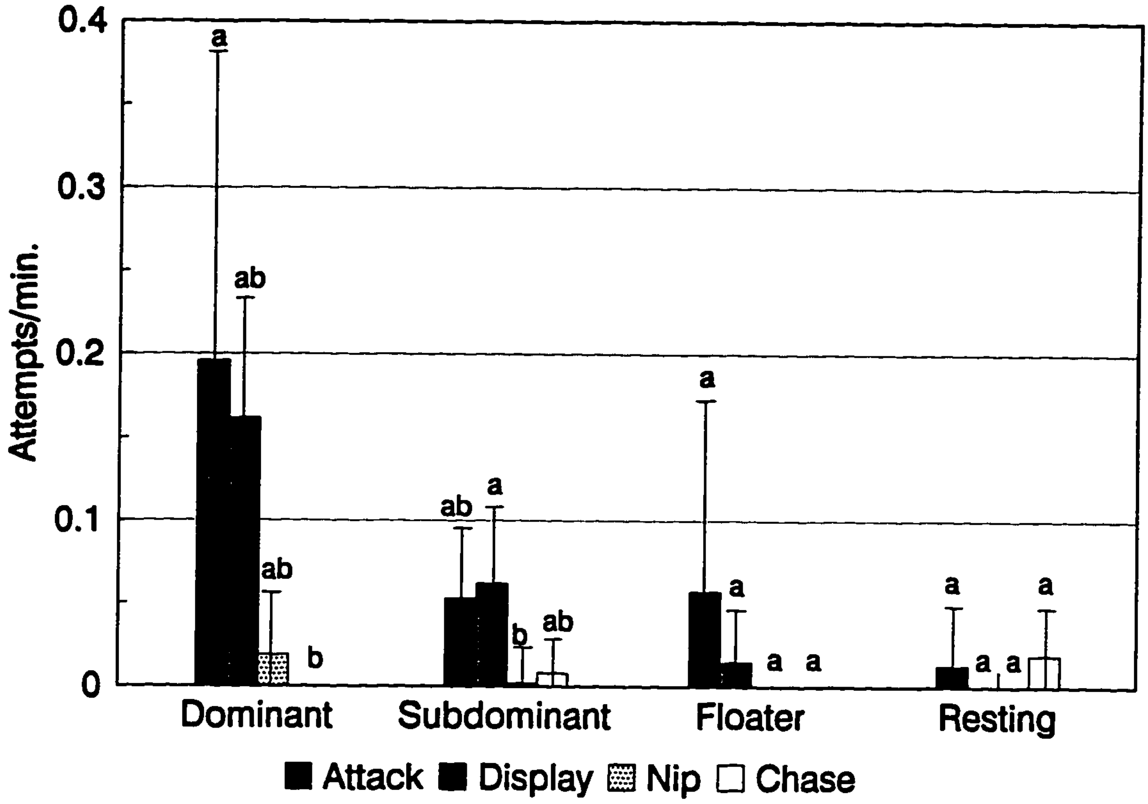

Figure 6.6. Mean (+/- 2 SE) attack, display, nip, and chase aggressive behavior displayed (attempts/min.) by juvenile coho salmon from the dominant, subdominant, and floater behavior classes of the foraging group, and individuals from the resting group during 1993. For each group, bars with different letters are significantly different (ANOVA and Tukey: $P<0.05$).

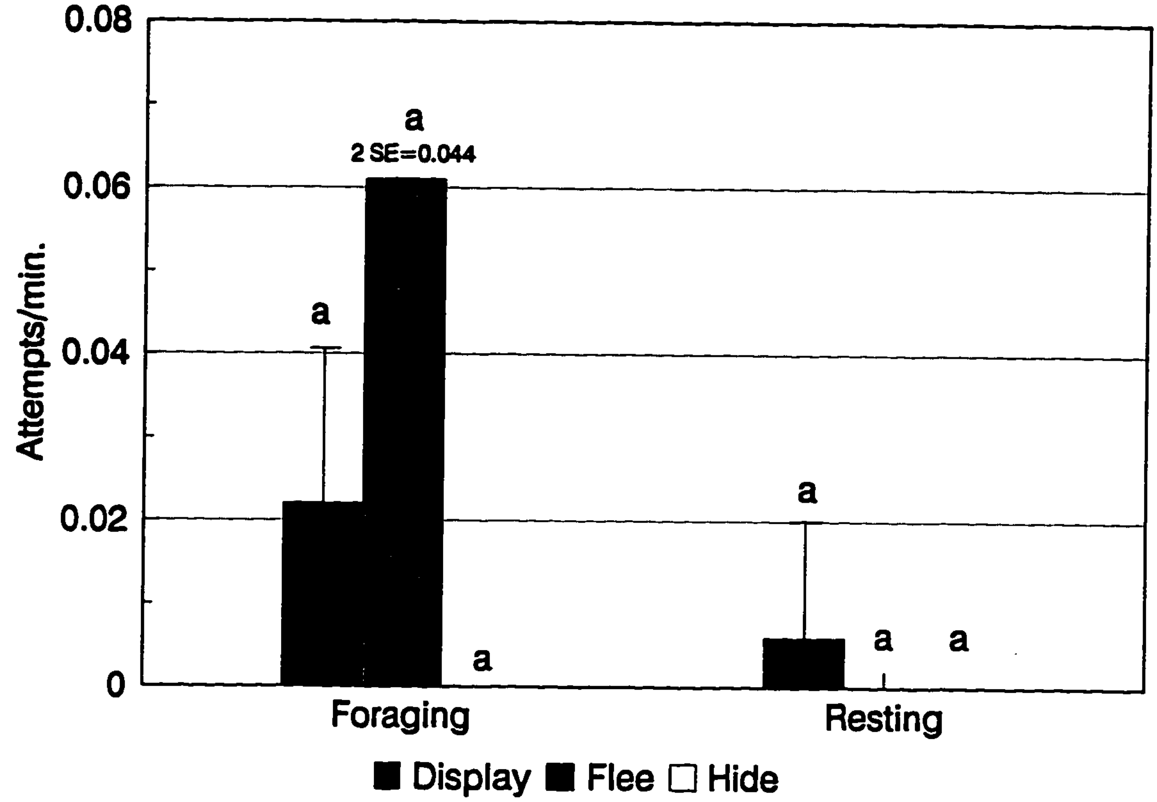

Figure 6.7. Mean (+/- 2 SE) submissive behavior displays, flees, and nips displayed (attempts/min.) by juvenile coho salmon from the foraging and resting groups during 1993. For each group, bars with different letters are significantly different (Two-way ANOVA (foraging group), ANOVA (resting group) and Tukey: $P<0.05$).

Movement

Of the 194 fish marked between 26 July and 2 August, 60 separate individuals were observed between 5 August and 18 August and 34 were observed between 13 September and 24 September. The determination of marked fish observed during snorkeling observations is somewhat suspect. Of 26 marked fish captured for growth evaluation, 5 had been misidentified by the snorkeler. Errors occurred almost exclusively between fish marked with the colors blue and green, and white and yellow. Since some marks may have been misidentified movement information obtained by snorkeling is not presented. Thus, only movement information from fish actually caught during beach and purse seining is reported.

Twenty-seven fish marked during 26 July and 2 August were recaptured between 13 September and 24 September. Fifteen (55.6%) were captured in the station in which they were marked, while the remaining 12 were captured elsewhere. Two of these 12 fish had moved upstream, both approximately 100 to 200 meters, through a riffle with currents exceeding 0.8 m/s. The 10 other fish had moved downstream: four had moved 20 m to 1.5 km, two between 1.5-3.0 km, and four between 3.0-9 km. Six of the fish occupied different habitat types from their original station. Two moved from pools to glides, and one each moved from a glide to a riffle, glide to pool, riffle to glide, and pool to riffle.

Growth

Due to the extensive movement of juveniles, comparisons of population growth rates of coho salmon from woody debris accumulations located in different riverine habitat types or from different station types would be invalid and therefore were not completed. Thus, comparisons of fish size and growth were completed using only data from marked fish caught at the same station where they were marked. The mean weight of fish marked (5.5 g, SD=1.49) at marking stations was greater than unmarked fish (5.0 g, SD=1.57) from the same station (two-way ANOVA: $P=0.0001$). For this reason a nested ANOVA (stations nested) was used to compare coho salmon weights from different stations types (introduced and natural) and habitat types (pool, riffle, glide). There was no difference (nested ANOVA: P=0.1244) in the weight of juvenile coho salmon from introduced (Mean=5.4, SD=1.35) and natural debris (Mean=5.1, SD=1.69) accumulations at the time of marking so the data was combined. Coho salmon in pools (Mean = 5.6, SD = 1.52) in late July and early August weighed more than those in glides (Mean = 5.1, SD = 1.31; Tukey: $P=0.0040$) and riffles (Mean = 4.5, SD = 2.05; Tukey: $P<0.001$), while no difference was found between weights of juvenile coho salmon rearing in glides and riffles (Tukey: $P=0.0640$).

Marked fish averaged 75.2 mm (SD=6.27) and 5.3 g (SD=1.41) during late July when they were marked. Marked fish recaptured in mid-September averaged 74.5 mm (SD = 5.96) and 5.2 g (SD = 1.32) during late July and 89.8 mm (SD=7.15) and 9.0 g (SD=2.12) in mid September. Specific growth rates (%/day) of the fish did not differ (t-test: $P=0.6922$) between introduced (Mean=1.1%/day, SD=0.13) and natural (Mean=1.0%/day, SD=0.08) woody debris accumulations. There was insufficient sample size to compare the growth rate of coho salmon from foraging and resting groups (n=2), or coho salmon rearing in different habitats.

Stomach Analysis

Eighteen marked juvenile coho salmon were caught following the final observation period in September. Of the eighteen, two were from the resting group and two were from unknown behavior groups, since they were not observed during snorkeling. The remaining 14 fish were from the foraging group. This small sample size precluded statistical analysis of this data set, to compare stomach contents of foraging and resting groups, or of coho from different habitat types. Damp weight of stomach contents ranged from 0.0 to 0.394 g (Mean=0.069 g, SD=0.0925), with the two groups from the resting group having stomach contents weighing 0.011 g and 0.085 g, which was within the range of the foraging group. The most common items were exuviae (aquatic insect exoskeletons), ephemeroptera, adult terrestrial insects, chironomidae larvae, and elmidae larvae. Other common invertebrates found included; chironomidae (pupae and adults), trichoptera, plecoptera, other diptera (larvae, adults), hymenoptera, and aracnidae.

DISCUSSION

Two distinct behavior classifications were observed in juvenile coho salmon rearing in the mainstem Clearwater River. Foraging and resting groups of coho salmon showed differences in habitat use and intensity of foraging and aggressive behavior. Foraging groups occupied focal positions with greater current velocities, water depth, and relative depths than resting groups. They also selected focal positions farther from woody debris cover than resting fish in glides, but were closer to woody debris in riffles. Foraging coho salmon generally fed more actively than those from resting groups, primarily foraging in midwater rather than the surface or bottom. Foraging fish were also more aggressive than resting fish with the most noted difference in the frequency of lateral displays. Focal velocities and location of focal positions, relative to depth occupied by juvenile coho salmon in the mainstem Clearwater River were similar to what would have been inferred from other work on coho salmon microhabitat use in small streams (e.g., Dolloff and Reeves 1990; Bugert et al. 1991; Nielsen 1992). Behavior also was similar to that described for coho salmon in small streams (Nielsen 1992).

Although only habitat use was measured in the present study, I assume that much of the information presented also represents habitat preferences. Habitat preferences are normally determined by comparing habitat use to habitat availability, so that habitat selection data can be adjusted according to habitat availability (Bovee 1986). Although habitat availability was not measured in the present study, habitat use was monitored over a wide range of habitat types. A broad range of water depths (0-8 m) and current velocities (0-3.0 m/s) were available for use at the stations we sampled and they included the most extreme cases available throughout most of the river. Areas both with and without woody debris were available at the stations we monitored. Therefore, it seems reasonable to conclude that information presented here represents preferred microhabitat use of juvenile coho salmon in the mainstem Clearwater River given the potential predators and competitors present in this system.

Coho salmon from the mainstem Clearwater River generally used focal velocities (0-0.09 m/s) similar to those reported in the literature (e.g., Sheppard and Johnson 1985; Dolloff and Reeves 1990;

Nielsen 1992). Different behavioral groups occupied a wide range of current velocities. Foraging groups used focal positions with much faster current velocities (0.07 m/s) than resting groups (0.004 m/s). Foraging fish also selected a wide range of focal velocities depending on foraging position and behavior (dominant: 0.09 m/s > subdominant: 0.07 m/s > floaters: 0.02 m/s). Differences in focal velocities selected by juvenile coho salmon displaying dominant, subdominant, and floater foraging behaviors have been observed in small streams (Nielsen 1992, 1994). Focal velocities selected by dominant, subdominant, and floater coho salmon in the mainstem Clearwater River were similar to those reported by Nielsen (1992) for a much smaller stream.

Juvenile coho salmon in the mainstem Clearwater River selected midwater positions within the water column as was observed in small streams (Dolloff and Reeves 1990; Bugert et al. 1991). Although focal depths and water depths were much deeper than those normally reported in small streams (Dolloff and Reeves 1990; Bugert et al. 1991), these differences were likely the result of the greater depths associated with the larger system. The differences observed in focal depth and water depth at the focal position of coho salmon rearing in different habitat types are assumed to be the result of physical differences between the habitats themselves. The greater relative depth used by foraging fish may have been related to the greater distance these fish were from woody debris. Coho salmon in southern Alaska occupied greater relative depths in pools lacking in-stream or riparian cover than those with in-stream or riparian cover (Bugert et al. 1991).

Juvenile coho salmon in the mainstem Clearwater River did not directly orient to woody debris cover. These results support the finding of Fausch (1993) but contradict results reported in Chapter V. These contrasting results are likely the result of habitat selection surveys being completed at different scales. Results presented in this study and by Fausch (1993) were obtained on a microhabitat scale, where habitat variables are measured with reference to the focal position of individual fish. In contrast, results presented in Chapter V were obtained at the macrohabitat scale, which examines the relationship between fish densities and general habitat features (i.e., presence of cover, substrate, current velocities). Differences in results from habitat use experiments conducted at different scales indicate that habitat variables influence habitat use differently at different scales. This emphasizes the importance of completing habitat selection studies at an appropriate scale to fully describe the fish/habitat relationship (Bozek and Rahel 1991).

The influence of woody debris cover on the habitat use by salmonids has been the subject of numerous studies (e.g., Wilzbach et al. 1986; Shirvell 1990; Fausch 1993). Numerous factors can influence habitat use with respect to cover including the presence or absence of predators and competitors (Hartman 1965; Bugert and Bjornn 1991; Abrahams and Healey 1993), food supply (Wilzbach et al. 1986), and current velocities (Shirvell 1990, Fausch 1993). Stream dwelling juvenile salmonids must integrate the importance of each of these factors when selecting rearing habitats (Dill and Fraser 1984). The importance given to each of these factors may influence habitat use differently in different habitats and at different scales. At a macrohabitat scale, woody debris may provide protection from predators (Everest and Chapman 1972; Grant and Noakes 1987; Lonzarich and Quinn 1995). However, at a microhabitat scale, direct association with complex woody debris cover may reduce the foraging efficiency of salmonids (Wilzbach 1985). Thus, while macrohabitat use in areas containing woody debris cover may provide security from intermittent predator attacks (macrohabitat importance), focal positions not directly associated with woody debris, providing better foraging opportunities (microhabitat preference), may outweigh the importance of continuous cover from predators. In habitats with current velocities faster than those preferred, juvenile salmonids may select focal positions near woody debris providing refuge from these currents (macro- and microhabitat preference). Protection from these currents may be more important than potential decreases in foraging efficiency resulting from the close association with complex cover in these areas. In these examples, the cover provided by woody debris may be an intermittent requirement during predator attacks or a continuous requirement in areas with extreme current velocities. The observation of coho salmon fleeing into woody debris cover (up to 3 m away) to avoid predators (otter, mergansers, and cutthroat trout) on several occasions during this study supports this concept. Bugert and Bjornn (1991) also observed coho salmon, not directly associated with woody debris, fleeing into woody debris cover in response to predators.

Differences in distance to woody debris cover between resting and foraging groups and between foraging groups in different habitats are likely the result of differences in foraging benefits, refuge from current velocities, and perceived risks of predation associated with these different behaviors and habitats. The relatively close proximity of juvenile coho salmon to woody debris cover in pools suggests that the perceived risks of predation are high, food supplies are not significantly different at differing distances from woody debris, or foraging efficiency is not reduced by complex cover in this habitat. In most cases, current velocities in pools of the Clearwater River are equal to, or less than, the preferred velocities of coho salmon. Thus, woody debris in pools likely does not provide refuge from current velocities on a continuous basis. Large trout were most commonly associated with pool habitats. Pools were also frequented by mergansers, kingfishers, and river otters. However, these terrestrial predators were also present in glides, where foraging coho salmon were generally located farther from woody debris. These differences may be the result of different frequencies of predator presence or food abundance in these habitats. No information is available regarding frequencies of predator presence or food availability in these two habitats. However, food transport should be greater in the faster current velocities associated with glides.

The close proximity of foraging juvenile coho salmon to woody debris in riffles was likely a response to high current velocities (McMahon and Hartman 1989; Shirvell 1990; Fausch 1993).

Foraging coho salmon were generally downstream or in current breaks provided by woody debris accumulations. Refuge from fast currents likely was more important than possible reduction in foraging success as a result of woody debris complexity (Wilzbach 1985). Food would be expected to be abundant in riffles due to steady transport in the high currents which may result in higher priority being given to refuge from extreme current velocities.

In contrast to foraging fish, resting fish were closely associated to woody debris in pools and glides, but not in riffles. Differences in distance of focal positions from woody debris may have been related to interspecific competition, food abundance, desire to forage, or willingness to risk predation. Foraging fish displayed more aggressive behavior than resting fish, suggesting that interspecific competition between these groups may have resulted in different distances of focal positions to woody debris cover.

Although food abundance was not measured in the present study, one would expect it to be greater in the faster current areas selected by foraging coho salmon than the slower areas use by resting coho salmon. Assuming competition did not determine habitat use of resting fish, these fish may have a somewhat reduced desire to forage than foraging fish. The different levels of aggressive behavior observed between these two groups may simply be the result of the greater desire of foraging fish to forage, which results in increased aggression towards perceived competitors (Dill and Fraser 1984) than would be the case with resting fish.

Differences in foraging intensity may result from differences in food availability or satiation of fish. If food abundance was reduced during certain periods of the day or the fish became satiated, coho salmon may have used focal positions in slower current velocities near cover. These areas would require less energy to maintain position and would provide better protection from predators (likely important to non-foraging fish).

Stream dwelling salmonids often move from foraging positions to slower waters, apparently as a result of satiation (Bachman 1984; Nielsen 1992). If this were the case for resting fish observed in the Clearwater River, one would expect resting fish to have fuller stomachs than foraging fish. However, the limited stomach samples collected in the present study did not support this conclusion. Both stomach samples from resting coho salmon contained prey weights within the range observed for foraging coho salmon. Twenty-five percent of the sixteen foraging fish sampled had total prey weights greater than one of the resting fish and seventy-five percent of the sixteen foraging fish had total prey weights greater than the second resting fish. These very limited observations suggests that the two resting fish were not satiated. Thus, either food abundance and/or other alteration of foraging desire in foraging fish, both of which may reduce a fish's willingness to risk predation, is responsible for differences in distances of focal positions of foraging and resting fish from woody debris cover. However, since food abundance was not measured in the present study, strong conclusions cannot be drawn.

The classification of foraging coho salmon as dominant, subdominant, and floaters in this study may not accurately reflect all behavior of coho salmon in this study. Wild coho salmon smolts form aggregates near woody debris in the lower reaches of Carnation Creek and its estuary (McMahon and Holtby (1992). Aggregates have been defined by Cunjak and Power (1986) as a close associated group of fish displaying common behavior but lacking the spatial homogeneity and polarity of schooling fish. Coho salmon in the present study seemed to form aggregates in areas with slower currents and with large areas of available space (pools and glides). In areas with faster current velocities and limited habitat availability (riffles and glides) they appear to form hierarchies. However, recognition of the differences between these two groups was not readily apparent until a substantial amount of behavioral data had been collected. It is likely that dominant and subdominant coho salmon observed in pools and glides during the present study represent aggregate coho salmon, while those observed in riffles represent social hierarchies. The separation of these groups cannot be done accurately with the data collected and elimination of data collected prior to the recognition of aggregates would weaken the statistical power of data presented. Some schooling behavior (one group of fish) also was observed during marking surveys used to monitor wall-base channel immigration (Chapter IV).

An understanding of fish behavior is important for successful habitat restoration/enhancement activities. Coho salmon displayed different behavior and these behavioral groups used significantly different habitats in this study. The extent of these differences were somewhat influenced by river habitat type. Habitat rehabilitation/enhancement efforts should be planned to provide rearing areas for all behavioral groups present in the area. Woody debris introductions in the mainstem Clearwater River would provide sufficient habitat for coho salmon in this system. Placement of woody debris should be such that areas on the outer edge and upstream of the woody debris possess current velocities used by foraging groups in the present study, to insure that foraging locations are available. Woody debris placements should also provide areas of slack water within the structure to provide habitat for resting groups of fish.

CHAPTER VII

General Discussion

Coho fry supplementation resulted in 19% and 89% increases in coho salmon summer rearing densities, however, these increases were not statistically significant. Statistical significance was not attained largely due to inherent differences between groups of study streams selected to receive different treatments (supplemented and controls). The result reduced statistical power and increased the likelihood of concluding that treatment groups are similar when they are actually different. In contrast, introducing woody debris bundles to the mainstem resulted in significant increases in coho salmon summer rearing densities. Wood debris was the most important factor determining coho salmon distribution and abundance was positively influenced by debris density (no. accumulations per kilometer of river), debris size, and complexity. However, the addition of woody debris to the mainstem did not result in significant increases in the number of coho salmon immigrating into wall-base channel ponds during the fall. Based on summer rearing densities in the areas of the mainstem and the tributaries we surveyed, as well as emigration of coho salmon from these tributaries, insufficient spawners seems to be the primary limiting factor to coho salmon production in this system. Emigration of coho salmon from the tributaries we sampled and summer rearing densities in the mainstem were low during years with poor escapement and increased as escapement increased. Lack of mainstem rearing appears to be limiting only during years when spawners are abundant.

The effect of stocking hatchery-reared coho fry (coho fry supplementation), obtained from a native broodstock, on total emigration, emigration timing, summer densities, and growth of wild coho fry and native trout was evaluated in six study streams. Stocking hatchery-reared coho fry (0.6-1.0 g) did not result in significant increases in the total number of wild coho fry and cutthroat trout emigrating from streams as compared to control streams. However, the strong relationship between numbers of wild coho fry emigrating from streams and early summer (June) rearing densities (fry/m^2) did not exist in supplemented streams. Wild coho fry emigration in control streams increased as early summer rearing densities increased. Conversely, wild coho fry emigration in supplemented streams was higher when early summer rearing densities were low and lower as early summer rearing densities increased. Cutthroat emigration was not influenced by early summer rearing densities of cutthroat trout in control streams; however, emigration increased as rearing densities increased in supplemented streams.

Contradictory evidence was obtained regarding the influence of coho fry supplementation on wild coho fry, cutthroat trout, and steelhead trout emigration timing. Emigration timing of wild coho fry and steelhead trout increased during one year, but not the other; while that of cutthroat trout was decreased one year, but not the other. The effect of groups of study streams receiving different treatments (supplemented and controls) on the emigration timing of wild coho fry may have masked any impacts of stocking hatchery-reared coho fry may have had on the emigration timing of wild coho fry.

Hatchery-reared coho fry emigrated much sooner than wild coho fry. The early emigration of hatchery-reared coho salmon fry and potential impacts of stocking hatchery-reared coho fry on wild coho fry emigration is hypothesized to be a primary cause of past failures of coho fry supplementation programs.

Coho fry supplementation (3 fish/m^2-based on summer low flow) during the spring (May 1-3) did not result in statistically significant increases in coho salmon summer rearing densities, although increases of 19% and 89% were observed. Non-significant results were likely caused by inherent differences in rearing potential of groups of study streams receiving different treatments, differences in natural seeding levels, and a major August freshet which compromised the original study design, resulting in reduced statistical power. The reduced power of the tests required two- to three-fold increases in coho fry rearing densities to occur for statistically significant ($\alpha=0.05$) results to be obtained 75% of the time. Chances of not rejecting the hypothesis that densities were increased (or wild densities decreased) when the hypothesis is false are increased as a result of low statistical power. Stocking hatchery-reared coho salmon fry did not appear to reduce wild coho fry densities (28% lower for one comparison, 13% greater the next) at summer low flow, although complete eradication of wild coho salmon would have been required for statistical significance. Cutthroat trout densities were unaffected by coho fry supplementation. The final size attained by wild coho salmon was significantly smaller in supplemented than control streams. This reduced size apparently resulted from reduced growth between the time coho fry were stocked (early May) and the first sampling period (late June), since differences were observed during this survey. This was probably caused by extreme rearing densities observed in supplemented streams, especially during 1991. However, the relative growth rate of wild coho salmon between June and August did not appear to be reduced by coho fry supplementation. Relative growth rates of wild coho salmon were greater than those of hatchery coho salmon and were influenced to a greater degree by increasing rearing densities than hatchery coho fry. Cutthroat trout growth was not reduced by stocking hatchery-reared coho fry.

Introducing evergreen tree bundles into the relatively large mainstem Clearwater River (mean discharge = 39 m^3/s) increased coho salmon summer rearing densities. Summer rearing densities were positively related to woody debris densities (number/km) in the study reaches examined. Although rearing densities may be increased through woody debris introductions, this did not appear to increase immigration of coho salmon into wall-base channels, which provide overwinter habitat for a significant proportion of coho salmon in this basin. This restoration technique appears to rely on adequate numbers of spawners to fully seed available habitat in this basin. Mainstem rearing densities were positively correlated to years with the greatest spawner escapements and subsequent emigration of coho fry from tributary streams during the spring.

The effect of woody debris on the distribution of summer rearing juvenile coho salmon in the mainstem Clearwater River was assessed by estimating coho salmon abundance in areas with and without woody debris. The effect of physical habitat variables on coho salmon abundance near woody debris, such as woody debris size and complexity, riverine habitat, substrate, water depth, and velocity were evaluated individually using one- or two-way analysis of variance, analysis of covariance, and linear regression models. General linear modelling was used to determine which combination of variables explained the greatest amount of variability in estimated coho salmon abundance at the stations sampled.

The presence of woody debris was the most important variable influencing summer rearing distribution of juvenile coho salmon in the mainstem Clearwater River. Similar numbers of juvenile coho salmon were observed at introduced and natural woody debris accumulations, while significantly fewer (zero in most cases) were observed in areas lacking woody debris. Juvenile coho salmon preferred large, dense structures in pool habitats to a greater degree than small, sparse structures, although woody debris structures in glide habitats also were frequently used by large numbers of juvenile coho salmon. Debris surface area and density were the most common variables included in general linear models and explained a majority of the variability in estimated coho salmon abundance at the stations sampled. Riverine habitat (pool, glide, riffle) and an interaction term between debris surface area and riverine habitat were also common variables included in general linear models. The positive influence of debris surface area on coho salmon abundance was generally greater in pools than in glides or riffles. Coho salmon abundance was generally positively correlated with depth, however, the influence was only occasionally significant. In contrast to findings from small streams, coho salmon abundance was not influenced by velocity. However, large variability in estimated coho salmon abundance and the influence of other variables (i.e., debris density and surface area) may have overshadowed the significance of velocity. Future habitat enhancement efforts in the mainstem Clearwater River should focus on the placement of large, dense woody debris in pools.

The microhabitat distribution and behavior of summer rearing juvenile coho salmon in the mainstem Clearwater River were examined using snorkeling. Two distinct behavior patterns (foraging and resting) were observed in juvenile coho salmon rearing in the mainstem Clearwater River. Foraging coho salmon foraged more actively and displayed more social behavior, while resting fish generally displayed little foraging or social behavior. Foraging and resting fish differed in habitat use and intensity of foraging and agonistic behaviors. Foraging coho salmon occupied faster water than resting coho salmon (0.07 vs. 0.004 m/s) and were generally in deeper water and deeper in the water column than resting fish. Coho salmon in the mainstem Clearwater River usually were not directly associated with woody debris cover; however, distance from woody debris varied with behavior classification and habitat type. Foraging fish were farther from woody debris cover than resting fish in glides, but resting fish were farther from woody debris cover than foraging fish in riffles. Foraging fish were more active, exhibiting more frequent aggressive and submissive behaviors than resting fish.

Different conclusions regarding the influence of woody debris on coho salmon habitat use in the mainstem Clearwater River were reached from surveys conducted at different scales (macrohabitat and microhabitat), emphasizing the importance of completing habitat selection studies at the appropriate scale and reporting that scale. These differences (e.g., preference for woody debris and no effect of current velocity at the macrohabitat scale and no direct association with woody debris and obvious preferences for specific current velocities at the microhabitat scale) are likely the result of 'choices' made by juvenile coho salmon risking exposure to predators to meet foraging requirements. At the macrohabitat scale woody debris is likely an important feature for predator avoidance. On several occasions during this study, juvenile coho salmon were observed fleeing to cover provided by woody debris from foraging locations up to 5 m away to avoid predator attacks (river otters, mergansers, and cutthroat trout). The intermittent nature of these attacks likely results in use of foraging areas not directly associated with woody debris cover, which would increase foraging efficiency. This is supported by observations of resting fish more closely associated with woody debris in glides and pools than foraging fish. Resting fish should be unwilling to risk exposure to predators, and would be closer to cover. However, resting fish were farther from woody debris than foraging fish in riffles. This may have been the result of displacement of resting fish by more competitive foraging individuals. Most foraging locations in riffles are in current breaks provided by woody debris, which would concentrate foraging individuals near woody debris. Non-foraging fish would occupy valuable foraging sites if they remained near woody debris in riffles and may be temporarily displaced by the more aggressive foraging individuals.

Mainstem habitat enhancement through the introduction of woody debris appeared to be more successful in increasing coho salmon summer rearing densities than coho fry supplementation. However, greater escapement and/or production from spawners are needed in the system for mainstem habitat enhancement to be effective. Mainstem habitat appeared to rely on emigration from tributaries, which was density dependent. Therefore, mainstem enhancement will have limited effects unless production is increased by increased spawner escapement or in conjunction with coho fry supplementation. Coho fry supplementation could result in increases in coho salmon production; however, supplementation must be completed in conjunction with accurate spawner escapement estimates. Potential negative impacts to wild coho fry increase with increasing rearing densities. Therefore, supplementing streams that already have good natural production should be avoided. Concurrent and coordinated use of mainstem habitat enhancement and coho fry supplementation in streams lacking spawners, or with very low spawner densities, provide the best opportunity for restoring coho salmon production in the Clearwater River Basin.

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APPENDIX A: Operation dates of fry traps in study streams during 1991-1993.

Table A.1. Dates of operation for spring fry traps in 6 streams within the Clearwater River system during 1991-1993.

Stream	Trap Installed	Trap Removed	Dates not Fishing
1991			
Bull	4/27	8/5	5/8-10, 5/30
Hunt	4/24	8/21	5/8-9, 5/13, 7/7, 8/6-9
0042	4/27	8/21	5/8, 8/9
Elkhorn	4/27	8/21	none
Peterson	4/27	8/21	7/12-13; 8/6-14
Prairie	4/27	8/21	5/8; 5/27; 6/16-17; 6/27-28; 8/6-9
1992			
Bull	4/2	8/27	4/8, 4/16-22, 4/27, 4/29-5/2
Hunt	4/4	8/28	4/14, 4/16-20, 4/27-5/1, 5/16
0042	4/1	9/1	4/16-19, 4/28-30
Elkhorn	4/2	9/1	4/16-19, 4/30, 5/23
Peterson	3/31	9/1	4/16-20, 4/27, 4/29-5/1, 7/18, 7/21, 7/25, 7/30-8/6
Prairie	4/1	8/27	4/17-19, 4/27-5/1, 5/20
1993			
Bull	4/21	8/1	4/23-5/3, 5/22, 5/31-6/2, 6/10-12
Hunt	4/19	8/1	4/24-5/4, 5/8, 5/21-23, 5/31-6/2, 6/9-12, 6/14-16
0042	4/22	8/1	4/24-5/4, 5/9, 5/21, 6/9-12, 6/14-16
Elkhorn	4/20	8/1	4/27-5/3, 6/10-12
Peterson	4/22	8/1	4/24-5/3, 6/1, 6/9-12
Prairie	5/3[a]	8/1	5/21, 6/1, 6/9-15, 6/30[b]

[a] Trap installed 4/20, however, high water prevented operation.

[b] Trap not fishing due to low water.

APPENDIX B: Regression of the number of fry consumed and by coho smolts, cutthroat and steelhead trout of different lengths in the live box.

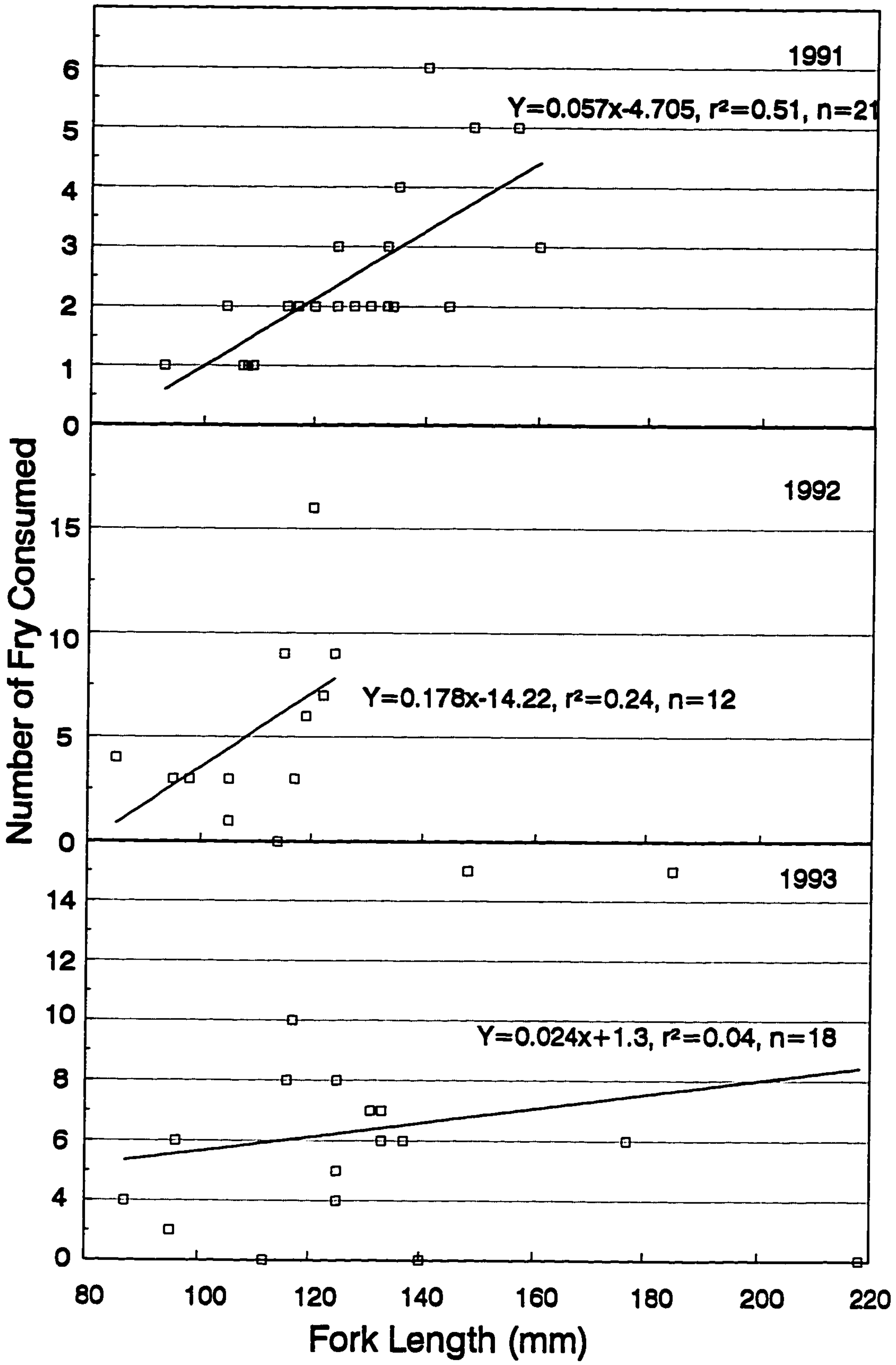

Figure B.1 Regression of the number of coho salmon fry consumed in the live-box by cutthroat trout, steelhead trout, and coho smolts of different length during 1991-1993.

APPENDIX C: Emigration pattern of wild and hatchery-reared coho salmon fry and smolts and cutthroat and steelhead trout.

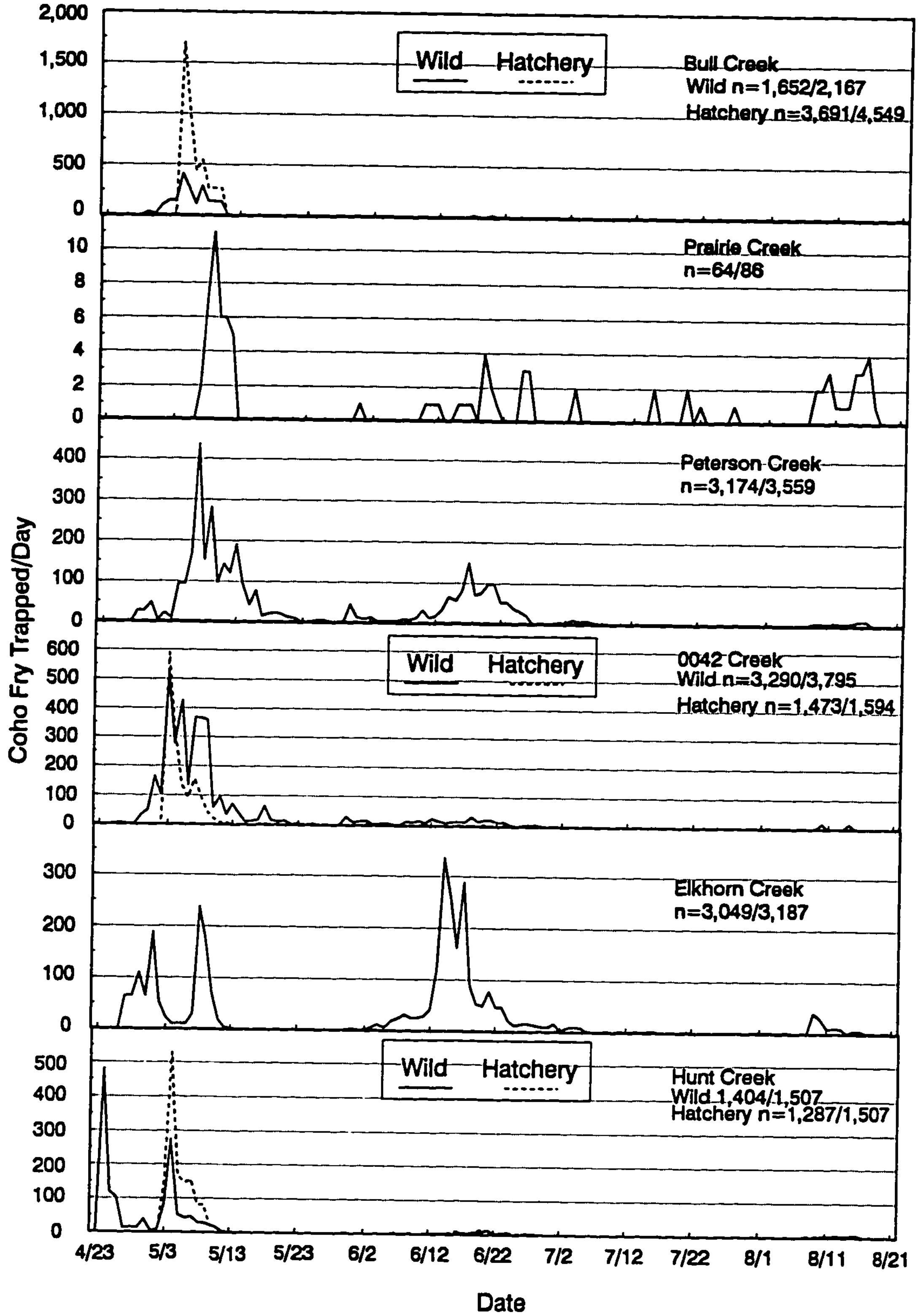

Figure C.1. Daily emigration of wild and hatchery-reared wild coho salmon fry from six tributaries of the Clearwater River, 1991. Numbers (n) in the upper right hand corner of each graph represents actual catch/estimated number of emigrants.

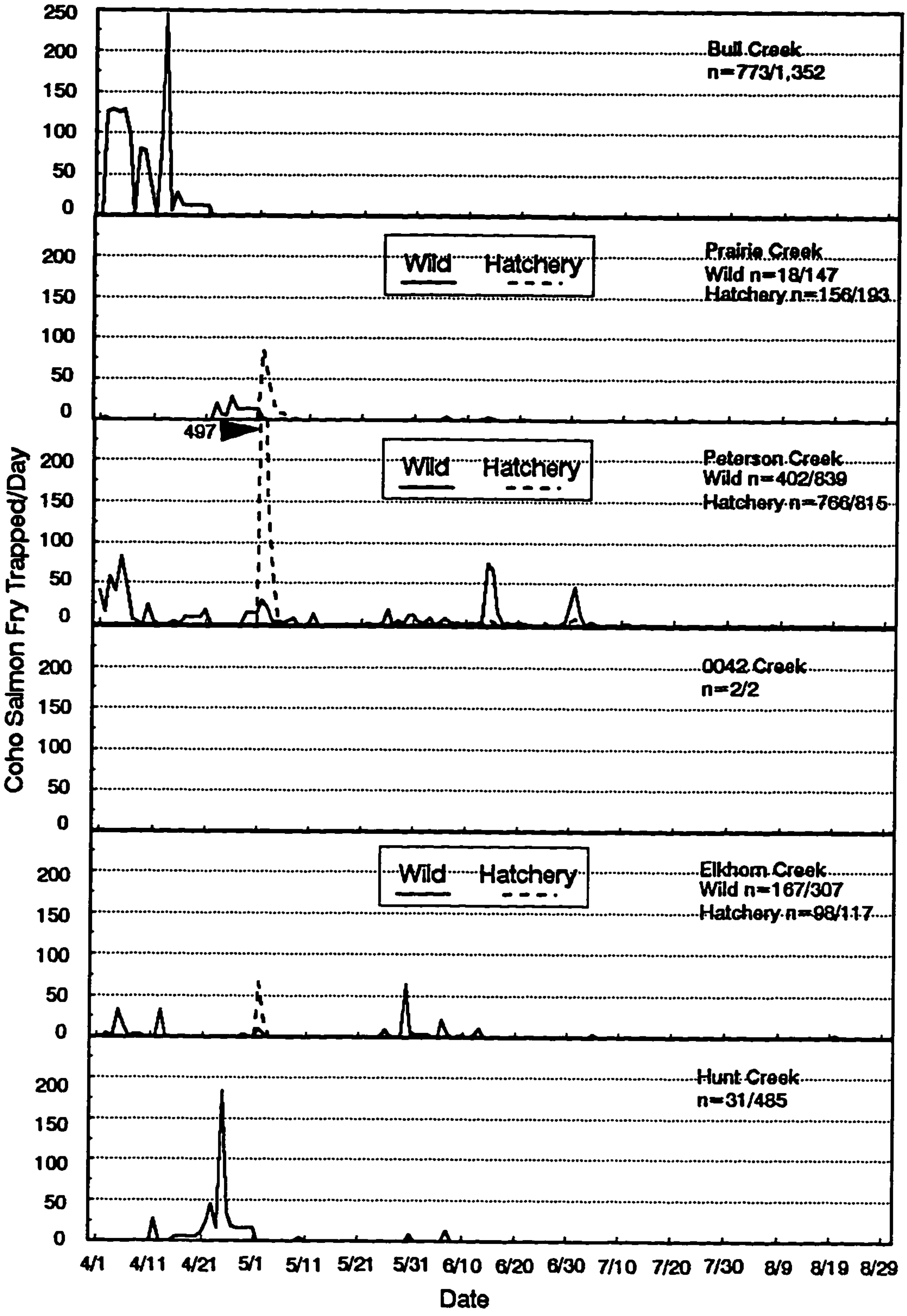

Figure C.2. Daily emigration of wild and hatchery-reared wild coho salmon fry from six tributaries of the Clearwater River, 1992. Numbers (n) in the upper right hand corner of each graph represents actual catch/estimated number of emigrants.

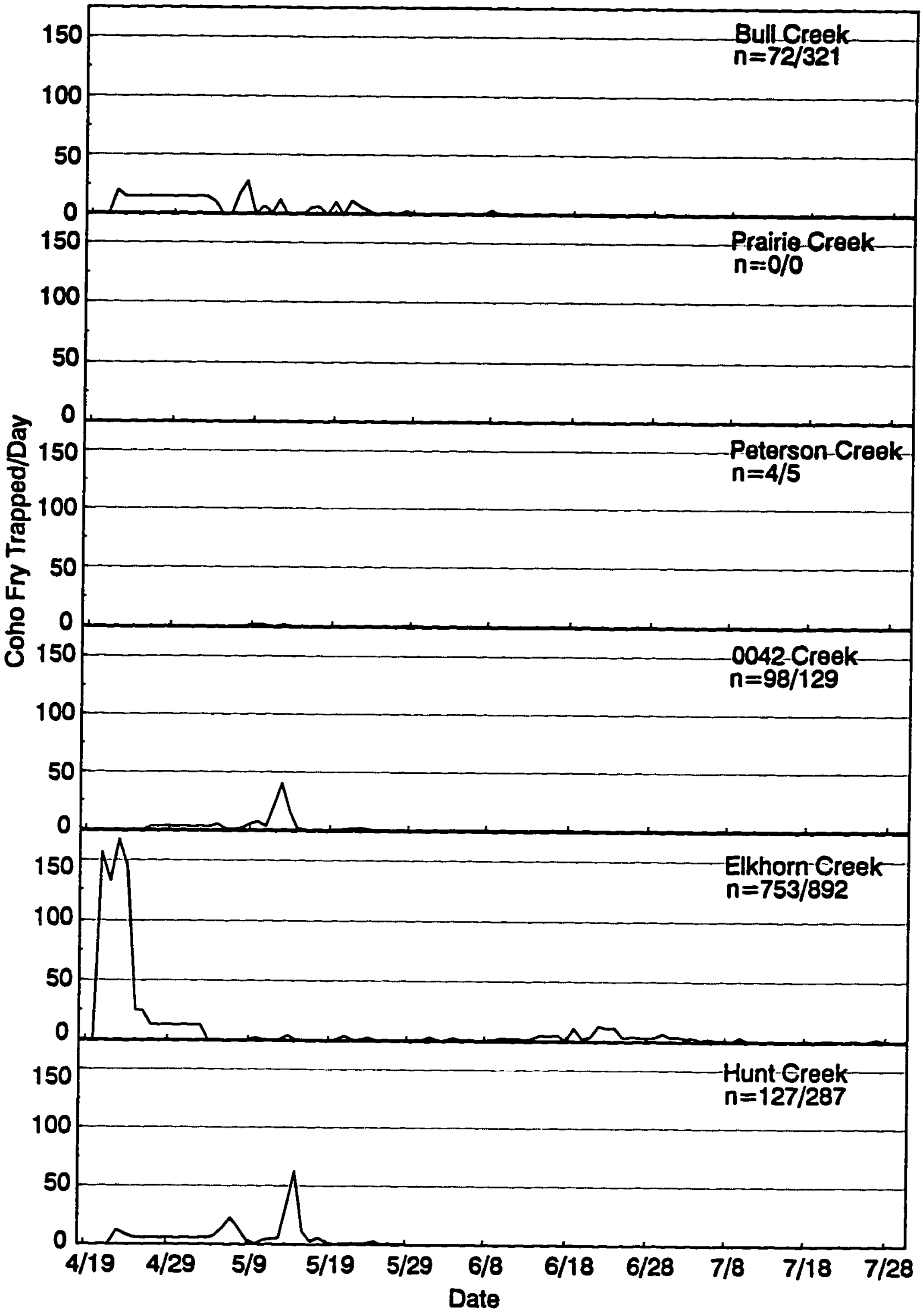

Figure C.3. Daily emigration of wild coho salmon fry from six tributaries of the Clearwater River, 1993. Numbers (n) in the upper right hand corner of each graph represents actual catch/estimated number of emigrants.

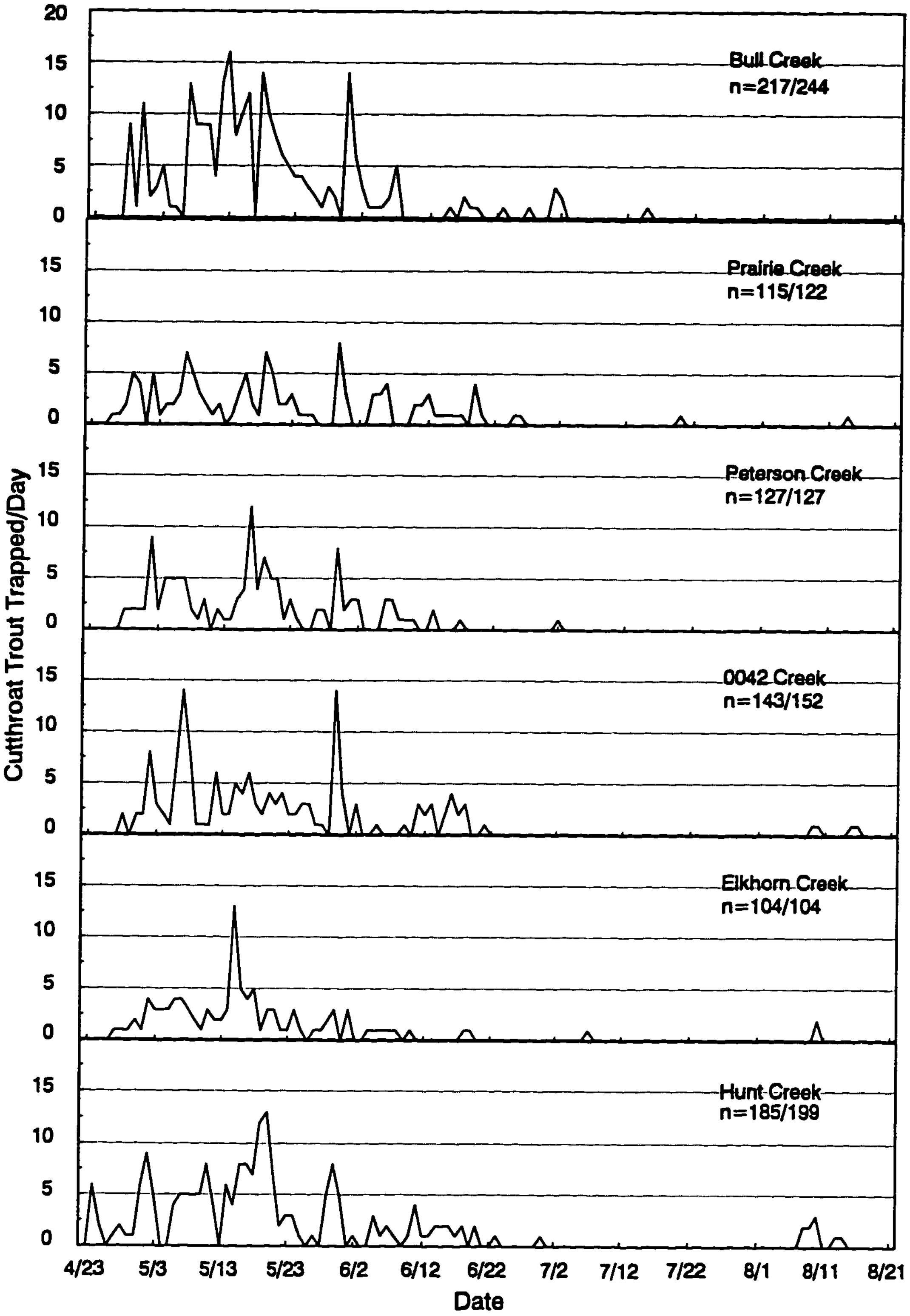

Figure C.4. Daily emigration of cutthroat trout from six tributaries of the Clearwater River, 1991. Numbers (n) in the upper right hand corner of each graph represents actual catch/estimated number of emigrants.

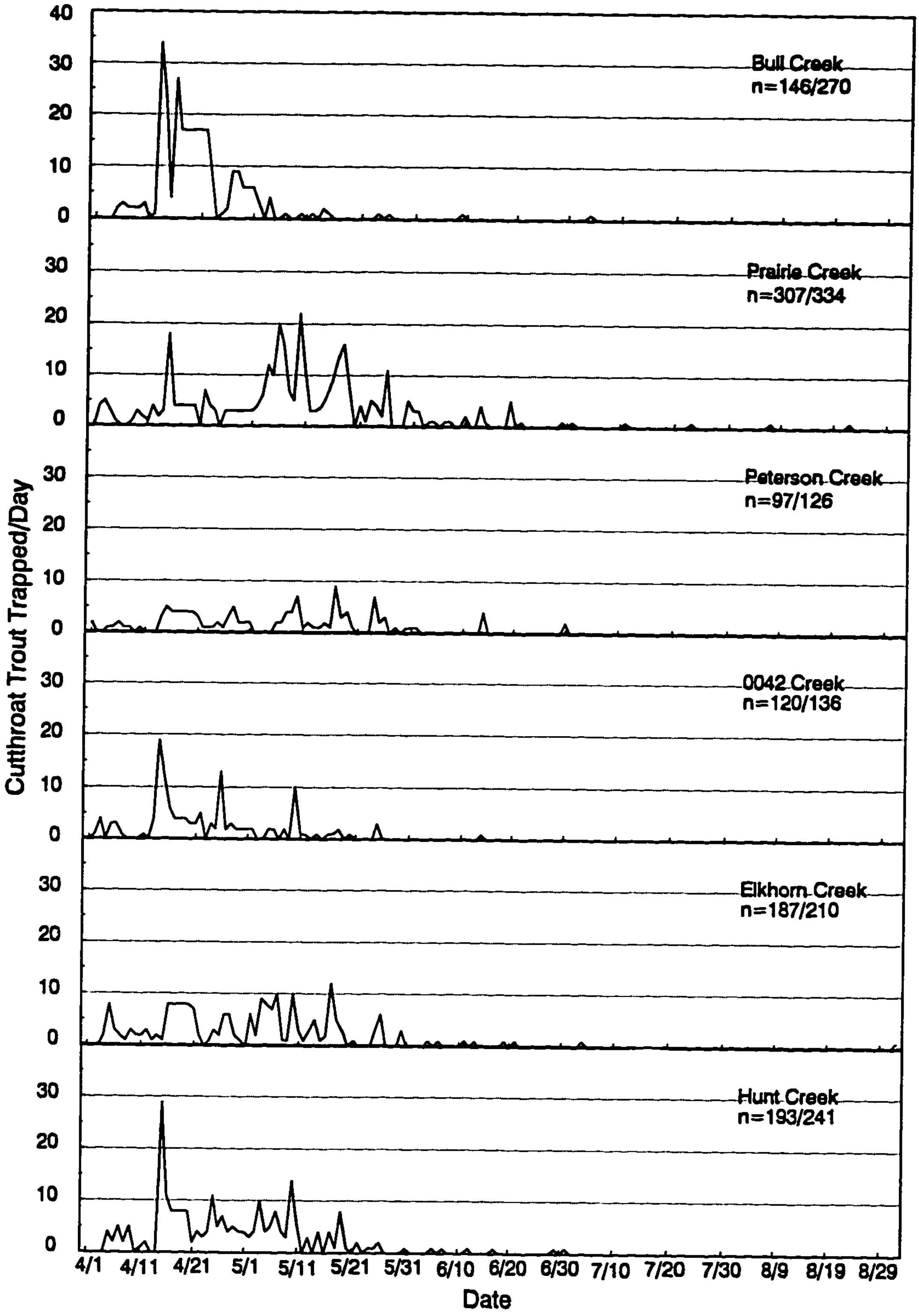

Figure C.5. Daily emigration of cutthroat trout from six tributaries of the Clearwater River, 1992. Numbers (n) in the upper right hand corner of each graph represents actual catch/estimated number of emigrants.

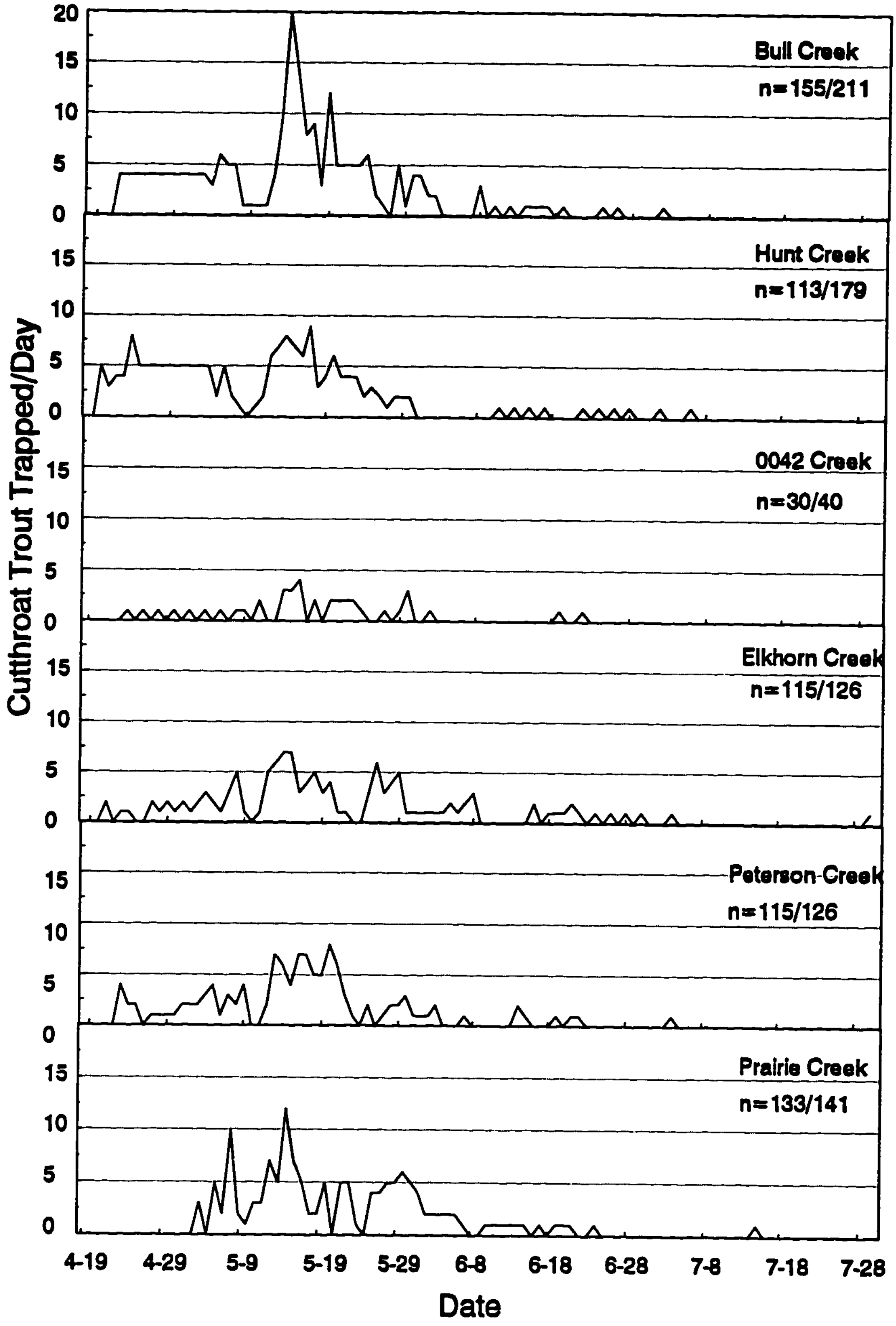

Figure C.6. Daily emigration of cutthroat trout from six tributaries of the Clearwater River, 1993. Numbers (n) in the upper right hand corner of each graph represents actual catch/estimated number of emigrants.

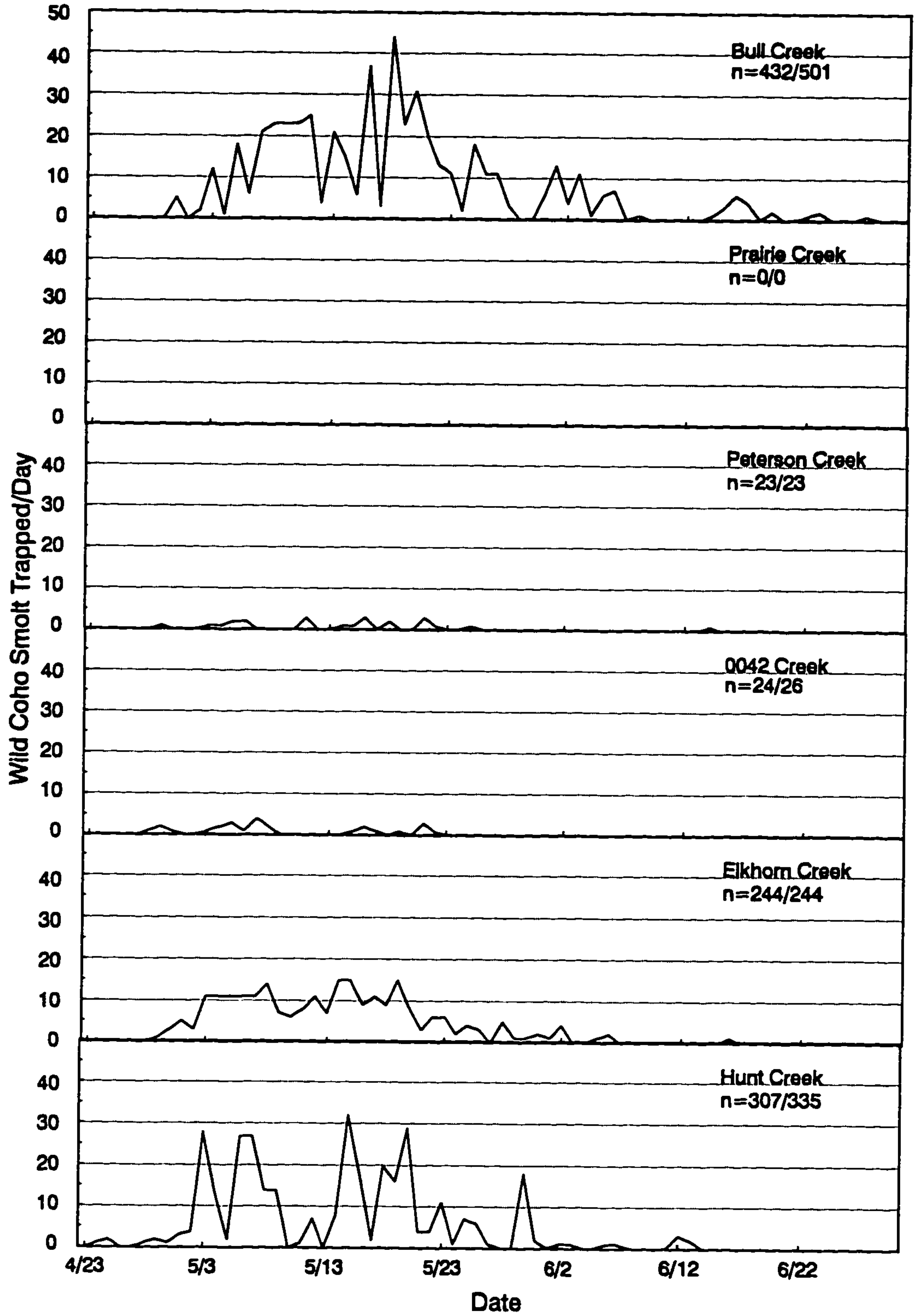

Figure C.7. Daily emigration of wild coho salmon smolts from six tributaries of the Clearwater River, 1991. Numbers (n) in the upper right hand corner of each graph represents actual catch/estimated number of emigrants.

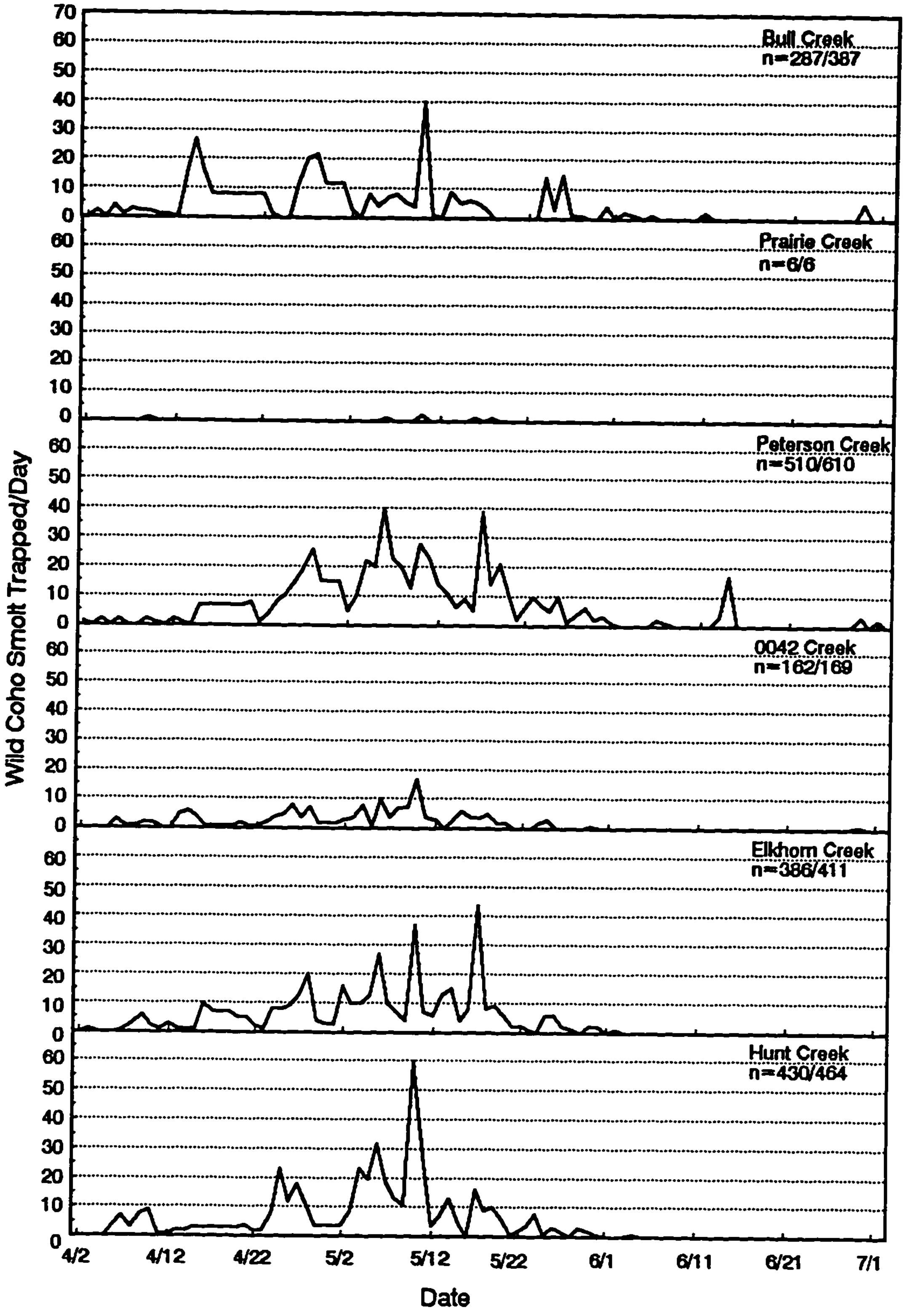

Figure C.8. Daily emigration of wild coho salmon smolts from six tributaries of the Clearwater River, 1992. Numbers (n) in the upper right hand corner of each graph represents actual catch/estimated number of emigrants.

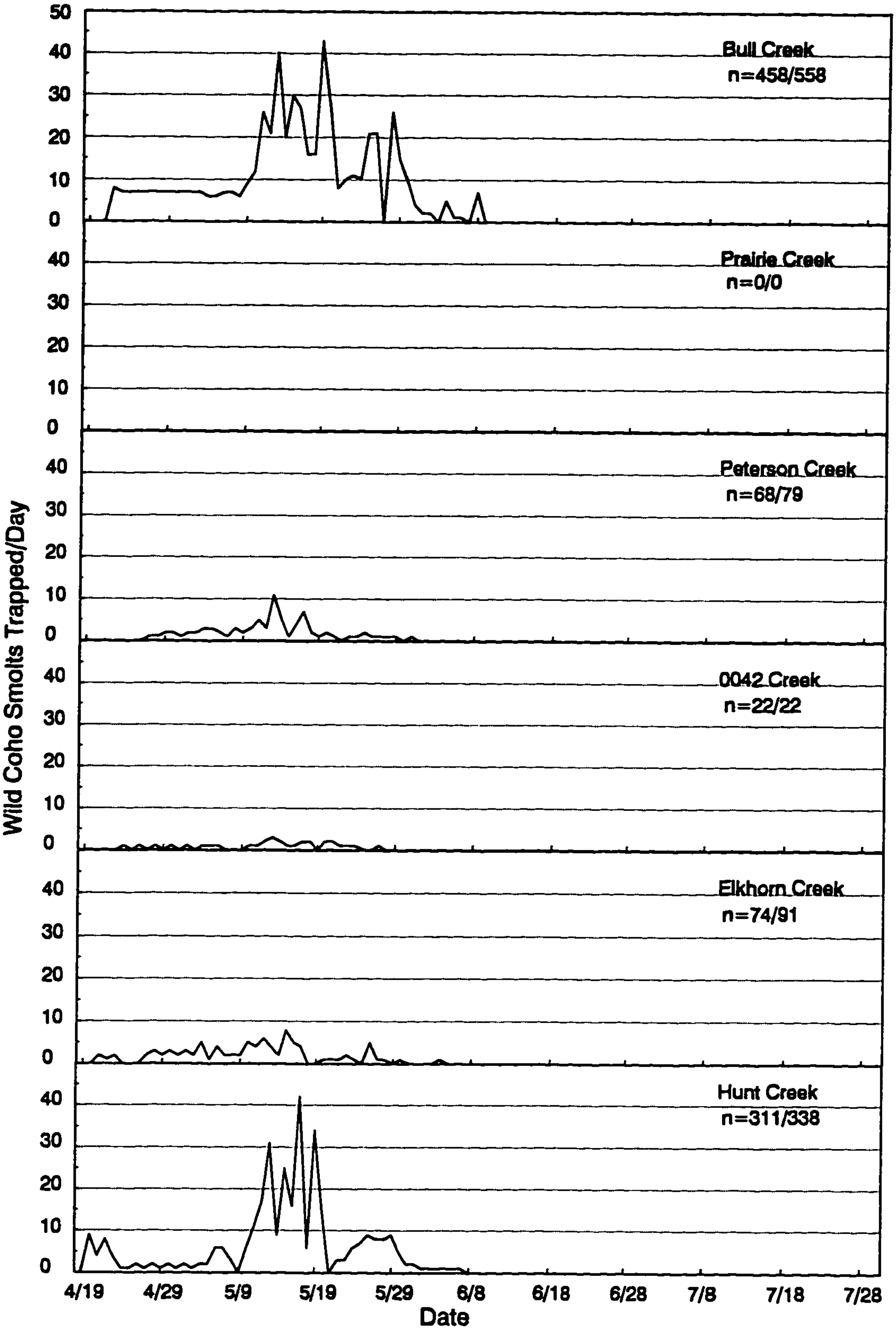

Figure C.9. Daily emigration of wild coho salmon smolts from six tributaries of the Clearwater River, 1993. Numbers (n) in the upper right hand corner of each graph represents actual catch/estimated number of emigrants.

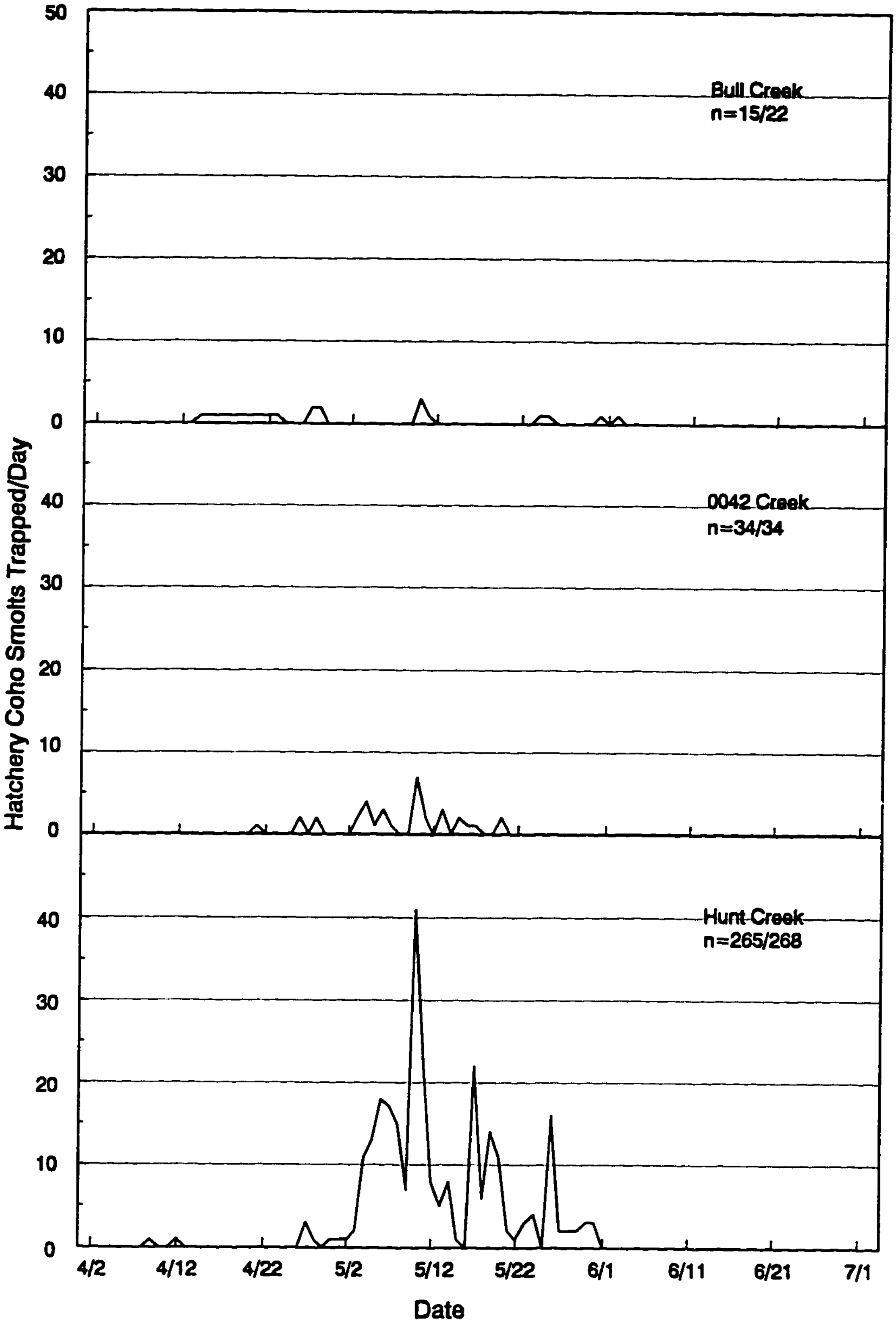

Figure C.10. Daily emigration of hatchery-reared wild coho salmon smolts from six tributaries of the Clearwater River, 1992. Numbers (n) in the upper right hand corner of each graph represents actual catch/estimated number of emigrants.

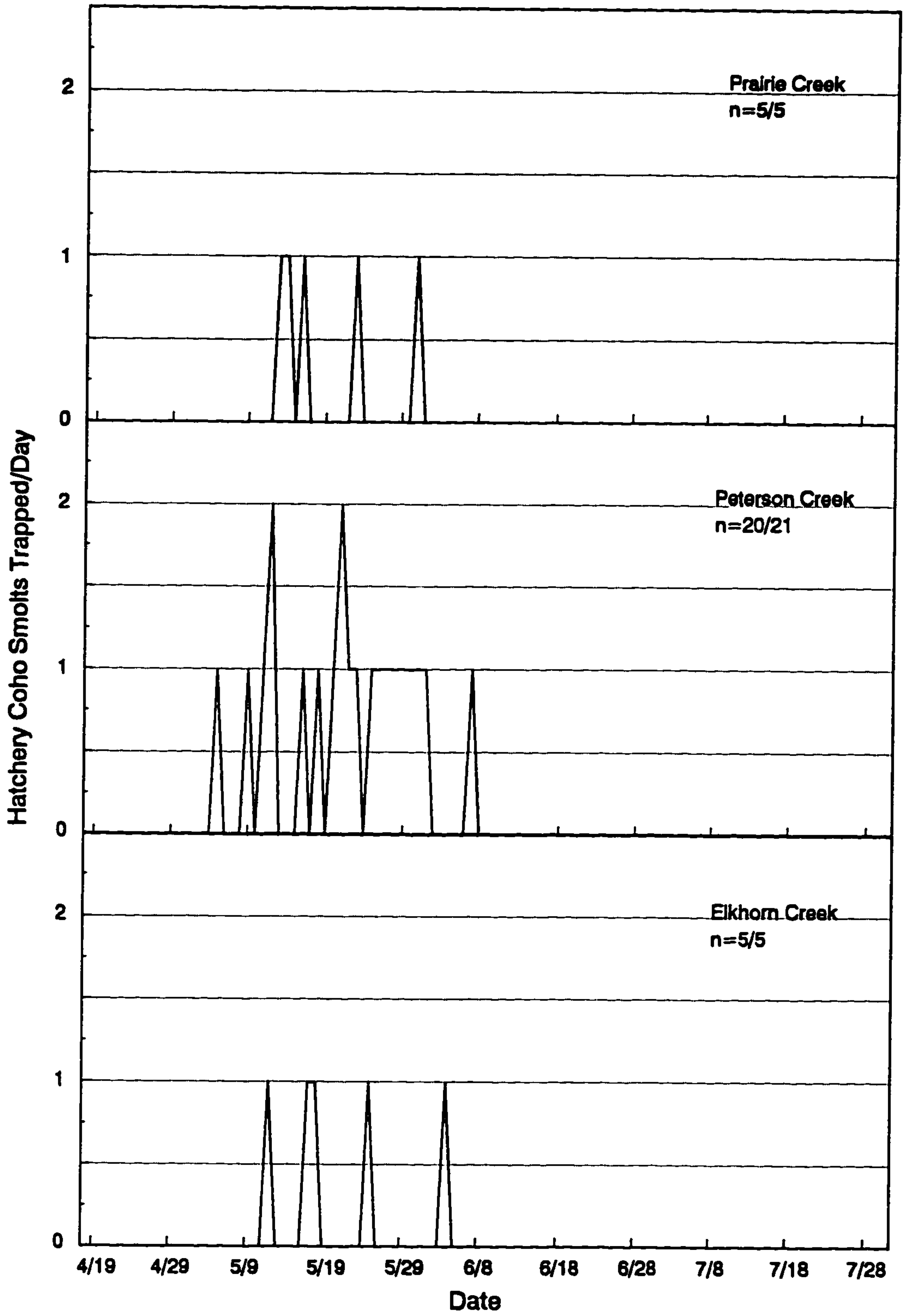

Figure C.11. Daily emigration of hatchery-reared wild coho salmon smolts from six tributaries of the Clearwater River, 1993. Numbers (n) in the upper right hand corner of each graph represents actual catch/estimated number of emigrants.

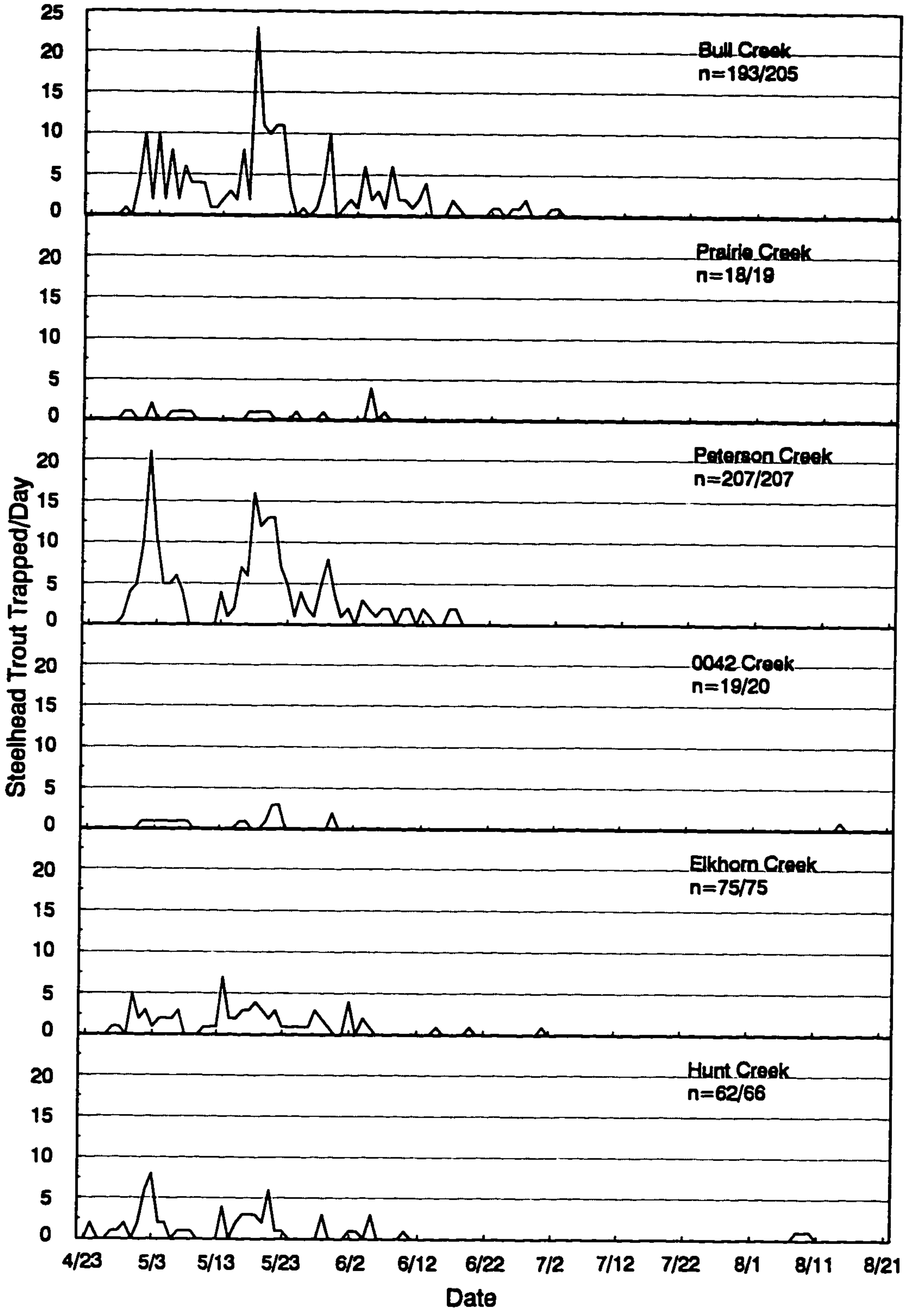

Figure C.12. Daily emigration of steelhead trout from six tributaries of the Clearwater River, 1991. Numbers (n) in the upper right hand corner of each graph represents actual catch/estimated number of emigrants.

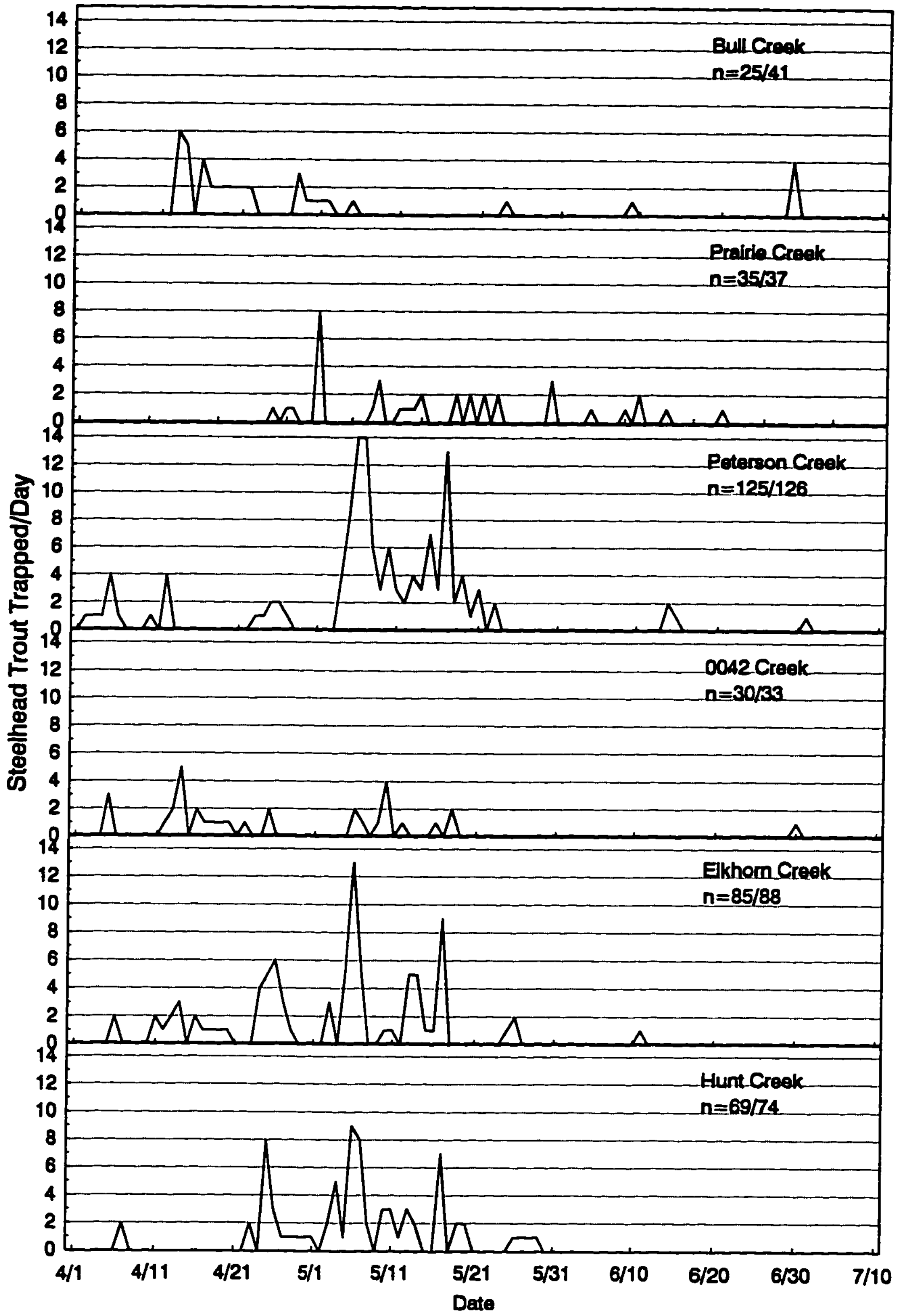

Figure C.13. Daily emigration of steelhead trout from six tributaries of the Clearwater River, 1992. Numbers (n) in the upper right hand corner of each graph represents actual catch/estimated number of emigrants.

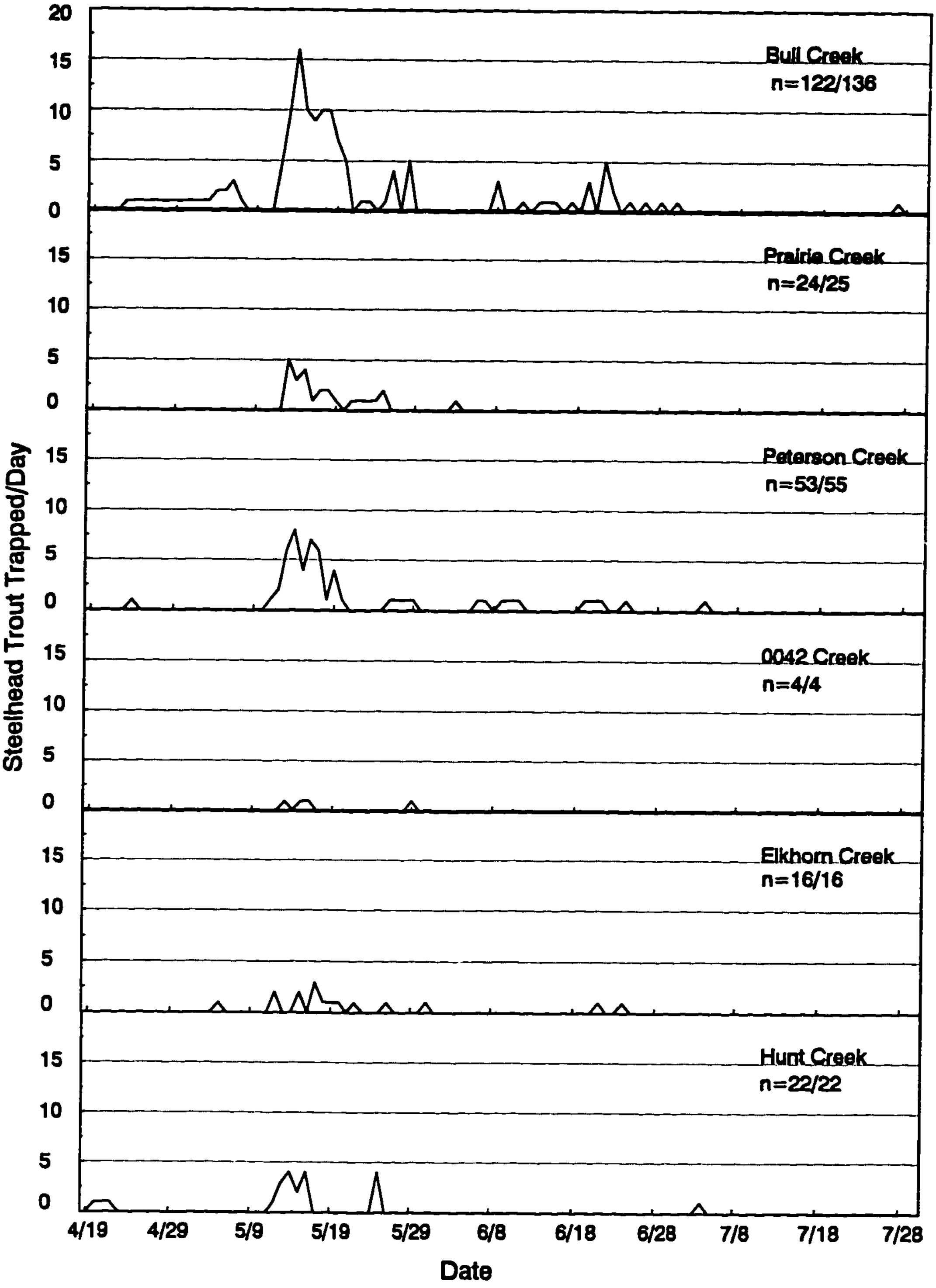

Figure C.14. Daily emigration of steelhead trout from six tributaries of the Clearwater River, 1993. Numbers (n) in the upper right hand corner of each graph represents actual catch/estimated number of emigrants.

APPENDIX D: Pond trapping data

Table D.1. Total coho salmon caught migrating into four wall-base channels of the Clearwater River, and the number of branded fish recovered during the fall of 1990.

Pond	Number Trapped	Brands
Coppermine Bottom	1,428	7
Pond 2	531	4
Swamp Creek	1,479	2
Paradise Pond	1,835	8
Total	5,002	21

Table D.2. Total coho salmon caught migrating into six wall-base channels of the Clearwater River, and the number of branded fish recovered during 1991.

Pond	Wild		Hatchery	
	Number Trapped	Brands	Number Trapped	Brands
Coppermine Bottom	1,007	4	17	0
Pond 2	796	7	8	1
Swamp Creek	913	6	35	0
Paradise	1,591	9	48	1
Airport	1,586	8	21	0
Morrison	1,115	3	22	0
Total	7,008	37	151	2

Table D.3. Total coho salmon caught migrating into six wall-base channels of the Clearwater River, and the number of branded fish recovered during the fall of 1992.

Pond	Wild		Hatchery	
	Number Trapped	Brands	Number Trapped	Brands
Coppermine Bottom	643	1	4	0
Pond 2	1,380	5	6	0
Swamp Creek	686	6	2	0
Paradise	972	10	3	1
Airport	1,012	8	6	0
Morrison	1,939	11	14	0
Total	6,632	41	35	1

Table D.4. **Total coho salmon caught migrating into six wall-base channels of the Clearwater River, and the number of branded fish recovered during the fall of 1993.**

Pond	Number Trapped	Brands
Coppermine Bottom	1,273	4
Pond 2	1,082	4
Swamp Creek	817	1
Paradise	875	2
Airport	668	5
Morrison	850	7
Total	5,565	23

APPENDIX E: Comparison of snorkel estimates to catch estimates using beach seining.

During the summer of 1994 we checked the accuracy of our snorkel estimates by comparing them to estimates made using a modified removal method (catch estimate). Only seven stations were used for this comparison due to time constraints. Following the initial snorkel estimate, a beach seine was used to capture as many fish as possible from the station. The fish were counted and stored in live net tanks. Once the water cleared, a second snorkel estimate was made, again followed by an attempt to capture fish with the beach seine. A final snorkel estimate was made once the water cleared.

The population estimate for the 'catch' method was conservatively calculated by adding the number of fish caught by the two seining efforts and the final snorkel estimate (Table E.1). The relationship between the initial snorkel estimates (dependent variable) and removal estimates (independent variable) was evaluated with linear regression model (Figure E.1).

Table E.1. Estimated juvenile coho salmon abundance estimates at seven debris stations using snorkel and 'catch' estimates.

Date	Station	Snorkel Estimate #1	Snorkel Estimate #2	Snorkel Estimate #3	Seine Estimate #1	Seine Estimate #2	Catch Estimate
8/10/94	B7&8	150	60	25	121	49	195
8/10/94	B13	20	18	6	9	22	37
8/10/94	B28	125	25	23	135	11	169
8/11/94	B29	185	95	36	135	102	273
8/11/94	B30	175	115	75	149	79	303
8/11/94	D1	25	15	8	19	9	36
8/11/94	D2	90	25	4	85	33	122

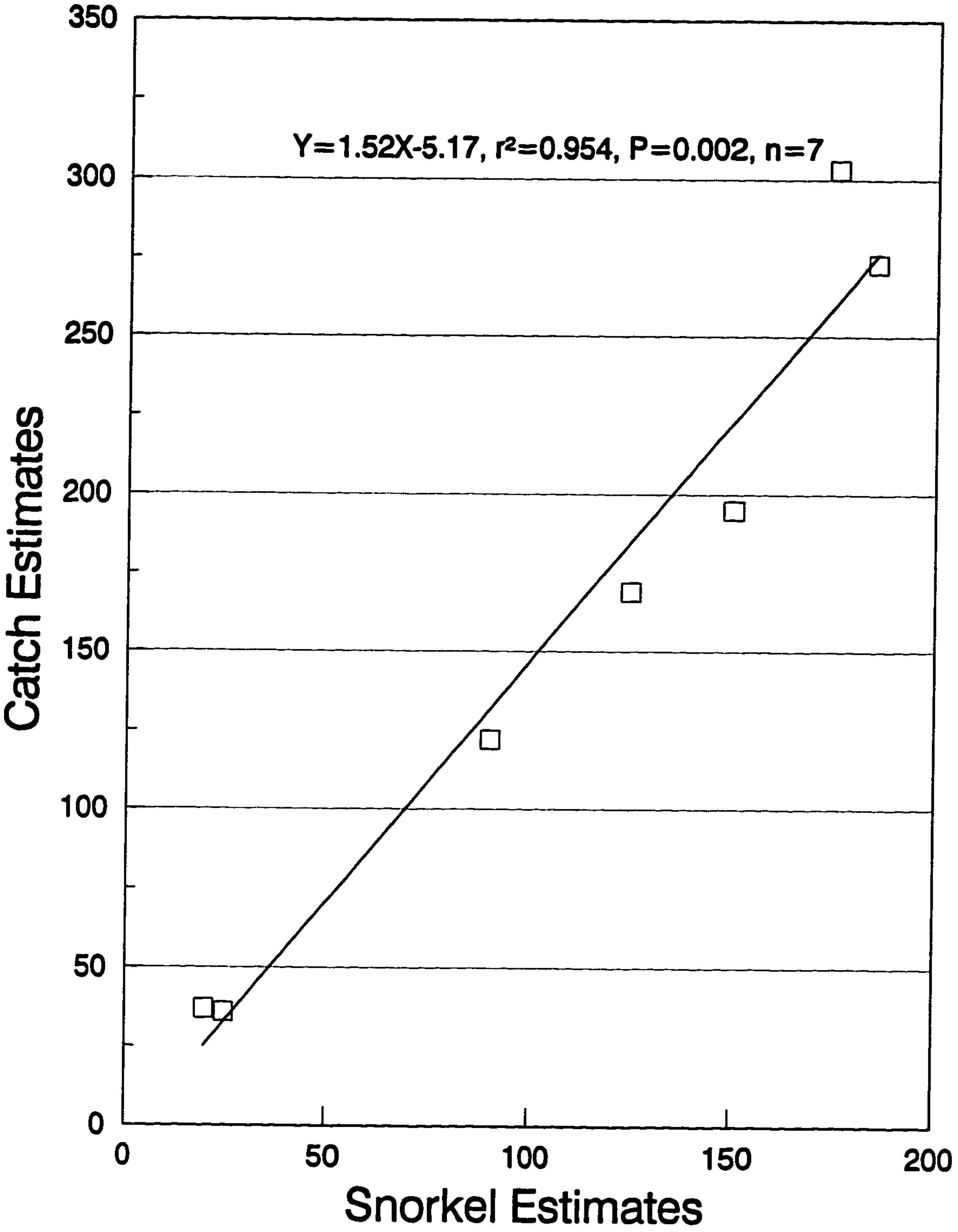

Figure E.1. Results of snorkel estimate and 'catch' estimate regression.

APPENDIX F: Comparison of habitat selection and behavioral data collected by the two observers during 1992.

Table F.1. Results of the comparison of coho salmon habitat selection data collected by the two observers during 1992.

Habitat Variable	Class	Observer 1			Observer 2			P
		Mean	SD	n	Mean	SD	n	
Water Depth	Foraging	1.199	0.4581	14	1.126	0.4755	18	0.6640
Water Depth	Resting	1.017	0.4918	12	1.120	0.5188	6	0.6851
Focal Velocity	Foraging	0.0736	0.0858	14	0.0711	0.0605	18	0.9248
Focal Velocity	Resting	0.0025	0.0087	12	0.0	0.0	6	0.4962
Distance to Surface	Foraging	0.5950	0.2173	14	0.6122	0.1840	18	0.8099
Distance to Surface	Resting	0.545	0.2373	12	0.612	0.2629	6	0.5947
Distance to Bottom	Foraging	0.658	0.3858	14	0.533	0.3738	18	0.3618
Distance to Bottom	Resting	0.486	0.3512	12	0.462	0.2726	6	0.8849
Relative Depth	Foraging	0.517	0.1339	14	0.594	0.1738	18	0.1694[a]
Relative Depth	Resting	0.571	0.1483	12	0.555	0.0499	6	0.7209[a]
Distance to Debris	Foraging	0.717	0.6458	14	0.787	0.8321	18	0.7968
Distance to debris	Resting	0.1200	0.1658	12	0.0767	0.1878	6	0.6232

[a] Statistical analysis completed using arcsine transformed data ($x' = \text{arcsine}(x)^{1/2}$)

Table F.2. Results of the comparison of juvenile coho salmon behavior collected by the two different observers during 1992.

		Observer 1			Observer 2			
Behavior	Class	Mean	SD	n	Mean	SD	n	*P*
Surface Foraging	Foraging	0.094	0.2226	48	0.280	0.4755	50	0.0154
Surface Foraging	Resting	0.0	0.0	37	0.0	0.0	20	1.0000
Midwater Foraging	Foraging	2.198	2.2043	48	3.290	3.2232	50	0.0541
Midwater Foraging	Resting	0.257	0.5086	37	0.400	0.5758	20	0.3369
Bottom Foraging	Foraging	0.010	0.0722	48	0.020	0.0990	50	0.5865
Bottom Foraging	Resting	0.0	0.0	37	0.0	0.0	20	1.0000
Total Foraging	Foraging	2.302	2.1971	48	3.590	3.080	50	0.0196
Total Foraging	Resting	0.257	0.5086	37	0.400	0.5758	20	0.3369
Chase	Foraging	0.073	0.2304	48	0.220	0.4861	50	0.0603
Chase	Resting	0.0	0.0	37	0.125	0.3582	20	0.0369
Attack	Foraging	0.146	0.3414	48	0.0	0.0	50	0.0032
Attack	Resting	0.0	0.0	37	0.0	0.0	20	1.0000
Nip	Foraging	0.0	0.0	48	0.040	0.1370	50	0.0460
Nip	Resting	0.014	0.0822	37	0.0	0.0	20	0.4672
Aggressive Display	Foraging	0.021	0.1010	48	0.090	0.3454	50	0.1855
Aggressive Display	Resting	0.0	0.0	37	0.0	0.0	20	1.0000
Total Aggression	Foraging	0.240	0.5553	48	0.350	0.7576	50	0.4142
Total Aggression	Resting	0.014	0.0822	37	0.125	0.3582	20	0.0743
Submissive Display	Foraging	0.0	0.0	48	0.020	0.0990	50	0.1648
Submissive Display	Resting	0.0	0.0	37	0.0	0.0	20	1.0000
Flee	Foraging	0.083	0.2596	48	0.060	0.1927	50	0.6136
Flee	Resting	0.041	0.1818	37	0.0	0.0	20	0.3249

Table F.2. (cont.)

Behavior	Class	Observer 1			Observer 2			
		Mean	SD	n	Mean	SD	n	*P*
Hide	Foraging	0.0	0.0	48	0.0	0.0	50	1.0000
Hide	Resting	0.0	0.0	37	0.0	0.0	20	1.0000
Total Submissive	Foraging	0.083	0.2596	48	0.080	0.2339	50	0.9468
Total Submissive	Resting	0.041	0.1818	37	0.0	0.0	20	0.3249
Wander	Foraging	0.313	0.5013	48	0.010	0.0707	50	0.0001
Wander	Resting	0.297	0.4781	37	0.050	0.1539	20	0.0289

APPENDIX G. August and September, 1993 habitat selection data.

Table G.1. Comparison of habitats selected by juvenile coho salmon from different foraging groups during August and September 1993.

Variable	August			September			
	Mean	SD	n	Mean	SD	n	*P* (t-test)
				Foraging Group			
Water depth (m)	1.01	0.588	36	0.85	0.314	19	0.1750
Focal depth (m)	0.54	0.219	36	0.58	0.233	19	0.4696
Focal Velocity (m/s)	0.06	0.054	36	0.07	0.074	19	0.6417
Distance to bottom (m)	0.47	0.462	36	0.27	0.238	19	0.0409
Relative Depth[a]	0.60	0.208	36	0.71	0.160	19	0.0555[b]
Distance to debris (m)	0.97	1.162	36	0.90	1.078	18	0.8297
				Resting Group			
Water depth (m)	0.92	0.753	14	0.58	0.133	6	0.1156
Focal depth (m)	0.38	0.162	14	0.38	0.096	6	0.9712
Focal Velocity (m/s)	0.004	0.0160	14	0.002	0.0041	6	0.5768
Distance to Bottom (m)	0.53	0.658	14	0.24	0.092	6	0.1286
Relative Depth[a]	0.53	0.191	14	0.69	0.255	6	0.5228[b]
Distance to debris (m)	0.52	0.410	14	2.85	2.212	6	0.0501

[a] Calculated as focal depth/water depth

[b] Statistical analysis completed on arcsine transformed data ($X' = \text{arcsine}(X)^{1/2}$)

Vita

Roger Peters, son of Calvin and Ina Peters, was born September 10, 1965 in Tacoma, Washington. After graduating from Franklin Pierce High School in Tacoma, Washington, he attended Fort Steilacoom Community College for two years receiving his Associates of Arts and Sciences Degree. He then transferred to Seattle Pacific University in Seattle, Washington where he received a Bachelor of Science Degree, with a Chemistry Minor. He entered the University of Washington, School of Fisheries during Autumn quarter 1987 and received his Masters Degree in August 1989. He entered the Doctoral Degree program during Autumn quarter 1989.

He married Leslie Conner in August 1990 and his two children, Kayla and Carly, were born in January 1993 and May 1995.