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Carrying Capacity of Habitats Used Seasonally by Coho Salmon in the Kametolook River, Alaska Peninsula National Wildlife Refuge, 2002-2003

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Key words: coho salmon, subsistence, carrying capacity, habitat inventory, escapement, weir, Perryville, Kametolook River, Alaska Peninsula, Refuge

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Disclaimers

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Abstract.- Coho salmon *Oncorhynchus kisutch* are an important subsistence resource for residents of the Native Village of Perryville. Recent returns to local streams (Kametolook, Three Star, and Long Beach rivers) have declined and cannot support subsistence needs of the village. This project was implemented to assess the quantity and quality of freshwater habitats used for spawning and rearing by coho salmon in streams near Perryville, and to use these data to conduct a limiting habitat analysis. The habitat inventory was repeated on Clear Creek, a small drainage that supports viable runs of coho salmon. Work was completed in 2002 and 2003 and includes: 1) a habitat inventory on Kametolook and Long Beach river tributaries, Three Star River, and Clear Creek, 2) sampling juvenile coho salmon in Clear Creek, 3) spawning escapement monitoring in Clear Creek (weir) and streams near Perryville (walking surveys), and 4) application of a habitat limiting factor model to all systems. Over 43 km of stream were inventoried in the Kametolook, 42 km in the Long Beach, 27 km in the Three Star, and 12 km in the Clear Creek drainages. Habitat composition and quality were similar between systems, except for a 7-ha drainage lake in the Clear Creek system. Juvenile coho salmon densities in Clear Creek in 2002 were similar to values reported in the literature for streams fully seeded. Juvenile densities were lower in 2003 and not at carrying capacity. Minimum estimates of coho salmon spawning escapement in Clear Creek were about 1,100 in 2002 and 1,000 in 2003. Estimates are minimum values due to weir failures. Age and sex compositions of adult coho salmon were similar between years. Two hundred ninety adult coho salmon were observed in Perryville streams during walking surveys in 2002, and 800 were observed in 2003. Results from the habitat limiting factor analysis indicate that winter habitat availability limits production in all systems and each system has the production potential of over 2,000 adult coho salmon given adequate marine survival. Results of the model are comparable to other reported population parameters for coho salmon throughout their range. Model predictions indicate that the physical habitat of the Kametolook, Three Star, and Long Beach drainages can support coho salmon populations in excess of current spawning escapement levels.

Introduction

Residents of Perryville depend on fish and wildlife resources for subsistence, and salmon (primarily coho salmon *Oncorhynchus kisutch*) account for more than half of the subsistence food they consume (Hutchinson-Scarborough and Fall 1993). The average harvest of coho salmon in the Perryville area from 1993 to 2000 was estimated at over 1,900 fish, ranging from 993 in 1995 to 3,501 in 1994 (ADFG 2002). Recent runs of coho salmon to streams in the Perryville area, the Kametolook, Three Star, and Long Beach rivers, have declined. Spawning escapement was estimated at about 200 fish in 1996 (ADFG 1997). Concerns over poor returns and the inability of local residents to meet their subsistence needs from these three systems motivated the Native Village of Perryville to pass an ordinance that prohibits subsistence harvest in the Kametolook River. In addition, the Alaska Department of Fish and Game (ADFG) engaged in a project in 1996 to rebuild coho salmon stocks in the Kametolook River drainage using incubation boxes, with the intent of improving adult returns by increasing survival from the green egg to swim-up fry stage (ADFG 1997).

Several reasons for the decline of coho salmon stocks in the Kametolook River drainage have been suggested, including a decrease in carrying capacity resulting from changes in habitat, and over fishing in the river and in the ocean. As the availability and quality of spawning and rearing habitats are not known, resource managers are unable to determine the bottleneck(s) limiting current production. This project was implemented to assess the freshwater habitat and its associated production potential for coho salmon. Specific objectives were to:

1. Inventory the physical habitat of clear-water tributaries in the Kametolook, Three Star, and Long Beach river drainages, and use the resulting data to estimate seasonal carrying capacities of spawning, summer rearing, and overwintering habitats for juvenile coho salmon.
2. Calculate a minimum index of escapement for adult coho salmon in the Kametolook, Three Star, and Long Beach rivers based on juvenile carrying capacities.
3. Estimate habitat-type specific densities of juvenile coho salmon to compare with values reported in the literature and with habitat condition data collected in the physical habitat inventory to validate carrying capacity estimates.
4. Collect data referenced in objectives 1 - 3 on Clear Creek, a small drainage that supports a viable run of coho salmon and compare the results to the Kametolook, Three Star, and Long Beach river drainages.
5. Estimate spawning escapement of adult coho salmon in the Kametolook, Three Star, and Long Beach river drainages, and in Clear Creek.

The quantity and quality of adult spawning and juvenile rearing habitat for coho salmon was measured in the Kametolook, Three Star, and Long Beach rivers using a modification of the stream survey methods developed by Hankin and Reeves (1988). Results from these inventories were compared to those of a parallel survey conducted on

Clear Creek, a clear-water stream located near the Yantarni Airstrip (Figure 1), to better understand the factors limiting smolt production. Stream inventory data were used to conduct a limiting habitat analysis for coho salmon for each of the drainages. This method, as detailed by Reeves et al. (1989), uses habitat data to model survival of a single cohort over time, by life-stage and season (spawning, and spring, summer, and winter rearing) to identify the principle bottleneck(s) that limit theoretical smolt production. The model is based on the assumption that when a specific habitat is in short supply, a bottleneck exists that may subject a cohort to density-dependent mortality, which may lead to an under seeding of habitats used by subsequent life stages. Results of the limiting habitat analysis, comparison of habitat-based carrying capacities to actual estimates of juvenile coho salmon densities, and current indices of adult escapement were used to determine what factors limit production of coho salmon in the Kametolook, Three Star, and Long Beach rivers, and in Clear Creek.

Study Area

The Kametolook, Three Star, and Long Beach rivers are below Mount Veniaminof volcano on the South Alaska Peninsula and share a common valley bottom (Figure 2). The entire area is within the boundaries of Alaska Peninsula National Wildlife Refuge. The Three Star River drains the middle of a wide, flat valley with little topographical relief. In contrast, the Kametolook and Long Beach systems are on the edges of the valley floor, each draining mountainous terrain on either side of the valley. As the valley evolved, numerous events, including eruptions of Mt. Veniaminof, have deposited vast amounts of small gravel and fine sediments on the alluvial valley floor. The Kametolook and Long Beach rivers are highly braided, and stream capture events frequently occur between the two systems. When the village of Perryville was founded in 1912, the Long Beach River provided the bulk of subsistence fish for the community. About 20 years ago, however, a stream capture event diverted highly turbid glacial water draining off the base of Mount Veniaminof into the Long Beach River. Since then, the Kametolook River has been the primary producer and most accessible source of coho salmon available to subsistence users in the local area. Over the past two years, the main flow of glacial melt water has alternated between the Kametolook and Long Beach rivers on several occasions. A natural hydraulic control at the toe of a hill adjacent to the floodplain controls the flow between the two systems (Figure 2). Depending on localized channel morphology at this critical point, the main flow of glacial melt water can enter either system.

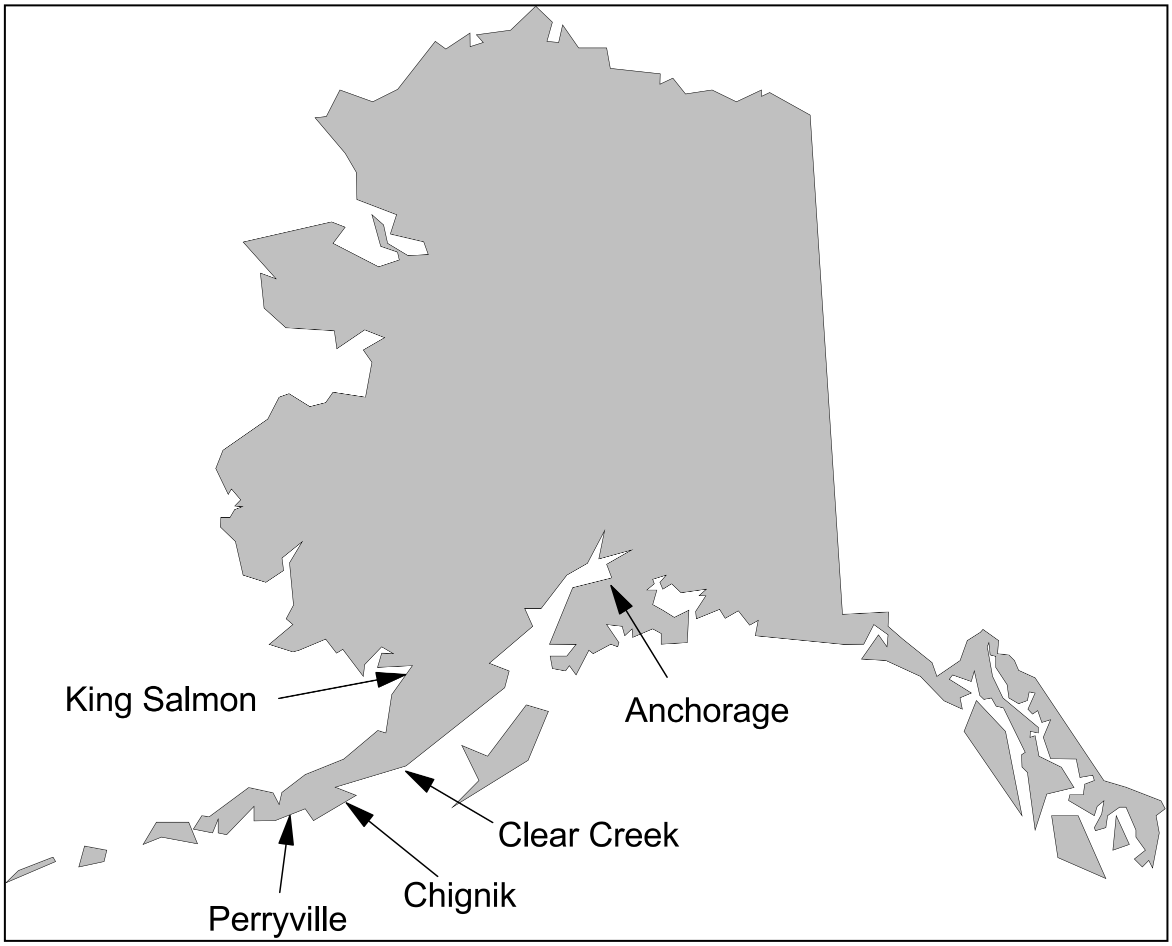


Figure 1. Location of Perryville and Clear Creek, Alaska Peninsula National Wildlife Refuge.

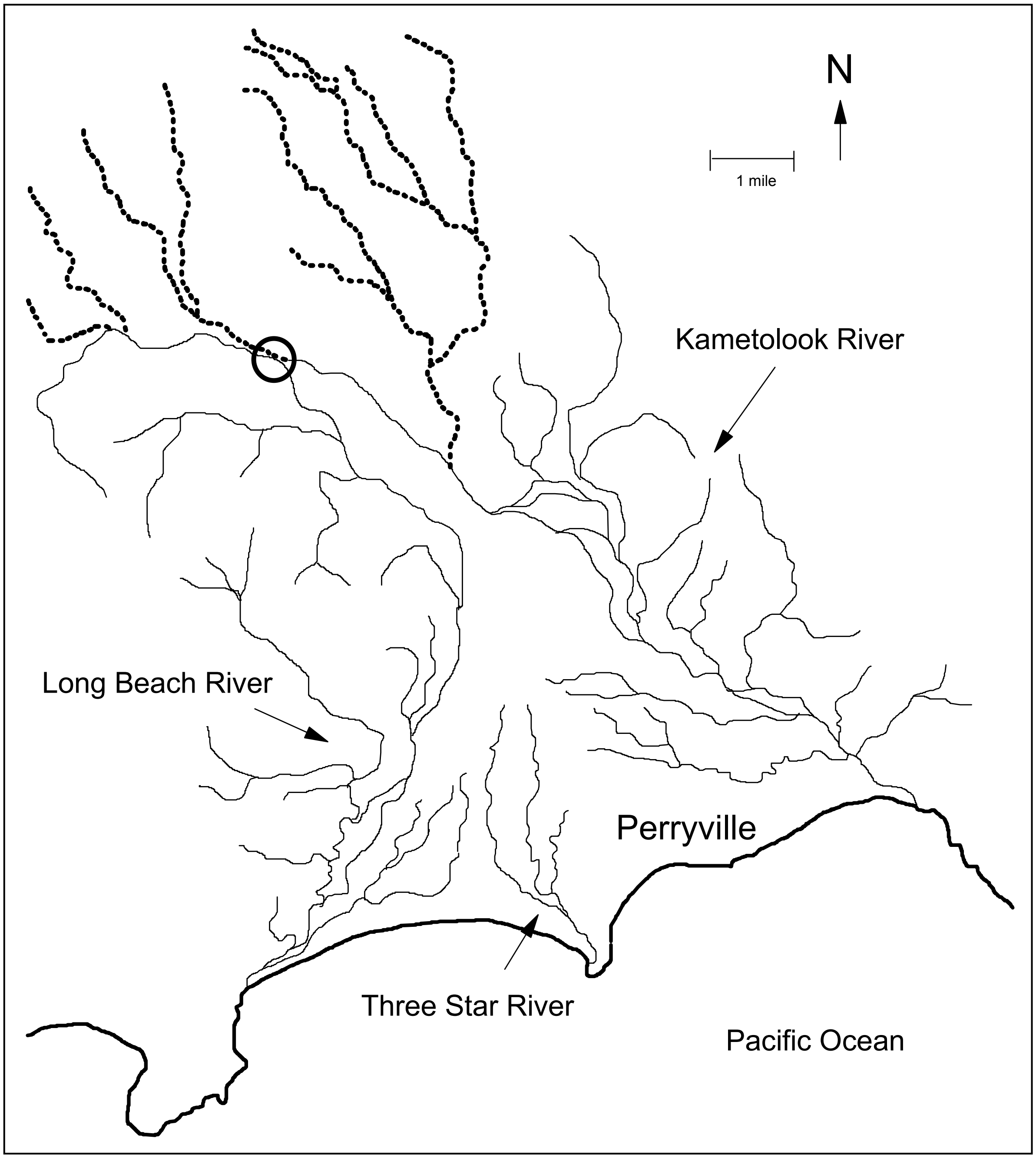


Figure 2. Kametolook, Three Star, and Long Beach rivers near Perryville, Alaska. Heavy dashed lines represent tributary streams draining Mt. Veniaminof glacier. The circled area is the hydraulic control point between the Kametolook and Long Beach rivers.

Camp Creek is on the South Alaska Peninsula near the Yantarni Airstrip, 60 miles north of Chignik (Figure 3). The Camp Creek drainage undergoes morphological changes similar to those documented for the Kametolook system: both are glacially influenced, undergo stream capture events, and are constantly changing. Clear Creek flows into Camp Creek about 2 km upstream from Camp Creek's confluence with the Pacific Ocean. Clear Creek is a clear-water stream and is about 13 km long, but a waterfall located 9 km upstream from its mouth blocks fish passage. A 7-ha drainage lake is present in the upper reaches of the system (Figure 3). Clear Creek supports a viable run of coho salmon, with escapements estimated to be greater than 3,000 adults in 1995 and 1996 (Hetrick and Nemeth 2003). Coho, Chinook *O. tshawytscha*, pink *O. gorbuscha*, chum *O. keta*, and sockeye *O. nerka* salmon, Dolly Varden *Salvelinus malma*, and threespine stickleback *Gasterosteus aculeatus* are present in the Perryville area streams and in Clear Creek.

Methods

Habitat Inventory

The Kametolook River and Clear Creek were inventoried during June and July 2002, and the Three Star and Long Beach rivers were inventoried during June and July 2003. The habitat inventory for the Kametolook and Long Beach rivers concentrated on clear water tributaries. Because of turbidity resulting from glacial outflow and geomorphology of the two rivers, we believe that much of the Kametolook and Long Beach rivers function primarily as corridors used by coho salmon to access clear-water areas for spawning and rearing (Milner and Petts 1994). The Kametolook and Long Beach rivers are high velocity, riffle-dominated systems that provide little mainstem rearing habitat for juvenile coho salmon. We assumed that the high turbidity of the glacial melt water limits the ability of juvenile coho salmon to forage successfully. Some juvenile coho salmon rearing probably occurs in lateral and backwater habitats in both systems, especially during times of reduced stream flow, but the ability to quantify those habitats was severely limited by flow regimes of both rivers. It was not possible to safely wade either the Kametolook or Long Beach rivers in most areas when the habitat inventory was conducted. The entire Three Star and Clear Creek watersheds were inventoried, as both are not influenced by glacial melt.

Methods used to classify habitat types were modified from Hankin and Reeves (1988), Bisson et al. (1982), and Overton et al. (1997). The habitat type classifications of Nickelson (1998) were used for later compatibility with the habitat limiting factor model analysis. Habitat types were classified as cascades, rapids, riffles, glides, trench pools, plunge pools, scour pools (lateral and mid-channel), dammed pools, alcoves, and beaver ponds. The terminology of Overton et al. (1997) was used to describe the formative features of pool types. Physical habitat features were descriptively compared between all systems.

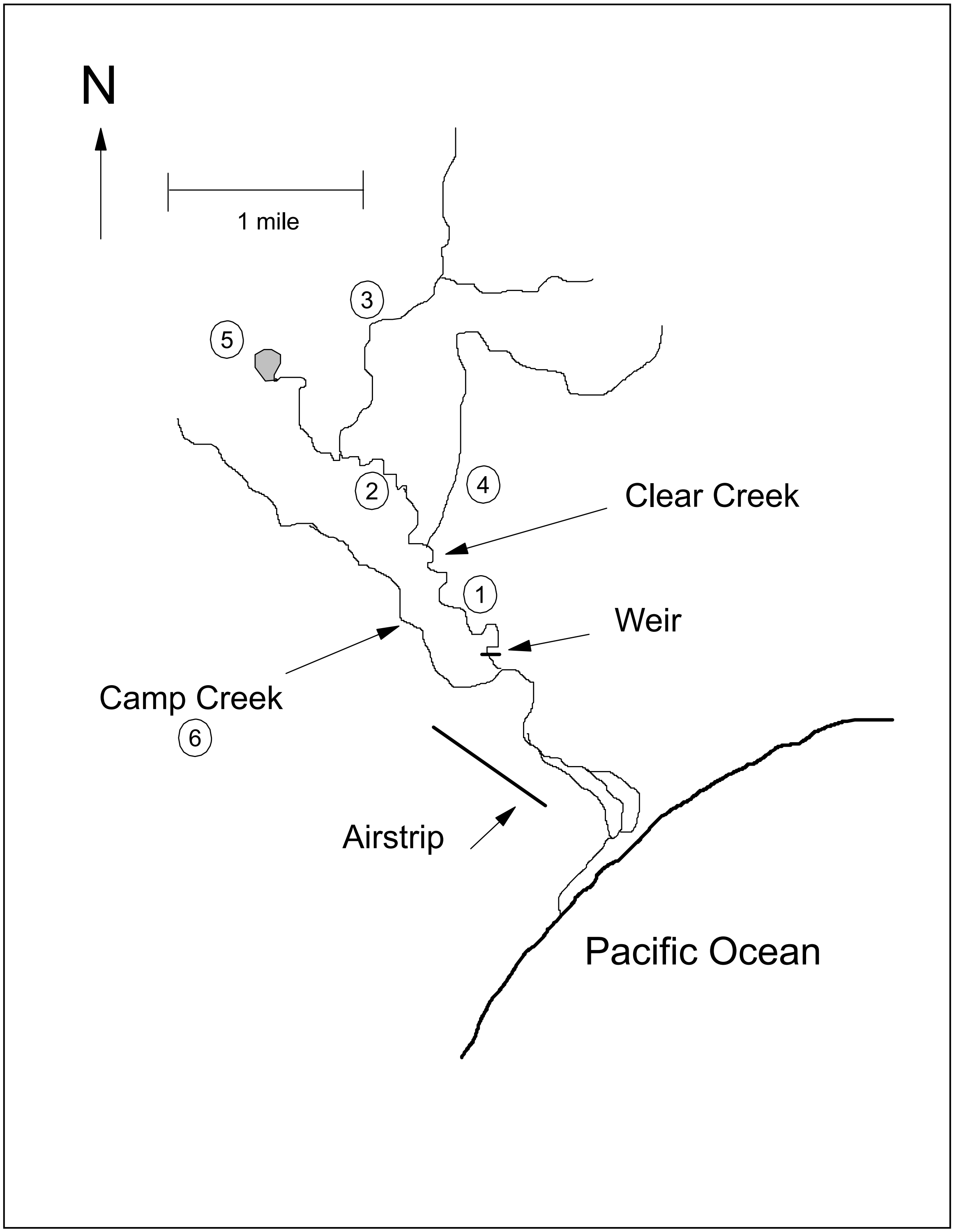


Figure 3. Clear Creek study area showing sampling strata (circled numbers), Alaska Peninsula National Wildlife Refuge.

Habitat inventories were conducted by beginning at the mouth of each clear-water tributary and working upstream until a barrier to upstream migration was reached, a terminal spring source was encountered, or the system became dispersed through vast marshy areas with no apparent feeder source. Individual habitat units were classified based on habitat type, and length, width, and depth measurements were taken. Length was measured along the thalweg. A minimum of three widths were measured perpendicular to the thalweg at cross-sections spaced at ¼, ½, and ¾ of the unit's length, and a mean width was calculated. Surface area of each habitat unit was calculated by multiplying the measured length of the unit by its mean width. Mean depth of each unit and maximum depth for pools were measured following the procedures of Overton et al. (1997).

Cover provided by turbulence, boulders, overhead vegetation, undercut banks, pocket water, and large woody debris (LWD) was visually estimated at each habitat unit and expressed as a percentage of the total surface area. Large woody debris was categorized by quantity (single pieces, aggregates of 2 to 4 pieces, and groups of more than 4 pieces) and type (root wad, log jam, debris pile, growth, or a combination of these). The percent of each habitat unit that was suitable for coho salmon spawning was visually estimated, and was classified qualitatively as poor, fair, or good based on best professional judgment using visual observation of depth, velocity, and substrate conditions compared to preferred values reported in the literature (McMahon 1983).

Surface substrate composition was estimated using a modified version of the pebble count procedure described by Bevenger and King (1995). The procedure differed from Bevenger and King (1995) in that only low gradient riffles suitable for salmonid spawning were sampled, and particles were selected by walking heel-to-toe and picking rocks from beneath our toes every one or two steps instead of at seven-foot intervals. A minimum of 100 particles were sampled along three to six transects across a riffle. Particles were measured to the nearest millimeter along the longest axis with a ruler and categorized according to a modified version of Wentworth Scale size classes described by Platts et al. (1983) (Table 1). Riffles sampled for substrate analysis were spaced evenly throughout the length of individual streams. Cobble embeddedness was visually estimated at each unit where pebble counts were performed according to the extent that larger particles were embedded by sand or finer sediments (0-25%, 26-50%, 51-75% or 76-100%).

Three Hobo® Temp data loggers were deployed in selected tributary streams in the Kametolook drainage in 2002, and one was deployed in Clear Creek at the weir to monitor water temperature in 2002 and 2003. Data loggers recorded temperature every two hours and were placed in secure, well-mixed, shaded sites.

Table 1. Modified Wentworth particle size categories used to classify stream substrate particles based on Platts et al. (1983).

Category	Particle Size (mm)
Organics	
Clay/Silt	$\leq$ 0.063
Sand	0.063 to 2
Small Gravel	> 2 to 4
Medium Gravel	> 4 to 32
Large Gravel	> 32 to 64
Small Cobble	> 64 to 128
Large Cobble	> 128 to 256
Boulder	> 256
Bedrock	

Clear Creek Juvenile Sampling

In 2002 and 2003, habitat type-specific densities of juvenile coho salmon in Clear Creek were estimated for selected habitat units as suggested by Reeves et al. (1989). Clear Creek was delineated into strata based on stream size (Figure 3), and habitat inventory data were summarized to determine total surface areas for each habitat type by stratum. Based on logistical constraints, 15 sites per stratum were selected for snorkel surveys. Sites were allocated to the different habitat types in proportion to the habitat type-specific surface areas in each stratum, and were sampled systematically using a random start. Fifteen snorkel sites were also sampled in lower Camp Creek in 2003. Juvenile fish counts were conducted during periods of low flow in August. Snorkel surveys were performed in discrete habitat units using standardized underwater observation techniques, and were conducted when the minimum depth, visibility, and water temperature criteria of Thurow (1994) were met or exceeded. Fish were counted by one to three observers, depending on stream width and visibility, as they moved upstream through the habitat unit. Densities (number of fish/m^2) for each species were calculated by dividing the number of fish observed by the surface area of the site, and were averaged by habitat type.

Passive capture removal techniques were also used to estimate juvenile coho salmon abundance and density in Clear Creek in 2002. Minnow traps were used to capture and remove fish from selected pools following the procedures of Bryant (2000). Block nets were used at the upstream and downstream ends of the habitat units to prevent immigration and emigration of fish during the removal events. Three to four capture events were used in each habitat unit. Between eight and 20 minnow traps were set on each event depending on the size of the habitat unit. Distances between traps depended upon habitat complexity, but traps were generally separated by about 1.5 m. Traps were set more densely in complex habitats. Traps were set on the stream bottom near large woody debris, root wads, or undercut banks where juvenile salmonids were suspected to be present, but were also distributed to cover the entire pool. Traps were baited with pink or coho salmon eggs (collected locally), placed on the stream bottom, left undisturbed for 60 ± 5 min, and picked up in the order in which they were set. Juvenile fishes were removed from the traps between capture occasions, identified to species, counted, and either placed in a live well or released below the sample area. Traps were then re-set in their original locations, and the procedure was repeated.

Removal estimates and probabilities of capture (P_c) for coho salmon were computed by the CAPTURE program (White et al. 1982). The CAPTURE program uses two different models to generate population estimates. The first model is equivalent to the trap response model for a closed population (M_b; Pollock et al. 1990) and is based on the assumption of a constant P_c for all capture events. The second model is equivalent to a heterogeneity and trap response model for a closed population (M_{bh}; Pollock et al. 1990) and is based on the assumption of two different probabilities: one P_c for the first capture event and a different P_c for the remaining capture events. CAPTURE performs a chi-square goodness of fit test for each model to determine whether observed P_c values followed those expected for either model. White et al. (1982) recommend using model results only if probabilities for the chi-square goodness of fit test were at least 0.20 to avoid bias. At least three capture events are necessary to test the assumption of constant P_c, and four capture events are needed to test P_c assumptions for the M_{bh} model. The model selected by CAPTURE was chosen for analysis purposes, and models were rejected if $p < 0.20$ for any model goodness of fit test, observed P_c values were less than 0.20, and population size was less than 200 individuals (White et al. 1982). Density (number of fish/m^2) for each habitat unit was calculated by dividing the population estimate by the surface area of the site. Mean densities of coho salmon by habitat type were estimated by averaging species densities for each habitat type.

A single census mark-recapture population estimate (Lincoln - Petersen type) was used to estimate juvenile coho salmon abundance and density in the Clear Creek drainage lake in 2003. The following assumptions are necessary for an unbiased estimate of population size (Pollock 1991):

a. The population is closed to additions or deletions
b. All fish are equally likely to be captured in each sample
c. Marks are not lost or overlooked

The drainage lake was stratified into two areas, shoreline and offshore, to test the assumption of mixing and equal capture probability of individuals between samples. Minnow traps were used to capture fish on both the capture and recapture events. Ten traps were distributed evenly around the shoreline, and 10 traps were distributed evenly throughout the offshore area of the lake. Traps were baited as previously described and were fished for about 1 h. Captured fish were anesthetized using tricaine methanesulfonate (MS-222), and marks were applied using a Syrijet dental inoculator tool using black India ink. Juvenile coho salmon captured in different areas were marked differentially to test the assumptions of equal capture probabilities and mixing between areas. Fish captured on the shoreline were marked with a single dot at the base of the caudal fin, and fish captured in the offshore area were marked with a single dot at the base of the anal fin. Marked fish were held overnight to estimate tagging mortality, and were released back into their original area of capture (shoreline or offshore). Twenty fish from each marking area were held in a live well throughout the duration of the census to test assumption (c). The second capture event was completed 12 d after marked fish were released to allow time for marked and unmarked fish to randomly mix. Fish captured during the second event were examined for marks and counted. Chi-square goodness of fit tests with the Yates correction for continuity (Zar 1996) were used to test the assumptions of equal capture probabilities and constant survival probabilities for marked fish (Seber 1982). Results were considered significant at $p < 0.05$.

Population size ($\hat{N}$) was estimated as

$$\hat{N} = \frac{MC}{R}$$

where M is the number of fish marked and released alive on the first sample event, C is the number of fish captured on the second sample event and examined for marks, and R is the number of marked fish found in sample C. The estimate was adjusted as per Seber (1982) to account for accidental deaths during the marking event by subtracting the accidental deaths from the population size estimate. An approximate 95% confidence interval for the abundance estimate was calculated using Equation 3.4 of Seber (1982) as

$$\hat{p} \pm \left\{ 1.96 \left[\frac{\hat{p}(1-\hat{p})}{(C-1)} \right]^{1/2} + \frac{1}{2C} \right\}$$

where $\hat{p}$ is the ratio of marked fish in the second sample to the total number captured during the second sample (R/C). Upper and lower bounds for the confidence interval were obtained by taking the inverse of the calculated value and multiplying by M. Guidelines of Robson and Regier (1964) were used to investigate potential bias in the estimate. Density (number of fish/m^2) of juvenile coho salmon in the drainage lake was calculated by dividing the population estimate by the surface area of the lake. Surface area was estimated using the area calculator of a Garmin® eTrex Venture™ global positioning system unit while walking the perimeter of the lake.

Sample size of fish to mark and capture on each occasion was determined following Robson and Regier (1964) as

$$M = C = \frac{NX}{(1 + X)}$$

with

$$X = \left\{ \frac{D}{N - 1} \right\}^{1/2}$$

where N is an estimate of population size, and a value of 392 for D was chosen from Table 2 of Robson and Regier (1964) such that the estimate would have a 95% probability of being within 10% of the true abundance. An estimate of 5,000 was used for N based on preliminary snorkel surveys in the lake. The sample size goal for M and C was calculated to be 1,100 juvenile coho salmon.

Length and age data were collected from juvenile coho salmon captured in Clear Creek in 2003. Fish were captured using baited minnow traps set at six systematically spaced pool and backwater sites dispersed throughout each stratum. At each site, two to five traps were set and allowed to fish until at least 20 juvenile coho salmon were captured. Captured coho salmon were anesthetized using MS-222 and measured (total length) to the nearest millimeter. Scale samples were collected from a random sample of 20 fish per site (for a total of n = 120 per stratum). Fish were allowed to recover in a live well and released. Fishes other than coho salmon were identified to species and counted. Scales were aged following the standards and guidelines of Mosher (1968), and juvenile ages were reported based on the number of winters the fish spent in fresh water followed by a plus sign (e.g., age 0+). Total length (mm) was measured for n = 109 juvenile coho salmon captured with minnow traps in stratum 1 in September 2002.

We hypothesized that more age 1+ juvenile coho salmon and larger fish of either age would be found lower in the system. A *G*-test of independence (Sokal and Rohlf 1981) was used to determine if juvenile coho salmon age proportions varied among strata; if significant, the Tukey-type multiple comparison test of Zar (1996) was used to determine which proportions were different from others. A Model II analysis of variance (ANOVA) was used to determine if mean lengths at age varied among strata; if significant, Tukey's honestly significant difference test was used to determine differences in strata means (Zar 1996). Residual analysis was used to detect any departures from the ANOVA model: non-independence of error terms, heteroscedastic error term variance, non-normality of error terms, and outliers (Neter et al. 1990). Length-frequency distributions of juvenile coho salmon between years were compared using a Kolmogorov-Smirnov two-sample test (Sokal and Rohlf 1981). Results of all tests were considered significant at $p < 0.05$.

Escapement Monitoring

Coho salmon spawning escapement was estimated for selected streams near Perryville in 2002 and 2003 using multiple-pass stream walking surveys. Streams were selected following consultations with local residents to determine those likely to support coho salmon spawning. Foot surveys were conducted with a crew of two observers and were scheduled at two-week intervals beginning in early October and ending in December. Surveys began at the mouth of selected streams and proceeded upstream, covering all areas accessible to adult salmon. Observers selected the route that maximized visibility of salmon with respect to angle of the sun, water clarity, and wind. Surveyors wore polarized glasses to reduce water surface glare. When oxbows, side channels, and backwaters were encountered, one observer maintained the count from a stationary position on the main channel while the other observer counted fish in the off-channel habitat. Streams were divided into 1-km reaches, and the following data were recorded: transect number, number and species of fish observed, time, water clarity (excellent, good, or poor), lighting conditions (sun, partial overcast, overcast), and wind generated surface turbulence (calm, moderate, rough). Escapement estimates using the trapezoidal approximation of the area-under-the-curve (AUC) model described by English et al. (1992) and Hilborn et al. (1999) could not be calculated because of infrequent survey intervals and inconsistencies in survey coverage resulting from high flows.

A fixed picket weir was installed on Clear Creek to estimate coho salmon escapement in 2002 and 2003. Although all species of salmon passing the weir were counted, picket spacing (38-mm) allowed small pink salmon and most Dolly Varden to pass through the weir without being counted during both years of the study. The weir was constructed of 12-mm diameter electrical metal tubing pickets separated by 38-mm lengths of polyvinyl chloride pipe. Aircraft cable was used to string the pickets and spacers together, and clamps were attached to the ends of the cables to create 3-m long weir panels of varying heights to accommodate differences in channel depth. Weir panels were supported by fence posts and galvanized aircraft cable stretched across the stream. The supporting cable was anchored to the stream banks using earth anchors buried vertically at a depth that allowed the cable to be suspended just above the water surface. Weir panels were connected together and placed across the channel at an angle to direct upstream migrant fish to the trap box. The continuous panel was tilted downstream in relation to the streambed to shunt debris to the water surface, thereby maintaining free-flow of water through the pickets. The tops of the panels were wired to the supporting cable. Stream banks at each end of the weir were armored with geotextile cloth to prevent erosion.

A fyke was installed in the weir, leading to an upstream migrant holding pen. The fyke was located as close to the stream bank as adequate depth would allow. A depth greater than 0.5 m was needed for the holding pen to decrease the chance of fish jumping out of the pen. The weir was inspected, cleaned, and maintained daily to insure integrity. Migrant fish were counted and identified to species as they were either passed through a counting panel in the weir or captured in the holding pen and sampled for biological data. We tried to reduce any negative effects of delaying migration by allowing fish to quickly pass above the weir rather than allowing them to hold position or mill about on the downstream face of the weir for long time periods. When many fish were holding below the weir, the fyke leading to the trap box was closed and the counting panel opened to facilitate upstream passage.

Age, Sex, and Length Data

Coho salmon age, sex, and length (ASL) data were collected in 2002 and 2003 using a sampling design temporally stratified by statistical week (Cochran 1977). Coho salmon were sampled most weeks for ASL data, and to the extent logistically feasible, the sample was collected uniformly throughout each week. To avoid potential bias caused by the selection or capture of individual fish, all fish in the trap were included in the sample, even if the target number of fish was exceeded. Although weir passage was stratified into statistical weeks for data collection, strata for the analysis of Clear Creek coho salmon biological data were redefined following both field seasons to account for escapement during weeks when few or no fish were sampled (Table 2).

Sample size goals were established such that simultaneous 90% confidence interval estimates of the age composition for each week had maximum widths of 0.20 (Bromaghin 1993). Calculated sample sizes were then increased to account for the expected number of unreadable scales. The weekly sample size goal for coho salmon at Clear Creek in 2002 and 2003 was $n = 109$, which was adjusted to 120 fish to allow for 10% unreadable scales. This weekly sample size goal was expected to be a substantial fraction of the weir passage in some weeks (Hetrick and Nemeth 2003), so a target of 20% of the weekly escapement was sampled during weeks of low passage when the maximum sample size goal was not practical. This was sufficient to describe the age composition and reduced the number of fish handled at the weir.

Table 2. Strata (time periods) used for analysis of Clear Creek weir coho salmon biological data in 2002 and 2003.

Stratum	2002	2003
1	Sept. 8 - Sept. 14	Aug. 28 - Oct. 4
2	Sept. 15 - Sept. 21	Oct. 5 - Oct. 13
3	Sept. 22 - Sept. 28	Oct. 14 - Oct. 25
4	Sept. 29 - Oct. 5	Oct. 26 - Nov. 1
5	Oct. 6 - Oct. 12	Nov. 1 - Nov. 14
6	Oct. 13 - Oct. 19	--

Coho salmon were removed from the holding pen with a dip net and sampled for ASL data at least once daily, or more often when passage rates were high. Length (mid-eye to fork of tail) was measured to the nearest millimeter, and sex was determined based on external characteristics when possible. Three scales were removed from the preferred area on the left side of the fish (Jearld 1983), cleaned, and mounted on gummed scale cards. Following the season, scale impressions were made on acetate cards, and ages were determined using the standards and guidelines of Mosher (1968). Salmon ages were reported according to the European method described by Jearld (1983) and Mosher (1968), where the number of winters the fish spent in fresh water and in the ocean is separated by a decimal. A *G*-test of independence (Sokal and Rohlf 1981) was used to determine if age and sex composition estimates for adult coho salmon were similar across all temporal strata within each year. Age composition between years was compared using chi square analysis, and sex composition between years was compared using chi square analysis with the Yates correction for continuity (Zar 1996). Length-frequency distributions between years were compared using a Kolmogorov-Smirnov two-sample test (Sokal and Rohlf 1981). Results for all tests were considered significant at $p \leq 0.05$.

Characteristics of coho salmon passing through the weir were estimated using standard stratified random sampling estimators (Cochran 1977). Within a given stratum m, the proportion of species i passing the weir that are of sex j and age k (p_{ijkm}) was estimated as

$$\hat{p}_{ijkm} = \frac{n_{ijkm}}{n_{i++m}},$$

where n_{ijkm} denotes the number of fish of species i, sex j, and age k sampled during stratum m and a subscript of "+" represents summation over all possible values of the corresponding variable, e.g., n_{i++m} denotes the total number of fish of species i sampled in stratum m. The variance of $\hat{p}_{ijkm}$ was estimated as

$$\hat{v}(\hat{p}_{ijkm}) = \left(1 - \frac{n_{i++m}}{N_{i++m}}\right)\frac{\hat{p}_{ijkm}\left(1 - \hat{p}_{ijkm}\right)}{n_{i++m} - 1},$$

where N_{i++m} denotes the total number of species i fish passing the weir in stratum m. The estimated number of fish of species i, sex j, age k passing the weir in stratum m ($\hat{N}_{ijkm}$) was

$$\hat{N}_{ijkm} = N_{i++m}\hat{p}_{ijkm},$$

with estimated variance

$$\hat{v}(\hat{N}_{ijkm}) = N_{i++m}^2 \hat{v}(\hat{p}_{ijkm}).$$

Estimates of proportions for the entire period of weir operation were computed as weighted sums of the stratum estimates,

$$\hat{p}_{ijk} = \sum_m \left(\frac{N_{i++m}}{N_{i+++}} \right) \hat{p}_{ijkm}$$

and

$$\hat{v}(\hat{p}_{ijk}) = \sum_m \left(\frac{N_{i++m}}{N_{i+++}} \right)^2 \hat{v}(\hat{p}_{ijkm}).$$

The total number of fish in a species, sex, and age category passing the weir during the entire period of operation was estimated as

$$\hat{N}_{ijk} = \sum_m \hat{N}_{ijkm}$$

with estimated variance

$$\hat{v}(\hat{N}_{ijk}) = \sum_m \hat{v}(\hat{N}_{ijkm}).$$

If the length of fish of species *i*, sex *j*, and age *k* sampled in stratum *m* is denoted x_{ijkm}, the sample mean length of fish of species *i*, sex *j*, and age *k* within stratum *m* was calculated as

$$\bar{x}_{ijkm} = \frac{\sum x_{ijkm}}{n_{ijkm}}$$

with corresponding sample variance s^2_{ijkm}

$$s^2_{ijkm} = \left(1 - \frac{n_{ijkm}}{\hat{N}_{ijkm}} \right) \frac{\sum (x_{ijkm} - \bar{x}_{ijkm})^2}{n_{ijkm} - 1}.$$

The mean length of all fish of species *i*, sex *j*, and age *k* ($\hat{\bar{x}}_{ijk}$) was estimated as a weighted sum of the stratum means,

$$\hat{\bar{x}}_{ijk} = \sum_m \left(\frac{\hat{N}_{ijkm}}{\hat{N}_{ijk}} \right) \bar{x}_{ijkm.}$$

An approximate estimator of the variance of $\hat{\hat{x}}_{ijk}$ was obtained using the delta method (Seber 1982),

$$\hat{v}\left(\hat{\hat{x}}_{ijk}\right) = \sum_{m} \left\{ \hat{v}\left(\hat{N}_{ijkm}\right) \left[\frac{x_{ijkm}}{\sum_{x} \hat{N}_{ijkx}} - \sum_{y} \frac{\hat{N}_{ijky}}{\left(\sum_{x} \hat{N}_{ijkx} \right)^{2}} x_{ijky} \right]^{2} + \left(\frac{\hat{N}_{ijkm}}{\sum_{x} \hat{N}_{ijkx}} \right)^{2} s_{ijkm}^{2} \right\}.$$

Carrying Capacity Estimates

We used the habitat limiting factor model of Nickelson (1998; hereafter referred to as the habitat model) to identify factors that could be limiting smolt production, and to estimate carrying capacities for juvenile coho salmon in the Kametolook, Long Beach, Three Star, and Clear Creek drainages. The model was also used to estimate adult coho salmon production potential, and the model estimate for Clear Creek was compared to escapement estimates to examine model performance. The habitat model used estimates of available surface area for each habitat type identified during the inventory. Habitat-type specific potential juvenile coho salmon rearing densities over three seasons (spring, summer, and winter; Table 3) were used to estimate production potential for each season, and estimated available spawning habitat was used to estimate potential egg production. We used a potential rearing density of 1.0 fish/m^2 for beaver ponds, instead of 1.84 fish/m^2 used by Nickelson (1998), in the habitat model. Density-independent survival rates (Table 4) were applied to potential seasonal carrying capacity estimates to generate potential smolt production estimates for each season. The specific life-stage that limits smolt production in the system was the life-stage capable of producing the fewest number of smolt.

Once an estimate of smolt production was obtained from the habitat model, back-calculations were used to determine the number of adult coho salmon needed to fully seed available habitat in all systems and to estimate potential production. The following equations and constants of Nickelson (1998) were used in the analysis. Potential smolt density (C, fish/m^2) was calculated as

$$C = \frac{M}{SA},$$

where M is the maximum smolt capacity from the habitat model and SA is the total surface area measured in m^2. Survival to the smolt stage (S_{smolt}) was calculated as

$$S_{smolt} = S_{egg} * S_{ow},$$

where S_{egg} was a constant egg-to-summer parr survival rate of 0.072 and overwinter survival (S_{ow}) was calculated as

Table 3. Seasonal juvenile coho salmon potential densities (fish/m^2) by habitat type used in the habitat limiting factor model of Nickelson (1998).

Habitat Type	Spring	Summer	Winter
Cascade	0.00	0.24	0.00
Rapid	0.60	0.14	0.01
Riffle	1.20	0.12	0.01
Glide	1.81	0.77	0.12
Trench Pool	0.99	1.79	0.15
Plunge Pool	0.84	1.51	0.28
Scour Pool	1.29	1.74	0.35
Dammed Pool	2.56	1.84	0.56
Alcove	5.75	0.92	1.84
Beaver Pond	2.56	1.84	1.84
Backwater	5.75	1.18	0.58

Table 4. Density-independent survival rates (survival to smolt) from specific life stages used by the habitat limiting factor model of Nickelson (1998).

Life stage	Survival rate to smolt
Egg	0.32
Spring fry	0.46
Summer parr	0.72
Winter pre-smolt	0.90

$$S_{ow} = 0.1361 * \log_e C + 0.487 + E,$$

where E is an error term. The egg deposition (D_M) needed to produce the maximum smolt capacity (M) was then calculated as

$$D_M = \frac{M}{S_{smolt}}.$$

The minimum number of spawners necessary to produce the required egg deposition (A_M) was calculated as

$$A_M = \left(\frac{D_M}{2{,}500}\right) * 2,$$

which assumes a 1:1 sex ratio and 2,500 eggs per female. The potential adult production (PP_x) of the system was then determined as

$$PP_x = M * x,$$

where x represents the marine survival rate. Following Nickelson (1998), three different marine survival rates (x = 0.03, 0.05, and 0.10) were used. Although Nickelson (1998) recommends measuring and using total surface areas by habitat type for each season in the habitat model, we were only able to measure summer habitat due to the difficulty and expense of working in this area year round. We assumed that if summer densities of juvenile coho salmon measured in Clear Creek were similar to those reported by Nickelson (1998), we could use potential spring and winter juvenile densities in the habitat model (Table 3) applied to available summer habitat to produce reasonable estimates of smolt production for the Kametolook, Three Star, Long Beach, and Clear Creek systems.

The habitat inventory data for the Kametolook, Three Star, Long Beach, and Clear Creek systems were also used to predict smolt abundance using other models developed in the literature. Stream length (km) and area (m^2) measured during the habitat inventory were used to predict smolt abundance in our study streams using these models. A marine survival rate of 5% was then applied to smolt estimates from all models to estimate adult production.

Bradford et al. (1997) related 474 estimates of smolt abundance to habitat features derived from maps and discharge records for 86 streams in western North America to predict average abundance of coho salmon smolt. Mean coho salmon smolt abundance (Y) was related to stream length (X, km) for 83 streams as

$$Log_e(Y) = 6.90 + 0.97 Log_e(X)$$

with $p < 0.001$ and $r^2 = 0.70$.

Marshall and Britton (1990) analyzed carrying capacity of coho salmon streams by comparing smolt yields expressed as numbers and biomass with rearing space expressed as length and area of streams accessible to spawners. Data were from 21 streams, two ponds, and two side channels in Oregon, Washington, California, and British Columbia. Mean annual smolt yield (Y) in numbers was related to stream length (X, km) by the curvilinear relationship

$$Y = 1{,}134.3X^{1.1507}.$$

Mean annual smolt yield (Y) in numbers was related to stream area (A, m^2) by the curvilinear relationship

$$Y = 3.1001A^{0.7899}$$

with $p < 0.05$ and $r > 0.90$ for both models.

Bradford et al. (2000) developed a model to establish general conservation goals for coho salmon harvest rates and spawning populations. The model was developed using 14 historical coho salmon data sets from coastal streams in Oregon, Washington, and British Columbia. They estimated that on average, 19 female spawners per km were necessary to produce full smolt recruitment in a system, and average productivity was about 85 smolts per female at low spawner abundance. This results in an estimated 1,615 smolt/km, which was multiplied by the available stream length measured in our study streams to estimate total smolt production for each system.

Results

Habitat Inventory

Over 43.7 km of stream were inventoried in the Kametolook drainage; all 12.9 km of channel accessible to salmon were inventoried in Clear Creek; 42.5 km of stream were inventoried in the Long Beach system; and 27.3 km of stream were inventoried in the Three Star system (Figures 3 and 4).

Habitat compositions were similar among all systems inventoried, with the notable exceptions of a shallow 7-ha drainage lake in Clear Creek, and relatively large amounts of backwater habitat in the Long Beach system (Table 5; Figure 5). The drainage lake accounts for almost 50% of the total surface area of available rearing habitat in Clear Creek, whereas riffles, glides, and scour pools constitute over 80% of available habitat in the other systems. Cascades, rapids, trench pools, and dammed pools were not observed in the Three Star system, trench pools and dammed pools were not observed in Clear Creek, and beaver pond habitat was not present in the Long Beach system. The drainage

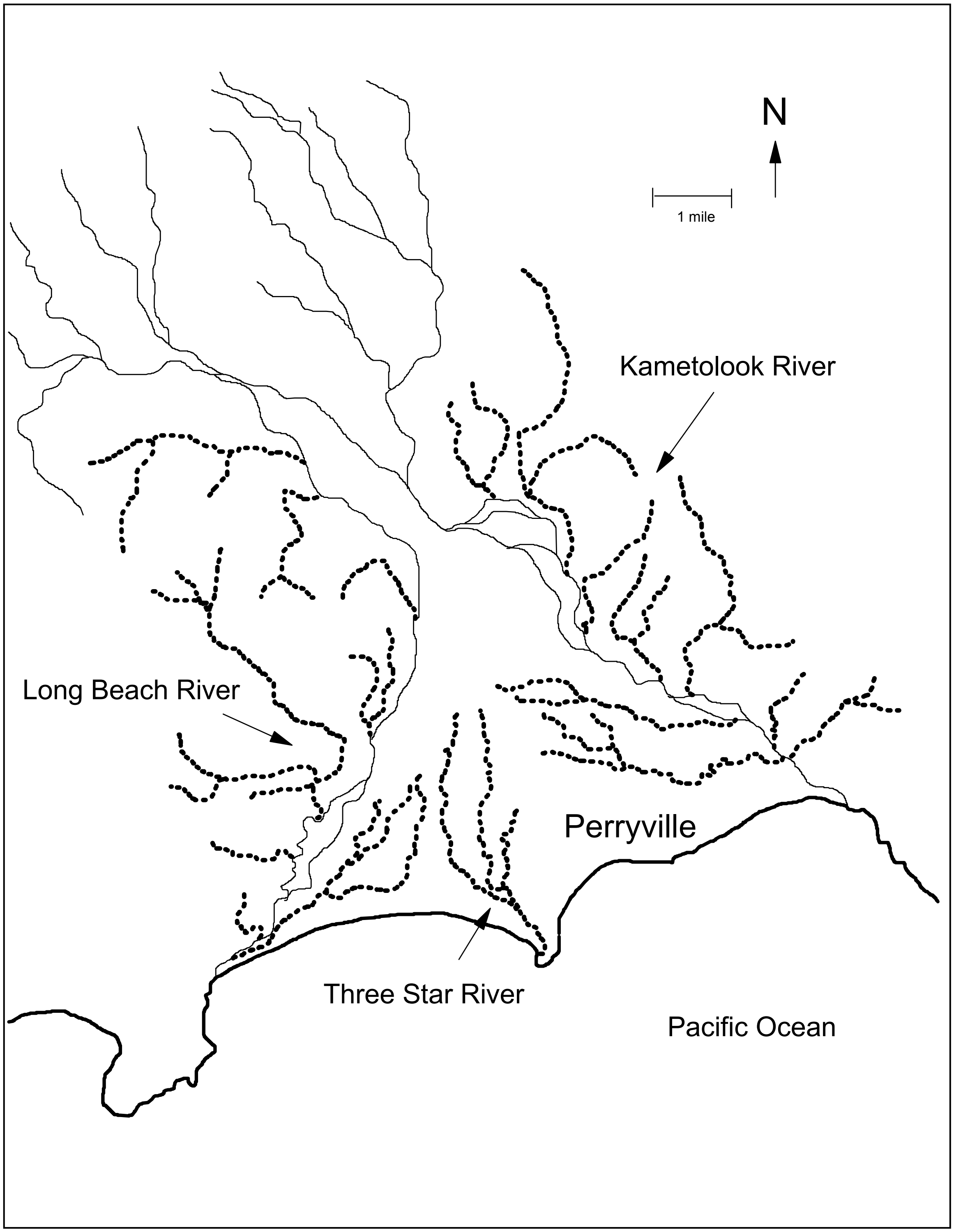


Figure 4. Streams near Perryville, Alaska, where habitat inventory was completed (heavy dashed lines) in 2002 (Kametolook) and 2003 (Three Star and Long Beach).

Table 5. Summary of habitat composition surveyed in streams near Perryville and in Clear Creek, 2002 and 2003.

	Kametolook River		Three Star River		Long Beach River		Clear Creek	
Habitat Type	Surface Area (m^2)	Percent Composition	Surface Area (m^2)	Percent Composition	Surface Area (m^2)	Percent Composition	Surface Area (m^2)	Percent Composition
Cascade	1,026	< 1	0	0	1,471	< 1	152	< 1
Rapid	1,806	1	0	0	214	< 1	9	< 1
Riffle	50,911	32	30,003	29	44,175	28	29,695	21
Glide	42,168	26	22,627	22	26,055	16	13,389	9
Trench Pool	1,389	< 1	0	0	336	< 1	0	0
Plunge Pool	538	< 1	27	< 1	536	< 1	153	< 1
Scour Pool	50,154	31	41,392	40	62,433	40	25,961	18
Dammed Pool	115	< 1	0	0	42	< 1	0	0
Alcove	289	< 1	165	< 1	612	< 1	32	< 1
Beaver Pond	10,437[a]	6	2,551[a]	2	0	0	70,013	49
Backwater	1,939	1	6,781	7	22,036	14	2,332	2
Total:	160,772		103,546		157,910		141,736	

[a] Beaver pond habitat in the Kametolook and Three Star systems consisted of small natural lakes and swamps.

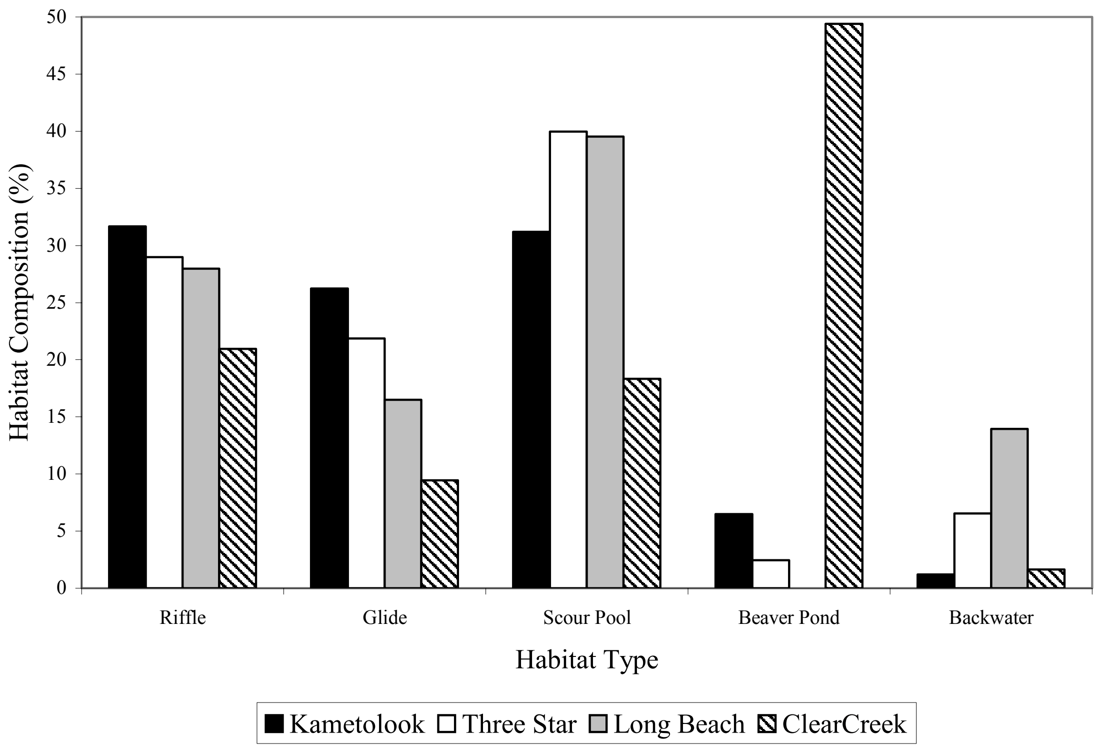


Figure 5. Relative composition of major habitat types by system as measured in 2002 and 2003.

lake in Clear Creek as well as small drainage lakes and swamps in the Kametolook and Three Star systems were classified as beaver pond habitat for use in the habitat model.

Habitat quality, as defined by cover availability, was generally similar among systems (Figures 6 - 11). Pocket water (Figure 6) and boulder (Figure 7) were usually the least common of the six cover types measured, whereas turbulence (Figure 8) and overhead (Figure 9) were usually the most common. Some differences in cover types were apparent between fast and slow water habitats. Fast water habitats tended to have more pocket water, more boulders, and more turbulence than slow water habitats. Slow water habitats tended to have more undercut bank (Figure 10) and LWD (Figure 11) than fast water habitats. For all habitat types, the Kametolook River tributaries generally had a greater percentage of LWD than the other systems (Figure 11).

Estimates of suitable spawning habitat, expressed as a percentage of total habitat inventoried, were greater in Clear Creek (15%) and the Kametolook (16%) than in the Three Star (6%) or Long Beach (2%) systems, and the distribution of spawning habitat varied among habitat types (Figure 12). Most (83% to 98%) available spawning habitat was classified as either good or fair in all systems except the Three Star, where 59% was

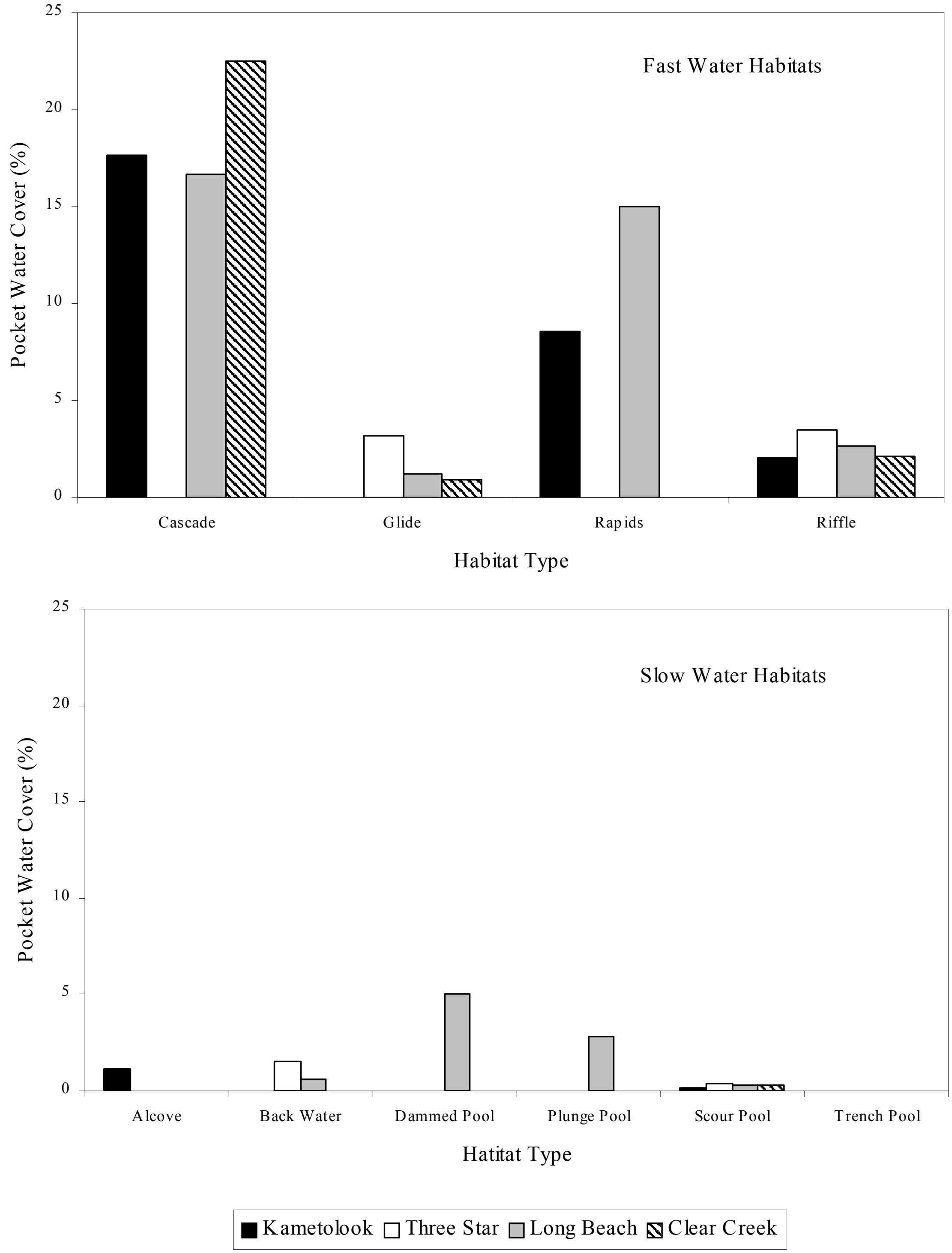


Figure 6. Mean percent pocket water cover by fast water (top) and slow water (bottom) habitat types for each system in 2002 and 2003.

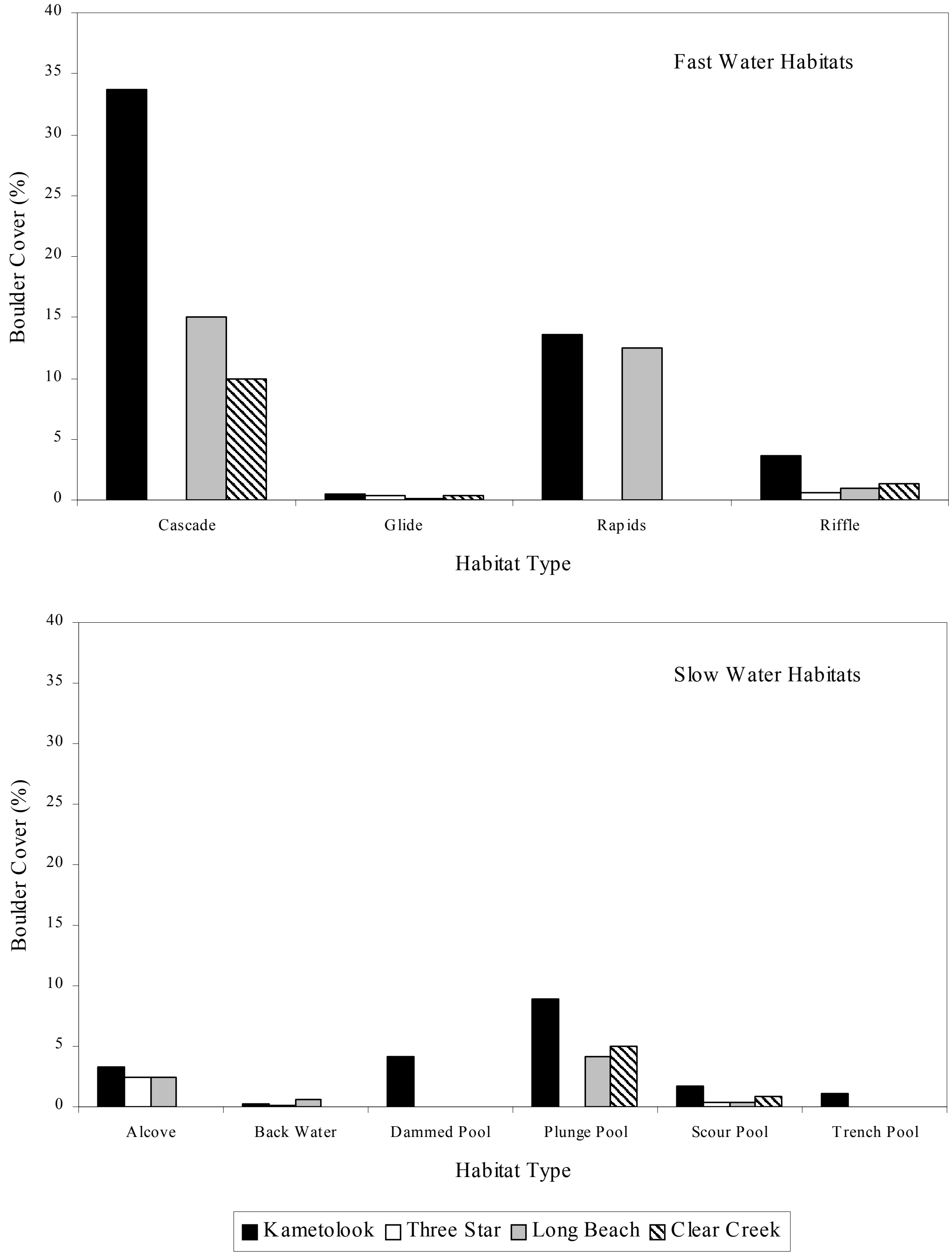


Figure 7. Mean percent boulder cover by fast water (top) and slow water (bottom) habitat types for each system estimated in 2002 and 2003.

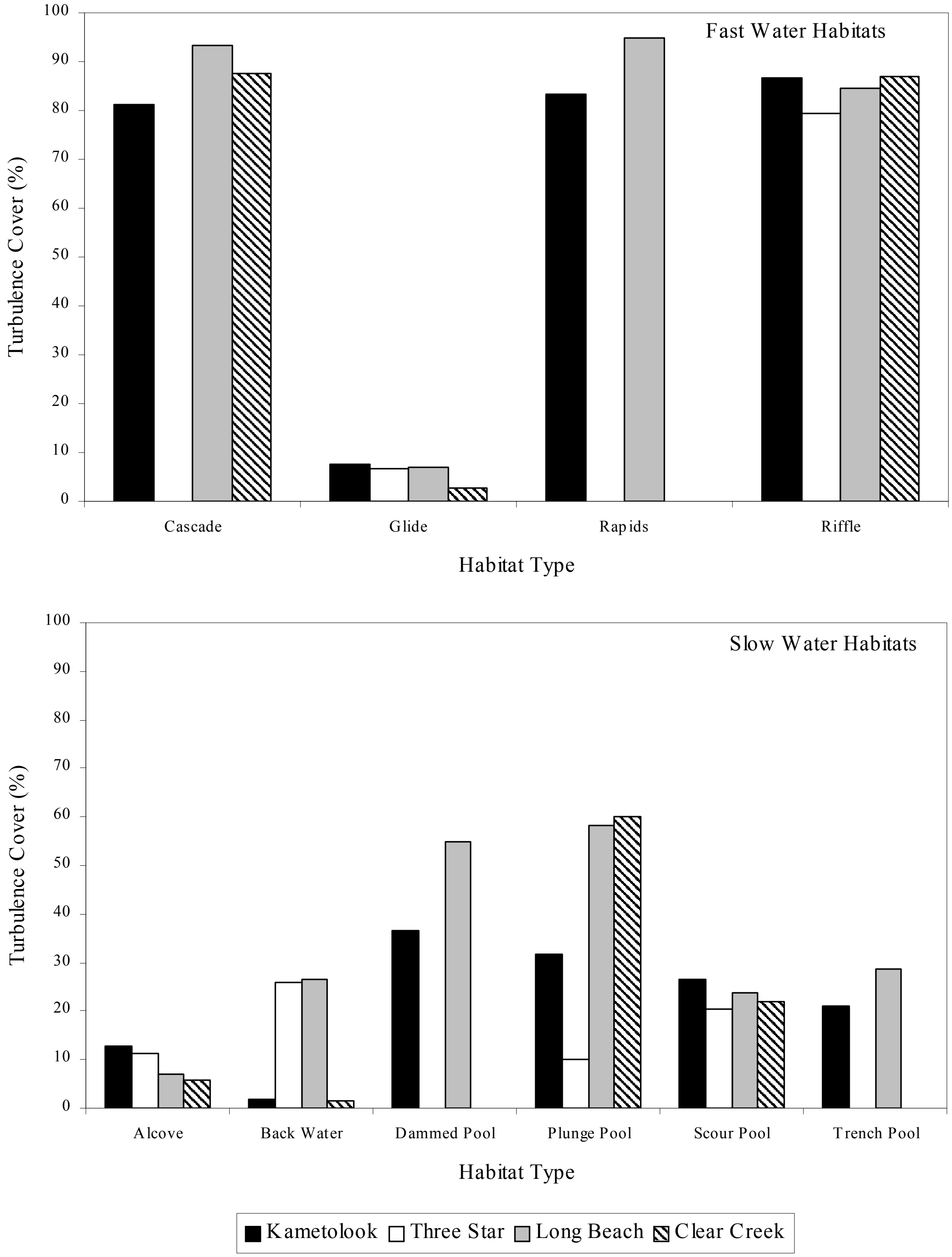


Figure 8. Mean percent turbulence cover by fast water (top) and slow water (bottom) habitat types for each system estimated in 2002 and 2003.

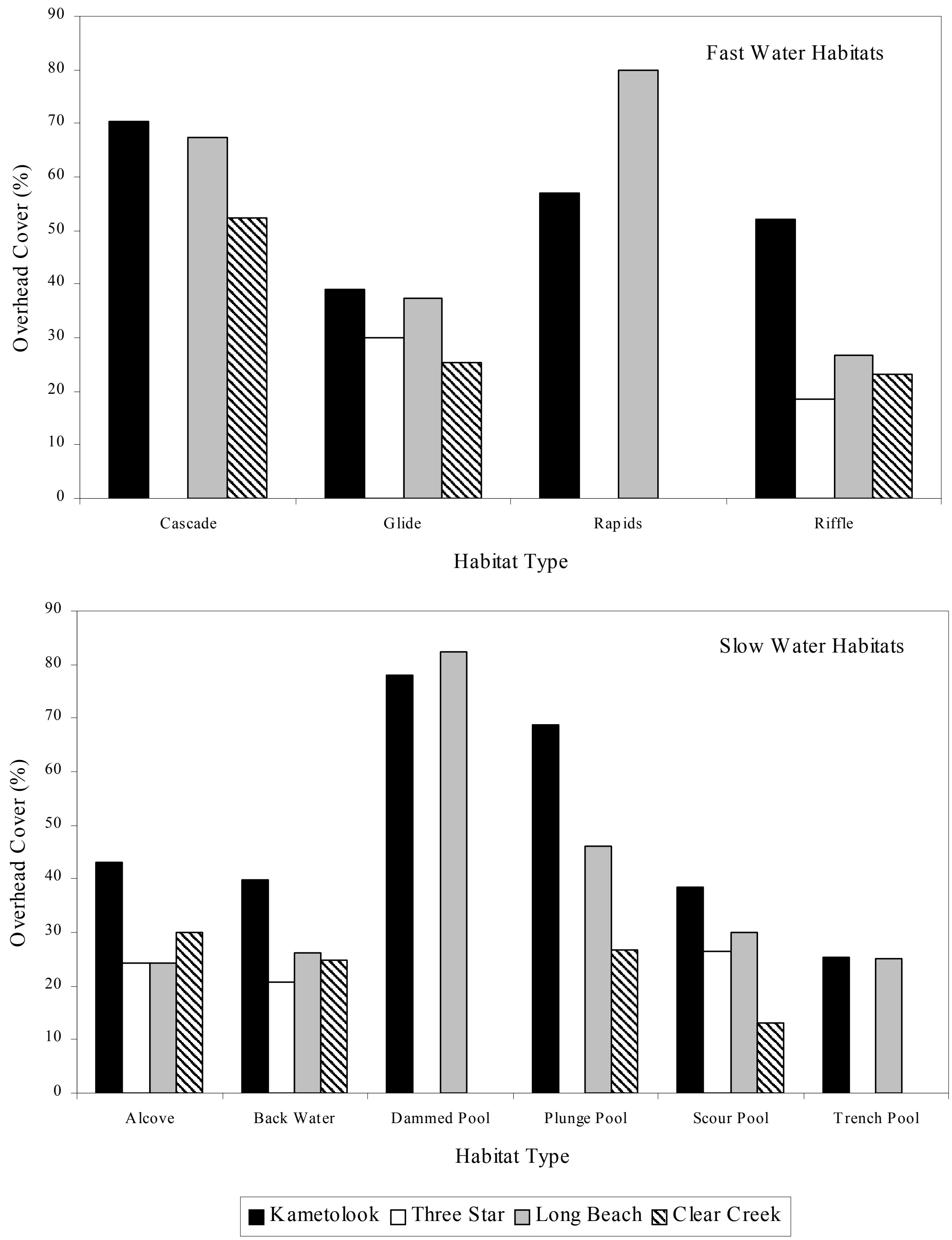


Figure 9. Mean percent overhead cover by fast water (top) and slow water (bottom) habitat types for each system in 2002 and 2003.

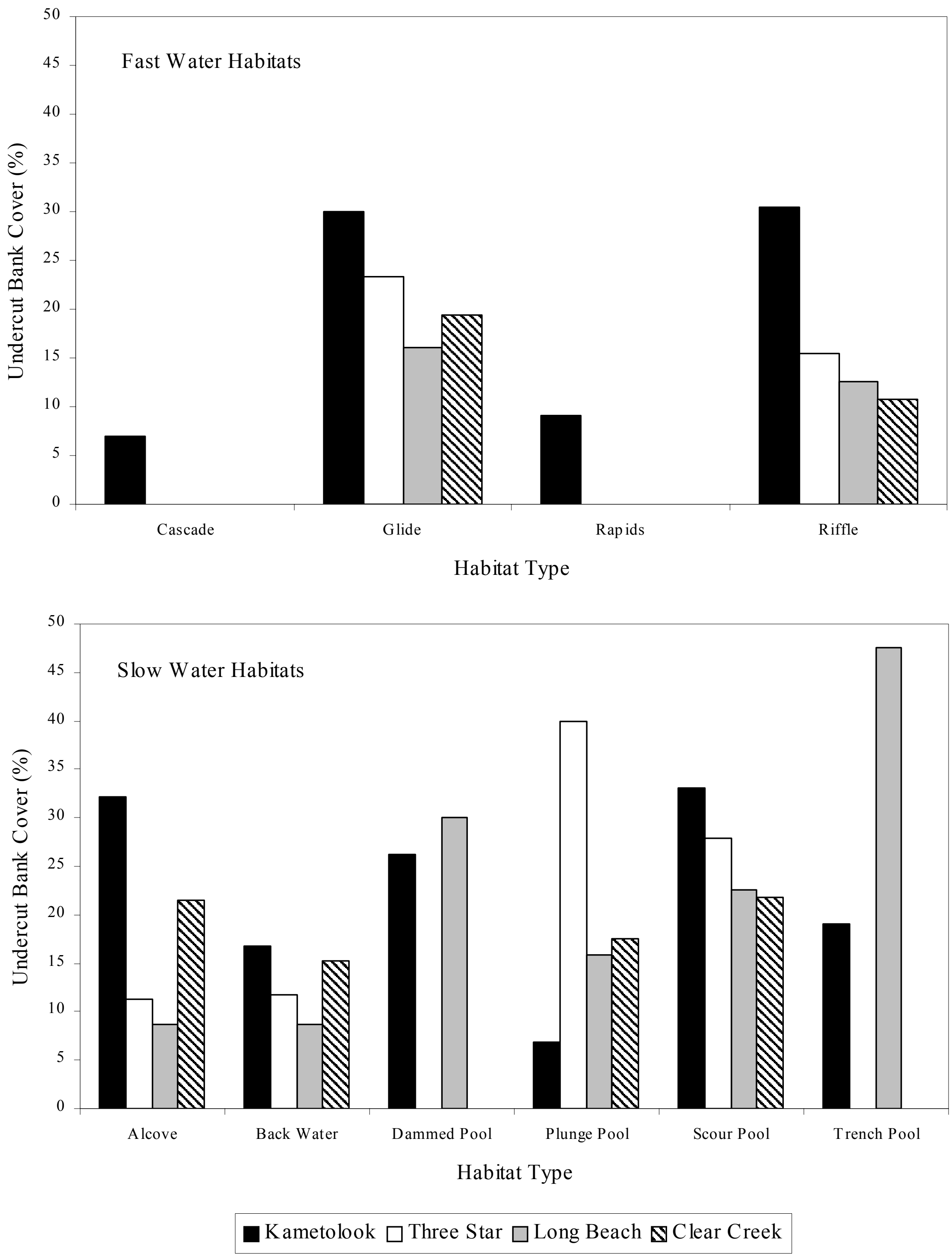


Figure 10. Mean percent undercut bank cover by fast water (top) and slow water (bottom) habitat types for each system estimated in 2002 and 2003.

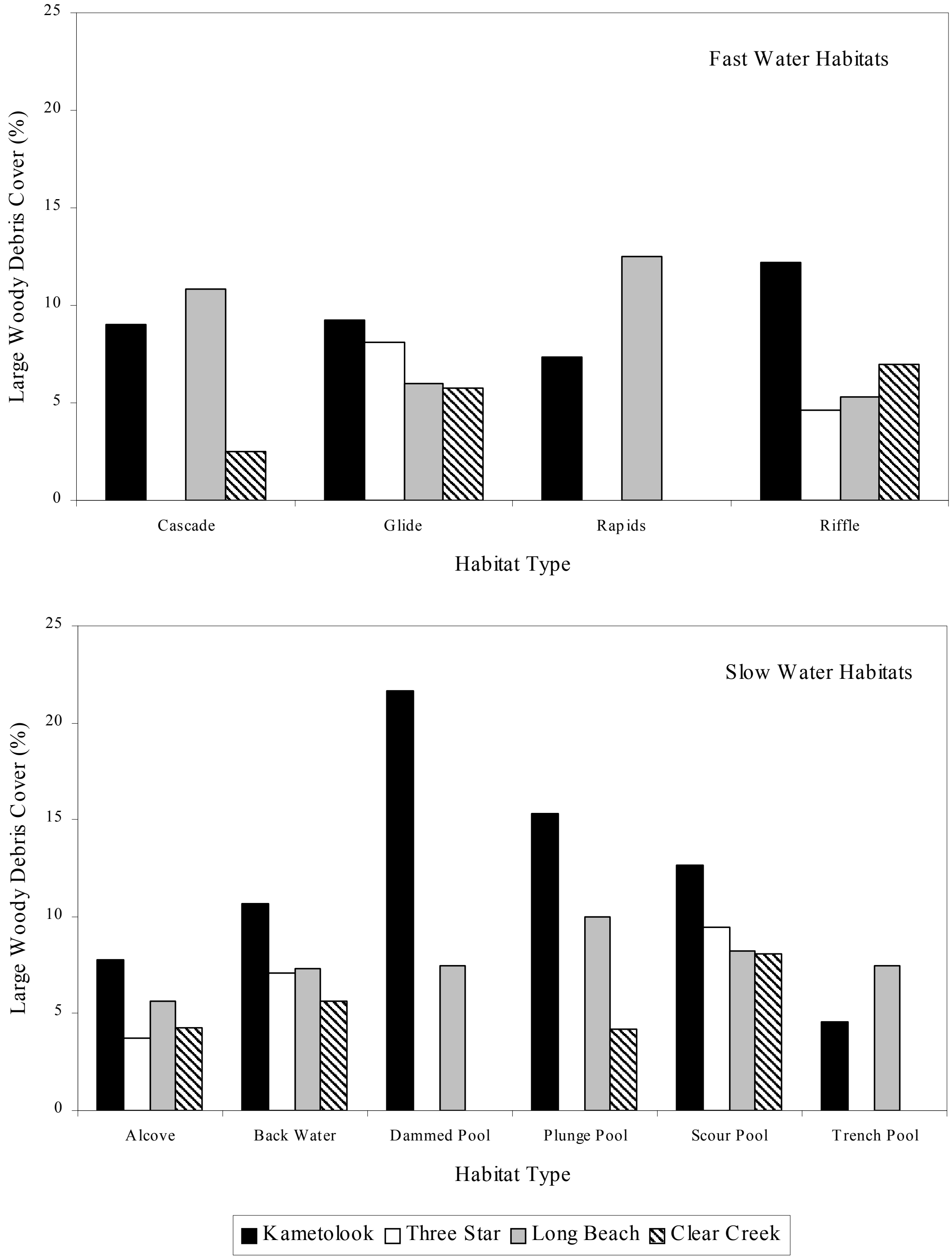


Figure 11. Mean percent cover provided by large woody debris by fast water (top) and slow water (bottom) habitat types for each system estimated in 2002 and 2003.

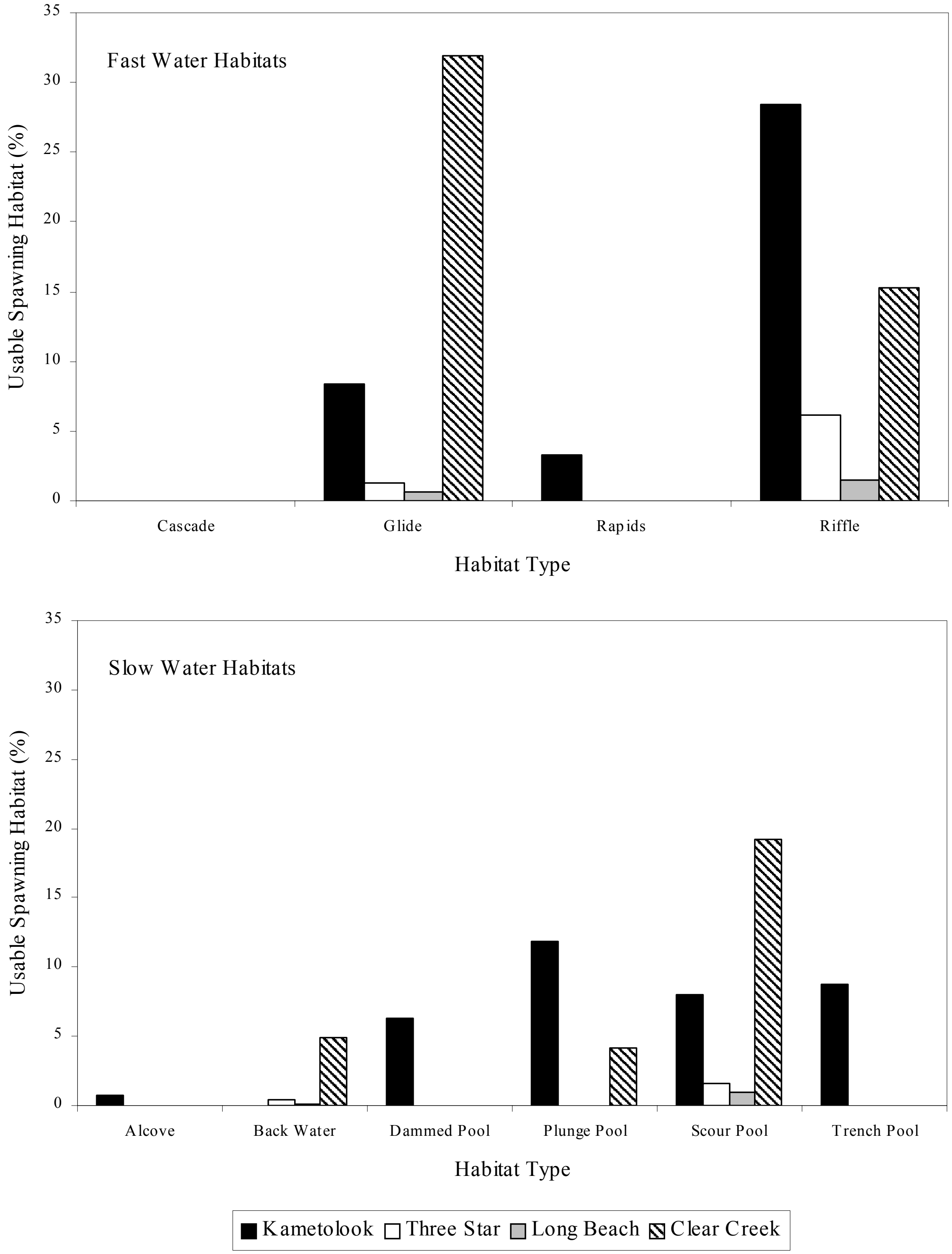


Figure 12. Mean percent available spawning habitat by fast water (top) and slow water (bottom) habitat types for each system estimated in 2002 and 2003.

classified as poor (Table 6). Width-to-maximum depth ratios were similar among systems, and at least 75% of pools in all systems had width-to-maximum depth ratios less than 10 (Figure 13).

Surface fine sediments (≤ 4 mm) were least common (8%) in the Long Beach system and most common (20%) in the Kametolook system (Table 7; Figure 14). Cobble embeddedness greater than 50% was not observed in Clear Creek habitats, but ranged from 16% in Kametolook River tributaries to 69% in the Three Star system (Table 8; Figure 14).

A limited amount of water temperature data was collected in 2002 and 2003 due to a variety of factors. Only one of the three data loggers deployed in the Kametolook drainage provided useful data in 2002 because one was lost following a flood event in mid-September, and another malfunctioned shortly after deployment. Additionally, the data logger deployed at the Clear Creek weir in 2003 malfunctioned in early September. However, some information was obtained from the data loggers that did function. Water temperatures were similar at sites monitored in the Kametolook River and Clear Creek during 2002 (Figure 15). Stream temperatures generally declined as the season progressed from summer to fall, and showed decreased daily fluctuations after early September. Water temperatures in Clear Creek were higher in 2003 than in 2002 within similar time periods (Figure 16). However, daily minimum and maximum water temperatures did not show much variation, which may have been due to placement near a spring or other source of groundwater recharge.

Table 6. Summary of spawning condition classifications of available spawning habitat by system, 2002 and 2003.

	Spawning Condition (%)		
System	Good	Fair	Poor
Kametolook	51	33	15
Three Star	0	41	59
Long Beach	76	22	2
Clear Creek	34	49	17

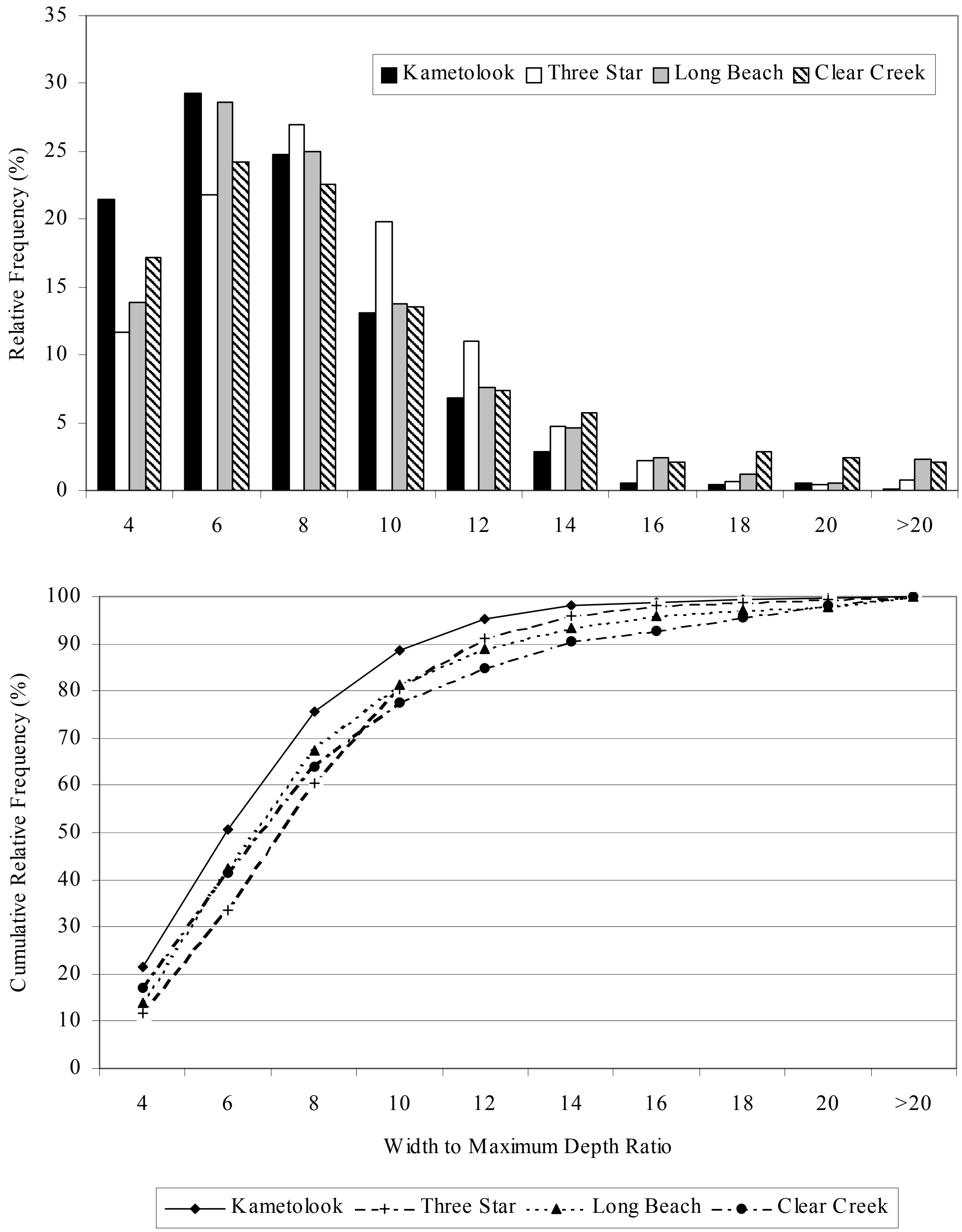
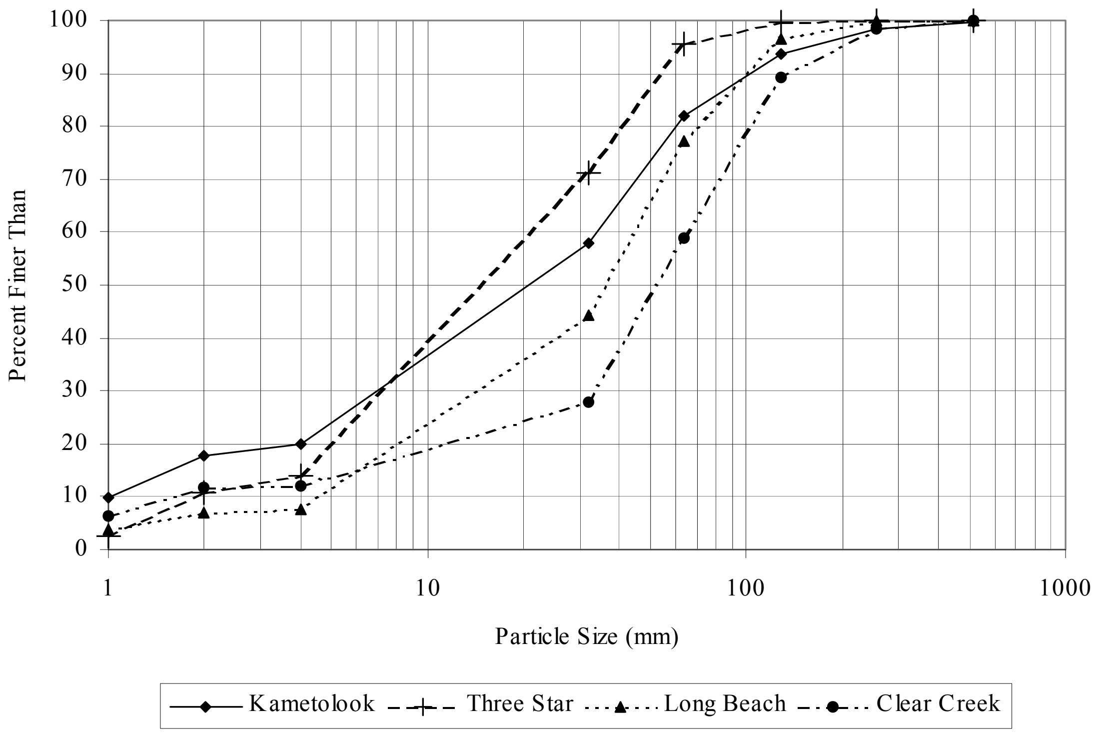


Figure 13. Relative (top) and cumulative (bottom) distributions of width-to-maximum depth ratios, 2002 and 2003.

Table 7. Summary of substrate composition by size category for each system, 2002 and 2003.

	Kametolook River		Three Star River		Long Beach River		Clear Creek	
Size Category	Percent	Cumulative %	Percent	Cumulative %	Percent	Cumulative %	Percent	Cumulative %
Organics	6	6	2	2	3	3	2	2
Clay/Silt	4	10	1	3	0	4	4	6
Sand	8	18	8	11	3	7	5	12
Small Gravel	2	20	3	14	1	8	0	12
Medium Gravel	38	58	57	71	37	44	16	28
Large Gravel	24	82	24	96	33	77	31	59
Small Cobble	12	94	4	100	19	97	30	89
Large Cobble	5	98	0	100	3	100	9	99
Boulder	1	100	0	100	0	100	1	100
Bedrock	0	100	0	100	0	100	0	100



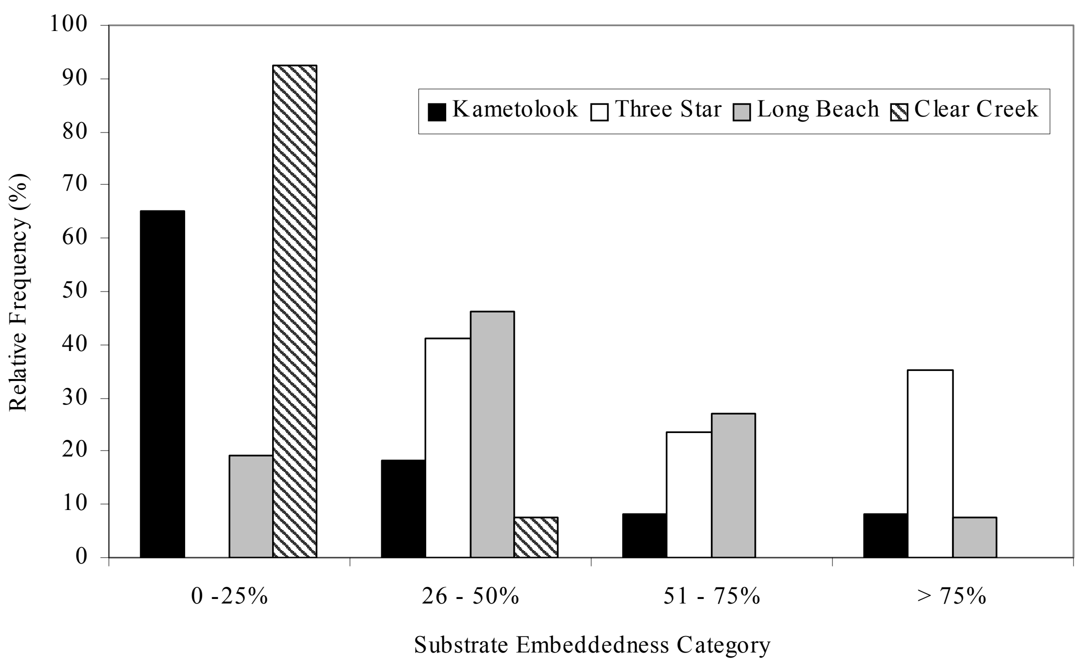


Figure 14. Summary of surface substrate particle size (top) and frequency of habitat units by percent embeddedness category (bottom), 2002 and 2003.

Table 8. Percent of habitat units classified by cobble embeddedness categories for each system, 2002 and 2003.

	Cobble Embeddedness Category			
System	≤ 25%	26 - 50%	51 - 75%	> 75%
Kametolook River	65	19	8	8
Three Star River	0	41	24	35
Long Beach River	19	46	27	8
Clear Creek	92	8	0	0

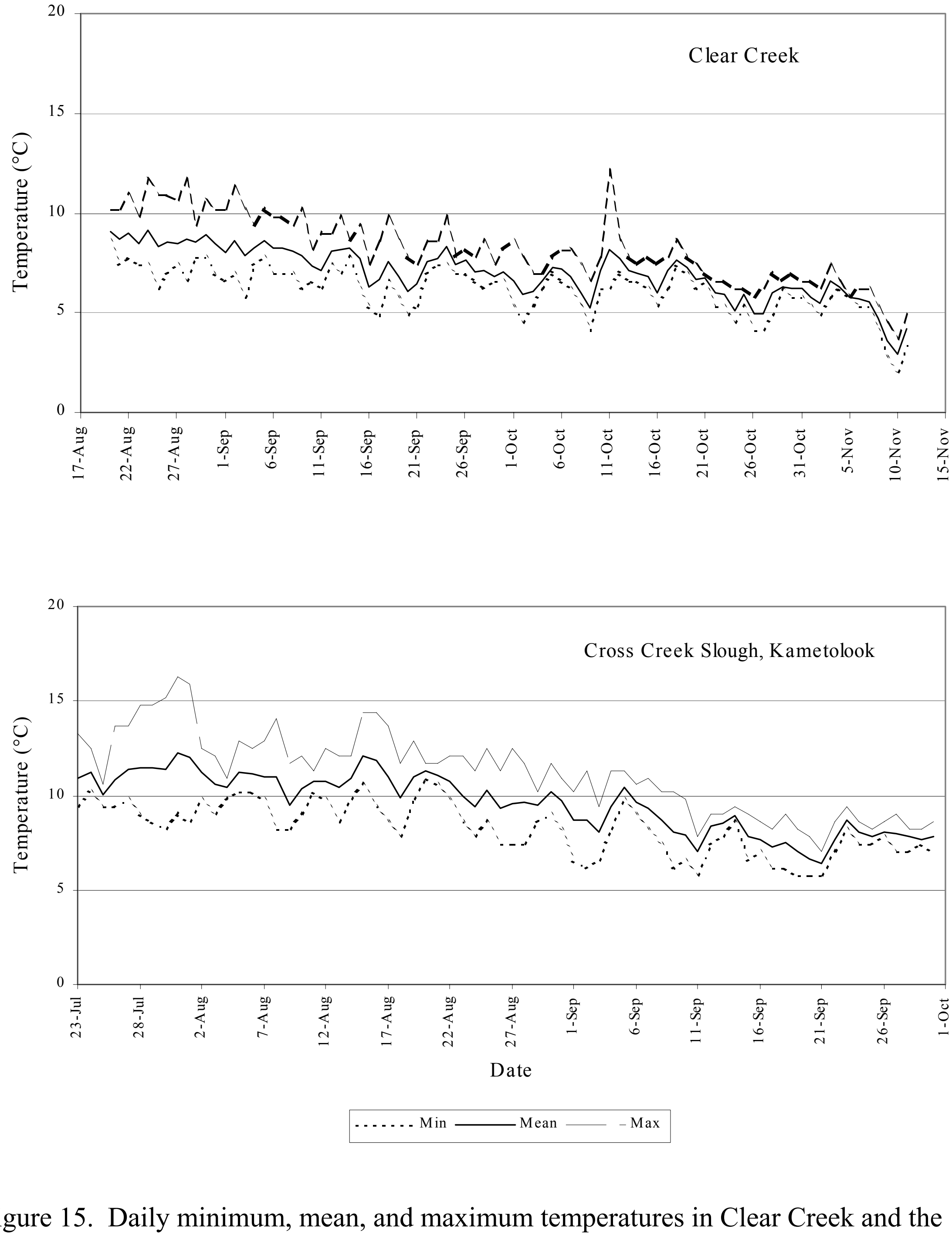


Figure 15. Daily minimum, mean, and maximum temperatures in Clear Creek and the Kametolook drainage, 2002.

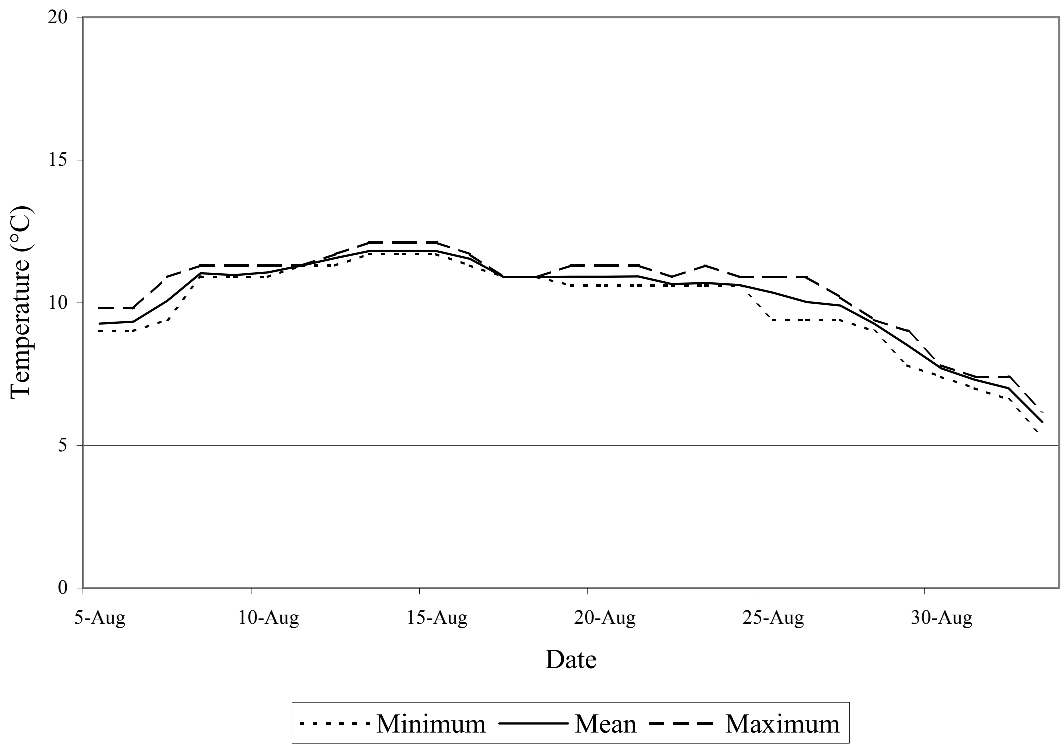


Figure 16. Daily minimum, mean, and maximum temperatures in Clear Creek, 2003.

Clear Creek Juvenile Sampling

Mean juvenile coho salmon density estimates derived from snorkel surveys were lower in 2003 than in 2002 across all habitat types except alcoves (Table 9). In 2002, only strata 3 and 4 were surveyed because spawning pink and chum salmon in strata 1 and 2 created poor visibility; strata 5 and 6 were not part of the sampling design in 2002. All strata were surveyed in 2003. On average, mean density estimates in strata 3 and 4 were 75% lower in 2003 than in 2002 for all habitat types except alcoves. Juvenile coho salmon were more abundant in slow (alcoves, backwaters, and pools) than in fast water habitat types (cascades, glides, riffles) in both years. Juvenile coho salmon were observed in all habitat types except cascades in both years.

Mean density estimates for juvenile Dolly Varden were also generally lower in 2003 than in 2002, whereas estimates for juvenile Chinook salmon were generally higher in 2003 than in 2002 (Table 10). Chinook salmon were observed in all habitat types except cascades in 2003, but were not observed in alcoves, cascades, or plunge pools in 2002. Dolly Varden were observed in all habitat types in 2003, and were observed in all habitat types except alcoves in 2002.

Table 9. Mean juvenile coho salmon density estimates (fish/m^2) and standard errors (SE) by habitat type for snorkel surveys in the Clear Creek drainage, 2002 and 2003.

	2002 - Strata 3 & 4			2003 - Strata 3 & 4			2003 - All Strata		
Habitat Type	*n*	Estimate	SE	*n*	Estimate	SE	*n*	Estimate	SE
Alcove	1	0.25	--	1	4.34	--	2	2.21	2.13
Backwater	2	5.22	0.43	2	1.03	0.70	9	0.65	0.24
Cascade	1	0.00	--	1	0.00	--	1	0.00	--
Glide	7	1.33	0.48	7	0.39	0.20	16	0.22	0.09
Plunge Pool	2	3.63	3.16	2	0.19	0.19	2	0.19	0.19
Pond	0	--	--	0	--	--	1	0.36[a]	--
Riffle	15	0.21	0.07	15	0.05	0.02	23	0.09	0.02
Scour Pool	5	1.43	0.34	5	0.60	0.19	28	0.43	0.06

[a] Pond estimate was generated from mark-recapture population estimate.

Table 10. Mean juvenile Chinook salmon and Dolly Varden density estimates (fish/m^2) and standard errors (in parentheses) by habitat type for snorkel surveys in the Clear Creek drainage, 2002 and 2003.

	Chinook Salmon				Dolly Varden			
	2002		2003		2002		2003	
Habitat Type	*n*	Estimate	*n*	Estimate	*n*	Estimate	*n*	Estimate
Alcove	1	0.00 (-----)	2	0.24 (0.17)	1	0.00 (-----)	2	0.10 (0.10)
Backwater	2	0.36 (0.36)	9	0.04 (0.04)	2	0.19 (0.19)	9	0.01 (0.01)
Cascade	1	0.00 (-----)	1	0.00 (-----)	1	0.69 (-----)	1	0.05 (-----)
Glide	7	0.03 (0.02)	16	0.10 (0.03)	7	0.01 (0.01)	16	0.07 (0.04)
Plunge Pool	2	0.00 (-----)	2	0.07 (0.04)	2	1.03 (0.64)	2	0.52 (0.33)
Riffle	15	0.02 (0.01)	23	0.03 (0.01)	15	0.21 (0.06)	23	0.02 (0.01)
Scour Pool	5	0.04 (0.03)	28	0.11 (0.02)	5	0.14 (0.10)	28	0.08 (0.03)

We attempted to estimate juvenile coho salmon abundance in six scour pools and two plunge pools using minnow trap removal methods in late summer and fall 2002 (Table 11). Six of these removal experiments used four capture events and the remaining two used three events. The 22 September experiment resulted in increasing, rather than decreasing catches during each removal event. Of the remaining seven experiments, none produced valid population estimates. Although capture probabilities were greater than 0.20 in all but one (9 October) of these seven experiments, capture probability assumptions were not met for five (chi-square goodness of fit test, $p < 0.05$), and initial population sizes appeared to be less than 200 individuals for three experiments.

Juvenile coho salmon abundance in the Clear Creek drainage lake in 2003 was estimated at 24,191 fish (95% confidence interval: 20,501 to 32,480) based on a Lincoln-Petersen model, and juvenile coho salmon density was 0.36 fish/m^2 (95% confidence interval: 0.29 to 0.46 fish/m^2) since lake surface area was estimated at 70,013 m^2 (7 ha). During the first sampling event on 25 September, 1,069 juvenile coho salmon were marked and released alive (*M*; Table 12). During the second sampling event on 7 October, 72 marked fish were recovered (*R*) from a total catch of 1,693 coho salmon (*C*; Table 13). Mixing of marked coho salmon between the shoreline and the offshore areas of the lake occurred between sampling events, but was not complete (Table 14). Most marked juvenile coho salmon, 88% of shoreline and 60% of offshore marks, were recaptured in the same area in which they were originally captured. Chi-square analyses of recapture data indicate that juvenile coho salmon in both areas of the lake were equally vulnerable to capture during the first event ($X^2 = 0.919$, $p = 0.338$; Table 13), and recapture and survival probabilities were the same for both groups of marked fish ($X^2 = 0.198$, $p = 0.656$; Table 14). Overall bias in the abundance estimate was less than 2%, as $MC >> 4N$.

All 20 marked fish from each pond area that were held through the course of the mark-recapture experiment retained their marks, and marks were clearly visible on recaptured fish. However, juvenile coho salmon mortality during the experiment was high. Inadequate circulation of fresh water through one of the live wells used to hold fish overnight for marking resulted in 846 deaths. Excluding deaths caused by the live well malfunction, the tagging mortality rate was over 8% (Table 12).

Based on analysis of scale samples collected in 2003, age 0+ coho salmon were more abundant than age 1+ fish in all strata, although proportions differed among strata (Table 15; $G = 16.9$, $p = 0.005$). Results of the Tukey-type multiple comparisons were ambiguous in that the only detectable difference in age proportions was between strata 2 and 3. With stratum 3 removed from the analysis, there was no difference in age proportions among strata ($G = 6.7$, $p = 0.245$). Overall, about 90% of juvenile coho salmon sampled in 2003 were age 0+ (Table 15, Figure 17).

Age 1+ coho salmon were larger than age 0+ fish across all strata in 2003 (Table 15, Figure 18). Mean length of age 0+ coho salmon varied among strata (ANOVA, $F = 8.512$, $p < 0.001$), whereas mean length of age 1+ coho salmon did not (ANOVA, $F = 1.345$, $p = 0.258$). The greatest difference in mean length among strata for age 0+ coho salmon was 5.7 mm (difference between strata 4 and 6; Table 15). Mean lengths of age

Table 11. Minnow trap removal experiments to estimate juvenile coho salmon abundance, Clear Creek, 2002. Two removal models were used, one based on constant catchability for all events (M_b), and the other on constant catchability for all events except the first (M_{bh}). Capture probabilities (P_c) are reported for each model. P-values refer to results of chi-square tests of catchability assumptions.

		Removal Event				Estimated		X^2
Sample Date	Habitat Type	1	2	3	4	Number (95% C.I.)	Model (P_c)	*p*-value
25 August	Plunge Pool	59	12	7	1	79 (79 to 79)	M_b (0.73)	0.205
26 August	Scour Pool	95	24	16	45	231 (203 to 289)	M_b (0.31)	0.000
27 August	Scour Pool	90	33	11	9	146 (143 to 155)	M_b (0.60)	0.225
21 September	Plunge Pool	415	260	82	--	856 (823 to 903)	M_b (0.51)	0.000
22 September	Scour Pool	41	86	94	222	--	--	--
28 September	Scour Pool	174	145	64	53	495 (467 to 547)	M_{bh} (0.35, 0.43)	0.032
29 September	Scour Pool	103	46	37	--	226 (204 to 271)	M_b (0.44)	0.090
9 October	Scour Pool	25	27	16	27	674 (129 to 9,734)	M_b (0.04)	0.170

Table 12. Summary of juvenile coho salmon marking event in the Clear Creek drainage lake, 2003. The value for *M* was used in abundance estimate calculations.

Pond Stratum	Total Captured	Total Marked	Total Marked & Released alive	Mortalities
Shoreline	1,717	865	774[a]	923[b]
Offshore	337	337	295[a]	22
Total:	2,054	1,202	1,069 (*M*)	945

[a] 20 fish from each pond sector were held for the duration of the census to investigate mark retention.
[b] Includes 846 mortalities from inadequate live well holding.

Table 13. Summary of juvenile coho salmon recapture event in the Clear Creek drainage lake, 2003. The values for *R* and *C* were used in abundance estimate calculations.

Pond Stratum	Total Unmarked	Total Marked	Event Total
Shoreline	1,094	53	1,147
Offshore	527	19	546
Total:	1,621	72 (*R*)	1,693 (*C*)

Table 14. Summary of juvenile coho salmon recaptures by location in the Clear Creek drainage lake, 2003.

	Recapture Location		
Release Location	Shoreline	Offshore	Not Recaptured
Shoreline	44	6	724
Offshore	9	13	273
Total:	53	19	997

Table 15. Summary of juvenile coho salmon age and length data by stratum collected in Clear Creek and Camp Creek, 2003. Standard errors are reported in parentheses for mean lengths.

	Age 0+			Age 1+		
Stratum	Mean length (mm)	Number sampled	Proportion	Mean length (mm)	Number sampled	Proportion
1	60.6 (0.76)	111	0.925	87.2 (3.03)	9	0.075
2	59.6 (0.79)	100	0.833	81.1 (1.35)	20	0.167
3	61.1 (0.65)	117	0.975	81.3 (7.13)	3	0.025
4	57.4 (0.78)	106	0.898	78.3 (3.38)	12	0.102
5	62.8 (0.63)	110	0.924	83.1 (3.33)	9	0.076
6	63.1 (0.70)	106	0.883	79.7 (1.57)	14	0.117

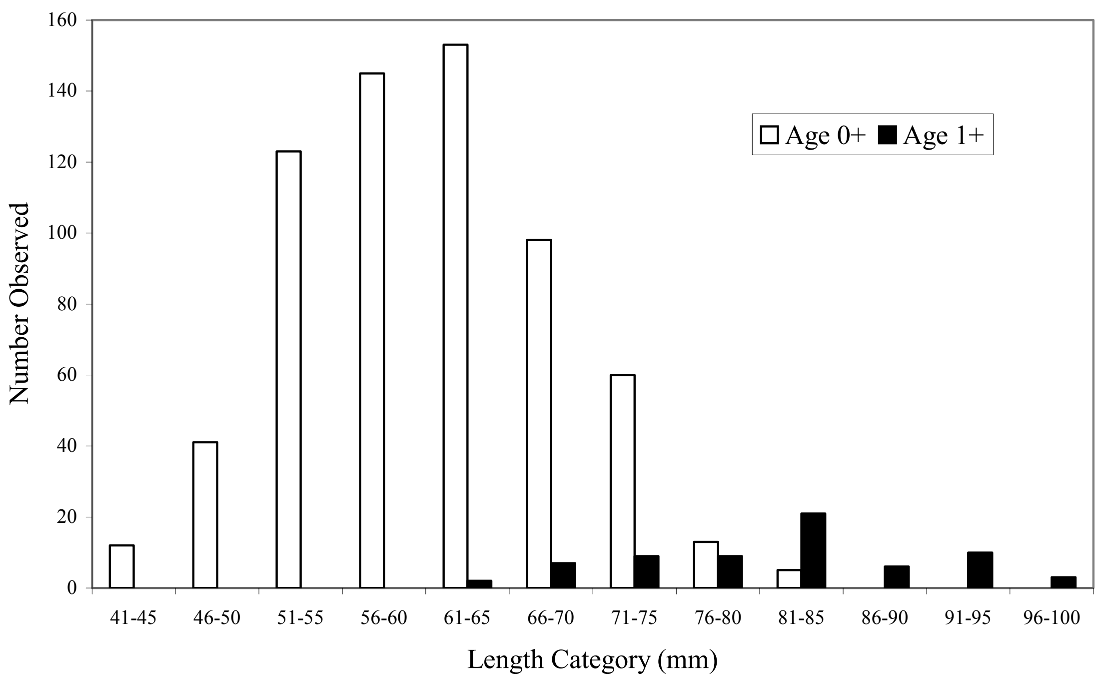


Figure 17. Length-frequency distribution by age class of juvenile coho salmon sampled in Clear Creek, 2003.

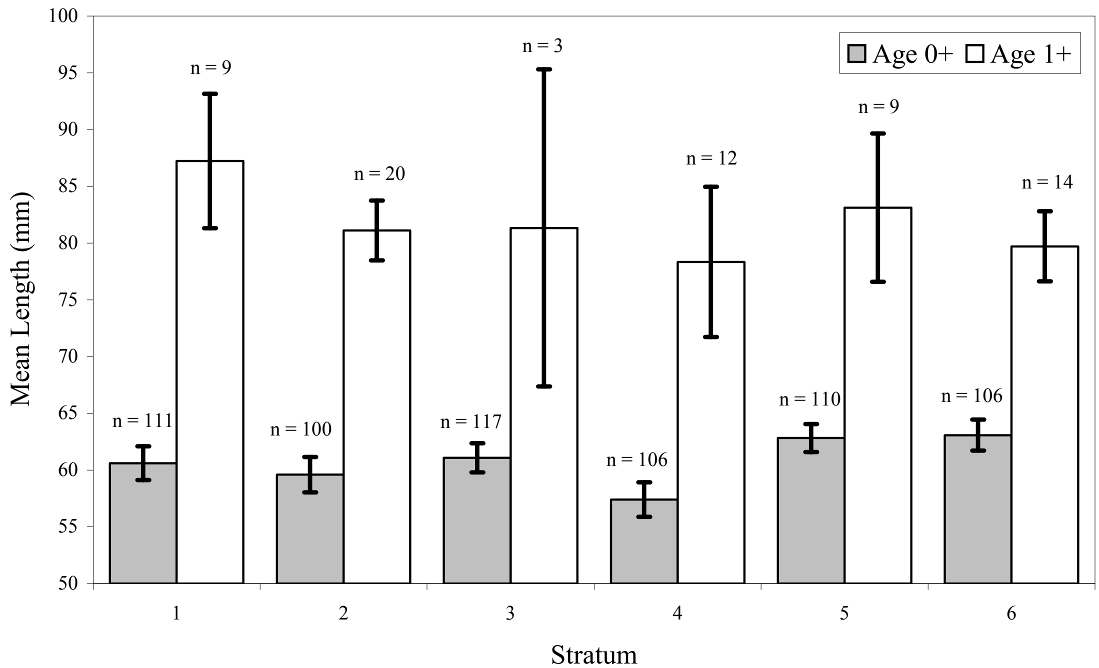


Figure 18. Mean length (mm) of juvenile coho salmon by age and stratum observed in Clear Creek and Camp Creek, 2003. Error bars represent 95% confidence intervals. Sample size for each category shown above bars.

1+ coho salmon were also smaller in Stratum 4 than the other strata, although the ANOVA was not significant for age 1+ length data. Residual analysis indicated that the ANOVA model was appropriate for both age classes: independence of error terms, homoscedastic error term variance, normality of error terms, and no outliers. Results of the Tukey test comparing age 0+ coho salmon lengths among strata were ambiguous (Table 16), indicating at least one Type II error (failure to reject a false null hypothesis) was committed. The conclusion drawn from the Tukey test for age 0+ coho salmon lengths is that strata 6 and 5 differed from strata 2 and 4. The mean length of juvenile coho salmon measured in 2002 (n = 109) was 59.7 mm (SE = 0.93). The two sample Kolmogorov-Smirnov test comparing length-frequency distributions between years (Figure 19) indicates that the two samples come from populations with similar distributions ($p > 0.05$). Juvenile coho salmon lengths used in the comparison from 2003 include all fish measured regardless of age (n = 1,200) as no age determinations were made in 2002.

Table 16. Results of the Tukey (honestly significant difference) test comparing mean lengths of age 0+ coho salmon among sampling strata in Clear Creek and Camp Creek, 2003. Results are considered significant at $p \leq 0.05$.

	p-values for Tukey HSD test					
Stratum	1	2	3	4	5	6
1	1.000	--	--	--	--	--
2	0.926	1.000	--	--	--	--
3	0.997	0.701	1.00	--	--	--
4	0.020	0.279	0.003	1.000	--	--
5	0.236	0.023	0.490	0.000	1.000	--
6	0.147	0.011	0.346	0.000	1.000	1.000

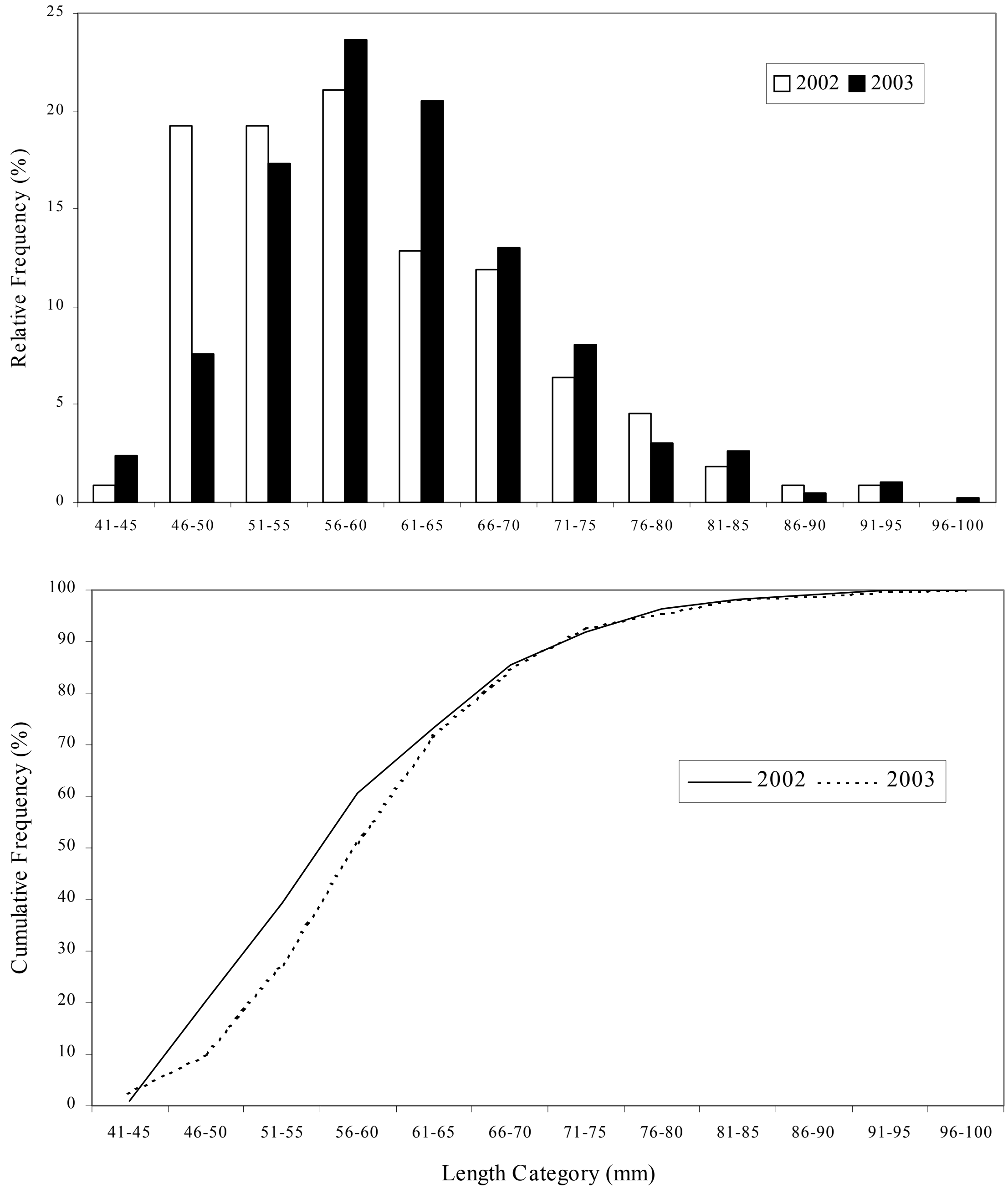


Figure 19. Length-frequency distribution (top) and cumulative length distribution of juvenile coho salmon sampled in Clear Creek, 2002 and 2003.

Escapement Monitoring

In 2002, coho salmon spawning escapement was monitored in three Kametolook River tributaries, the entire Three Star River, and one Long Beach River tributary (Figure 20). Two hundred ninety coho salmon were observed in the Perryville area in 2002, with most counted during the second survey of the season (Table 17). The same streams were selected for surveys in 2003, but high water prevented crossing the mainstem Kametolook River throughout the survey period, and Spring Creek and Candlefish Slough could not be surveyed. Several backwater sloughs on the Kametolook River were surveyed in 2003, although effort was not consistent for all surveys due to changing river conditions. Eight hundred coho salmon were observed in streams near Perryville in 2003, most in the Kametolook River sloughs (Table 18). High water conditions resulted in extended intervals between surveys for the different streams and unequal geographical coverage among sampling events, so area-under-the-curve methods for estimating coho salmon escapement could not be used in either 2002 or 2003.

In 2002, the Clear Creek weir was installed on 1 September and removed on 12 November, resulting in counts of 1,097 coho, 5,153 pink, 269 chum, and 32 sockeye salmon (Appendix A). Coho salmon were first counted at the weir on 14 September (Figure 21). Peak counts occurred in mid- to late-September, and smaller numbers were counted until 11 November. The pink, chum, and sockeye salmon runs were effectively over in late September. The weir was nonfunctional on five different occasions in 2002 because of high water, a combined total of about 10 days (Table 19).

In 2003, the Clear Creek weir was operated from 24 August through 14 November, resulting in counts of 549 coho, 3,907 pink, 369 chum, 31 sockeye, and two Chinook salmon (Appendix B). Coho salmon were first counted at the weir on 28 August (Figure 21). Peak counts occurred in late-October and early-November, and smaller numbers were counted until 13 November. The pink and chum salmon runs were effectively over in mid-September, whereas sockeye salmon occurred sporadically through early November. Two Chinook salmon also passed the weir, one on 29 August, and the other on 6 October. The weir was nonfunctional for 70 hours from 30 September to 3 October 2003 because of high water. Four coho salmon were found dead in the trap box on 1 October following the high water event, probably a result of being trapped when the weir collapsed. A walking survey conducted above the weir on 20 October, when flows receded and water clarity improved, resulted in a count of 618 coho salmon. Prior to the failure on 30 September, only 58 coho salmon had passed the Clear Creek weir, and an additional 143 coho salmon passed the weir between 3 October and 20 October. Therefore, at least 417 coho salmon counted above the weir during the walking survey on 20 October had not been enumerated at the weir. If these are added to the final count of coho salmon at the Clear Creek weir (549; Appendix B), the minimum escapement estimate would be about 1,000 adult coho salmon in 2003.

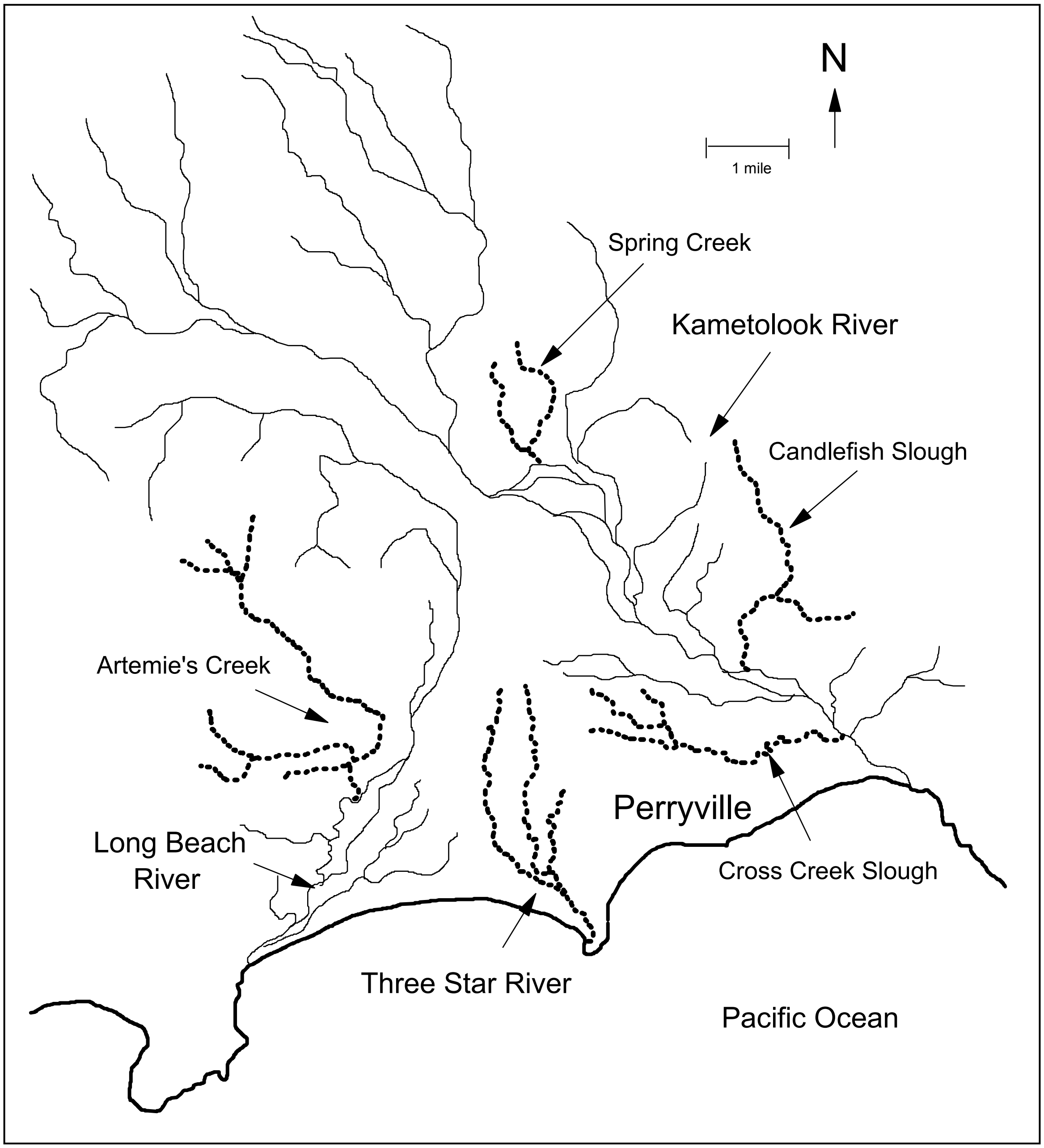


Figure 20. Streams near Perryville, Alaska, where walking surveys for adult coho salmon were completed in 2002 and 2003 (heavy dashed lines).

Table 17. Numbers of coho (CO), pink (PK), and sockeye (SE) salmon observed during stream walking surveys in streams near Perryville, 2002.

	Three Star River			Artemie's Creek			Cross Creek Slough			Spring Creek			Candlefish Slough		
Survey Period	CO	PK	SE	CO	PK	SE	CO	PK	SE	CO	PK	SE	CO	PK	SE
1 - 3 October	14	0	10	1	4	7	2	1	28	15	11	36	0	5	3
15 - 16 October	117	0	2	128	0	0	13	0	0	NC	NC	NC	NC	NC	NC
25 - 26 November	0	0	0	0	0	0	0	0	0	NC	NC	NC	NC	NC	NC
Total:	131	0	12	129	4	7	15	1	28	15	11	36	0	5	3

NC = Stream could not be counted due to high water.

Table 18. Numbers of coho (CO), pink (PK), and sockeye (SE) salmon observed during stream walking surveys in streams near Perryville, 2003.

	Three Star River			Artemie's Creek			Cross Creek Slough			Kametolook sloughs		
Survey Period	CO	PK	SE	CO	PK	SE	CO	PK	SE	CO	PK	SE
16 - 19 October	12	0	0	0	0	0	99	0	120	480	0	173
3 - 5 November	NC	NC	NC	NC	NC	NC	37	0	0	74	0	24
10 November	9	0	0	3	3	0	NC	NC	NC	NC	NC	NC
18 November	NC	NC	NC	NC	NC	NC	NC	NC	NC	86	0	0
Total:	21	0	0	3	3	0	136	0	120	640	0	197

NC = Stream could not be counted due to high water.

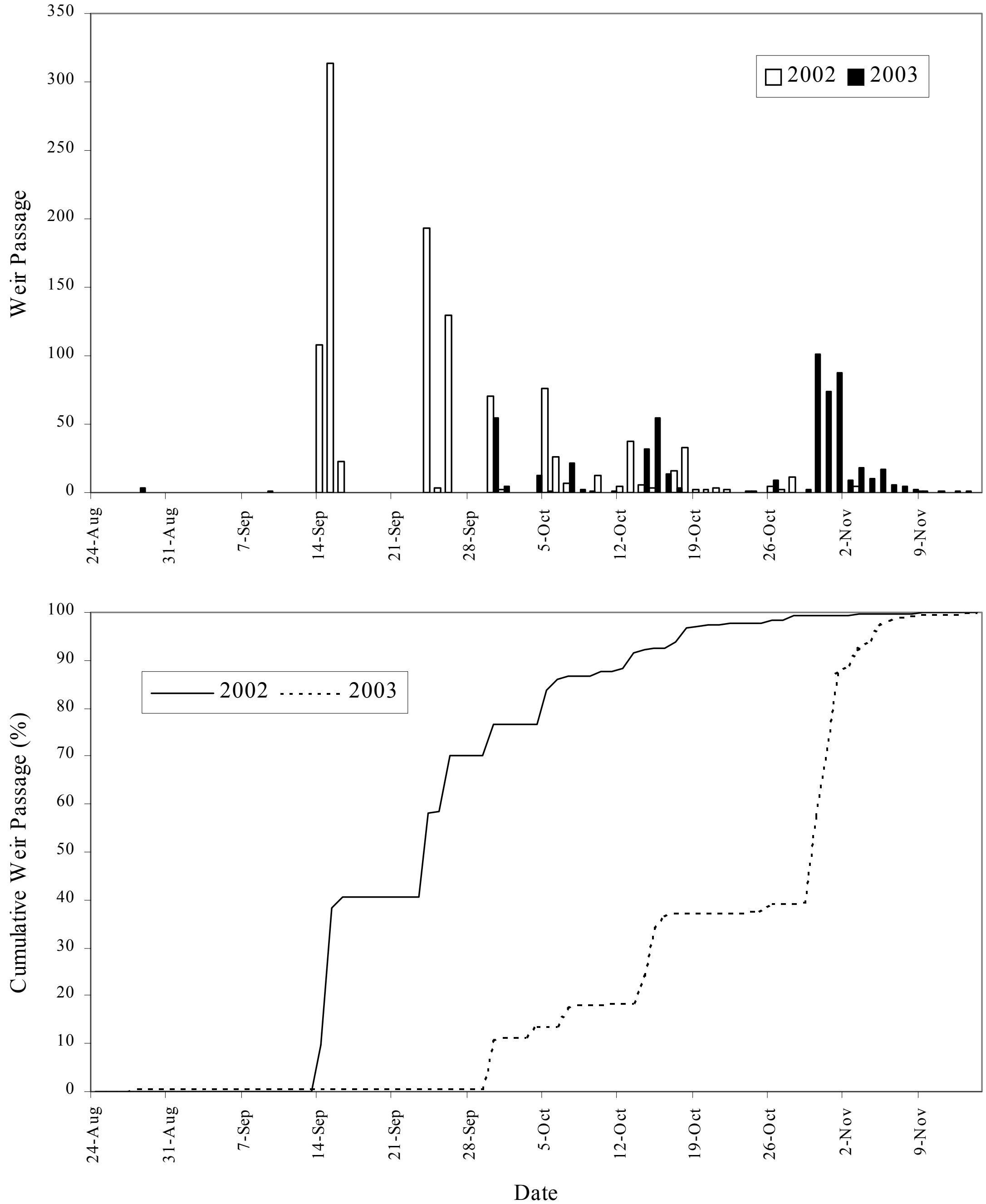


Figure 21. Daily (top) and cumulative (bottom) weir passage of adult coho salmon at the Clear Creek weir, 2002 and 2003.

Table 19. Summary of Clear Creek weir failures, 2002.

Date/Time down	Date/Time repaired	Hours Not Functioning
10 October, 18:30	12 October, 12:00	41
21 October, 19:00	22 October, 15:00	20
24 October, 19:00	26 October, 15:00	44
29 October, 17:00	1 November, 14:00	69
4 November, 17:00	7 November, 09:00	64
	Total:	238

Age, Sex, and Length Data

Age, sex, and length data were collected from 175 adult coho salmon during 14 September to 18 October 2002, and 125 adult coho salmon during 28 August to 4 November 2003. Samples were not obtained from 32 coho salmon that passed the weir after 19 October 2002. Scale samples were unreadable from 28 coho salmon (16%) in 2002, and 15 coho salmon (12%) in 2003. Coho salmon with unreadable scales were not included in data analyses in either year.

Three age classes were identified from scale samples in both years. Ages 2.1 and 1.1 were the most common age classes in samples over all strata in both years (Table 20, Table 21); only one age 3.1 coho salmon was sampled in 2002, and four were sampled in 2003. Age composition varied by sample period in both years, although this was not significant (*G*-test, $p > 0.05$ for both years). Age compositions ranged from 44% age 2.1 coho salmon in stratum 4 to 77% age 2.1 in stratum 6, 2002 (Table 20), and from 47% age 2.1 coho salmon in stratum 3 to 20% age 2.1 in stratum 5, 2003 (Table 21). Overall, sex composition of coho salmon sampled at the Clear Creek weir in 2002 was 54% males and 46% females (Table 22), and was 46% males and 54% females in 2003 (Table 23). Again, although not significant (*G*-test, $p > 0.35$ for both years), sex composition also varied by sample period in both years. Sex composition ranged from 44% males in stratum 4 to 64% males in stratum 5, 2002 (Table 22), and from 64% males in stratum 1 to 35% males in stratum 4, 2003 (Table 23). No significant differences were found comparing sex ($X^2 = 1.681$, $p > 0.19$) or age ($X^2 = 2.97$, $p > 0.20$) compositions between years for adult coho salmon sampled at the Clear Creek weir.

Lengths of coho salmon sampled in 2002 ranged from 530 to 691 mm for females, and from 508 to 693 mm for males (Table 24; Figure 22). Lengths of coho salmon sampled in 2003 ranged from 591 to 703 mm for females, and from 495 to 699 mm for males (Table 25, Figure 22). Mean lengths of age 2.1 coho salmon were greater than age 1.1

Table 20. Estimated age composition and standard error (SE) of coho salmon by stratum in Clear Creek, 2002.

	Number Sampled				Proportion of Escapement					
Stratum	*n*	1.1	2.1	3.1	1.1	SE	2.1	SE	3.1	SE
1	15	4	11	0	0.27	0.11	0.73	0.11	0	--
2	38	16	22	0	0.42	0.08	0.58	0.08	0	--
3	54	20	34	0	0.37	0.06	0.63	0.06	0	--
4	16	9	7	0	0.56	0.12	0.44	0.12	0	--
5	11	3	7	1	0.27	0.12	0.64	0.13	0.09	0.08
6	13	3	10	0	0.23	0.11	0.77	0.11	0	--
Total:	147	55	91	1	0.39	0.04	0.61	0.04	0.007	0.004

Table 21. Estimated age composition and standard error (SE) of coho salmon by stratum in Clear Creek, 2003.

	Number Sampled				Proportion of Escapement					
Stratum	*n*	1.1	2.1	3.1	1.1	SE	2.1	SE	3.1	SE
1	14	6	8	0	0.43	0.12	0.57	0.12	0	--
2	10	3	5	2	0.30	0.12	0.50	0.13	0.20	0.11
3	19	8	9	2	0.42	0.11	0.47	0.11	0.11	0.07
4	57	18	39	0	0.32	0.06	0.68	0.06	0	--
5	10	3	7	0	0.30	0.14	0.70	0.14	0	--
Total:	110	38	68	4	0.35	0.04	0.62	0.04	0.03	0.01

Table 22. Estimated sex composition and standard errors (SE) of coho salmon by stratum in Clear Creek, 2002.

	Number Sampled			Proportion of Escapement		
Stratum	*n*	Female	Male	Female	Male	SE
1	15	8	7	0.53	0.47	0.12
2	38	20	18	0.53	0.47	0.08
3	54	30	24	0.56	0.44	0.06
4	16	7	9	0.44	0.56	0.12
5	11	7	4	0.64	0.36	0.13
6	13	8	5	0.62	0.38	0.13
Total:	147	80	67	0.54	0.46	0.04

Table 23. Estimated sex composition and standard errors (SE) of coho salmon by stratum in Clear Creek, 2003.

	Number Sampled			Proportion of Escapement		
Stratum	*n*	Female	Male	Female	Male	SE
1	14	5	9	0.36	0.64	0.12
2	10	5	5	0.50	0.50	0.13
3	19	9	10	0.47	0.53	0.11
4	57	37	20	0.65	0.35	0.06
5	10	4	6	0.40	0.60	0.15
Total:	110	60	50	0.54	0.46	0.04

Table 24. Mean, standard error (SE), range, and sample size of mid-eye-to-fork lengths (mm) by age class taken from coho salmon at the Clear Creek weir, 2002.

	Age Class		
	1.1	2.1	3.1
Females			
Mean Length	617	633	--
SE	15.4	10.4	--
Range	530 - 691	580 - 680	--
Sample Size	28	39	0
Males			
Mean Length	606	623	631
SE	17.5	15.6	--
Range	508 - 671	546 - 693	--
Sample Size	27	52	1
All Fish			
Mean Length	612	627	631
SE	16.1	13.7	--
Range	508 - 691	546 - 693	--
Sample Size	55	91	1

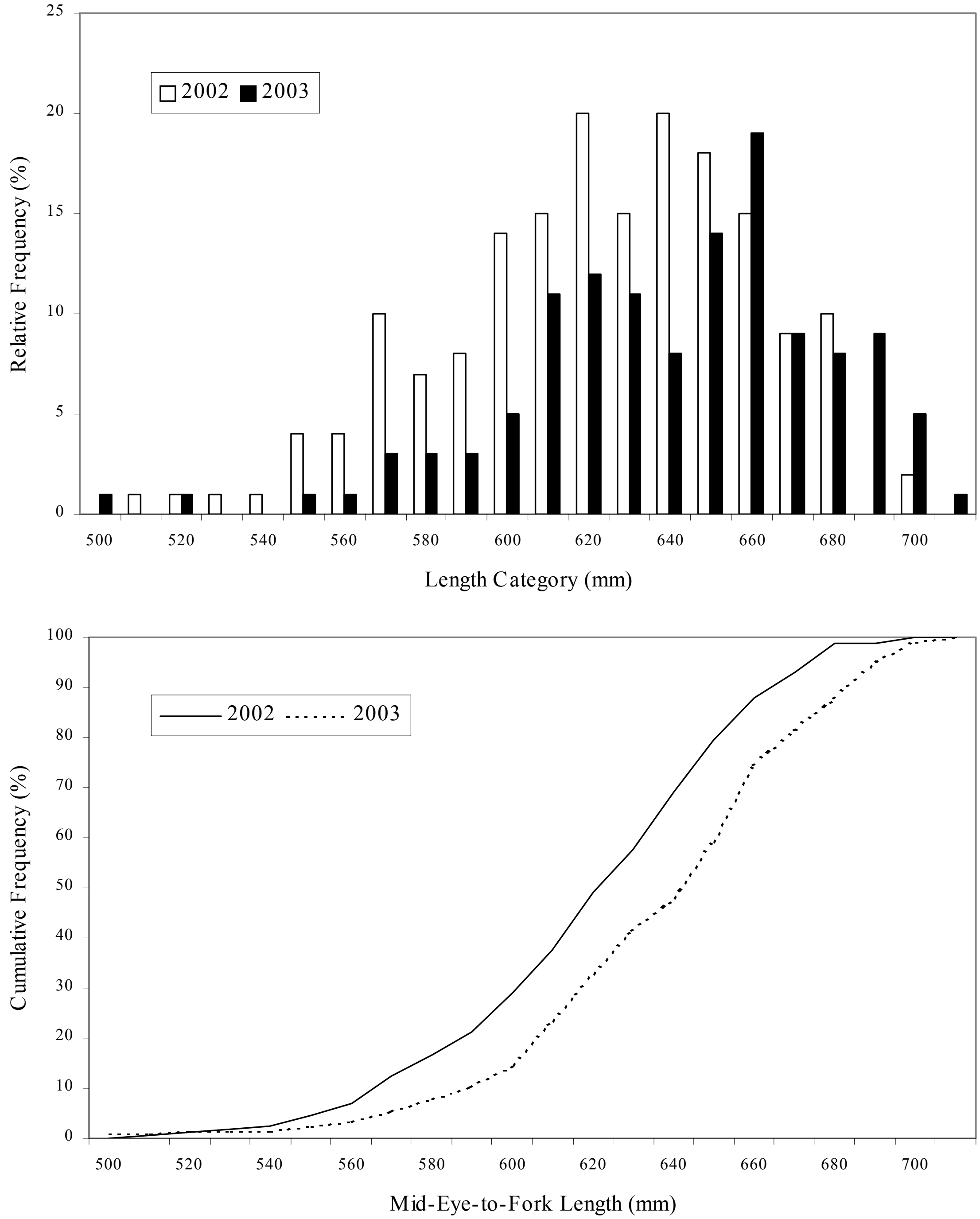


Figure 22. Length-frequency distribution (top) and cumulative length distribution of adult coho salmon sampled at the Clear Creek Weir, 2002 and 2003.

Table 25. Mean, standard error (SE), range, and sample size of mid-eye-to-fork lengths (mm) by age class taken from coho salmon at the Clear Creek weir, 2003.

	Age Class		
	1.1	2.1	3.1
Females			
Mean Length	635	656	--
SE	12.9	17.1	--
Range	591 - 672	599 - 703	--
Sample Size	19	41	--
Males			
Mean Length	591	642	647
SE	12.6	16.5	19.5
Range	495 - 683	541 - 699	601 - 686
Sample Size	19	27	4
All Fish			
Mean Length	612	651	647
SE	16.8	16.5	19.5
Range	495 - 683	541 - 703	601 - 686
Sample Size	38	68	4

coho salmon, and mean lengths of females were slightly greater than males in both years. The two sample Kolmogorov-Smirnov test comparing length-frequency distributions between years (Figure 22) indicates that the two samples do not come from populations with the same distribution ($p < 0.01$). Mean lengths of fish of either age class for each sex were greater in 2003 than in 2002.

Carrying Capacity Estimates

Application of the habitat model to the Kametolook, Three Star, Long Beach, and Clear Creek systems suggests that availability of overwintering habitat limits juvenile coho salmon capacity in all these systems (Table 26). Minimum adult escapements necessary to fully seed available overwintering habitat with juveniles were 852 adults for Three Star River, 1,209 for Kametolook River, 1,392 for Long Beach River, and 2,067 for Clear Creek (Table 27). The habitat type making the greatest contribution to smolt production in Clear Creek was beaver pond (actually a drainage lake; 85%), whereas scour pool was the greatest contributing habitat type in the Kametolook (61%), Three Star (64%), and Long Beach (55%) rivers (Table 28). The abundance of overwintering habitat provided by the drainage lake in Clear Creek, which accounted for almost 50% of available habitat in that system, resulted in greater estimates of potential smolt density, overwinter survival, and egg-to-smolt survival than the other systems (Table 27). Because of these differences, marine survival rates would have to be greater than 5% to produce a harvestable surplus of adult coho salmon for the Kametolook, Three Star, and Long Beach rivers, but only greater than 3% to produce a harvestable surplus for Clear Creek (Table 27).

Production estimates based on the habitat model for the Kametolook, Three Star, Long Beach, and Clear Creek systems are similar to those derived from other models presented in the literature (Table 29). Other models yield higher production estimates for all systems compared to the habitat model, except for Clear Creek. All other models (based on stream length or area) consistently underestimate production in Clear Creek compared to the habitat model.

Table 26. Potential seasonal carrying capacities by system for juvenile coho salmon calculated using the habitat limiting factor model of Nickelson (1998).

Season	Kametolook	Three Star	Long Beach	Clear Creek
Spawning	21,870,000	5,422,500	2,485,000	17,645,000
Spring	244,855	176,848	311,952	286,319
Summer	151,615	135,816	251,044	132,108
Winter	28,875	22,640	39,552	82,458

Table 27. Summary of results of the habitat limiting factor model of Nickelson (1998) by system, 2002 and 2003.

Model parameter	Kametolook	Three Star	Long Beach	Clear Creek
Surface area (m^2)	160,772	103,546	157,910	141,736
Stream length (km)	43.7	27.3	42.5	12.9
Maximum smolt capacity (M)[a]	26,000	20,400	35,600	74,200
Potential smolt density (C, fish/m^2)	0.16	0.20	0.23	0.52
Smolt capacity (fish/km)	595	747	838	5,752
Overwinter survival (S_{ow})	0.24	0.27	0.28	0.40
Egg-to-smolt survival (S_{smolt})	0.017	0.019	0.020	0.029
Required egg deposition (D_M)	1,510,673	1,065,535	1,739,439	2,583,392
Minimum number of adults necessary (A_M)	1,209	852	1,392	2,067
Potential adult production (PP_x)				
10% marine survival (PP_{10})	2,600	2,040	3,560	7,420
5% marine survival (PP_5)	1,300	1,020	1,790	3,710
3% marine survival (PP_3)	780	612	1,068	2,226

[a] Estimates are rounded to the nearest 100 fish.

Table 28. Summary of coho salmon maximum smolt capacity estimates by habitat type for all systems using the habitat limiting factor model of Nickelson (1998).

Habitat Type	Kametolook	Three Star	Long Beach	Clear Creek
Cascade	0	0	0	0
Rapid	16	0	2	0
Riffle	458	270	398	267
Glide	4,554	2,444	2,814	1,446
Trench Pool	188	0	45	0
Plunge Pool	136	7	135	39
Scour Pool	15,798	13,039	19,666	8,178
Dammed Pool	58	0	21	0
Alcove	479	273	1,013	53
Beaver Pond	3,288	804	0	63,012
Backwater	1,012	3,540	11,503	1,217
Total:	25,987	20,376	35,597	74,212

Table 29. Comparison of coho salmon production estimates for study streams using different models from the literature. The number of adults assumes a 5% marine survival rate from smolt capacity.

Model	Kametolook	Three Star	Long Beach	Clear Creek
Nickelson (1998)[a]				
Smolt Capacity	26,000	20,400	35,600	74,200
Smolt/m^2	0.16	0.20	0.23	0.52
Smolt/km	595	747	838	5,752
Adults	1,300	1,020	1,790	3,710
Bradford et al. (1997)[b]				
Smolt Capacity	38,717	24,531	37,685	11,855
Smolt/m^2	0.24	0.24	0.24	0.08
Smolt/km	886	899	887	919
Adults	1,936	1,227	1,884	593
Marshall and Britton. (1990)[b]				
Smolt Capacity	87,585	50,971	84,823	21,512
Smolt/m^2	0.54	0.49	0.54	0.15
Smolt/km	2,004	1,867	1,996	1,668
Adults	4,379	2,549	4,241	1,076
Marshall and Britton (1990)[a]				
Smolt Capacity	40,157	28,368	39,591	36,352
Smolt/m^2	0.25	0.27	0.25	0.26
Smolt/km	919	1,039	932	2,818
Adults	2,008	1,418	1,980	1,818
Bradford et al. (2000)[b]				
Smolt Capacity	70,576	44,090	68,638	20,834
Smolt/m^2	0.44	0.43	0.43	0.15
Smolt/km	1,615	1,615	1,615	1,615
Adults	3,529	2,204	3,432	1,042

[a] Model developed based on stream area.
[b] Model developed based on stream length.

Discussion

Habitat Inventory

We assumed that limiting our habitat analysis to clear water tributaries of the Kametolook and Long Beach rivers was appropriate, as both rivers are influenced by highly turbid glacial runoff and have minimal slow velocity habitat types suitable for rearing juvenile coho salmon. Although some juvenile rearing probably occurs in mainstem backwater and lateral habitats, we assumed contributions from these areas to be negligible compared to that of tributary streams. Murphy et al. (1989) observed low densities (0.01 - 0.03 fish/m^2) of juvenile coho salmon rearing in habitat units (even slow velocity areas) in the mainstem Taku River, a large, glacially influenced river in southeast Alaska, whereas juvenile coho salmon were abundant in off-channel habitats and tributary streams. Although these investigators found that juvenile coho salmon distribution was influenced primarily by velocity in the Taku River, turbidity probably also played a role since summer measurements were typically 200 nephelometric turbidity units (NTU). Bisson and Bilby (1982) reported that juvenile coho salmon avoided turbidity levels of 70 NTU, and Sigler et al. (1984) observed immediate emigration or mortality of juvenile coho salmon at turbidities between 100 and 300 NTU. Juvenile coho salmon rely on visual cues for locating and capturing food items from the surface or in the water column (Hoar 1958), and Sigler et al. (1984) observed a reduction in growth of juvenile coho salmon caused by turbidities as low as 25 NTU. The swift and highly turbid glacial water of the Kametolook and Long Beach rivers make them marginal habitat for rearing juvenile salmonids (Milner and Petts 1994).

The 7-ha drainage lake in the Clear Creek system was the most influential habitat feature identified in any of the four systems we inventoried in 2002 and 2003. Although it is not actually formed by beavers, it was classified as a beaver pond for the habitat model. The large size of the lake relative to the rest of the system (Table 5) warranted its inclusion in the analysis, and classifying it as a beaver pond in the habitat model recognizes the lake as off-channel habitat with the potential to support high densities of juvenile coho salmon. Various other studies have shown off-channel habitats to be important areas for different life history stages of juvenile coho salmon (Bustard and Narver 1975; Peterson 1982; Tschaplinski and Hartman 1983; Swales et al. 1986; Swales and Levings 1989; Nickelson et al. 1992). Therefore, we felt it was necessary to include the drainage lake in the habitat model to adequately model potential coho salmon production in Clear Creek.

Aside from the Clear Creek drainage lake and relatively large amount of Long Beach backwater, habitat composition and quality were similar among the Kametolook, Three Star, Long Beach, and Clear Creek systems. Riffles, glides, and scour pools were the most common habitat types in all systems other than Clear Creek, representing over 80% of available habitat. Also, no major differences in cover availability were observed among systems. Turbulence cover was the most common cover type available in fast-water habitat types, and overhead cover was the most common type available in slow-water habitat types.

Egg-to-fry survival should be relatively high for the systems in our study since surface fine sediments were 20% or less (Table 7). Excessive amounts of fine sediments in spawning substrates decrease egg-to-fry survival by reducing water flow through the redd, vital for providing oxygen and removing waste, and blocking interstitial spaces in the substrate, making it difficult for fry to emerge (Iwamoto et al. 1978). Sediment also decreases suitable rearing habitat by filling pools and interstitial spaces and reducing macroinvertebrate production (Bjornn et al. 1977). However, Bjornn and Reiser (1991) showed that embryo survival was relatively unchanged when the substrate composition was less then 25% fine sediments (< 6.35 mm). Chapman and Mcleod (1987) estimated survival to emergence for Chinook salmon was near 80% for fine sediment (< 6.4 mm) levels near 20%, declined rapidly as fine sediment levels reach 30%, and decreased to 25% as levels approach 45%.

Although the estimated amount of suitable spawning habitat was much lower in the Three Star (6%) and Long Beach (2%) rivers than in either the Kametolook River (16%) or Clear Creek (15%), this difference may in part be due to differences among crews conducting the inventories in 2002 and 2003. Classification of suitable spawning habitat was largely subjective since it was based on professional judgment, which included visual examination of the substrate. Areas of suitable depth and velocity with high cobble embeddedness or that were largely sand and small gravel were classified as poor spawning habitat in 2002 (Kametolook and Clear Creek), but were not classified as suitable spawning habitat in 2003 (Three Star and Long Beach). Even with the low estimated availability of spawning habitat in the Three Star and Long Beach rivers, the habitat model predicted that potential juvenile production was limited by rearing conditions, particularly during winter, rather than spawning capacity in all four systems (Table 26).

Most available spawning habitat in the Three Star system was classified as poor (59%) due to observed substrate conditions rather than depth or velocity (Tables 6 - 8). The mainstem Three Star River and most of its tributaries had typical riffle-pool channel morphology, and suitable spawning habitat based on depth and velocity was available in pool tails and low gradient riffles. However, cobble embeddedness values were high for the Three Star system (69%), indicating most large gravels and cobbles were covered with a layer of fine sediments and sand, even though the estimated percent of surface fine sediments less than 4 mm (organics, clay/silt, sand) was low (14%). The actual percent of surface fine sediments may have been greater, since most of the medium gravel present in the Three Star system was between 4 and 10 mm. However, we did not record actual particle sizes for our study and collected information using the somewhat subjective classification system of Platts et al. (1983) (Table 1).

Juvenile Sampling

Mean juvenile coho salmon densities observed in Clear Creek in 2002 were similar to those of Nickelson (1998), with the exception of backwaters and plunge pools; but, with the exception of alcoves, mean densities observed in 2003 were less than those of

Nickelson (1998) (Table 30). Only two backwater habitat units were sampled in Clear Creek in 2002, and both had high densities compared to adjacent units. Fifty-two coho salmon were observed in one backwater that was situated in the middle of a long glide with minimal cover. One hundred and one juvenile coho salmon were observed near a large root wad in the other backwater unit, which was located near the end of a long riffle. A similar situation occurred in one of the two plunge pools sampled in 2002: 57 juvenile coho salmon were observed in a relatively short (3.5 m) pool with abundant cover provided by LWD. The mean juvenile coho salmon density for alcoves was higher in 2003 than in 2002 (Table 30), but the density estimate was influenced by the presence of 21 coho salmon in a 4.8-m^2 alcove in 2003. The scour pool density estimate of 1.43 fish/m^2 in 2002 is above the level believed to represent fully seeded habitat for juvenile coho salmon (1.0 fish/m^2 of pool; Nickelson et al. 1992). However, the scour pool density estimate of 0.43 fish/m^2 in 2003 is well below that threshold.

Our inability to obtain accurate abundance estimates of juvenile coho salmon based on removal experiments (Table 11) was probably due to several factors. For two experiments (25 and 27 August), initial abundance of juvenile coho salmon may have been too small to allow for effective sampling, as White et al. (1982) suggest population sizes of 200 individuals are needed for reliable estimates. Minnow traps may not have been an effective means to sample juvenile coho salmon in Clear Creek, since depletion was not clearly evident in three experiments (26 August, 22 September, 9 October) and capture probability was not constant among removal events (chi-square test, $p < 0.05$) for three of the seven experiments where this could be examined. It is also likely that the behavior and movement patterns of juvenile coho salmon played some role in our inability to conduct removal experiments. We were particularly surprised with results of the 22 September experiment, which resulted in increasing rather than decreasing catches over the course of four removal events. We are unable to explain this since block nets appeared to be functioning (allowing no immigration or emigration), traps were set in the same places for each capture event, there were no areas where fish were congregated or observed in schools between capture events, and there were no localized areas of cover present where fish could have been hiding between capture events. We may have been successful in obtaining reliable abundance estimates by conducting a greater number of removal events, but it was not practical to do so.

Snorkel density estimates in Clear Creek in 2002 and 2003 represent minimum values. This was well illustrated by comparing counts of juvenile coho salmon for two habitat units where a snorkel count and removal estimate were conducted within a 2 d period in 2002. In both units, the numbers of juvenile coho salmon observed snorkeling were less than the cumulative number sampled with minnow traps (Table 31). Both habitat units sampled with snorkel and minnow trap removal techniques had long (> 10 m), shallow (< 5 cm) riffles at the upper and lower ends, and juvenile fish movement in or out of the unit was thought to be minimal between samples. Although conditions for snorkeling were excellent (visibility was greater than 7 m in both units), many juvenile coho salmon managed to avoid detection by snorkel teams. In the plunge pool sampled using both methods, a considerable amount of LWD and turbulence cover was present, providing ample opportunity for fish to avoid visual detection. However, there was little cover in

Table 30. Habitat-type specific mean summer densities of coho salmon observed in Clear Creek in 2002 and 2003 (standard errors in parentheses), and those used by Nickelson (1998).

	Mean Summer Density (fish/m^2)		
Habitat Type	Nickelson (1998)	Clear Creek, 2002	Clear Creek, 2003
Cascade	0.24	0.00	0.00
Rapid	0.14	--	--
Riffle	0.12	0.21 (0.07)	0.09 (0.02)
Glide	0.77	1.33 (0.48)	0.22 (0.09)
Trench Pool	1.79	--	--
Plunge Pool	1.51	3.63 (3.16)	0.19 (0.19)
Scour Pool	1.74	1.43 (0.34)	0.43 (0.06)
Dammed Pool	1.84	--	--
Alcove	0.92	0.25	2.21 (2.13)
Beaver Pond	1.84	--	0.36[a]
Backwater	1.18	5.22 (0.43)	0.65 (0.24)

[a] Calculated from mark-recapture estimate.

Table 31. Comparison of snorkel and minnow trap sampling techniques for two habitat units sampled in Clear Creek, 2002.

	Snorkel Survey		Minnow Trap Removal	
Habitat Type	Date Sampled	Number Observed	Date Sampled	Number Observed
Plunge Pool	24 August	57	25 August	79
Scour Pool	24 August	135	26 August	180

the scour pool and all juvenile fish should have been visible to the snorkel teams. Rodgers et al. (1992) reported that snorkel estimates accounted for only 40% of the actual number of juvenile coho salmon in pools, and were less accurate and precise than mark-recapture or removal techniques. However, snorkel surveys can allow for the sampling of more stream area in a given time compared to removal or mark-recapture methods (Rodgers et al. 1992), and the high variability associated with the accuracy of individual snorkel counts may be offset by the ability to sample a larger portion of the total stream (Hankin and Reeves 1988).

The assumptions necessary for an unbiased Lincoln-Petersen estimate of population size were probably met for the drainage lake mark-recapture experiment in Clear Creek. The period between the marking event and the recapture event (12 d) was chosen to allow marked fish time to redistribute throughout the lake, while providing limited time for immigration or emigration to occur. Although fish had to cross a low, remnant beaver dam at the outlet to Clear Creek, the lake itself was not a closed system. A freshet did occur during the course of the experiment, so we would expect some immigration into the lake for fish avoiding high flows in Clear Creek. However, even with immigration, the estimate would be valid for the time when the second sample was taken (Seber 1982). There was no indication that mortality of marked coho salmon was greater than that of unmarked fish. Although initial mortality from the marking event was over 8%, all 40 marked coho salmon held during the experiment survived, and survival of marked fish was constant between sampling periods.

Minnow traps were spread throughout the shoreline and offshore areas of the lake to address the assumption of equal capture probability during both sampling events. Examination of the recapture data indicate that juvenile coho salmon in both areas of the lake were equally vulnerable to capture during the first event, and recapture probabilities were the same for both groups of marked fish. Some movement did occur between the shoreline and offshore sampling areas (Table 14), so at least partial mixing occurred between the two areas.

All 40 fish that were marked and held throughout the duration of the census retained their marks, and marks were readily apparent to the crew when examining fish during the recapture census. Other studies have examined retention of tattoo ink marks on juvenile fish, and found high retention rates. Thedinga and Johnson (1995) reported mark retention for juvenile coho salmon using black India ink applied with a jet injector was 100% after six weeks. Haines and Modde (1996) found over 97% mark retention after 21 days for juvenile Colorado pikeminnow *Ptychocheilus lucius* using tattoo ink applied with a dental inoculator. Thedinga et al. (1994) successfully used jet-injected India ink to mark migrating juvenile salmonids in a mark-recapture census, and found 100% short-term mark retention (1 d) for coho salmon. It is unlikely that any marked fish lost their mark or that marks were overlooked in the recapture census in the drainage lake on Clear Creek in 2003.

We assumed both age classes of juvenile coho salmon were equally vulnerable to capture in minnow traps, although this assumption was not tested. However, minnow traps have been used extensively to sample juvenile coho salmon populations (Bloom 1976; Heifetz et al. 1986; Murphy et al. 1986; Swales et al. 1986; Swales et al. 1988; Swales and Levings 1989; Thedinga et al. 1989; Bryant 2000). Bloom (1976) found that minnow traps were effective for sampling juvenile salmonids within the size range 50 - 100 mm. Swales et al. (1986) captured juvenile coho salmon from 40 to 140 mm, Swales et al. (1988) captured coho salmon from 55 to 125 mm, and Swales and Levings (1989) captured coho salmon from 40 to 130 mm. Bryant (2000), Heifetz et al. (1986), Thedinga et al. (1989), and Murphy et al. (1986) all captured coho salmon fry (age 0+) and parr (age 1+) in minnow traps. Our studies captured age 0+ and age 1+ coho salmon ranging from 40 to 98 mm in 2002 and 2003 (Figure 19).

Lengths at age of juvenile coho salmon in Clear Creek were similar across all strata in 2003 (Table 15, Figure 18), and were similar to mean length at age data collected from other systems sampled during summer and fall (Table 32). Mean lengths of coho salmon in the Clear Creek drainage lake (strata 5) were similar to other areas in the system, although other studies have found larger coho salmon in off-channel ponds (Swales et al. 1986) and lakes (Swales et al. 1988; Irvine and Ward 1989; Quinn and Petersen 1996).

Juvenile coho salmon mean lengths were smaller in stratum 4 than the remaining strata for both age groups. Part of the difference could be due to the greater amount of overhead cover available in the tributary streams of stratum 4 compared to mainstem areas (strata 1 and 2), making conditions for growth less optimal. Over 20% of habitat units in stratum 4 had greater than 80% overhead cover, whereas only 2% of units in strata 1 and 2 did (Table 33, Figure 23); almost 50% of habitat units in strata 1 and 2 had no overhead cover. Although the habitat inventory was not completed on Camp Creek (stratum 6), overhead cover availability on mainstem Camp Creek was less than that on mainstem Clear Creek as it is a much wider stream, and vegetation on the stream banks provides cover for a smaller proportion of overall habitat. Open-canopy systems, including those created from clear-cut logging, can be more productive during summer than closed-canopy systems for juvenile coho salmon (Chapman and Knudsen 1980; Murphy et al. 1986; Bilby and Bisson 1987; Holtby 1988; Thedinga et al. 1989). Part of the increase in production has been attributed to increases in stream temperatures (Holtby 1988; Hetrick et al. 1998a), which can increase primary production (Murphy et al. 1986; Hetrick et al. 1998a) and standing crop of invertebrates (Hetrick et al. 1998b).

Adult Sampling

Spawning escapement estimates of adult coho salmon in the Perryville area in 2002 and 2003 could not be made using the area-under-the-curve methods to analyze visual counts from ground surveys. High water due to steady rain and rain-on-snow events caused rivers to flood at different times throughout the survey period both years, limiting access and visibility. Flooding also affected the planned survey intervals as high water prevented access to all streams after mid-October in 2002 (Table 17) and for the initial survey in early October 2003. A considerable number of coho salmon could have entered the streams, spawned, and died undetected during these intervals. When access to the streams was possible again in late November 2002, coho salmon had completed

Table 32. Mean lengths at age for juvenile coho salmon observed throughout the Pacific Northwest and Alaska.

Stream	Location	Mean Length (mm)	Age	Sample Time	Source
Clear Creek	SW Alaska	60.8	0+	July-August	Current Study, 2003
Clear Creek	SW Alaska	81.4	1+	July-August	Current Study, 2003
Clear Creek	SW Alaska	59.7	Unknown	September-October	Current Study, 2002
Sashin Creek	SE Alaska	60	0+	September	Crone and Bond (1976)
Sashin Creek	SE Alaska	80	1+ & 2+	September	Crone and Bond (1976)
7 streams	SE Alaska	39	0+	Late June	Bjornn et al. (1991)
7 streams	SE Alaska	63	1+	Late June	Bjornn et al. (1991)
Salmon River	British Columbia	59.5	0+	July	Fausch (1993)
Big Beef Creek	Washington	74	0+	October	Quinn and Peterson (1996)
Big Beef Creek	Washington	77	0+	October	Peterson et al. (1994)
Big Beef Creek	Washington	70	0+	July-August	Kahler et al. (2001)
Big Beef Creek	Washington	60	0+	July-August	Kahler et al. (2001)
Griffith Creek	Washington	60	0+	July-August	Kahler et al. (2001)
Shuwah Creek	Washington	67	0+	July-August	Kahler et al. (2001)
Huckleberry Creek	Washington	60	0+	August	Nielsen (1992)

Table 33. Comparison of overhead cover availability in mainstem Clear Creek (Strata 1 and 2) and tributary streams of stratum 4.

	Habitat Units with Overhead Cover:	
Stratum	≤ 20%	≥ 80%
1 and 2	87%	2%
4	60%	21%

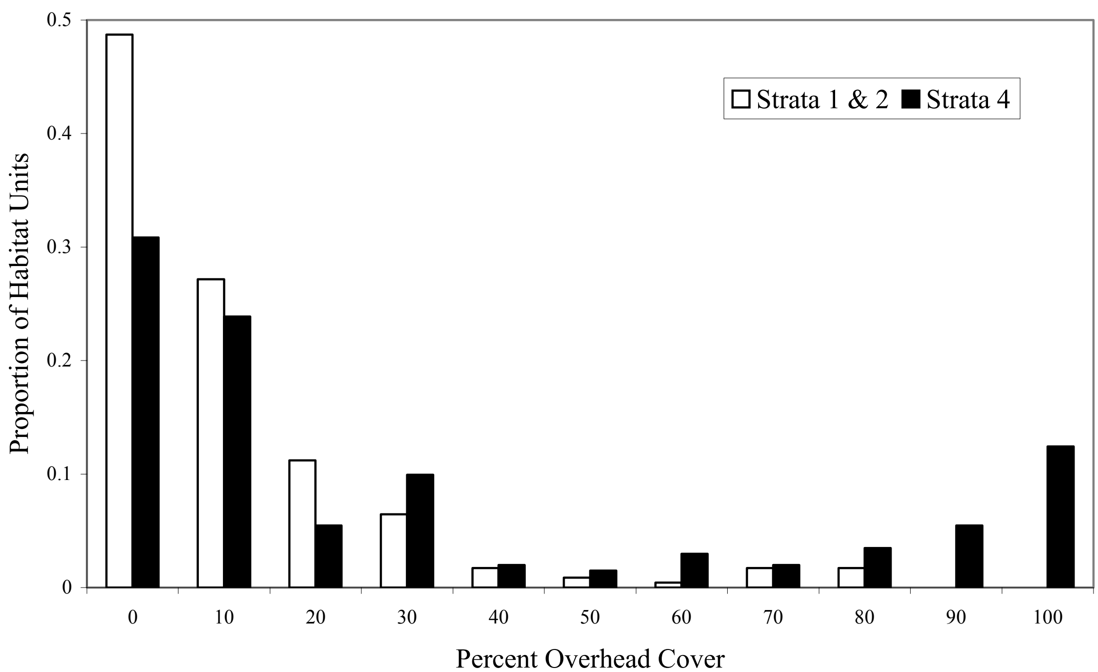


Figure 23. Distribution of overhead cover availability in mainstem Clear Creek (strata 1 and 2) and the tributary streams of stratum 4.

spawning for the season. Hetrick and Nemeth (2003) recommended survey intervals near the expected residence time specific to the species and survey period (i.e., early or late in the season) for maximum efficiency. Surveys were planned at two-week intervals for streams near Perryville in 2002 and 2003 based on a mean coho salmon residence time in October of 13.7 d (Hetrick and Nemeth 2003). Bue et al. (1998) also found that accuracy and precision of AUC estimates decreased as surveys became less frequent. Unfortunately, weather and water conditions for streams near Perryville prevented us from making surveys at prescribed intervals in 2002 and 2003.

High water also affected operation of the Clear Creek weir in 2002 and 2003. During 2002, the weir was not functional on five occasions (Table 19). A walking survey was conducted above the Clear Creek weir following the final high water event in early November 2002, resulting in a count of 50 coho salmon. Based on this count, it is unlikely that many coho salmon entered the system during the last two periods the weir was inoperable. Weir failures in mid-October 2002, however, may have allowed a considerable number of coho salmon to enter the system undetected. Escapement estimates for coho salmon in Clear Creek in 1995 (4,068) and 1996 (3,118) (Hetrick and Nemeth 2003), were considerably higher than the 1,097 coho salmon counted past the Clear Creek weir in 2002. Peak counts of coho salmon in 1995 and 1996 also occurred following high water events in mid- to late-October (Hetrick and Nemeth 2003), periods when the Clear Creek weir failed in 2002. Coho salmon often move into smaller tributary streams to spawn with the onset of fall rains and increased flows (Meehan and Bjornn 1991; Sandercock 1991; Irvine et al. 1992). During 2003, the weir was not functional on only one occasion. High water overtopped the weir and washed out the support cables on the evening of 30 September, and repairs were not possible due to continued high water until 3 October. Considering the weir failures associated with high water events in both years, the numbers of coho salmon counted past the Clear Creek weir should be considered minimum estimates of total escapement.

Habitat Model

Although classified as a beaver pond, we used a potential density for juvenile coho salmon of 1.00 fish/m^2 in the habitat model for the Clear Creek drainage lake instead of the 1.84 fish/m^2 value developed by Nickelson (1998). Our potential density value for the drainage lake was similar to values reported by other investigators. Swales and Levings (1989) observed overwinter densities in off-channel ponds for juvenile coho salmon of 0.10 to 1.00 fish/m^2, and Swales et al. (1988) observed winter densities in a small lake (8 ha) of 0.017 fish/m^2. Observed density of juvenile coho salmon in the Clear Creek drainage lake in autumn 2003 was 0.36 fish/m^2, well below that reported by Nickelson (1998) for summer and winter habitat use. The observed value of 0.36 fish/m^2 was not used in the habitat model for the drainage lake, as the Clear Creek system was probably not at carrying capacity for juvenile coho salmon in 2003. The potential density of juveniles rearing in beaver pond habitat can be highly influential in the habitat model. If the observed density of 0.36 fish/m^2 was used, potential smolt capacity would be 33,000 instead of 74,000, and the minimum number of adults necessary to fully seed the habitat would decline from 2,000 to 1,300. Conversely, if the beaver pond density of

1.84 fish/m^2 was used, the smolt capacity estimate would be 127,100 (9,853 smolt/km) with a minimum of 2,990 adults necessary to fully seed available habitat. Our potential value of 1.00 fish/m^2 represents potential rearing capacity in pond habitat above what was observed in 2003, and is more consistent with densities observed in systems less influenced by high winter stream flows.

The habitat model of Nickelson (1998) was developed for coastal Oregon streams where peak stream flows occur during the wet winter months. Beaver ponds, alcoves, backwaters, tributary streams, and other off-channel habitats during these periods of high flow provide refuge for juvenile coho salmon from the high velocity main channel areas (Bustard and Narver 1975; Peterson 1982; Tschaplinski and Hartman 1983; McMahon and Hartman 1989; Nickelson et al. 1992; Bell et al. 2001). Consequently, these habitat types account for the highest observed rearing densities for juvenile coho salmon, which are reflected in the habitat model. Thus, the limiting factor for juvenile coho salmon survival during winter months in Oregon streams is the amount of habitat available as refuges from high water velocities. The restrictive range of winter habitat preferences observed for coho salmon play a large role in the overall model fit, and make winter habitat availability the limiting factor for coho salmon production in the systems where Nickelson (1998) applied the model.

Although the amount of suitable winter habitat probably limits coho salmon production in many systems (Bustard and Narver 1975; Mason 1976; Tschaplinski and Hartman 1983; Murphy et al. 1984; Heifetz et al. 1986; Nickelson et al. 1992; Solazzi et al. 2000), Alaska Peninsula streams do not fit this model. These streams exhibit a flow regime more typical of interior snowmelt and glacial systems in which peak discharge occurs in late spring or early summer, and gradually decreases until a base flow period of low discharge is reached during winter months. The hydrographs of glacial rivers are usually dominated by an early-summer maximum due to snow and ice melt, and a winter minimum when runoff declines to zero (Milner and Petts 1994; Murphy et al. 1997). Peak discharge in the Kametolook and Long Beach rivers typically occurs in early to mid-July. Fall rain events can, however, cause freshets and high flows, as was observed in Clear Creek in 2002 and 2003.

Fall freshets were an important factor affecting the distribution and survival of juvenile coho salmon in Carnation Creek in coastal British Columbia, particularly in sections affected by logging that had little instream or riparian cover (Tschaplinski and Hartman 1983). The largest seasonal reduction in numbers of juvenile coho salmon fry (age 0+) and yearlings (age 1+) in logged sections of Carnation Creek occurred during autumn (late September and October), which coincided with the onset of freshets and low water temperatures. A reduction of juvenile coho salmon numbers in mainstem Carnation Creek in autumn was also noted, and this coincided with movement of juveniles into side channel sloughs and tributary streams. Freshets occurring later in the winter (mid-December and February) did not cause further reductions in juvenile coho salmon numbers, as most fish had already been displaced by freshets in late September and early November. Mainstem sections of Carnation Creek with deep pools and undercut banks in association with tree roots and debris lost fewer fish during freshets, and held more fish through the winter than sections lacking suitable cover. Complex cover, which includes velocity refuge, overhead cover, and LWD, has been shown to support significant numbers of juvenile coho salmon during simulated winter freshets in artificial channels, with abundance increasing with increasing cover complexity (McMahon and Hartman 1989). Murphy et al. (1986) found that the winter abundance of age 0+ coho salmon depended on the amount of LWD present in the stream. Cederholm et al. (1997), and Roni and Quinn (2001) were able to increase winter abundance of juvenile coho salmon by the addition of LWD to streams.

Although flow regimes of Clear Creek and other southwestern Alaska streams differ somewhat from those of coastal Oregon streams, similar habitat features likely influence the survival of juvenile coho salmon during fall and winter. Swales et al. (1986) found habitat use for juvenile coho salmon during winter in interior streams of British Columbia was similar to coastal systems. Interior systems are less affected by oceanic influences, and usually experience harsher winter conditions than coastal systems. Although winter conditions differed, juvenile coho salmon still made extensive use of off-channel areas during winter, and their use of main channel habitats decreased. Juvenile coho salmon found in main channel habitats during winter were usually associated with dense instream or riparian cover (Swales et al. 1986). In Carnation Creek, British Columbia, Brown and Hartman (1988) found that off-channel habitats had high smolt production per unit area, but less productive mainstem habitats were responsible for nearly 80% of overall smolt production due to their greater availability. Mainstem pools with abundant LWD, undercut banks, and other cover, in addition to beaver ponds, backwaters, alcoves, and other off-channel habitats are necessary for the survival of juvenile coho salmon during winter conditions throughout their range.

Nearly all juvenile coho salmon in Oregon coastal streams spend only one winter in freshwater after hatching before entering the ocean as smolt and returning as age 1.1 adults (Nickelson et al. 1992; Sandercock 1991). However, most adult coho salmon returning to many streams in more northern latitudes, including Alaska, are age 2.1, having spent two winters in freshwater after hatching (Crone and Bond 1976; Sandercock 1991; Bradford et al. 1997). In Clear Creek, age 2.1 coho salmon made up over 60% of the adult runs in 2002 and 2003 (Tables 20 and 21). However, only 10% of the juvenile coho salmon sampled in Clear Creek in 2003 had spent one winter in freshwater. These fish should spend one more winter in freshwater before migrating as smolt in 2004, and then return as age 2.1 adults in 2005. Although this appears to be an anomaly (10% of the juvenile population responsible for 60% of the adult return), differential survival of the two age classes may account for some of the observed differences in age composition between Clear Creek juvenile and adult coho salmon.

In Sashin Creek, southeast Alaska, the age 2.1 cohort averaged 66% of the adult return over four years of study (27% age 1.1, 7% age 3.1; Crone and Bond 1976). However, as in Clear Creek, most juveniles rearing during summer months in Sashin Creek were age 0+. Nearly 90% of the juvenile coho salmon in Sashin Creek in June were age 0+ fish, which gradually decreased over the summer until the composition of age 0+ fish dropped to less than 70% in August and September. Instantaneous mortality coefficients for juvenile coho salmon in Sashin Creek were greatest during the summer months, which Crone and Bond (1976) attributed to predation. On average, Sashin Creek abundance of age 0+ parr decreased 40% from late July to September, whereas abundance of age 1+ and 2+ parr decreased 15%.

Bjornn et al. (1991) reported a similar decrease in the standing crop of age 0+ coho salmon during summer months in streams on Prince of Wales Island in southeast Alaska, where abundance declined as fish grew and excess fish left the system throughout the summer. Keith et al. (1998), using a downstream migrant trap, documented a large post-emergence emigration of age 0+ coho salmon (21,125 fish) in late May and early June on Eleven Creek in southeast Alaska. This emigration continued throughout the summer, but at a lesser rate. Emigrating age 0+ coho salmon were 1.1 - 1.6 mm smaller, on average, than non-migrants. Over this same period, only 51 age 1+ coho salmon were captured, even though this age class accounted for 33% of the juvenile population above the trap. Thedinga et al. (1989) observed a change in proportions of age 0+ and age 1+ coho salmon from summer to winter in six southeast Alaska streams. The mean proportion of age 0+ fish declined from 89% to 71% from summer to winter, and the mean proportion of age 1+ fish increased from 9% to 26% over the same time frame. We found 90% age 0+ coho salmon in Clear Creek samples during late July and early August 2003, but did not collect samples during the winter. Based on observations in Sashin Creek and other systems, the proportion of age 0+ fish in Clear Creek should decline through the summer and fall.

The observed age composition of smolt emigrating from Sashin Creek (37% age 1+, 56% age 2+, 4% age 3+) more closely resembled that of the adult return than did the summer parr population (Crone and Bond 1976). Furthermore, the smolt migration in 1968 was composed of 4% of the age 0+ and 28% of the age 1+ parr from the previous summer (Table 34). Applying these values to the Clear Creek summer parr population in 2003, we would expect to find about 1,900 age 1+ and 1,100 age 2+ smolt emigrating from the system in 2004, and 8,200 age 1+ parr remaining in the system (Table 34). However, this estimate of smolt age composition is not similar to the observed age composition of adults returning to Clear Creek in 2002 and 2003.

Part of the difference between observed juvenile and adult age compositions in Clear Creek could be due to higher survival rates for age 2+ smolt because of their larger size. However, existing studies provide conflicting views on the relationship between coho salmon smolt size and marine survival. Quinn and Petersen (1996) observed higher overwinter survival rates for larger juvenile coho salmon in the wild, and smolt size has sometimes been positively correlated with adult returns of hatchery-reared coho salmon. Bilton et al. (1982) found that releasing large smolt had the potential to provide exceptional (> 40%) adult returns, although time of release was also an important factor. Hager and Noble (1976) also observed a substantial increase in marine survival corresponding to greater size at release for hatchery-reared coho salmon. Mathews and Ishida (1989), however, in a study of 9 smolt release groups from two different Columbia River hatcheries, found little correlation between size of release of coho salmon smolt and adult returns. For the release groups that did show a correlation between smolt size

Table 34. Estimated population size by age class at different life stages for juvenile coho salmon in Sashin Creek (1967 and 1968), with survival estimates applied to Clear Creek (2003 and 2004).

	Sashin Creek		Clear Creek	
Life Stage	Age 0+	Age 1+	Age 0+	Age 1+
July/August Parr	12,346	3,043[a]	44,171	3,850
Smolt (following year)	553	850	1,906	1,075
Remain in system (Age 1+)	2,296[b]	--	8,216	

[a] Includes some age 2+ juveniles as no distinction between age 1+ and 2+ was made by Crone and Bond (1976) for summer population estimates.
[b] Value estimated using Crone and Bond (1976) survival estimates.

and adult returns, size-dependent stress from forced acclimation in a steep salinity gradient was suspected. Results obtained from hatcheries, however, may not be directly applicable to wild coho salmon. Irvine and Ward (1989) demonstrated that most wild coho salmon smolt do not migrate at times considered optimal for hatchery fish, and that most wild smolt are considerably smaller than sizes found to result in high survival of hatchery-reared smolt. Holtby et al. (1990), investigating several hypotheses concerning marine survival of wild coho salmon, found that smolt size and early ocean growth were good predictors of marine survival. This was especially obvious in years when overall marine survival was low; larger smolt survived better and exhibited faster growth rates in the ocean. However, Fisher and Pearcy (1988) found no strong evidence for selective mortality based on smolt size and early-ocean growth rates.

Based on juvenile coho salmon densities observed in Clear Creek in 2003, we think the system was below its carrying capacity. The 2003 estimated juvenile coho salmon population of 48,000 age 0+ and 1+ fish (Table 34) is roughly one third of that predicted by the habitat model for summer rearing (132,108; Table 26). Mean densities of juvenile coho salmon in 2003 were below those observed in 2002, and were well below the density of 1.0 fish/m^2 in pools that Nickelson et al. (1992) identified. Observed densities of juvenile coho salmon in pools in 2002 suggest the system was fully seeded with juveniles from adults that had successfully spawned the previous fall. The low densities observed in 2003 could be due to several factors, including inadequate escapement of adults in 2002 to fully seed available habitat, and low survival through the winter and spring for the brood year 2002 juveniles. The adult coho salmon run to Clear Creek in 2002 (minimum of 1,100) was less than that estimated by Hetrick and Nemeth (2003) in both 1995 and 1996 (3,000 - 4,000). The 2002 escapement was also below the minimum seeding levels for Clear Creek predicted by the habitat model, so egg deposition may have been below the threshold for producing high juvenile densities in 2003. A combination of low egg deposition and low survival from the egg to parr stage is probably responsible for the low observed juvenile densities in 2003. Based on the relatively low numbers of adult coho salmon estimated to have returned to Clear Creek in 2003, we believe the system will also not reach its potential carrying capacity for juvenile coho salmon in 2004.

Low juvenile coho salmon densities observed in 2003 and expected to occur in 2004 may affect the age composition of adults returning to Clear Creek in future years since smoltification is more dependent on size than age (Weisbart 1968; Crone and Bond 1976; Sandercock 1991). With relatively low number of juveniles present in Clear Creek in 2003, there should be little competition for food and habitat resources, and age 0+ parr should grow at a faster rate than attained in previous years when habitat was fully seeded. A faster growth rate could allow more age 0+ coho salmon to reach the threshold size for smolt transformation than in previous years. Investigators have documented this phenomenon in other systems. Crone and Bond (1976) observed faster growth of age 0+ juvenile coho salmon during summers when fewer age 1+ juveniles were present. Bilby and Bisson (1987) observed that growth of hatchery coho salmon fry stocked in logged streams in Washington was related to food availability and population density. Holtby (1988) determined that increased water temperatures in Carnation Creek (due to climate change and logging) changed the smolt age composition from about equal numbers of age 1+ and 2+ smolt to mostly age 1+ smolt. This change was attributed to faster egg development, earlier emergence, increased growth, and improved overwinter survival of age 0+ parr due to warmer temperatures.

The relatively large proportion of age 1+ smolt expected to migrate from Clear Creek in 2004 may result in a larger proportion of age 1.1 adults returning to the system in 2005. Additionally, fewer age 1+ juveniles will remain in Clear Creek to rear for another year and low age 0+ juvenile densities are expected in 2004 as a result of the small spawning escapement in 2003. This should result in good growth conditions for age 0+ parr in 2004, perpetuating the trend of more juveniles migrating as age 1+ smolt and a greater proportion of the adults returning as age 1.1 spawners in 2006.

Marine survival rates used for estimating potential adult production can have a large effect on model performance, with higher marine survival rates dramatically increasing production estimates of adult coho salmon. For example, the habitat model indicates at least 3% to 5% marine survival is needed to sustain the minimum number of adults to fully seed available habitat within the Kametolook, Three Star, and Long Beach systems (Table 27). A 10% marine survival rate would provide sufficient "excess" production for harvest. Coho salmon marine survival rates reported for other Pacific Northwest streams have ranged from 0.5% to over 40% (Table 35). However, commercial, sport, and subsistence harvests can contribute greatly to overall mortality (over 80%; Beers 2001), and information is often not available to allow separation of fishing and natural mortality. Few data on marine survival are available for southwest Alaska coho salmon, and further investigations are needed to determine the range of marine survival to use in modeling Alaska Peninsula systems.

Table 35. Comparison of coho salmon marine survival rate estimates throughout the Pacific Northwest and Alaska.

Stream	Location	Survival Estimate	Source
Porcupine Creek[a]	SE Alaska	4.5 - 6.5%	Thedinga (1986)
Slippery Creek[a]	SE Alaska	8.4%	Beers (2001)
Bear Lake[b]	SC Alaska	1.1 - 5.1%	McHenry (1981)
14 stocks[c]	British Columbia	0.5 - 23.1%	Labelle et al. (1997)
Black Creek[a]	British Columbia	3 - 20%	Bradford et al. (2000)
Thompson River[c]	British Columbia	< 5%	Bradford and Irvine (2000)
Rosewall Creek[b]	British Columbia	3.1 - 43.3%	Bilton et al. (1982)
Various hatcheries[b]	Oregon	0.1 - 11.0%	Nickelson and Lawson (1998)
Various hatcheries[b]	Pacific Northwest	0.9 - 6.2%	Coronado and Hilborn (1998)
Various streams[a]	Pacific Northwest	9.8%	Bradford (1995)

[a] Natural production.
[b] Hatchery production.
[c] Combination of natural and hatchery production.

Although we applied the habitat model to our study streams using habitat inventory data collected only during the summer, Nickelson (1998) highly recommended using winter habitat inventory data as well. Unfortunately, this was not practical for the streams in our study since they are usually ice-covered for long periods during the winter. To collect winter habitat data would necessitate scheduling inventories during times of fall and winter freshets, which is not practical for streams accessible only by aircraft. Having a crew ready on-site to complete an inventory during high water events was also not practical due to various constraints, including the safety and cost of operating remote field camps during Alaska winters. In general, we felt that flow conditions during summer inventories were probably similar to those during winter. Our use of summer habitat data in place of winter data probably overestimated winter habitat availability and smolt capacity, although our results appear reasonable when compared to other studies (Table 36). Estimated smolt densities for the Kametolook, Three Star, and Long Beach systems were generally at the low end of observed values, except for the values reported by Crone and Bond (1976) for a southeast Alaska stream. Although this trend was not as clear for smolt/km data, this was not surprising since this measurement does not account for habitat area.

Table 36. Comparison of coho salmon smolt capacity estimates for the streams we studied calculated using the habitat limiting factor model of Nickelson (1998) to estimates reported in the literature for other streams in the Pacific Northwest and Alaska.

Stream	Location	Smolt/km	Smolt/m^2	Source
Kametolook River	SW Alaska	595	0.16	Current study
Three Star River	SW Alaska	747	0.20	Current study
Long Beach River	SW Alaska	838	0.23	Current study
Clear Creek	SW Alaska	5,752	0.52	Current study
Sashin Creek	SE Alaska	--	.055 - 0.169	Crone and Bond (1976)
Lymn Creek	British Columbia	--	0.25	Mason (1976)
14 streams	Oregon	205 - 2,100[a]	--	Nickelson et al. (1992)
Deer Creek	Oregon	730 - 1,378	0.36 - 0.67	Chapman (1965)
Flynn Creek	Oregon	582 - 1,043	0.28 - 0.52	Chapman (1965)
Needle Branch Creek	Oregon	212 - 611	0.15 - 0.39	Chapman (1965)
9 streams	Washington	218 - 4,145[b]	--	Sharma and Hilborn (2001)
Multiple streams	OR, WA, BC	363 - 3,018[c]	0.17 - 1.57[d]	Marshall and Britton (1990)

[a] Estimated using model similar to habitat model. Mean for all streams was 762 smolt/km. Estimates calculated by combining data from Tables 3 and 4, Nickelson et al. (1992).
[b] Mean for all streams was 1,778 smolt/km.
[c] Data from 22 streams. Mean for all streams was 1,804 smolt/km.
[d] Data from 14 streams. Mean for all streams was 0.54 smolt/m^2.

Overwinter juvenile coho salmon survival estimates for the Kametolook, Three Star, Long Beach, and Clear Creek systems are also similar to those reported in the literature, except for estimates in off-channel habitats (Table 37). Estimates of production potential (smolt capacity) of the habitat model in Oregon were closely related to actual smolt production when summer habitat was fully seeded (Nickelson 1998). Overall, the habitat model appears to provide reasonable estimates for smolt capacities and overwinter survival in the four systems. Estimates of adult production potential are also likely to be reasonable for these systems, if winter habitat is the primary bottleneck for smolt production.

Production estimates based on the habitat model for the Kametolook, Three Star, Long Beach, and Clear Creek systems are similar to those derived from other models presented in the literature (Table 29). However, these models consistently underestimate production in Clear Creek compared to the habitat model. This makes intuitive sense, as models developed based on stream length would not capture the fact that the drainage lake in Clear Creek is responsible for nearly 50% of available rearing area; the model of Marshall and Britton (1990) based on stream area does not differentiate between habitat types: riffle habitat would be just as productive as beaver pond habitat. The model of Bradford et al. (1997) based on stream length yields production estimates most similar to those of the habitat model.

Management Implications

The Kametolook, Three Star, Long Beach, and Clear Creek systems all appear to be capable of supporting much larger adult coho salmon runs than were observed during our study. Routledge and Irvine (1999) demonstrated that stocks with modest growth potential at low abundance can rapidly be driven to extinction and that even under benign conditions, chance variation in recruitment can dramatically reduce survival rates. Small population size can also lead to loss of genetic variation and population fitness (Kalinowski and Waples 2002). Allendorf et al. (1997) considers stocks to have a high risk of extinction if population sizes are less than 2,500. Nickelson and Lawson (1998) determined that marine survival and exploitation rates are highly influential when predicting extinction risk, and that extinction risk was high for populations with less than 300 individuals. However, part of the success of coho salmon as a species is their ability to inhabit numerous small coastal streams that do not support large numbers of fish (Sandercock 1991). Stock structure information for coho salmon on the Alaska Peninsula is lacking, and it is unknown what geographic scale represents a genetically unique coho salmon population.

The physical habitat of the Kametolook, Three Star, and Long Beach rivers can support coho salmon populations in excess of current escapement levels. Neighboring drainages in Ivanof, Humpback, Anchor, and Ivan bays, which are vulnerable to the same commercial fisheries, still support viable runs of coho salmon (Anderson 2004). Subsistence harvesting of coho salmon in the Kametolook, Three Star, and Long Beach rivers may not have allowed sufficient spawning escapement to fully utilize available spawning and rearing habitat. The local ordinance passed by the Native Village of

Table 37. Comparison of coho salmon overwinter survival estimates for the streams we studied calculated using the habitat limiting factor model of Nickelson (1998) to estimates reported in the literature for other streams in the Pacific Northwest and Alaska.

Stream	Location	Overwinter Survival	Source
Kametolook River	SW Alaska	0.24	Current study
Three Star River	SW Alaska	0.27	Current study
Long Beach River	SW Alaska	0.28	Current study
Clear Creek	SW Alaska	0.40	Current study
Sashin Creek	SE Alaska	0.20 - 0.57	Crone and Bond (1976)
Treatment streams	Oregon	0.13 - 0.38	Solazzi et al. (2000)
Control streams	Oregon	0.17 - 0.20	Solazzi et al. (2000)
Big Beef Creek	Washington	0.25 - 0.46	Quinn and Peterson (1996)
Coldwater River	British Columbia	0.54 - 0.87[a]	Swales et al. (1986)
Carnation Creek	British Columbia	0.67 - 0.72[b]	Tschaplinski and Hartman (1983)
Carnation Creek	British Columbia	0.35[c]	Bustard and Narver (1975)
Carnation Creek	British Columbia	0.61[b]	Bustard and Narver (1975)

[a] Overwinter survival estimated for off-channel ponds.
[b] Overwinter survival estimated for off-channel sloughs and tributary streams.
[c] Overwinter survival estimated for entire basin.

Perryville to prevent subsistence harvest on the Kametolook River may be allowing the coho salmon run to rebuild. With 640 adults observed in Kametolook River sloughs and another 136 adults observed in Cross Creek Slough, coho salmon escapement in 2003 may have approached the 1,200 adults necessary to fully seed that system with juveniles. Harvest restrictions may also be needed for coho salmon spawning in the Three Star and Long Beach rivers.

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Appendix A. Summary of daily salmon passage at the Clear Creek weir, 2002.

	Coho			Sockeye	Chum	Pink
Date	Daily Count	Cumulative	Cumulative %	Daily Count	Daily Count	Daily Count
9/1/02	0	0	0	0	38	358
9/2/02	0	0	0	4	19	314
9/3/02	0	0	0	0	26	409
9/4/02	0	0	0	8	36	1265
9/5/02	0	0	0	1	44	779
9/6/02	0	0	0	2	18	391
9/7/02	0	0	0	1	14	486
9/8/02	0	0	0	4	24	698
9/9/02	0	0	0	1	10	140
9/10/02	0	0	0	1	2	33
9/11/02	0	0	0	0	2	24
9/12/02	0	0	0	0	1	20
9/13/02	0	0	0	5	19	182
9/14/02	108	108	10	1	4	8
9/15/02	314	422	38	1	3	35
9/16/02	23	445	41	1	3	4
9/17/02	0	445	41	0	5	1
9/18/02	0	445	41	0	0	1
9/19/02	0	445	41	0	0	0
9/20/02	0	445	41	1	0	1
9/21/02	0	445	41	0	0	1
9/22/02	0	445	41	0	0	0
9/23/02	0	445	41	0	0	0
9/24/02	193	638	58	1	0	1
9/25/02	3	641	58	0	1	0
9/26/02	129	770	70	0	0	0
9/27/02	0	770	70	0	0	0
9/28/02	0	770	70	0	0	0

Appendix A. continued.

Date	Coho			Sockeye	Chum	Pink
	Daily Count	Cumulative	Cumulative %	Daily Count	Daily Count	Daily Count
9/29/02	0	770	70	0	0	0
9/30/02	70	840	77	0	0	1
10/1/02	2	842	77	0	0	0
10/2/02	0	842	77	0	0	0
10/3/02	0	842	77	0	0	0
10/4/02	0	842	77	0	0	1
10/5/02	76	918	84	0	0	0
10/6/02	26	944	86	0	0	0
10/7/02	7	951	87	0	0	0
10/8/02	0	951	87	0	0	0
10/9/02	0	951	87	0	0	0
10/10/02	12	963	88	0	0	0
10/11/02	0	963	88	0	0	0
10/12/02	5	968	88	0	0	0
10/13/02	37	1005	92	0	0	0
10/14/02	6	1011	92	0	0	0
10/15/02	3	1014	92	0	0	0
10/16/02	0	1014	92	0	0	0
10/17/02	16	1030	94	0	0	0
10/18/02	33	1063	97	0	0	0
10/19/02	2	1065	97	0	0	0
10/20/02	2	1067	97	0	0	0
10/21/02	3	1070	98	0	0	0
10/22/02	2	1072	98	0	0	0
10/23/02	0	1072	98	0	0	0
10/24/02	1	1073	98	0	0	0
10/25/02	0	1073	98	0	0	0

Appendix A. continued.

Date	Coho			Sockeye	Chum	Pink
	Daily Count	Cumulative	Cumulative %	Daily Count	Daily Count	Daily Count
10/26/02	5	1078	98	0	0	0
10/27/02	2	1080	98	0	0	0
10/28/02	11	1091	99	0	0	0
10/29/02	0	1091	99	0	0	0
10/30/02	0	1091	99	0	0	0
10/31/02	0	1091	99	0	0	0
11/1/02	0	1091	99	0	0	0
11/2/02	0	1091	99	0	0	0
11/3/02	4	1095	99	0	0	0
11/4/02	0	1095	99	0	0	0
11/5/02	0	1095	99	0	0	0
11/6/02	0	1095	99	0	0	0
11/7/02	0	1095	99	0	0	0
11/8/02	0	1095	99	0	0	0
11/9/02	1	1096	99	0	0	0
11/10/02	0	1096	99	0	0	0
11/11/02	1	1097	100	1	0	0
Total:	1097			33	269	5153

Appendix B. Summary of daily salmon passage at the Clear Creek weir, 2003.

	Coho			Sockeye	Chum	Pink
Date	Daily Count	Cumulative	Cumulative %	Daily Count	Daily Count	Daily Count
8/24/03	0	0	0	0	30	163
8/25/03	0	0	0	1	23	47
8/26/03	0	0	0	0	39	78
8/27/03	0	0	0	3	42	170
8/28/03	3	3	1	2	31	295
8/29/03	0	3	1	0	22	476
8/30/03	0	3	1	2	24	280
8/31/03	0	3	1	1	25	494
9/1/03	0	3	1	1	14	302
9/2/03	0	3	1	0	29	446
9/3/03	0	3	1	0	11	374
9/4/03	0	3	1	0	6	131
9/5/03	0	3	1	1	4	173
9/6/03	0	3	1	0	2	23
9/7/03	0	3	1	0	15	105
9/8/03	0	3	1	0	17	118
9/9/03	1	4	1	0	14	71
9/10/03	0	4	1	0	12	52
9/11/03	0	4	1	0	2	36
9/12/03	0	4	1	0	0	10
9/13/03	0	4	1	0	0	21
9/14/03	0	4	1	0	1	16
9/15/03	0	4	1	0	1	14
9/16/03	0	4	1	0	2	1
9/17/03	0	4	1	0	0	3
9/18/03	0	4	1	0	0	0
9/19/03	0	4	1	0	0	1
9/20/03	0	4	1	0	0	0
9/21/03	0	4	1	0	0	0
9/22/03	0	4	1	0	0	0
9/23/03	0	4	1	1	0	4
9/24/03	0	4	1	0	0	0
9/25/03	0	4	1	0	0	0
9/26/03	0	4	1	0	1	3
9/27/03	0	4	1	0	0	0
9/28/03	0	4	1	4	0	0
9/29/03	0	4	1	0	2	0

Appendix B. continued.

	Coho			Sockeye	Chum	Pink
Date	Daily Count	Cumulative	Cumulative %	Daily Count	Daily Count	Daily Count
9/30/03	54	58	11	0	0	0
10/1/03	4	62	11	0	0	0
10/2/03	0	62	11	0	0	0
10/3/03	0	62	11	0	0	0
10/4/03	12	74	13	2	2	0
10/5/03	1	75	14	0	0	0
10/6/03	0	75	14	3	1	0
10/7/03	22	97	18	1	0	0
10/8/03	2	99	18	1	0	0
10/9/03	1	100	18	0	0	0
10/10/03	0	100	18	2	3	0
10/11/03	1	101	18	0	1	0
10/12/03	0	101	18	0	1	0
10/13/03	0	101	18	3	1	0
10/14/03	32	133	24	0	0	0
10/15/03	55	188	34	0	0	0
10/16/03	14	202	37	0	0	0
10/17/03	3	205	37	0	0	0
10/18/03	0	205	37	0	0	0
10/19/03	0	205	37	0	0	0
10/20/03	0	205	37	0	0	0
10/21/03	0	205	37	0	0	0
10/22/03	0	205	37	0	0	0
10/23/03	0	205	37	0	0	0
10/24/03	1	206	38	0	0	0
10/25/03	0	206	38	0	0	0
10/26/03	9	215	39	0	0	0
10/27/03	0	215	39	0	0	0
10/28/03	0	215	39	0	0	0
10/29/03	2	217	40	1	0	0
10/30/03	101	318	58	0	0	0
10/31/03	74	392	71	0	0	0
11/1/03	88	480	87	0	0	0
11/2/03	9	489	89	0	0	0
11/3/03	18	507	92	0	0	0
11/4/03	10	517	94	0	0	0
11/5/03	17	534	97	1	1	0

Appendix B. continued.

Date	Coho			Sockeye	Chum	Pink
	Daily Count	Cumulative	Cumulative %	Daily Count	Daily Count	Daily Count
11/6/03	6	540	98	0	0	0
11/7/03	4	544	99	0	0	0
11/8/03	2	546	99	1	0	0
11/9/03	1	547	100	0	0	0
11/10/03	0	547	100	0	0	0
11/11/03	0	547	100	0	0	0
11/12/03	1	548	100	0	0	0
11/13/03	1	549	100	0	0	0
11/14/03	0	549	100	0	0	0
Total:	549			31	379	3,907