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Nearshore Habitat Use by Juvenile Chinook Salmon in Lentic Systems of the Lake Washington Basin

Annual Report, 2003 and 2004

March 2006

By Roger A. Tabor, Howard A. Gearns, Charles M. McCoy III and Sergio Camacho
U.S. Fish and Wildlife Service
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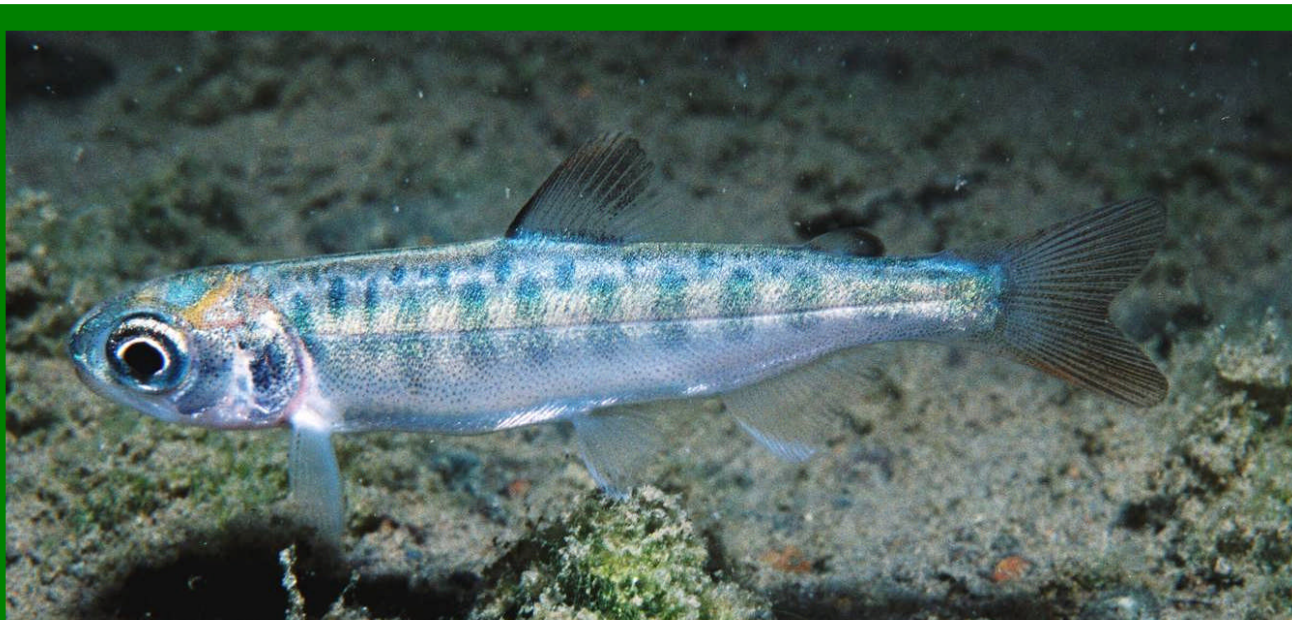

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NEARSHORE HABITAT USE BY JUVENILE CHINOOK SALMON IN LENTIC SYSTEMS, 2003 AND 2004 REPORT

by

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SUMMARY

In 2003 and 2004, we continued our assessment of juvenile Chinook salmon (*Oncorhynchus tshawytscha*) habitat use in the nearshore areas of Lake Washington and Lake Sammamish. Additional work was conducted in Lake Quinault to study habitat features that are rare in the Lake Washington basin and serve as a more natural "reference system" to Lake Washington. Juvenile Chinook salmon are found in Lake Washington and Lake Sammamish between January and July, primarily in the littoral zone. Little is known of their habitat use in lakes, as ocean-type Chinook salmon rarely occur in lakes throughout their natural distribution. Research efforts in 2003 and 2004 focused on juvenile Chinook salmon distribution, residence time and movements, shoreline structure use (woody debris, overhanging vegetation, and emergent vegetation), depth distribution, use of nonnatal tributaries, feeding at the mouths of tributaries, abundance at restoration sites, and behavior of migrating smolts. Data on Chinook salmon habitat use were collected primarily through snorkel surveys.

We repeatedly surveyed nine index sites in 2003 in south Lake Washington to examine the temporal and spatial distribution of juvenile Chinook salmon. We surveyed four sites on the east shoreline, four on the west shoreline, and one on Mercer Island. Similar to 2002 results, the two sites closest to the Cedar River had substantially higher densities of Chinook salmon from the beginning of February to the end of May than the other seven sites. Overall, the abundance of Chinook salmon displayed a strong, negative relationship with the shoreline distance from the mouth of the Cedar River to each site. Juvenile Chinook salmon were present on Mercer Island on each survey date.

To better understand the residence time and movement patterns of juvenile Chinook salmon, we conducted a marking study at Gene Coulon Park. Approximately 100 Chinook salmon (mean, 45 mm fork length) were collected from each of two sites and each group was marked with a different color of dye and were later released where they were captured. At 1, 7, 15 and 21 days after release, we snorkeled the entire shoreline of Gene Coulon Park at night to look for marked fish. Results indicated many Chinook salmon remain in a small area. We never found any Chinook salmon that had moved more than 150 m. The median distance moved within the study area remained the same from day 1 to day 21 but the number of marked fish observed declined substantially. Therefore, it is possible that some fish moved outside of our survey area.

We continued to monitor restoration sites, both pre- and post-project, to help determine if lake-shoreline habitat can be improved for juvenile Chinook salmon rearing. A restoration project at Seward Park was completed in December 2001. The restoration site as well as other Seward Park shoreline sites were surveyed in 2002-2004 and compared to 2001 data. Numbers of juvenile Chinook salmon were generally low for each year. Overall, we found no evidence of increased Chinook salmon use of the Seward Park restoration site.

We also continued to collect baseline information at Beer Sheva Park and Martha Washington Park. In addition, we also began collecting baseline data at Rainier Beach Lake Park and Marina and the old Shuffleton Power Plant Outflow site. The boat ramp area at Beer Sheva Park had high densities of Chinook salmon, and there appear to be

sufficient numbers of juvenile Chinook salmon at Beer Sheva Park to rear at the mouth of Mapes Creek if it were restored. Overall, restoration sites close to the mouth of the Cedar River likely have a higher chance of success than further north sites because juvenile Chinook salmon are substantially more abundant near the mouth of the Cedar River than at more northerly sites.

Both day and night surveys were conducted to better quantify the water depth of the area where juvenile Chinook salmon are located. Daytime surveys consisted of surface observations of juvenile Chinook salmon feeding at the surface. Surveys were conducted once every two weeks from February to June. Nighttime surveys were conducted once a month from March to May and consisted of a series of perpendicular snorkel/scuba diving transects between 0- and 3- m depth. During the day from February 19 to April 14, Chinook salmon were only observed in water between 0- and 0.5-m deep. From late April to June, surface feeding activity by Chinook salmon was observed in progressively deeper water and by June most activity was observed in an area where the water was between 2- and 3-m deep. Results of nighttime surveys clearly showed that juvenile Chinook salmon progressively shift to deeper waters as they grow.

In 2002, we surveyed 17 tributaries and found juvenile Chinook salmon are often present at the tributary mouths. We surveyed six tributaries in 2003 and 2004 to determine if Chinook salmon forage on prey items that come into the lake via the tributary and how storm events affect the diet and abundance of juvenile Chinook salmon. Under baseflow conditions, differences in the diet between the lake shore and the tributary mouth were not pronounced; however, Chinook salmon at tributary mouths do appear to utilize prey from the tributary to some extent. Chironomid pupae and adults were the most important prey at both the tributary mouths and lakeshore sites. However, benthic and terrestrial insects were more prevalent in the diet at tributary mouths than at lakeshore sites. The diet breadth was usually higher at the tributary mouths than along the lakeshore. Tributary mouths appeared to be especially valuable habitat for Chinook salmon during high streamflow conditions. The diet breadth was much broader at high streamflow than during base streamflow conditions. A large percentage of the diet during high streamflow conditions consisted of benthic prey such as chironomid larvae and oligochaetes. These prey items were a minor component of the diet at tributary mouths during base streamflow conditions and at lakeshore sites. At May Creek, we were also able to demonstrate that the abundance of Chinook salmon can increase during a high flow event.

Of the 17 tributaries examined in 2002, Johns Creek was by far the most used by Chinook salmon. We continued surveys of Johns Creek in 2003 and 2004, to determine the spatial and temporal distribution of Chinook salmon within the tributary. We surveyed the lower 260 m of the creek once every two to three weeks. Results from Johns Creek indicated that Chinook salmon extensively use this nonnatal tributary from year to year. They use slow-water habitats and moved into deeper habitats as they increased in size. Density of Chinook salmon in the convergence pool was considerably lower than in pools and glides upstream. The convergence pool is larger and deeper than the other habitats and has very low water velocities. Also, other fish species, including predators, were often present in the convergence pool and rare or absent in the other habitats.

An overhanging vegetation/small woody debris (OHV/SWD) experiment was conducted in Gene Coulon Park in 2003. We compared the abundance of Chinook salmon at two shoreline sections with OHV and SWD to two sections with only SWD and to two sections where no structure was added. The site was surveyed during two time periods; March 24 through April 9 and May 2 through 16. During daytime in the early time period, we found a significantly higher abundance of Chinook salmon at the OHV/SWD sites than the other two shoreline types. Large numbers of Chinook salmon were located directly under the OHV. At night, no significant difference was detected. Also, there was no significant difference during the late time period (May 2 through 16), either day or night. Results indicated that overhead cover is an important habitat element early in the season; however, an additional experiment is needed to determine if OHV alone is used as intensively as OHV is in combination with SWD.

Because large woody debris (LWD) and emergent vegetation are rare in Lake Washington, we examined their use by juvenile Chinook salmon in Lake Quinault. Nearshore snorkel transects were surveyed in 2004 during a 2-week period in April and a 2-week period in June. The nearshore area was divided into one of five habitat types: open beach, bedrock, emergent vegetation, LWD, or tributary mouth. During the April daytime surveys, tributary mouths generally had higher numbers of Chinook salmon than the other habitat types and bedrock sites often had a lower number. Beach, emergent vegetation, and LWD sites were not significantly different from each other. Within LWD sites, juvenile Chinook salmon were often resting directly under a large piece of LWD. There was no difference in their nighttime abundance between habitat types. In June, few Chinook salmon were observed during the day except at tributary mouths. Apparently, Chinook salmon were further offshore during the day. At night, they were abundant in the nearshore area but there was no difference in their abundance between habitat types.

Earlier Lake Washington work in June 2001 indicated that Chinook salmon can be observed moving along the lake shoreline. In 2003 and 2004, we undertook a more in-depth sampling approach to determine when they can be observed. Additionally, we wanted to collect information on their behavior in relation to piers. In 2003 and 2004, weekly observations (May-July) were conducted at one site, a public pier near McClellan Street. Observations at other piers were only conducted when large numbers of Chinook salmon had been seen at McClellan Pier. The timing of the migration appeared to coincide with the June moon apogee, which has been also suggested to be related to the passage of Chinook salmon smolts at the Ballard Locks. When migrating Chinook salmon approach a pier they appear to move to slightly deeper water and either pass directly under the structure or swim around the pier. The presence of Eurasian milfoil (*Myriophyllum spicatum*) appeared to cause juvenile Chinook salmon to be further offshore in deeper water. The top of the milfoil appeared to act as the bottom of the water column to Chinook salmon. At some piers with extensive milfoil growth, Chinook salmon were located on the outside edge of the pier and the pier had little effect on their behavior.

A summary table is presented below which lists various habitat variables and displays conclusions about each variable for three time periods (Table 1). The table was developed from results of this report as well as two earlier reports (Tabor and Piaskowski 2002, Tabor et al. 2004b).

TABLE 1.-- Summary table of juvenile Chinook salmon habitat use during three time periods in Lake Washington. Summary designations are based on 2001 (Tabor and Piaskowski 2001), 2002 results (Tabor et al. 2004b) and 2003-2004 results presented in this report. (++ indicates a strong preference + indicates a slight to moderate preference; = indicates no selection (positive or negative); - indicates a slight to moderate negative selection; - - indicates a strong negative selection; ?? indicates that no data is available; and (?) indicates that only preliminary data is available. Sand/gr. indicates sand and gravel.

	February - March		April - mid-May		mid-May - June	
Habitat variable	**Day**	**Night**	**Day**	**Night**	**Day**	**Night**
Water column depth (m)	0.2-1.3	0.1-0.5	??	0.2-0.9	(?)0.5-7+	(?)0.2-7+
Location in water column	entire	bottom	middle/top	bottom	middle/top	(?) bottom
Behavior	schooled, feeding	solitary, resting	schooled, feeding	solitary, resting	schooled, feeding	??
Distance from shore (m)	1-12	1-12	1-12	1-12	variable	variable
Substrate	sand/gr.	sand/gr.	??	sand/gr.	??	??
Slope	< 20%	< 20%	< 20%	< 20%	??	??
Bulkheads	-	-	??	- -	??	??
Rip rap	- -	- -	??	-	??	??
Small woody debris	+	=	+	=	??	??
Large woody debris	+	-	=	-	??	??
Overhanging vegetation	++	- -	+	- -	(?) =	(?) =
Overhead structures	+	- -	(?) -	- -	(?) --	(?) --
Emergent vegetation	+	+	=	=	(?) =	(?) =
Aquatic marcophytes	(?) +	(?) -	(?) -	(?) -	(?) -	(?) -
Tributaries (low gradient, small streams, and close to natal stream)	++	++	+	+	+	+
Tributary mouth	++	++	++	++	+	+

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INTRODUCTION

Juvenile ocean-type Chinook salmon (*Oncorhynchus tshawytscha*) primarily occur in large rivers and coastal streams (Meehan and Bjornn 1991) and are not known to commonly inhabit lake environments. Consequently, little research has been conducted on their habitat use in lakes (Graynoth 1999). In western Washington, juvenile Chinook salmon inhabit three major lakes, Lake Washington, Lake Sammamish and Lake Quinault. These lakes are used as either a migratory corridor from their natal stream to the marine environment (mostly in June) or as an extended rearing location before outmigrating (January-July) to the marine environment. Prior to 1998, little research had been conducted on juvenile Chinook salmon in the lentic environments of the Lake Washington system. Initial work in 1998 to 2000 focused on macrohabitat use and indicated that juvenile Chinook salmon in Lake Washington are primarily restricted to the littoral zone until mid-May when they are large enough to move offshore (Fresh 2000). Subsequent research in 2001 focused on mesohabitat and microhabitat use (Tabor and Piaskowski 2002). Results indicated juvenile Chinook salmon were concentrated in very shallow water, approximately 0.4-m depth, and prefer low gradient shorelines with small particle substrates such as sand and gravel. Armored banks, which make up 71% of the Lake Washington shoreline (Toft 2001), reduce the quality and quantity of the nearshore habitat for juvenile Chinook salmon. In 2002, research efforts focused on juvenile Chinook salmon distribution, shoreline structure use, use of non-natal tributaries, and abundance at restoration sites (Tabor et al. 2004b).

In 2003 and 2004, we continued to examine the habitat use of juvenile Chinook salmon in the nearshore areas of Lake Washington and Lake Sammamish. Additionally, we began an investigation of habitat use in Quinault Lake, a relatively pristine environment. This report outlines research efforts which focused on juvenile Chinook salmon distribution, use of small woody debris (SWD) and overhanging vegetation (OHV), use of non-natal tributaries, and abundance at restoration sites.

STUDY SITE

We examined habitat use of juvenile Chinook salmon in Lake Washington, Lake Sammamish, and Lake Quinault. Lake Washington is a large monomictic lake with a total surface area of 9,495 hectares and a mean depth of 33 m. The lake typically thermally stratifies from June through October. Surface water temperatures range from 4-6EC in winter to over 20EC in summer. During winter (December to February) the lake level is kept low at an elevation of 6.1 m. Starting in late February the lake level is slowly raised from 6.1 m in January to 6.6 m by May 1, and 6.7 m by June 1. The Ballard Locks, located at the downstream end of the Ship Canal, control the lake level. Over 78% of the lake shoreline is comprised of residential land use. Shorelines are commonly armored with riprap or bulkheads with adjacent landscaped yards. Man-made overwater structures (i.e., docks, piers, houses) are common along the shoreline. Natural shoreline structures, such as SWD and large woody debris (LWD) and emergent vegetation, are rare.

The major tributary to Lake Washington is the Cedar River, which enters the lake at its southern end (Figure 1). The river originates at an approximate 1,220-m elevation, and over its 80-km course falls 1,180 m. The lower 55 km are accessible to anadromous salmonids. Prior to 2003, only the lower 35 km were accessible to anadromous salmonids. Landsburg Dam, a water diversion structure, prevented Chinook salmon from migrating further upstream. A fish ladder was completed in 2003, which allows access past Landsburg Dam to an additional 20 km of the Cedar River. The escapement goal for adult Cedar River Chinook salmon is 1,250; however, this goal has not been met in recent years.

Historically, the Duwamish River watershed, which included the Cedar River, provided both riverine and estuarine habitat for indigenous Chinook salmon. Beginning in 1912, drainage patterns of the Cedar River and Lake Washington were extensively altered (Weitkamp and Ruggerone 2000). Most importantly, the Cedar River was diverted into Lake Washington from the Duwamish River watershed, and the outlet of the lake was rerouted through the Lake Washington Ship Canal (Figure 1). These activities changed fish migration routes and environmental conditions encountered by migrants. The existence of a Chinook salmon population in the Lake Washington drainage prior to 1912 is not well documented.

Lake Sammamish is within the Lake Washington basin and is located just east of Lake Washington. Lake Sammamish has a surface area of 1,980 hectares and a mean depth of 17.7 m. Most of the shoreline is comprised of residential land use. Issaquah Creek is the major tributary to the lake and enters the lake at the south end (Figure 1). A Washington Department of Fish and Wildlife salmon hatchery (Issaquah State Hatchery), which propagates Chinook salmon, is located at river kilometer 4.8.

The largest run of wild Chinook salmon in the Lake Washington basin occurs in the Cedar River. Large numbers of adult fish also spawn in Bear Creek, a tributary to the Sammamish River, which connects lakes Washington and Sammamish (Figure 1). Small numbers of Chinook salmon spawn in several tributaries to Lake Washington and Lake Sammamish. Most hatchery production occurs at Issaquah State Hatchery. Chinook salmon also spawn below the hatchery in Issaquah Creek and other adults are allowed to migrate upstream of the hatchery if the hatchery production goal of returning adults is met. Additional hatchery production occurs at the University of Washington (UW) Hatchery in Portage Bay. Production goals are 2 million for Issaquah State Hatchery and 180,000 for UW Hatchery.

Adult Chinook salmon enter the Lake Washington system from Puget Sound through the Chittenden Locks in July through September. Peak upstream migration past the locks usually occurs in August. Adult Chinook salmon begin entering the spawning streams in September and continue until November. Spawning occurs from October to December with peak spawning activity usually in November.

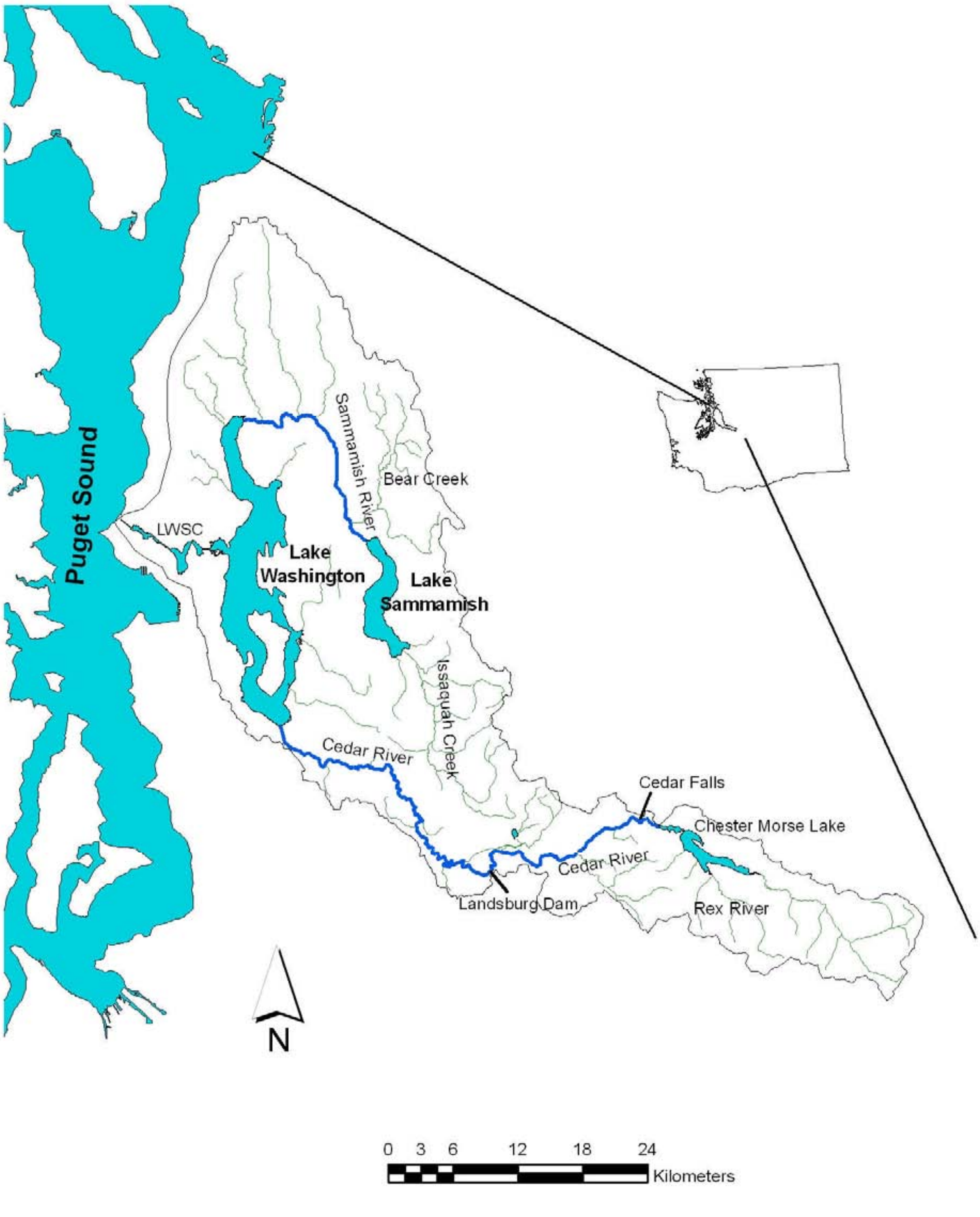


FIGURE 1.-- Map of the Lake Washington basin showing the major streams and lakes. Cedar Falls is a natural barrier to anadromous salmonids. A fish ladder facility at Landsburg Dam is operated to allow passage for all salmonids except sockeye salmon. LWSC = Lake Washington Ship Canal. The location of the basin within Washington State is shown.

Fry emerge from their redds from January to March. Juvenile Chinook salmon appear to have two rearing strategies: rear in the river and then emigrate in May or June as pre-smolts, or emigrate as fry in January, February, or March and rear in the south end of Lake Washington or Lake Sammamish for three to five months. Juvenile Chinook salmon are released from the Issaquah State Hatchery in May or early June and large numbers enter Lake Sammamish a few hours after release (B. Footen, Muckleshoot Indian Tribe, personal communication). Juveniles migrate past the Chittenden Locks from May to August with peak migration occurring in June. Juveniles migrate to the ocean in their first year, and thus Lake Washington Chinook salmon are considered "ocean-type" fish.

Besides Chinook salmon, anadromous salmonids in the Lake Washington basin includes sockeye salmon (*O. nerka*), coho salmon (*O. kisutch*), and steelhead (*O. mykiss*) Sockeye salmon are by far the most abundant anadromous salmonid in the basin. Adult returns in excess of 350,000 fish have occurred in some years. In comparison to other similar-sized basins in the Pacific Northwest, the Lake Washington basin is inhabited by a relatively large number of fish species. Besides anadromous salmonids, there are 22 extant native species of fishes in the Lake Washington basin. An additional 27-28 species have been introduced, 20 of which are extant.

In addition to the lentic systems of the Lake Washington basin, we also examined the habitat use of Chinook salmon in Lake Quinault, a natural 1,510 ha lake located in north Grays Harbor County, Washington and part of the Quinault Indian Reservation. The lake is approximately 6.3 km miles long and its outlet is at river kilometer 53.7 on the Quinault River. The mean depth is 40.5 m and the maximum depth of the lake is approximately 73 m deep. Similar to Lake Washington, Lake Quinault has steep-sloping sides and an extensive, flat profundal zone. Some recreational and residential development has occurred on the shores of Lake Quinault but the level of development is minimal in comparison to Lake Washington and Lake Sammamish. Very little of the shoreline of Lake Quinault is armored and few docks are present. Besides the Quinault River and its tributaries, Chinook salmon have also been observed spawning in Canoe Creek, Zeigler Creek, Gatton Creek, Falls Creek, and Willaby Creek. Preliminary information suggests that Chinook salmon fry enter Lake Quinault later in the year than in Lake Washington, probably due to the colder water temperatures of the Quinault River and other natal tributaries and thus the incubation time is longer. The average escapement for the past ten years of adult Chinook salmon above Lake Quinault is approximately 1,500 fish. Juvenile Chinook salmon in Lake Quinault may also come from the Quinault Indian Nation hatchery located on Lake Quinault. Approximately 300,000 to 400,000 fish are released annually. Because they are released in late summer, they would not be present when we conducted our surveys in April and June. Besides Chinook salmon, Lake Quinault is also an important nursery area for coho salmon and sockeye salmon. Unlike Lake Washington, few introduced fish species are present in Lake Quinault. The only introduced species we observed was common carp (*Cyprinus carpio*).

CHAPTER 1. INDEX SITES

Introduction

In 2003, we continued our surveys of index sites in south Lake Washington to determine the temporal and spatial distribution of juvenile Chinook salmon. Index sites were initially surveyed in 2002. Results indicated that, from January to June, juvenile Chinook salmon were concentrated in the two sites closest to the mouth of the Cedar River. Because of cooler water temperatures in 2002, movement to more northerly sites may have been delayed. We repeated surveys of most of the index sites in 2003 to examine the level of variability between years and to determine if cooler temperatures in 2002 reduced movements to more northerly locations.

Index site surveys were continued in 2004 on a limited basis to provide additional information for the City of Mercer Island. The city is planning to remove some aging sewer pipes along the shore of northwest Mercer Island; however, little is known about the abundance of Chinook salmon at this location.

Methods

2003 surveys.-- Twelve index sites were surveyed in 2002; however, in 2003 we reduced the number of sites to nine so a two-person crew could easily get all the sites surveyed in one night. Of the nine sites, four were on the west shoreline, four were on the east shoreline and one was on Mercer Island (Figure 2). Sites typically had sand and small gravel substrate and a gradual slope; nearshore habitat that juvenile Chinook salmon typically prefer. Many of the sites were public swimming beaches. Habitat conditions of each index site were measured in 2002 (Table 2). Index sites were surveyed once every two weeks from February 4 to July 7. At each site, we surveyed a 50- to 125-m transect depending on the amount of high quality habitat available (sandy beach with gradual slope). Two transects were surveyed at each site, 0.4- and 0.7- m depth contour. Surveys were all done at night. Snorkelers swam parallel to shore with an underwater flashlight, identifying and counting fish. Transects widths were standardized to 2.5 m (0.4- m depth) and 2 m (0.7- m depth). Snorkelers visually estimated the transect width and calibrated their estimation at the beginning of each survey night by viewing a pre-measured staff underwater.

Fish densities (Chinook salmon/m^2) were calculated by dividing the number of Chinook salmon observed by the area surveyed for each site and transect. A regression was developed between Chinook salmon density and distance of each site from the mouth of the Cedar River.

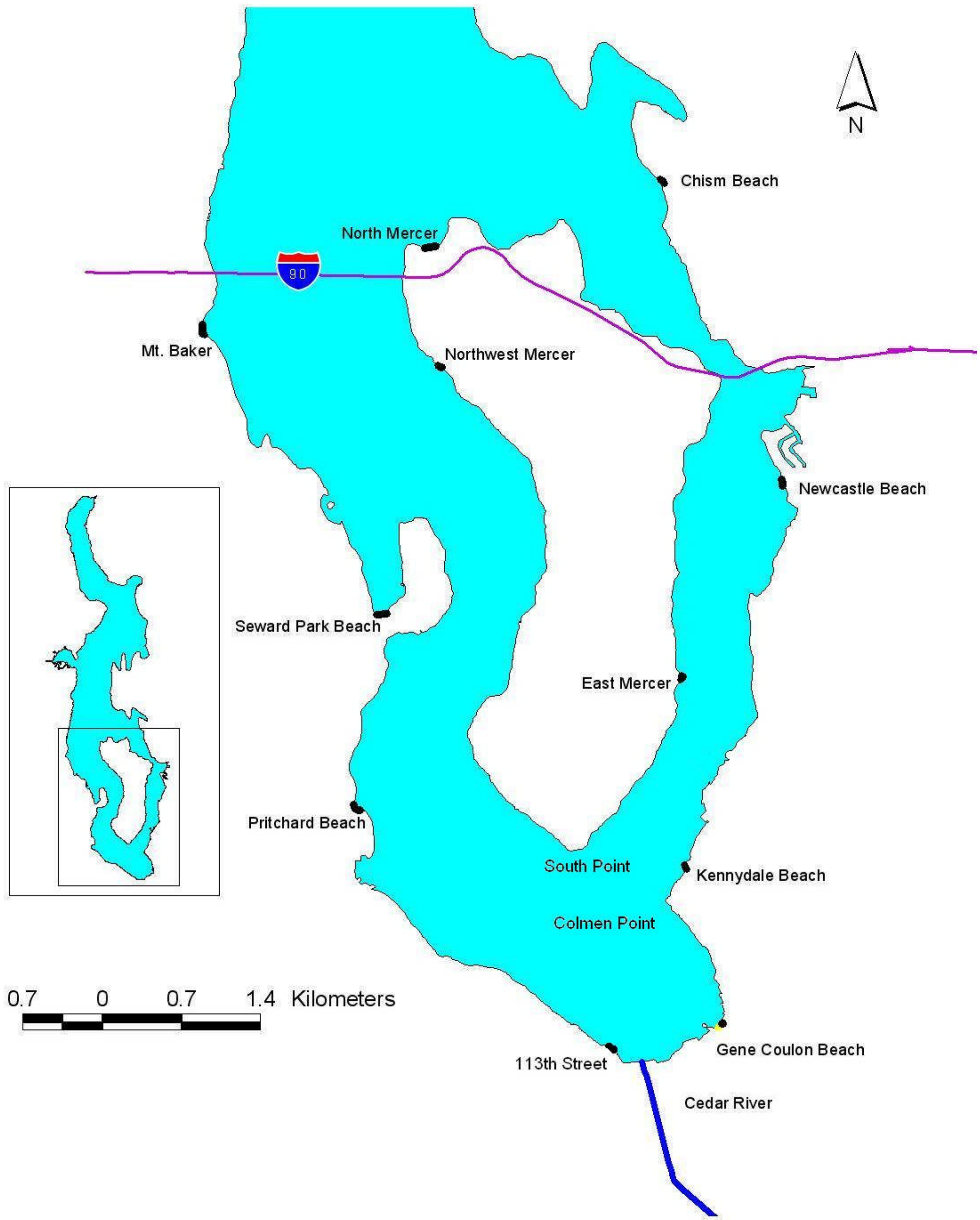


FIGURE 2.—Location of index sites in south Lake Washington used to study the temporal and spatial distribution of juvenile Chinook salmon. In 2003 (January to July), we surveyed four sites each on the west and east shorelines and East Mercer site on Mercer Island. In 2004 (February to June), the north Mercer and northwest Mercer sites were surveyed as well as the East Mercer, Kennydale Beach, and Gene Coulon Beach sites. The Cedar River, the major spawning tributary for Chinook salmon in south Lake Washington, is also shown.

TABLE 2. —Distance from the mouth of the Cedar River and habitat characteristics of index sites surveyed in southern Lake Washington, February to July, 2003. The distance from Cedar River is an approximate length of the shoreline from the mouth of the Cedar River to each site. The number of piers is the number of overwater structures or piers along the transect; each pier was perpendicular to shore and was approximately 2-3 m wide.

Shoreline Site	Distance from Cedar River (km)	Transect length (m)	Substrate			Distance to 1 m depth (m)	Bulkhead length (m)	Number of piers
			Sand	Gravel	Cobble			
West								
113th Street	0.5	121	60	38	2	12.5	63	5
Pritchard Beach	5.7	78	98	2	0	23.3	0	0
Seward Park Beach	12	53	94	6	0	22.9	16.5	0
Mt. Baker	17	122	38	41	21	11.3	0	1
East								
Gene Coulon Beach	1.3	60	100	0	0	18	0	0
Kennydale Beach	4	73	64	36	0	15	60	1
Newcastle Beach	9.4	66	75	16	9	19.6	0	0
Chism Beach	15	50	88	10	2	13.3	19.3	0
Mercer Island								
East Mercer	7.6	73	56	27	17	14.4	23	2

2004 surveys.-- In 2004, we surveyed two new sites on the northwest part of Mercer Island (North Mercer site and Northwest Mercer site) as well as three original index sites (East Mercer, Kennydale Beach, Gene Coulon Beach; Figure 2). Surveys of the original sites enabled us to make comparisons between the two new Mercer Island sites and other areas of south Lake Washington. Both of the northwest Mercer Island sites had a steeper slope than the original index sites. The North Mercer site was along the shoreline of two residential homes. The transect was 92 m long (70-m bulkhead length) and the substrate was mostly sand and gravel. The Northwest Mercer site was located from Calkins Landing to Slater Park (two public beaches) and included four private residential homes that were between the two beaches. The transect was 140 m long (118-m bulkhead length) and the substrate was mostly sand and gravel. All five sites were surveyed once every 2 weeks from February to June. Sampling at each site was done through nighttime snorkeling and survey protocols were the same as in 2002 and 2003.

Results

2003 surveys.-- In general, results of index sites in 2003 were similar to 2002 (Tabor et al. 2004b). The mean abundance of juvenile Chinook salmon from February 4 to May 27 was negatively related to the shoreline distance from the mouth of the Cedar River (Figure 3). The data was best fit with a logarithmic function (abundance (y) = -0.137ln (distance(x)) + 0.36). During this time period, the two sites closest to the Cedar River (113th Street and Gene Coulon) had substantially higher densities than the other sites on most dates (Figure 4). Unlike 2002, large numbers of juvenile Chinook salmon were observed in February. Large numbers were observed as early as February 4 and were present at all sites except Mt. Baker and Chism, the two furthest north sites. A high streamflow event in the Cedar River from January 31 to February 6, coupled with a high adult return in 2002 had apparently resulted in large numbers of fry moving downstream in early February, which were also observed at the fry trap (Seiler et al. 2005a).

In June, there was no relationship between Chinook salmon abundance and distance to the mouth of the Cedar River (Figure 3; log regression, $r^2 = 0.0012$). Generally, Chinook salmon abundance in June was higher on the west shoreline sites (Figure 3; mean, east = 0.14 fish/m^2, west = 0.33 fish/m^2) but they were not statistically different (Mann-Whitney U test = 2.0, $P = 0.83$).

From February to April, densities of Chinook salmon were usually considerably higher in the 0.4-m transect than the 0.7-m transect. For example, at the two southern sites (Gene Coulon and 113th St.) the density in the 0.4-m transect was 3.2 to 77 times higher than in the 0.7-m transect (Figure 5). In May and June, Chinook salmon were commonly found along both the 0.4- and 0.7-m depth contours.

<u>2004 surveys</u>.-- Few Chinook salmon were observed at the sewer replacement sites on Mercer Island (north and northwest sites) until May 24 (Figure 6). Substantially more Chinook salmon were observed at the east Mercer Island site than at either of the sewer replacement sites. Between February 7 and May 10, juvenile Chinook salmon were observed at the east Mercer Island site (mean density, 0.045 fish/m^2) on each survey night; whereas they were only present on 2 of 8 nights at the northwest site (mean density, 0.0042 fish/m^2) and on 1 of 5 nights at the north site (mean density, 0.0008 fish/m^2). On June 10, several Chinook salmon were observed at each Mercer Island site and the density at each site was substantially higher than at the two east shoreline sites (Figure 6). Many of these fish may have been Issaquah hatchery fish, which had been released in late May.

Abundance of Chinook salmon at Gene Coulon and Kennydale in 2004 was generally lower than either 2002 or 2003 (Figure 7). Peak abundance in Gene Coulon was 1.14 fish/m^2 in 2002 and 0.80 fish/m^2 in 2003; whereas it was only 0.27 fish/m^2 in 2004. In contrast, 2004 abundance of Chinook salmon at the east Mercer Island site was generally the same as or higher than 2002 or 2003.

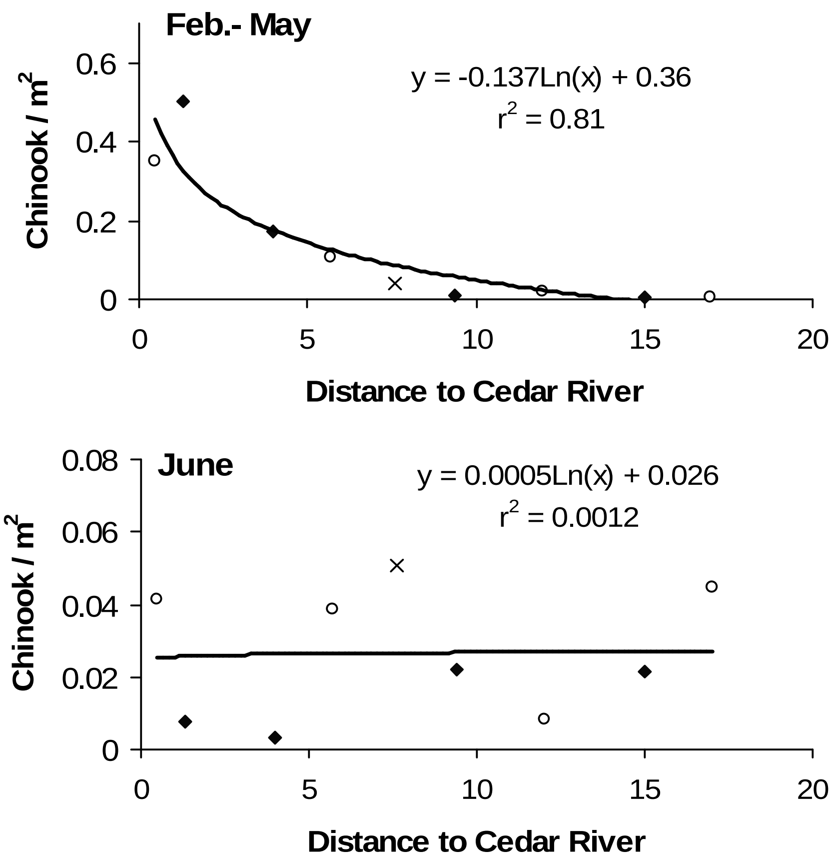


FIGURE 3.—Relationship (logarithmic function) between the mean juvenile Chinook salmon density and the shoreline distance to the mouth of the Cedar River in south Lake Washington, 2003. The February – May density represents the mean of nine surveys dates from February 4 to May 27. The June density represents the mean of June 9 and June 23. Sites include four west shoreline sites (open circles), four east shoreline sites (solid diamonds) and one site on Mercer Island (cross mark). The distance to the Cedar River for the Mercer Island site includes the distance from Coleman Point to South Point (see Figure 2).

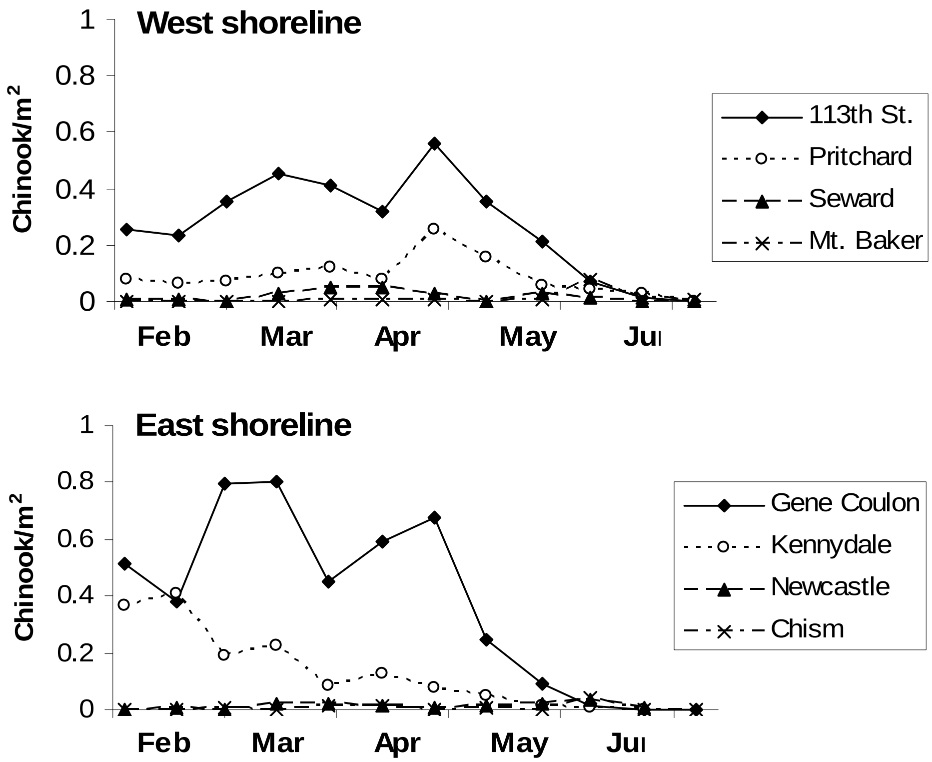


FIGURE 4.—Juvenile Chinook salmon density (number/m^2) at four east shoreline sites and four west shoreline sites in south Lake Washington, 2003. Data represents the mean of nighttime snorkel transects along two depth contours; 0.4 and 0.7 m.

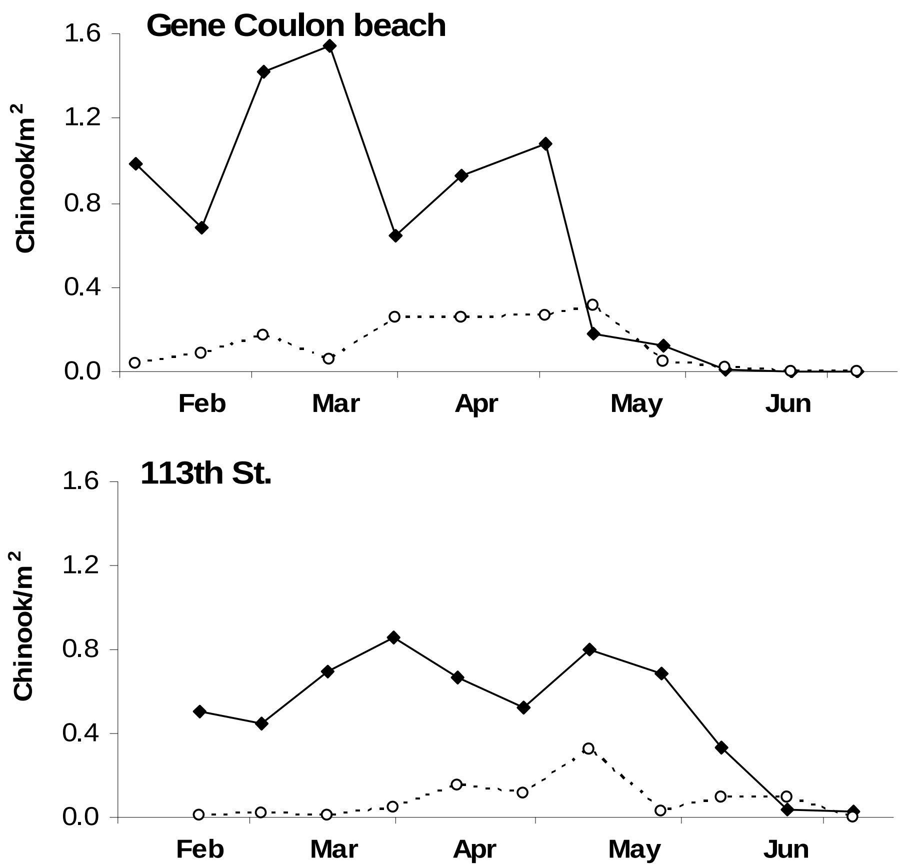


FIGURE 5.—Juvenile Chinook salmon density (number/m^2) along two depth contours; 0.4 m (solid line) and 0.7 m (dashed line) at two sites in south Lake Washington, 2003

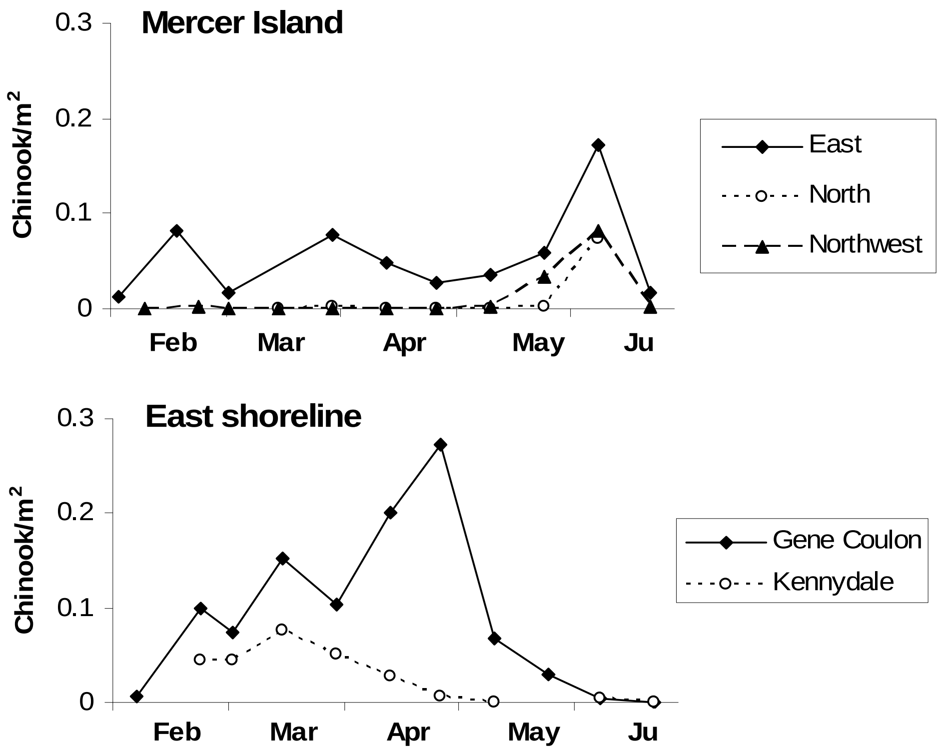


FIGURE 6.— Juvenile Chinook salmon density (number/m^2) at three Mercer Island sites and two east shoreline sites, Lake Washington, February to June, 2004. Data represents the mean of two nighttime snorkel transects (0.4- and 0.7-m depth contours).

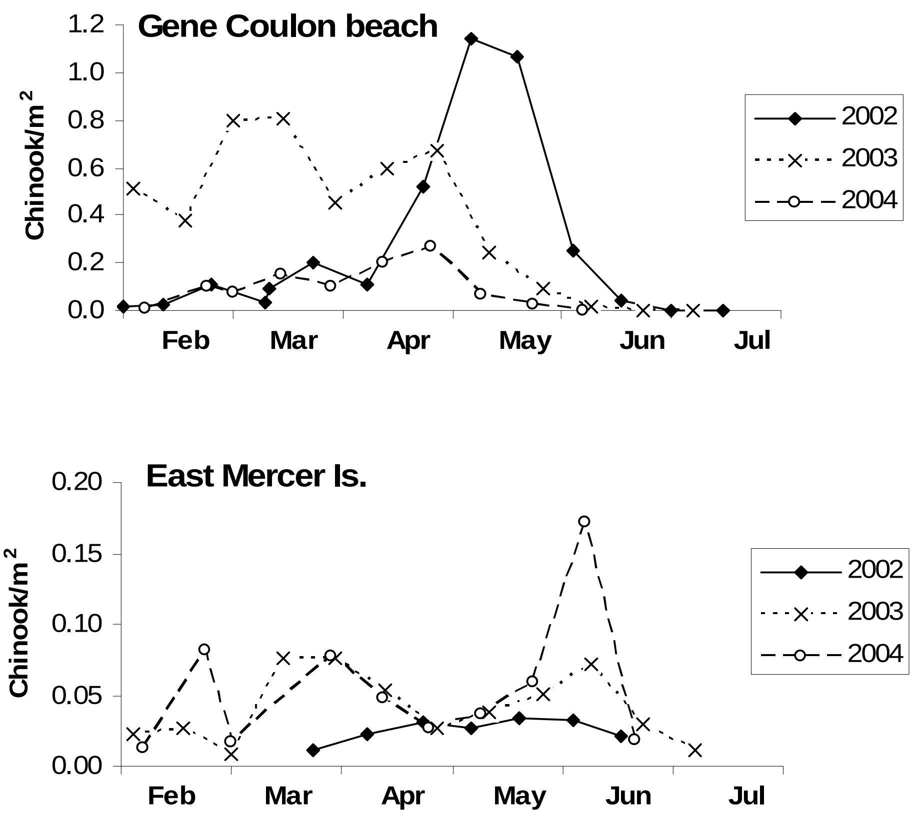


FIGURE 7—Juvenile Chinook salmon density (number/m^2) at two shoreline sites in south Lake Washington, February to June, 2002 to 2004. Data represents the mean of two nighttime snorkel transects (0.4- and 0.7-m depth contours).

Discussion

Similar to results of 2002, juvenile Chinook salmon were concentrated in the south end of Lake Washington from February to May. Washington Department of Fish and Wildlife conducted a beach seining project in Lake Washington in 1998 and 1999 and observed the same trend that we observed (Fresh 2000). Shortly after emergence, juvenile Chinook salmon in Lake Coleridge, New Zealand were found 240 m away from the mouth of their natal streams. After a couple of months they were found about 740 m away from the natal stream but absent at 7 km away (Graynoth 1999). Therefore, it appears that the lake shore area near the natal stream is an important nursery area for juvenile Chinook salmon. In Lake Washington, the major part of this nursery area appears to be roughly from Pritchard Beach on the west shoreline and the mouth of May Creek on the east shore and the south part of Mercer Island. The distance from the mouth of the Cedar River to the edge of the nursery area is around 6 km. North of this area, the number of Chinook salmon would be expected to be relatively low until mid-May or June. Because Chinook salmon are closely associated with nearshore habitats from February to May, restoring and protecting shallow water areas in the south end would be particularly valuable. Shoreline improvements in more northern locations would be beneficial, but the overall effect to the Chinook salmon population would be small in comparison to restoration efforts in the south end.

In Lake Quinault, juvenile Chinook salmon in April were relatively small but appeared to have dispersed around the entire lake. Lake Quinault is much smaller than Lake Washington and there are natal systems on the east and south shorelines and every shoreline area is probably within 7 km of a natal stream. However, even at our sites that were the furthest from a natal stream, juvenile Chinook salmon were relatively abundant. Chinook salmon in Lake Quinault may disperse around the lake faster than in Lake Washington because of habitat conditions. Most of the shoreline of Lake Quinault appeared to have good quality habitat (small substrates and gentle slope) for juvenile Chinook salmon. In Lake Washington, much of the shoreline is armored with riprap or bulkheads, which may be a partial barrier to juvenile Chinook salmon if they are moving along the shore. Juvenile Chinook salmon may also disperse faster in Lake Quinault than in Lake Washington if prey availability is lower. In Lake Washington, prey abundance appears to be high (Koehler 2002) and thus Chinook salmon may be less inclined to move.

Our results of surveys of index sites appear to be in general agreement with the Cedar River WDFW fry trap results with one notable exception (Seiler et al. 2004; Seiler et al. 2005a; Seiler et al. 2005b). In early February 2003, a large pulse of Chinook salmon was observed in the lake and at the fry trap. Similar to fry trap results, we observed fewer juvenile Chinook salmon in 2002 than 2003 and they moved into the lake later in 2002. However, a large pulse of Chinook salmon was observed in late February 2002 at the fry trap but we did not detect it in the lake. Instead, we did not observe large numbers of Chinook salmon at the southernmost index sites until late April. Similarly, we did not observe a pulse of Chinook salmon in early February in 2004. In 2002 and 2004, juvenile Chinook salmon fry may have remained near the mouth of the river or perhaps they dispersed rapidly around the south end of the lake. Little is known about the movement patterns of Chinook salmon fry as they enter the lake.

CHAPTER 2. RESIDENCE TIME AND MOVEMENTS

Introduction and Methods

Little is known about the residence time and movement patterns of juvenile Chinook salmon in south Lake Washington. In 2003, we undertook a study to test the feasibility of conducting a mark-recapture study and collecting initial data on Chinook salmon movements. Preliminary testing of the marking technique was conducted on juvenile coho salmon at the USFWS Quilcene National Fish Hatchery in February 2004. We tested different methods of marking including syringes and needless injectors (Microjet and Panjet). Also the dye was placed in different locations of the fishes' body including the caudal fin, dorsal fin, and other locations. Overall, syringes appeared to provide the best mark. They took longer to apply than injectors but the mark was more visible. Placing the mark in the caudal peduncle area appeared to be the best location.

Collection of Chinook salmon in south Lake Washington was done with a beach seine on March 25 at two Gene Coulon Park sites: the swim beach and the north experimental site (Figure 8). We marked approximately 100 fish at each site. The caudal peduncle of each Chinook salmon was marked with a photonic dye that was injected with a syringe. The swim beach fish were dyed yellow and the north Gene Coulon fish were dyed red.

After release, locations of marked fish were determined through nighttime snorkeling. To maximize the number of fish observed over a large distance, we conducted nighttime snorkeling transects along one depth contour at 0.4 m. Except for a few inaccessible locations, we snorkeled the entire Gene Coulon Park, a shoreline length of approximately 1,700 m. The shoreline was divided in 100-m transects that were established in 2001 as part of our random transect survey to determine substrate use by Chinook salmon (Tabor and Piaskowski 2002). Residence-time snorkel surveys were conducted 1, 7, 15, and 21 days after marking. The location where each marked fish was found was flagged and the shoreline distance to the release site was determined. The number of unmarked Chinook salmon was also counted within each 100-m transect.

Results

A total of 210 juvenile Chinook salmon were marked and released on March 24. One hundred and eight were marked yellow (mean, 46.0 mm FL; range, 40-60 mm FL) and 102 were marked red (mean, 43.9 mm FL; range, 38-57 mm FL). A total of 113 marked Chinook salmon observations (65 yellow and 48 red) were made for the four snorkel surveys. Twenty-nine percent of the all marked fish released were observed one day after release. For both groups, the number of marked Chinook salmon we observed progressively declined from the first survey (1 day after release) to the fourth survey (day 21 after release) (Figure 9). For the four survey dates, 60 of the 113 (53%) total marked fish observations were made on March 25, one day after release.

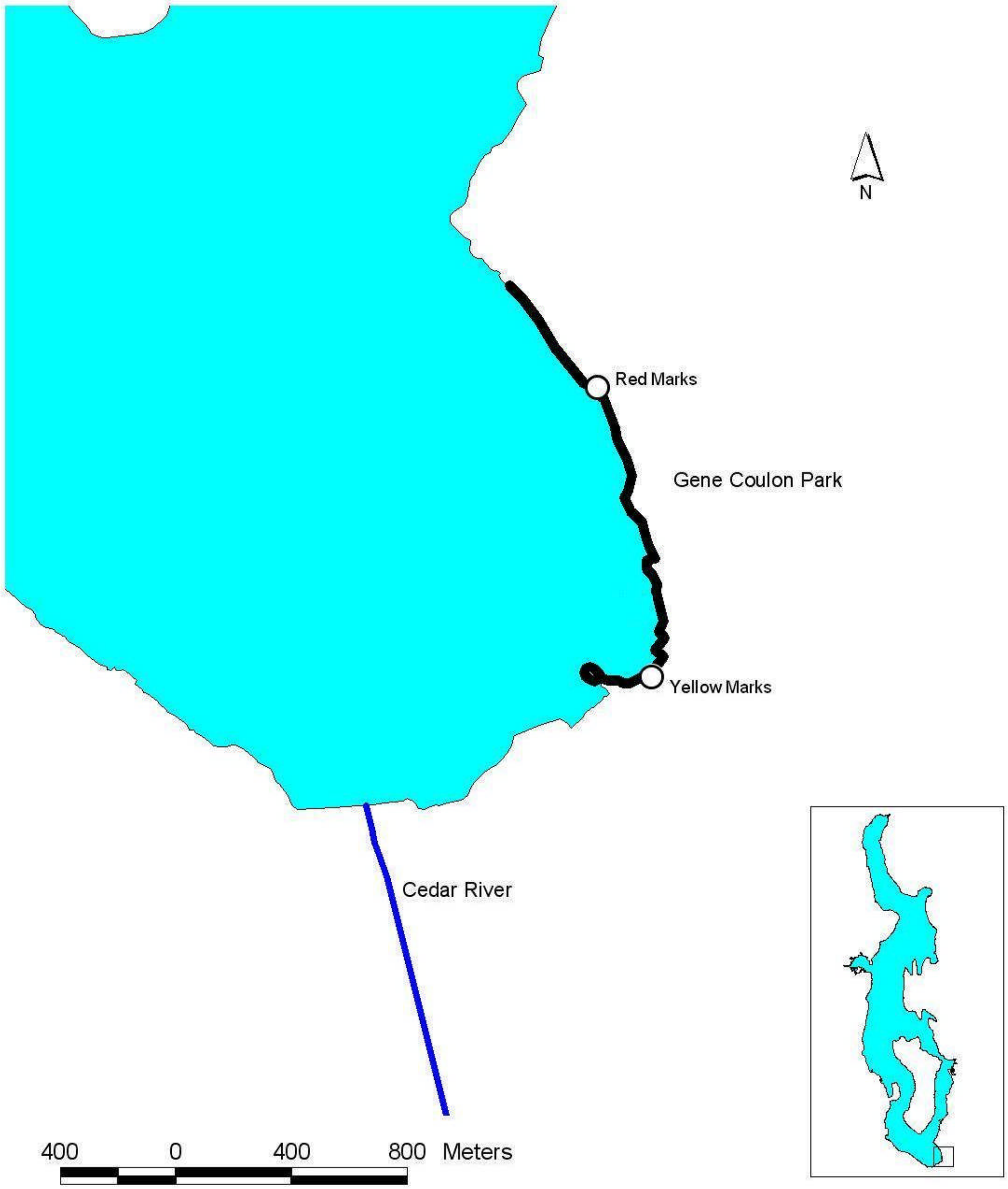


FIGURE 8.—Map of south Lake Washington displaying the shoreline of Gene Coulon Park surveyed (bolded line) to determine movements of juvenile Chinook salmon, March to April 2003. The release site (open circles) of each group of dye-marked fish is also shown.

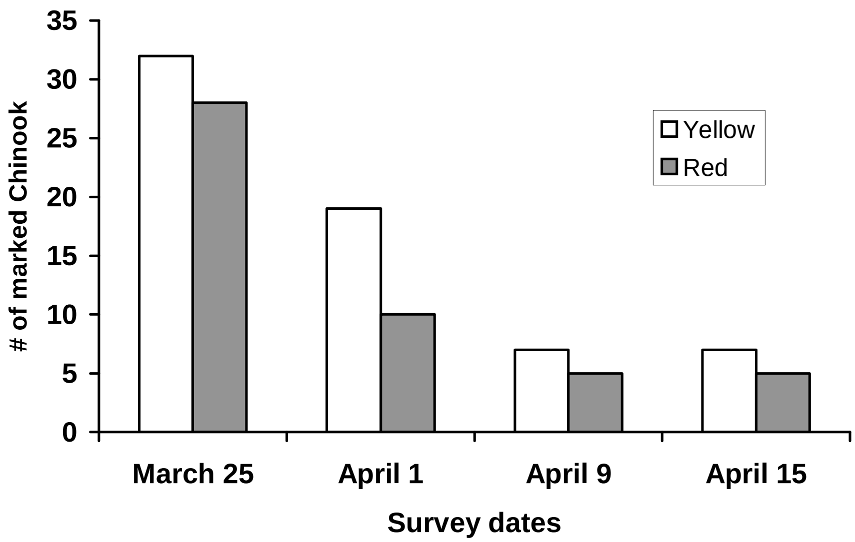


FIGURE 9. — Number of marked Chinook salmon observed 1, 7, 15, and 21 days after release (March 24), Gene Coulon Park, south Lake Washington, 2003. One hundred and eight yellow-marked fish were released at south part of the park and 102 red-marked fish were released at the north part of park.

Marked Chinook salmon that were observed after release did not move appreciably from the release site. All marked Chinook salmon we observed had moved less than 150 m from the release site (Figures 10, 11, and 12). Movement from the release site occurred both towards (south to southeast) and away (north to northeast) from the mouth of the Cedar River. However, slightly more fish appeared to move away from the Cedar River than towards the river (Figure 13). On all dates, the distance moved by fish that moved towards the Cedar River appeared to be similar to those that moved away from the river (Figure 13) except on day 1, when red-marked fish that moved away from the river had moved substantially further than those that had moved towards the river.

Unmarked Chinook salmon were observed along the entire shoreline surveyed. The total number of Chinook salmon we observed ranged from 3,424 on March 25 to 1,779 on April 9. Similar to earlier sampling in 2001, their abundance appeared to be related strongly to shoreline armoring (rip rap or bulkhead). In the seven transects that were mostly armored, the number of juvenile Chinook salmon was three times lower than in transects that had little or no armoring (Mann-Whitney U test = 9.0; P = 0.005). Additionally, large numbers of Chinook salmon were present on the boat ramps, as was observed in previous years.

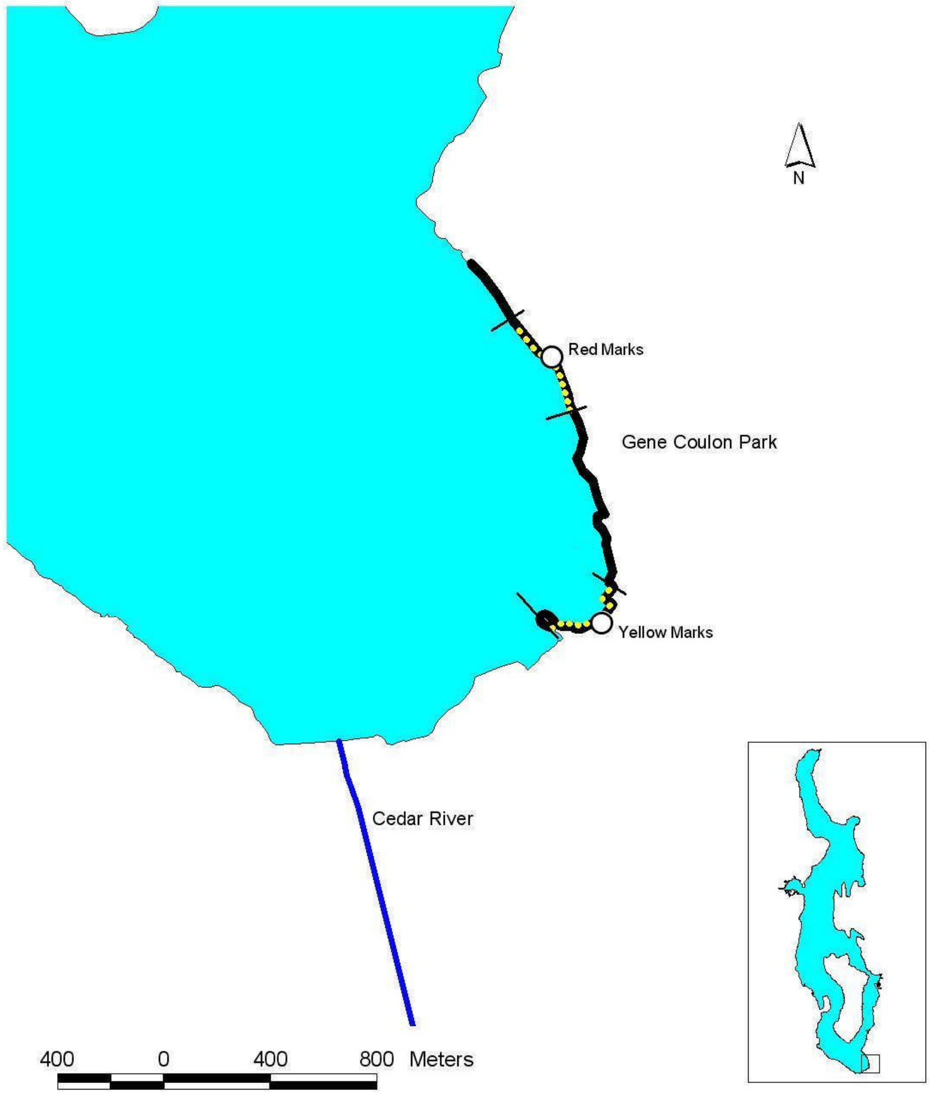


FIGURE 10—Map of south Lake Washington displaying the overall shoreline area (dashed lines) where marked Chinook salmon were found for each release group. The perpendicular lines to shore indicate the boundaries of the shoreline area where marked Chinook salmon were found. The bolded line is the shoreline area of Gene Coulon Park surveyed. The release site (open circles) of each group of dye-marked fish is also shown. Marked Juvenile Chinook salmon were released on March 24, 2003, and snorkel surveys were conducted 1, 7, 15, and 21 days after release.

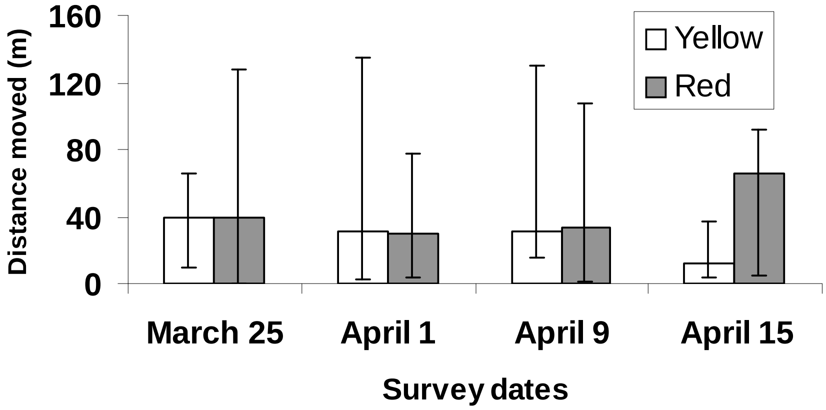


FIGURE 11. —Median distance (m, ± range) moved from release site of two groups of marked Chinook salmon, Gene Coulon Park, south Lake Washington, 2003. Fish were released on March 24. One hundred and eight yellow-marked fish were released at the south part of the park and 102 red-marked fish were released at the north part of park.

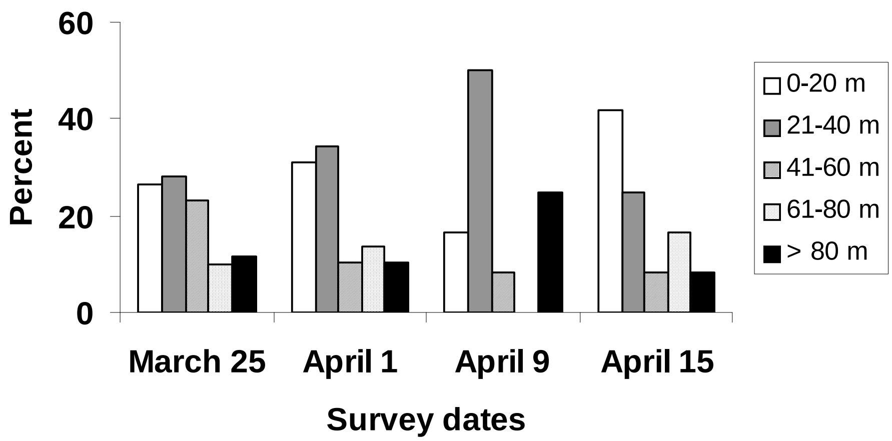


FIGURE 12. —Frequency of the distance moved (20-m increments) from the release site by marked Chinook salmon for each survey date, Gene Coulon Park, south Lake Washington, 2003. Fish were released on March 24. Data were combined from two release groups.

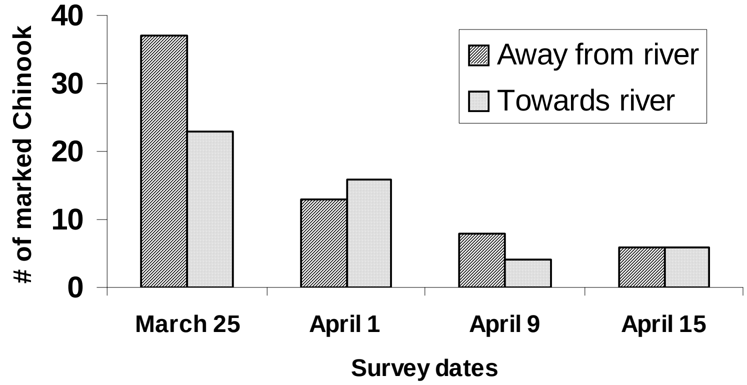


FIGURE 13. —Number of marked Chinook salmon in Gene Coulon Park (south Lake Washington) that moved away from and towards the mouth of the Cedar River, March-April 2003. Fish were released on March 24. Data were combined from two release groups.

Discussion

Results of the residence time investigation indicated many Chinook salmon remain in a small, localized area; however, it is possible other Chinook salmon moved outside our study area. Some of the marked Chinook salmon had moved over 80 m after 1 day and therefore, may have left the study area by the next survey, which was 6 days later. Because the median distance moved remained the same from day 1 to day 21 and the number of recaptures was greatly reduced, it would seem reasonable that some of the marked Chinook salmon remained close to the release site and another substantial portion of the marked fish moved a relatively long distance by moving outside the survey area. Results of index site surveys in February 2003 also indicate that some Chinook salmon are capable of moving a long distance in a relatively short period of time. For example, we observed Chinook salmon on Mercer Island as early as February 3 in 2004 and they were first captured in the Cedar River fry trap on January 18 and large numbers of fry were not observed at the trap until January 29 (Seiler at al. 2005b). Therefore, Chinook salmon fry appear capable of moving approximately 8.5 km (Cedar River trap to Mercer Island) in two weeks or less.

In general, the movement patterns of Chinook salmon in Lake Washington may be similar to patterns observed in other salmonids and other fishes. Fausch and Young (1995) reviewed several studies of fish movements in streams and concluded that often a large percentage of the fish population is resident but a substantial percentage move a considerable distance. The authors suggested that often these long distance movements are not known unless some type of radio telemetry project is undertaken. In Lake Washington, detecting long distance movements of juvenile Chinook salmon in February through April would be difficult because the fish are too small for radio tags.

Use of marked fish and snorkel surveys appeared to be an effective method to determine residence time, but to accurately determine the overall movement and residence time of juvenile Chinook salmon, a larger, more involved study is needed. Marking more fish would increase the probability of observing marked fish at locations that are a fair distance from the release site. Probably 1,000 to 2,000 fish would need to be marked to effectively estimate movement patterns. Enlarging the survey area would help determine if some fish are moving long distances. Besides increasing the number marked and enlarging the survey area, additional work needs to be done on the marking technique. We did observe a few marked Chinook salmon that appeared to have some type of injury in the caudal peduncle due to the marking process. Further testing of the location of the mark, type of mark, and marking instrument needs to be conducted.

CHAPTER 3. RESTORATION SITES

Introduction and Methods

We continued to monitor restoration sites in 2003 and 2004. A total of five locations were surveyed: Seward Park (Figure 14), Martha Washington Park, Beer Sheva Park, Rainier Beach Lake Park and Marina, and the old Shuffleton Power Plant Outflow (Figure 15). Except for one site in Seward Park, surveys were conducted to collect pre-project baseline information. The only restoration project that has been undertaken thus far was a substrate replacement project in Seward Park.

Seward Park. In December 2001, the City of Seattle and the Army Corps of Engineers (ACOE) deposited 2,000 tons of gravel along a 300-m shoreline section in the northeast part of the park. This shoreline section was divided into two equal sections. The north section (site 3b) received fine substrate and the south section (site 3a) received coarse substrate. The general size composition of the substrate was 0.5 to 5.0 cm for the north section and 2.5 to 15 cm for the south section. The new substrate extended out approximately 5 m from shore.

Pre-project snorkel surveys were conducted in 2001 and post-project surveys were initially conducted in 2002. Results from 2002 indicated that few Chinook salmon were present in Seward Park sites and no increase in the use of the restored site was observed. Surveys were conducted in 2003 and 2004 to continue monitoring of the restoration site and determine if the use of the restoration site may have been somewhat reduced in 2002 because of cool water temperatures, which may have limited Chinook salmon movements to northerly locations such as Seward Park. Also, Chinook salmon may have avoided the restoration site because of low prey abundance associated with the new, clean substrates.

Similarly to 2001 and 2002, snorkel surveys in 2003 were conducted at the restoration site as well as five additional sites in Seward Park (Figure 14). The additional sites served as controls and enabled us to make between-year comparisons of the restoration site. Also, the other five sites are potential restorations sites and the survey data could serve as baseline information. The restoration site and the five control sites were the same sites used in 2000 by Paron and Nelson (2001) to assess the potential for bank rehabilitation projects in Seward Park.

In 2003, we continued nighttime snorkeling surveys of the six sites in Seward Park. A total of nine night snorkeling surveys were completed on an approximate biweekly schedule from 19 February through 30 June. Survey protocols in 2003 were the same as restoration project monitoring survey methods used in 2001 and 2002 (Tabor and Piaskowski 2002; Tabor et al. 2004b). Surveys were conducted at a depth contour of 0.4 m water depth.

In addition to the six sites surveyed in 2000 to 2003, two supplemental sites (S-1 and S2) were also surveyed in 2003. We expected the abundance of Chinook salmon at site S-1 would be the highest of any site in Seward Park from February to May because the site had high quality habitat (gradual sloping beach with sand substrate) and was the closest to the Cedar River of any site in Seward Park. Thus, this site should indicate the maximum number of Chinook salmon that would be possible at any restoration site in Seward Park. Site S-1 was surveyed five times from April 7 to June 10. The other transect (S-2) was located in the southeast corner of the park and was identified by park managers as a potential site for a substrate replacement project. Site S-2 was surveyed seven times from March 26 to June 30. Snorkeling procedures of the supplemental transects were the same as the other transects.

Surveys of Seward Park sites were also conducted in 2004; however, only four sites were surveyed (sites 1, 3, 5, and S-1) and they were only surveyed once a month from February to June.

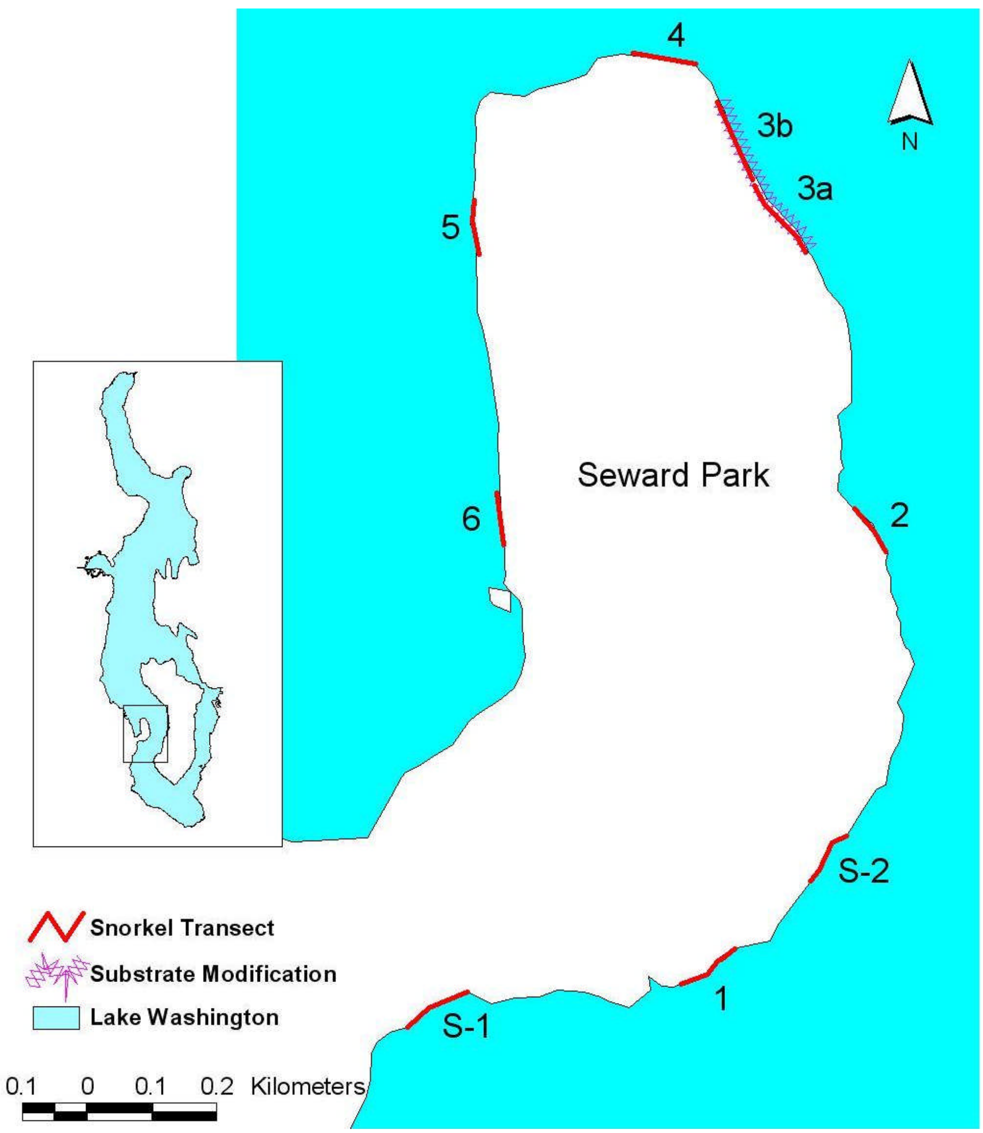


FIGURE 14.—Location of snorkel transects in Seward Park, Lake Washington, March to July, 2002. Sites 3a and 3b are the completed restoration site, a substrate modification project finished in December 2001. Sites 1 through 6 are the original sites used in 2000 to 2003. Sites S-1 and S-2 are supplemental sites surveyed in 2003. In 2004, only sites 1, 3a, 3b, 5, and S-1 were surveyed.

Beer Sheva Park.—At Beer Sheva Park, the City of Seattle has proposed to daylight the mouth and lower 100 m of Mapes Creek, which currently is in a culvert and enters the lake a few meters below the lake surface. We continued our monitoring of Beer Sheva Park in 2003 to provide an estimate of the temporal abundance of juvenile Chinook salmon in the vicinity of Mapes Creek. Only the boat ramp area was surveyed in 2003. Results from 2001 and 2002 indicated that most of the Chinook salmon were present on the boat ramps and few were present in other park locations where fine soft sediments (silt/mud) predominate. The boat ramp site was 65 m long, which included four boat ramps totaling 42 m and a 23-m shoreline section at the south end of the boat ramps. The average distance from the shore to one-meter depth was 6.9 m. Eight night snorkeling surveys were conducted from February to June. Beer Sheva Park was not surveyed in 2004.

Martha Washington Park.—Martha Washington Park was surveyed in 2002 and 2003 to provide the City of Seattle with baseline information on Chinook salmon abundance. We surveyed one 80-m long shoreline transect from March to May. Substrate was composed predominately of boulders and cobble with some gravel. Riprap was present along the entire shoreline except for two small coves that were each about 6 m long. Within the small coves, small gravel was the predominant substrate type. All surveys were conducted at night. Snorkelers swam close to the shore along the 0.4-m depth contour. Because of the steep slope, we were able to survey from 0.0- to approximately 0.9-m depth. In October 2003, the Seattle Parks and Recreation undertook a restoration project at Martha Washington Park; 61 m of shoreline in the south part of the park was restored by removing riprap and adding gravel and LWD. No post-project monitoring of this site was conducted in 2004.

Rainier Beach Lake Park and Marina.—The Seattle Parks and Recreation owned a small, old marina at the south end of Rainier Beach. The marina was removed in 2004 and modifications to the shoreline to improve habitat conditions for juvenile Chinook salmon began in summer 2005. We began snorkel surveys of the marina in 2003 to provide the city with baseline information on Chinook salmon abundance. Baseline surveys were also conducted in 2004. The Rainer Beach site was separated into two transects: a 100-m transect within the marina and an adjacent undeveloped shoreline transect (150 m long) south of the marina. The shoreline of the marina transect consisted mostly of riprap and bulkhead. The substrate of the undeveloped shoreline transect was mostly small gravel; however, the southernmost 20 m was riprap (because no Chinook salmon were observed in the riprap and it did not represent an undeveloped shoreline, it was not included in the final calculations of abundance). The shoreline was vegetated with various trees and shrubs; however, there was little vegetation that provided overhead cover. A depth contour of 0.4 m was used for both transects. In 2003, night snorkeling surveys were conducted on four dates from March to May. In 2004, surveys were conducted once a month from February to June.

Shuffleton Power Plant Outflow.—The City of Renton has proposed to build a trail between Gene Coulon Park and the Cedar River Trail Park. Part of the project includes restoring a shoreline section that is currently a steel wall that is part of the old Shuffleton Power Plant outflow channel. Because the power plant has been demolished, the outflow channel is no longer needed. Proposed restoration work includes removing the steel wall and replacing it with a more natural shoreline that could improve fish habitat conditions. Snorkel surveys of the proposed restoration site were conducted in 2003 to provide the City of Renton with baseline information on Chinook salmon abundance. This restoration site area was divided into two transects: one transect along a steel wall for approximately 200 m and another transect along an adjacent sandy beach cove (approximately 70 m long). The cove is located south of the west end of the steel wall. Night snorkeling was conducted proximal to the wall. The sandy beach transect depth contour was 0.4 m. The site was only snorkeled on 2 nights in 2003: April 8 and May 6.

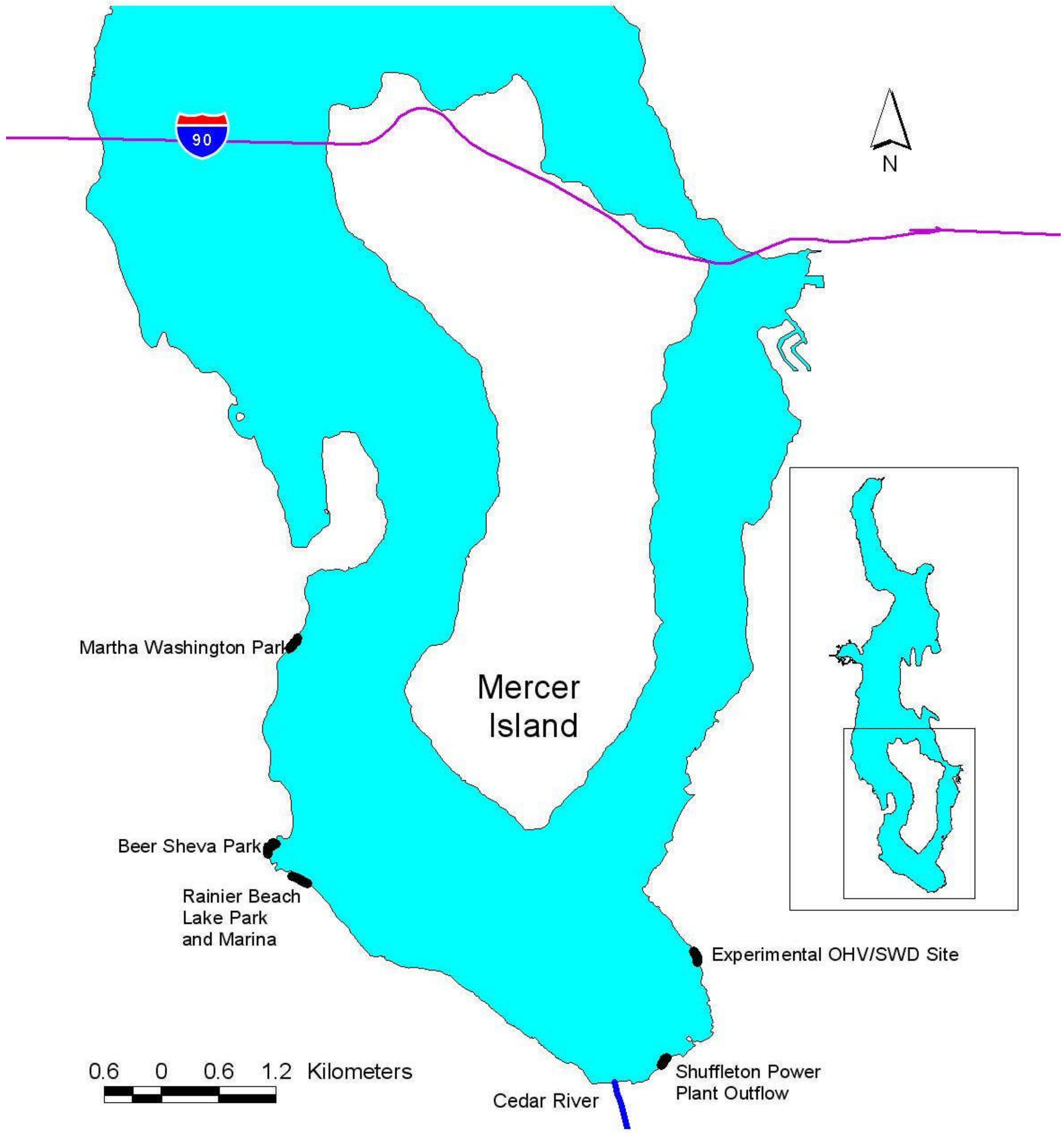


FIGURE 15.—Map of south Lake Washington displaying restoration monitoring sites (Martha Washington Park, Beer Sheva Park, Rainier Beach Lake Park and Marina, and Shuffleton Power Plant Outflow), and the experimental overhanging vegetation (OHV) and small woody debris (SWD) site (Chapter 7).

Results

Seward Park, 2003.—In 2003, all six Seward Park sites were surveyed nine times between February 19 and June 30. Combined, 171 juvenile Chinook salmon were observed; over 45% (n = 79) were found at the west sites (sites 5 and 6). With the exception of May 22, the west sites had the highest number of juveniles per 100 m on all survey dates (Figure 16). Of the 79 Chinook salmon observed in the west sites, 59 were present at site 5. A comparison between 2001, 2002 and 2003 for the months of April, May, and June indicated the overall abundance of Chinook salmon was similar in 2001 and 2003 (except June) but the abundance in 2002 was substantially lower (Figure 17).

A total of 38 juvenile Chinook salmon (9 at site 3a and 29 at 3b) were observed at the restoration site in 2003. Chinook salmon were observed at site 3b (small substrate) on each survey in 2003 except June 30; although, on three dates only one Chinook salmon was observed. At site 3a (large substrate), Chinook salmon were only observed on four of nine survey dates and most Chinook salmon (78%) were observed on the last three surveys which were after mid-May. Although Chinook salmon abundance was low throughout 2003, there was a significantly more Chinook salmon at site 3b (small substrate) than at site 3a (large substrate) (Wilcoxon sign rank test; $Z = 2.4$; $P = 0.019$).

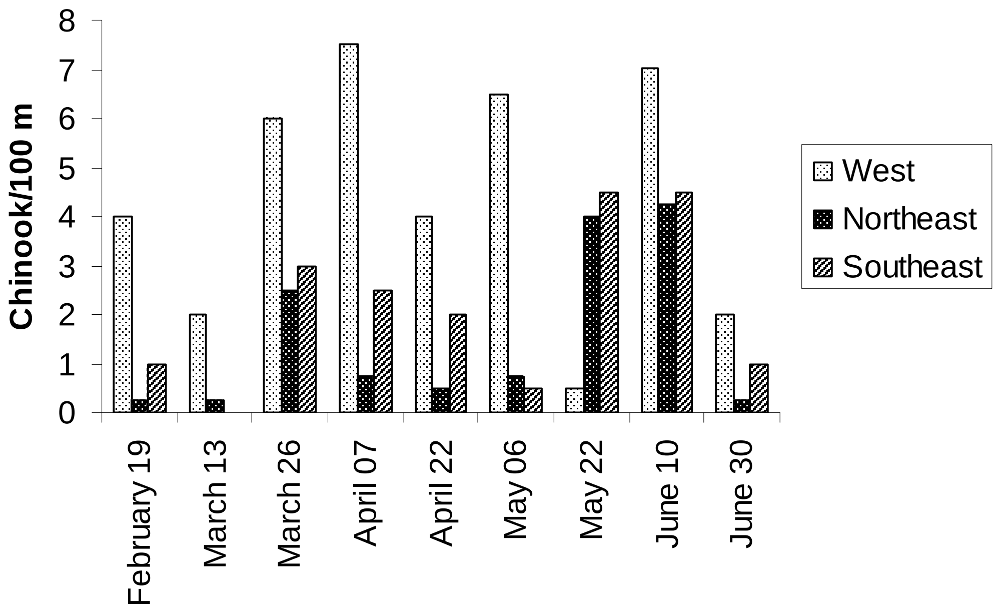


FIGURE 16. — Number of juvenile Chinook salmon (number/100 m) observed at night along three shoreline areas of Seward Park, south Lake Washington, 2003.

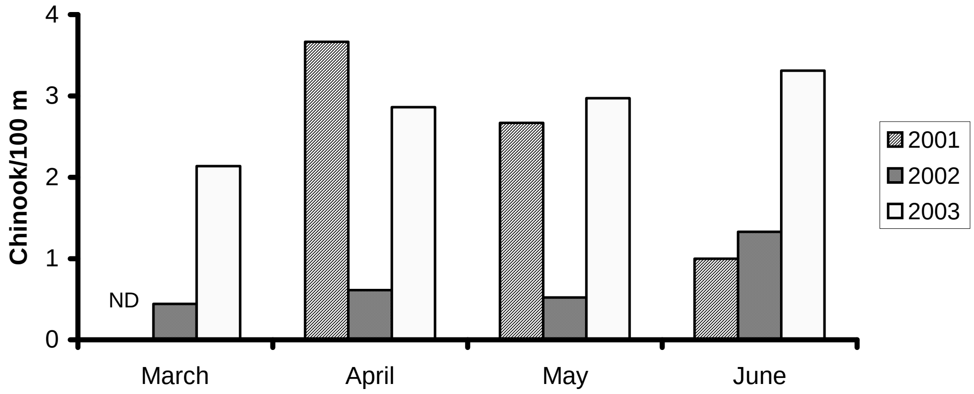


FIGURE 17. —Monthly abundance (mean number per 100 m of shoreline) of juvenile Chinook salmon observed during night snorkel surveys of six shoreline sites in Seward Park, south Lake Washington, 2001-2003. ND = no data.

At site 3b (small substrate), there appeared to be a slight increase in Chinook salmon abundance in 2003 from the pre-project abundance; however, at site 3a (large substrate) the abundance appeared to be reduced (Figure 18). The ratio of Chinook salmon at site 3 to the other sites combined was 0.46:1 in 2001; therefore the expected mean abundance of Chinook salmon at site 3 in 2003 would be 1.5 Chinook salmon/100 m of shoreline (mean abundance of the other sites 1,2,4,5,6 was 3.4 Chinook salmon/100 m of shoreline). The observed abundance in 2003 was 0.8 in site 3a (large substrate) and 2.1 Chinook salmon/100 m of shoreline in site 3b (small substrate). No increase in abundance at either site 3a (expected 0.4; observed 0.2 Chinook/100m of shoreline) or site 3b (expected 0.4; observed 0.3 Chinook/100m of shoreline) was observed in 2002.

During the first three surveys of supplemental site S-1 in 2003 (April 7 through May 6), a total of 76 Chinook salmon were observed and their abundance was higher on each date than any other site in Seward Park. On two of these three surveys, more Chinook salmon were observed at site S-1 than the other sites combined. Only six Chinook salmon were observed at site S-1 during the last two surveys in 2003 (May 22 and June 10) and their abundance was similar to other sites in Seward Park.

The high abundance of Chinook salmon at site S-1 is likely due to better habitat conditions, specifically the sand substrate and gradual slope and the site is closer to the Cedar River than other Seward Park sites. The abundance at S-1 was also substantially higher than the Seward Park beach index site (Figure 2)(mean abundance April 7-May 12, 2003, site S-1, 19.5 fish/100 m, index site, 7.1 fish/100 m), which has similar habitat conditions but is approximately 3.7 km further away from the Cedar River than site S-1.

A total of 23 Chinook salmon were observed at site S-2 during seven surveys in 2003 (March 26 to June 30). In general, abundance of Chinook salmon was similar to that of site 1 which was close by and had similar habitat conditions.

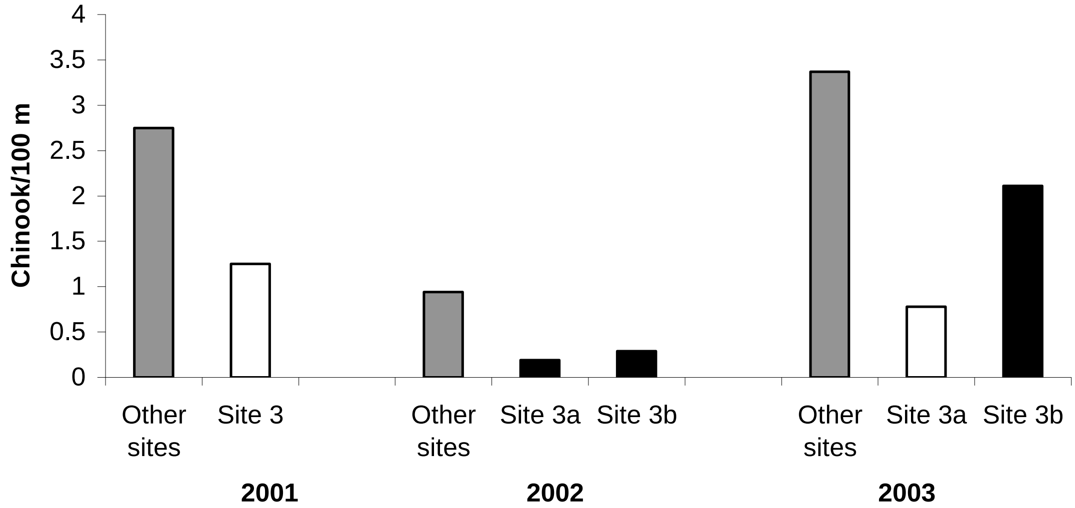


FIGURE 18. —Mean abundance (number observed per 100 m of shoreline) of juvenile Chinook salmon at the restoration site (open bars, site 3) and other sites (shaded bars, sites 1,2,4,5,6 combined) in Seward Park, south Lake Washington, April–June 2001-2003. Site 3 is located on the northeast side of Seward Park. Site 3a is the southern section of site 3 that received large gravel and cobble while site 3b is the northern section that received small gravel.

Seward Park, 2004. –From February to April, no Chinook salmon were observed at any of the five sites (1,3a, 3b, 5, S-1) surveyed in Seward Park in 2004. In contrast, large numbers of Chinook salmon were observed at most of these sites in May and June (Figure 19). More Chinook salmon were observed at site 1 than the other three sites combined. On both May 11 and June 4, 37 Chinook salmon were observed. Prior to 2004, the highest number of Chinook salmon observed in May or June at site 1 was 9 fish and at all sites the highest number was 13 fish. At the restoration site (sites 3a and 3b), no Chinook salmon were observed throughout the study period.

Beer Sheva Park, 2003.–Eight night snorkeling surveys were conducted at Beer Sheva Park (boat ramp transect only) from February 19 to June 30. Chinook salmon were observed on each survey date (Figure 20). Similar to 2002, the highest abundance occurred in May. The mean abundance (March-June) of Chinook salmon was substantially higher in 2003 (51 fish/100 m) than 2002 (33 fish/100 m) but differences were not significant (Wilcoxon sign rank test; Z = 1.2; P = 0.25).

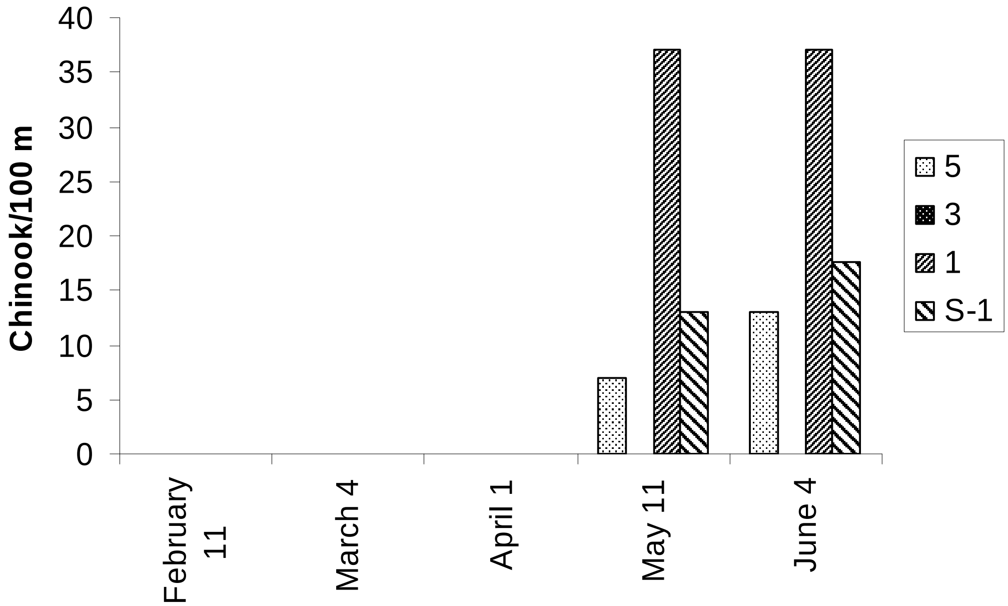


FIGURE 19. —Number of juvenile Chinook salmon (number/100 m) observed at night at four sites (shoreline transects) of Seward Park, south Lake Washington, 2004. Site 3 is the restoration site and includes two transects; site 3a (large substrate) and 3b (small substrate).

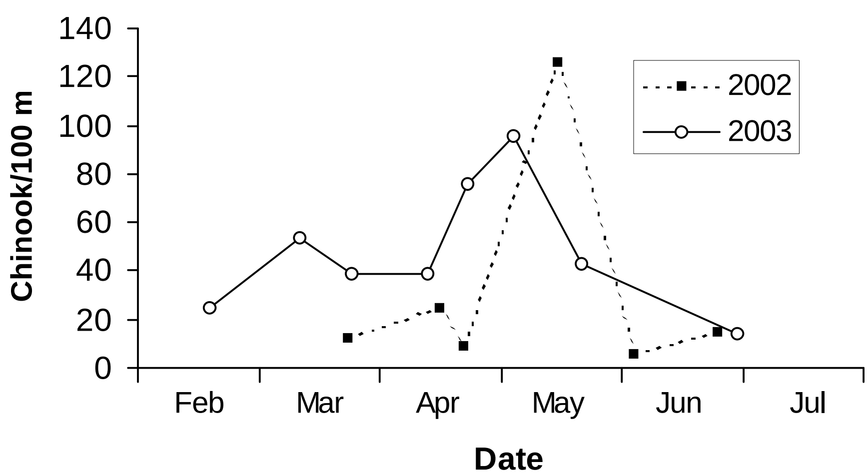


FIGURE 20. —Abundance (number observed per 100 m of shoreline) of juvenile Chinook salmon observed along the Beer Sheva Park boat ramp transect, south Lake Washington, 2002 and 2003.

Martha Washington Park, 2003. —In 2003, a total of 40 juvenile Chinook salmon were observed along the 80-m-long transect during four night snorkeling surveys. In contrast, only two Chinook salmon were observed during three surveys of the same transect in 2002. This transect was surveyed from March to early May in both years.

Rainier Beach Lake Park and Marina, 2003. —Four night snorkeling surveys were conducted at the Rainier Beach site from March to May 2003. On all survey dates, the abundance of juvenile Chinook salmon at the undeveloped transect exceeded that of the developed marina transect (Figure 21). On average, their abundance was four times higher on the undeveloped transect than on the marina transect. The mean number observed was 85 Chinook salmon (65 fish/100 m shoreline) on the undeveloped transect and 20 Chinook salmon (20 fish/100 m shoreline) on the marina transect.

Rainier Beach Lake Park and Marina, 2004. —Five night snorkeling surveys were conducted at the Rainier Beach site from February to June 2004. Substantially fewer Chinook salmon were observed at the Rainier Beach Lake Park and Marina site in 2004 (Figure 22). In 2003, a total of 420 Chinook salmon were observed; whereas in 2004, only 57 were observed. In 2003, the number of early migrants from the Cedar River was 195,000 (Seiler et al 2005a), whereas in 2004 it was 67,000 (Seiler et al 2005b). In both years, the highest number of Chinook salmon at the Rainier Beach Lake Park and Marina site was observed in March; in 2003, 146 Chinook salmon were observed along the undeveloped shoreline and in 2004, 32 were observed. Similar to 2003, most Chinook salmon in 2004 were along the undeveloped shoreline transect.

Shuffleton Power Plant Outflow, 2003. —Two night snorkeling surveys were conducted at the Shuffleton Power Plant Outflow in 2003. On both surveys, the abundance of juvenile Chinook salmon was substantially higher at the sandy beach transect than along the steel wall (Figure 23). Because of the gradual slope of the sandy beach area, we only surveyed a part of the nearshore habitat while we were able to survey the entire nearshore area of the steel wall because of its 90^{o} slope and depth. Therefore, the difference in abundance between the two transects is probably greater than shown in Figure 23.

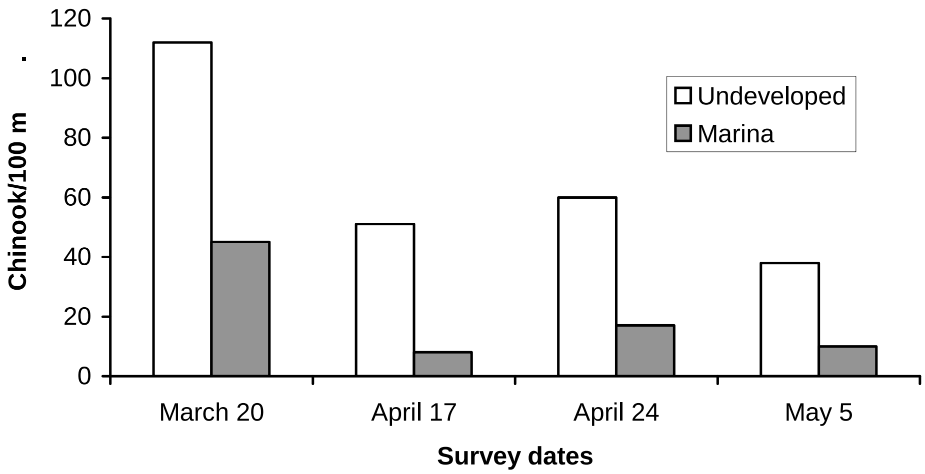


FIGURE 21. —Juvenile Chinook salmon abundance (number/100 m of shoreline) at two adjacent shoreline transects (undeveloped and marina shoreline) at the Rainier Beach Lake Park and Marina, March-May 2003, south Lake Washington.

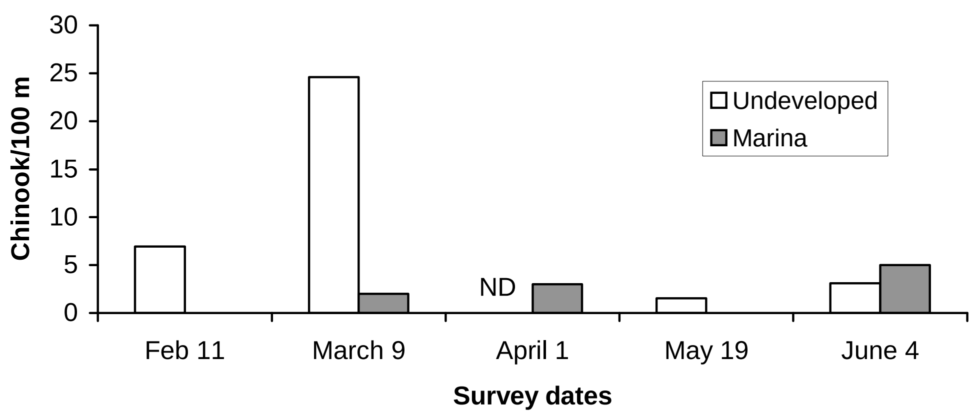


FIGURE 22. —Juvenile Chinook salmon abundance (number/100 m of shoreline) at two adjacent shoreline transects (undeveloped and marina shoreline) at the Rainier Beach Lake Park and Marina, February to June 2004, south Lake Washington. ND = No data

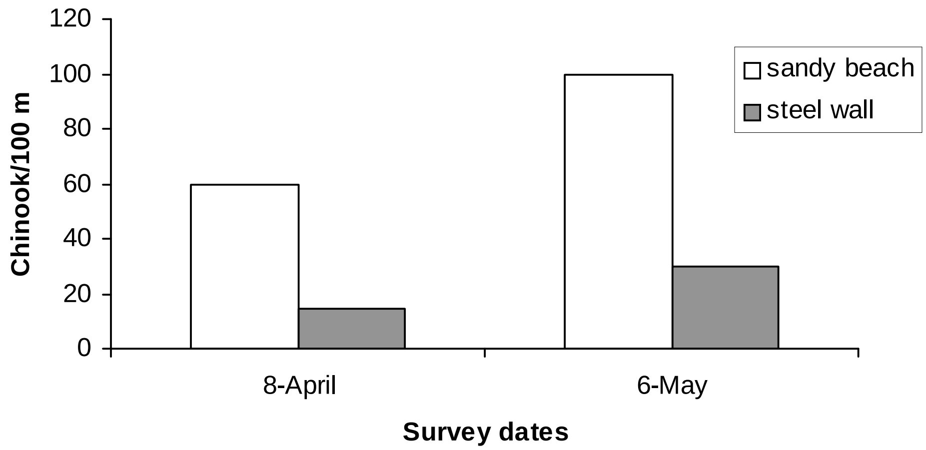


FIGURE 23. —Juvenile Chinook salmon abundance (number/100 m shoreline) at the Shuffleton Power Plant Outflow (steel wall) and an adjacent sandy beach area, south Lake Washington (2003).

Discussion

We surveyed a variety of potential restoration sites in 2003. Because juvenile Chinook salmon are concentrated in the south end of the lake, restoration projects in that area would most likely be more beneficial than those in other areas of the lake. The Shuffleton Power Plant Outflow is much closer to the mouth of the Cedar River than the other sites and thus would probably be a better site for a restoration project. The habitat at this site is highly degraded; there is little shallow water habitat or riparian vegetation due to the steel wall. Both Beer Sheva Park and Rainier Beach Lake Park are relatively close to the mouth of the Cedar River and good numbers of Chinook salmon appear to be present and thus these sites would be good restoration sites. Chinook salmon were abundant at the Beer Sheva Park boat ramps in 2002 and 2003 and therefore, there should be several juvenile Chinook salmon in the area to use the mouth of Mapes Creek if it is daylighted. The undeveloped section of Rainier Beach Lake Park appeared to have good quality habitat due to its small gravel substrate and gentle slope. This site could be improved, however, with some additional shoreline vegetation (e.g., willows *Salix* spp.) to provide overhead cover as well as small woody debris for structural complexity. Certainly, the marina shoreline could be improved with the removal of the armoring and replacing it with small substrates and some riparian vegetation on a gentle sloping bank.

Seward Park has been surveyed for the past five years (2000 by USACOE and 2001-2004 by USFWS) and during that period the nearshore abundance of juvenile Chinook salmon has been relatively low at all six sites. Even at the best location in Seward Park (supplemental site S-1 in the southwest corner of other park), the abundance of Chinook salmon in 2003 was 1.4 to 6 times lower than the undeveloped restoration transect at the Rainier Beach Lake Park. Restoration projects in Seward Park will have a positive effect on Chinook salmon habitat but the effect will most likely be small.

CHAPTER 4. DEPTH SELECTION

Introduction

Detailed information on the water depth of the lake where juvenile Chinook salmon are located has not been available. Preliminary work conducted in 2001 consisted of one nighttime scuba survey and a few visual daytime observations in May and June (Tabor and Piaskowski 2002). In 2004, we examined the water column depths used by juvenile Chinook salmon during day and night. At night, we could survey Chinook salmon by snorkeling/scuba diving because the surveyor can get close enough to the fish to accurately measure the fishes' depth. During the day, juvenile Chinook salmon are difficult to survey because they avoid snorkelers/scuba divers, especially after March. Other techniques that could be used during the day, such as vertical gill nets, pop-up nets, or hydroacoustics are either very harmful to the fish, are labor intensive, or are ineffective during some part of the sampling period (February to June). One technique that appeared to be consistent throughout the sampling period (February to June) and was unobtrusive to Chinook salmon was visual surface observations. When the water is calm in the early morning, Chinook salmon can be observed feeding at the surface. Chinook salmon appear to feed extensively on surface prey such as chironomid pupae and adults (Koehler 2000). Also, Chinook salmon are concentrated in the south end of Lake Washington and are the most abundant fish species present in many areas. Therefore, we felt it was a reasonable assumption that the vast majority of surface feeding would be Chinook salmon. Also, we assumed that the number of feeding events at the surface was related to Chinook salmon abundance. The water column depth (surface to bottom) where Chinook salmon were located was estimated by determining the location of feeding fish.

Methods

Visual surface observations were conducted in south Lake Washington at the swim beach in Gene Coulon Park (Figure 2). Observations were only conducted at dawn. The evening before observations were conducted buoy lines were laid out to delineate depth contours (0.5-, 1-, 2-, 3-, 4-, and 5-m depth). The lines were laid out parallel to shore and each line was 20 m long. The next morning, if the water was calm, visual observations were conducted. The observer counted the number of times a Chinook salmon surfaced between the depth contours. Observations were made from shore for 15 minutes. Surveys were conducted approximately once every 2 weeks; however, some surveys had to be moved to the next week because of weather conditions. We used results of index snorkel surveys at the swim beach to determine the abundance of Chinook salmon in relation to other fish species. Because the depth categories had different areas, we used Chesson's selectivity index to make comparisons (Chesson 1978).

At night, Chinook salmon are inactive, appear to be resting near the bottom, and can be easily approached. Therefore, we used snorkeling/scuba diving transects to measure their depth distribution at night. A series of transects were conducted at night that were each perpendicular to shore. The depth from 0 to 1 m was surveyed by a snorkeler and the depth from 1 to 3 m was surveyed by a scuba diver. Each time a Chinook salmon was located, a weighted flag was placed at that location. After the snorkeling and scuba diving were completed, each weighted flag was retrieved and the water column depth was measured. Nighttime surveys were conducted once a month from March to May in the north part of Gene Coulon Park. At this location the distance from shore to 3-m depth was approximately 14 m. Water depths where Chinook salmon were located were compared between months with an ANOVA and Fisher's LSD test. Beach seining was also conducted shortly after each survey to collect information on the sizes of Chinook salmon.

Results

From February 19 to April 14, all surface activity at dawn was observed in the shallowest section (0 and 0.5 m deep; Figure 24). Feeding activity was observed in deeper and deeper sections from April 27 to June 2. By the last date, June 2, feeding activity was observed primarily between 2 and 3 m, and some between 3 and 4 m, but little between 4 and 5 m. Results of Chesson's selectivity index (α) indicated the same trend (Figure 25).

We assumed that that the vast majority of surface feeding was Chinook salmon. From February 24 to April 13, approximately 70% of the salmonids observed at Gene Coulon swim beach during night snorkeling (index site surveys) were Chinook salmon. The rest were almost all sockeye salmon fry, which were considerably smaller than Chinook salmon. Sockeye salmon appeared to feed somewhat at the surface but their feeding activity was barely noticeable and was not counted. From April 26 to June 7, 65% of the salmonids were sockeye salmon and 35% were Chinook salmon. Therefore some of the feeding activity may have been due to sockeye salmon, which were considerably smaller and closer to shore than Chinook salmon. Based on the size of the fish we observed feeding at the surface, we felt most of the feeding activity was from Chinook salmon. In some cases, fish were observed jumping completely out of the water and all of these fish appeared to be Chinook salmon. Threespine stickleback (*Gasterosteus aculeatus*) and prickly sculpin (*Cottus asper*) were also common throughout the study period but it is doubtful if they were feeding at the surface to any significant degree.

Nighttime water column depths were measured for a total of 117 juvenile Chinook salmon (March 10, n = 31; April 7, n = 40; May 12, n = 46). Snorkel surveys indicated the same general pattern as dawn visual observations. In February, the mean nighttime depth was only 0.2 m (range, 0.12 to 0.48 m). In April and May, Chinook salmon progressively used deeper waters; however, none were ever observed between 1 and 3 m deep. Water column depths were significantly different between each monthly sample (Figure 26; ANOVA and Fisher's LSD; $P < 0.001$).

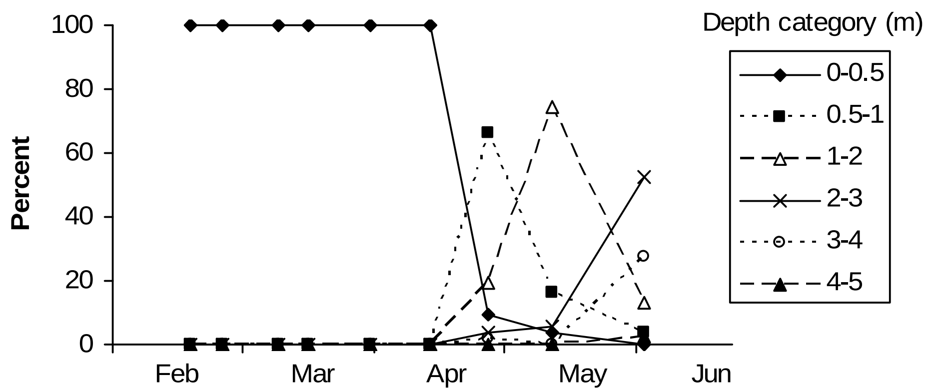


FIGURE 24. —Percent of surface activity observed within six depth categories (m) at Gene Coulon Park, Lake Washington, 2004. Observations were made from shore at dawn.

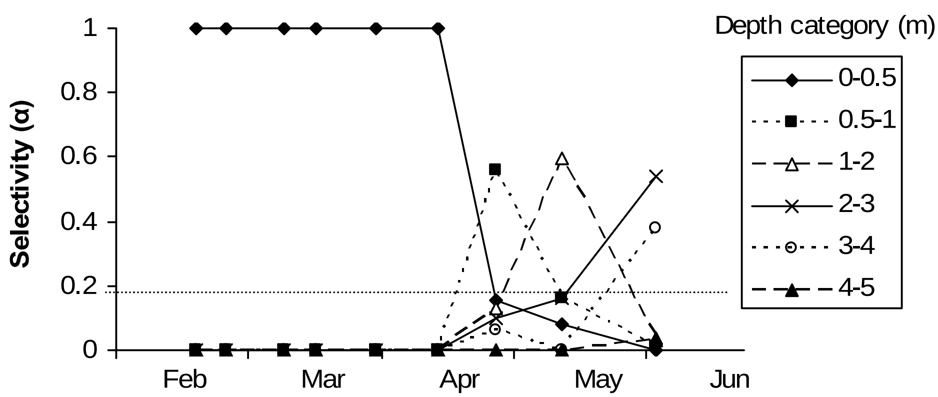


FIGURE 25. —Selectivity values (Chesson's α) of surface activity within six depth categories (m), Gene Coulon Park, Lake Washington, 2004. Observations were made from shore at dawn. The dashed line indicates the level of selectivity if all depth categories were used at random.

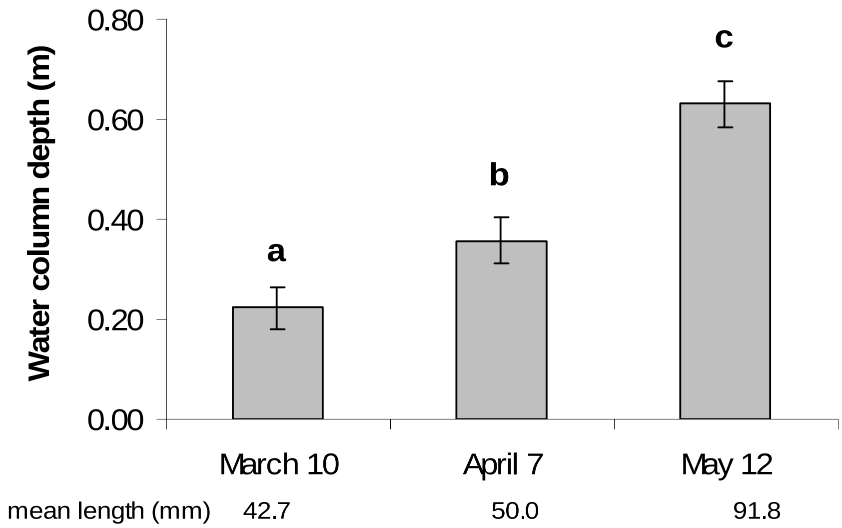


FIGURE 26. —Nighttime water column depth (mean ± 2SE) of juvenile Chinook salmon in Gene Coulon Park, Lake Washington, 2004. Bars with different letters are significantly different (ANOVA and Fisher's LSD; $P < 0.001$). The mean length of Chinook salmon on each date is also given. Data were collected along perpendicular snorkeling/scuba diving transects between 0- and 3-m deep.

Discussion

Observations of both day and night depth distribution clearly showed that juvenile Chinook salmon progressively shift to deeper waters as they grow. Juvenile Chinook salmon in riverine environments have also been shown to inhabit deeper waters as they increase in size (Lister and Genoe 1970; Allen 2000; R. Peters, USFWS, unpublished data). The same general pattern has been shown in several other fish species including salmonids as well as non-salmonids. McIvor and Odum (1988) and Ruiz et al. (1993) demonstrated that predation risk for juvenile fish decreases in shallow water. Power (1987) suggested small juvenile fish inhabit very shallow water because they are especially vulnerable to piscivorous fishes and less vulnerable to wading birds because juvenile fish are very small. As juvenile fish grow they shift to deeper waters because they are less vulnerable to fish and more vulnerable to wading birds. In Lake Washington, small juvenile Chinook salmon may be in shallow water to avoid cutthroat trout (*O. clarki*) and prickly sculpin which are important predators in the littoral zone (Nowak et al. 2004; Tabor et al. 2004a). When they increase in size they may become more attractive to wading birds such as great blue herons (*Ardea herodias*) but less vulnerable to piscivorous fishes.

The last survey (June 2) indicated some juvenile Chinook salmon had moved into water that was 4-5 m deep but no feeding activity was observed in deeper waters. Recent results of ultrasonic tracking at Gene Coulon swim beach (May 24 to June 5, 2004) indicated some Chinook salmon may be in water > 7 m deep (M. Celedonia, USFWS, unpublished data). However, only fish greater than 100 mm FL were tagged. Fresh (2000) also found that Chinook salmon are further offshore in the upper pelagic area after mid-May. Thus our results may reflect the water column depth for the portion of the population that still inhabits the nearshore area and could be a gross underestimate for the entire population. Chinook salmon that are further offshore may be difficult to observe because they may be spread out over a large area. Also, their surface activity may be reduced because the abundance of surface prey may be lower at offshore areas and Chinook salmon often switch to feeding on *Daphnia* (Koehler 2002) as the season progresses. After mid-May, the use of visual observations to determine the location of Chinook salmon may be problematic.

CHAPTER 5. FEEDING AT TRIBUTARY MOUTHS

Introduction

Little is known about the importance of nonnatal tributaries for juvenile Chinook salmon. The lower sections of many small tributaries to Lake Washington are in culverts and enter the lake several meters below the lake surface and thus, are of little value to juvenile Chinook salmon which inhabit shallow nearshore areas of the lake. Restoring these streams to their natural location may provide additional habitat. In 2002, we surveyed 17 tributaries of Lake Washington and Lake Sammamish (Tabor et al. 2004b). Results indicated that Chinook salmon can often be quite abundant at the mouths of tributaries. Additionally, K. Fresh (NOAA Fisheries, unpublished data) found that the abundance of Chinook salmon may be much higher at the mouth of tributaries following a storm event. In 2003 and 2004, we surveyed six tributaries to determine if Chinook salmon forage on prey items that come into the lake via the tributary and determine how storm events affect the diet and abundance of juvenile Chinook salmon.

Methods

The six tributary mouths that we examined included: Tibbetts Creek and Laughing Jacobs Creek in Lake Sammamish (Figure 27) and Taylor Creek, Kennydale Creek, Kennydale Beach tributary, and May Creek in Lake Washington (Figure 28). Our goal was to sample each tributary mouth once during base flow and once during a high flow event. Each time a tributary mouth was sampled, streamflow (Table 3) was measured according to TFW stream ambient monitoring protocol (Pleus 1999). Stomach samples of Chinook salmon were collected primarily during late March or April. Each time a tributary mouth was sampled, we also collected stomach samples of Chinook salmon from a lake reference site to compare their diets. All six tributaries were sampled in 2003 during base streamflow conditions. Because there were few storm events in 2003, we were only able to survey one of the tributaries, Kennydale Creek, during high streamflow conditions. At Kennydale Creek, we also surveyed once a mouth (base flow conditions) in 2003 from February to June to determine if there is any type of temporal effect. In 2004, we sampled May Creek and Taylor Creek during a high flow event as well as during base flow conditions. An additional sample was also taken in 2004 at Kennydale Creek during base flow conditions.

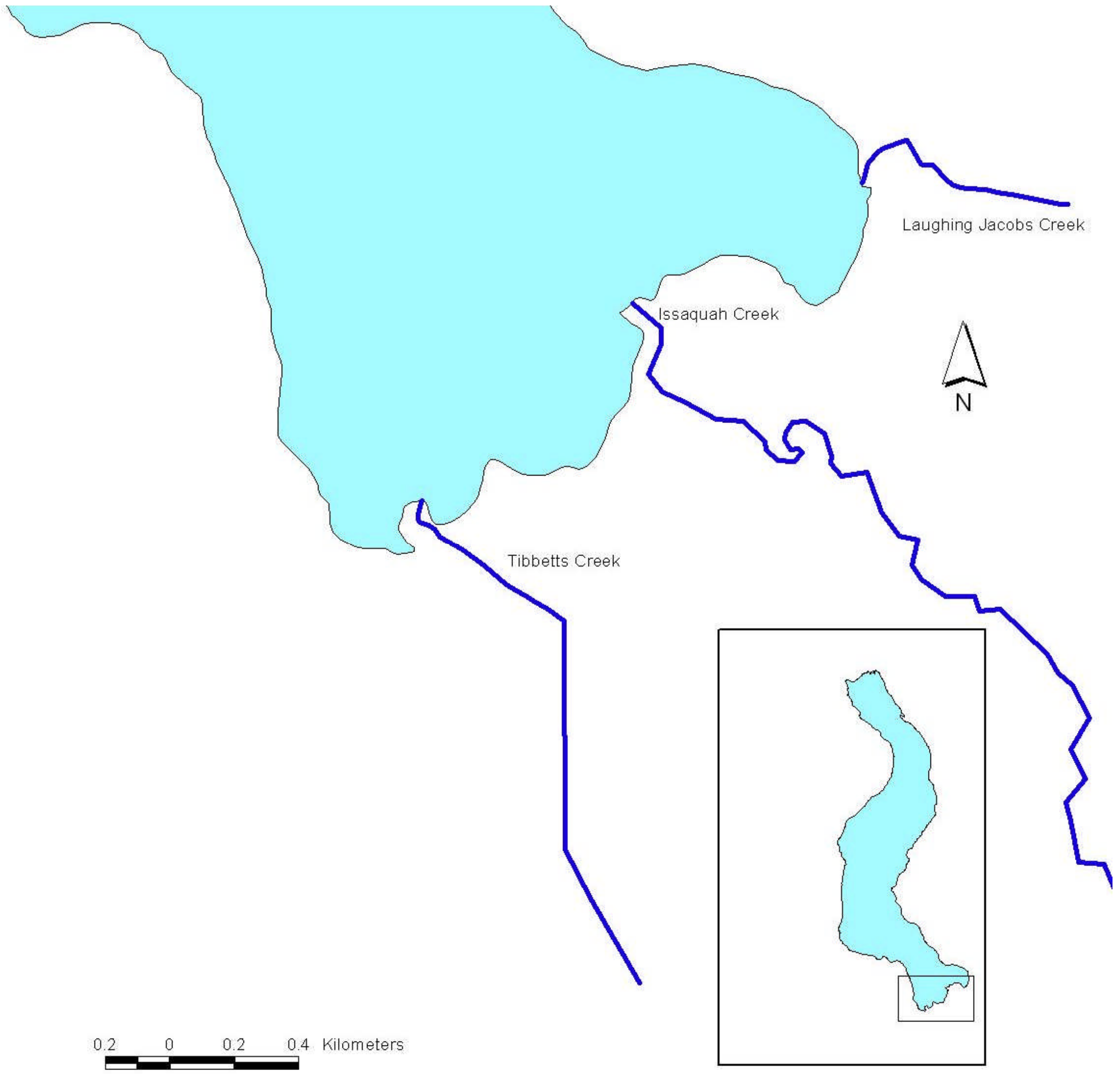


FIGURE 27.—Location of two south Lake Sammamish tributaries studied to examine the diet of juvenile Chinook salmon at tributary mouths, March to June, 2003. Issaquah Creek, a major spawning tributary and hatchery release site for Chinook salmon, is also shown.

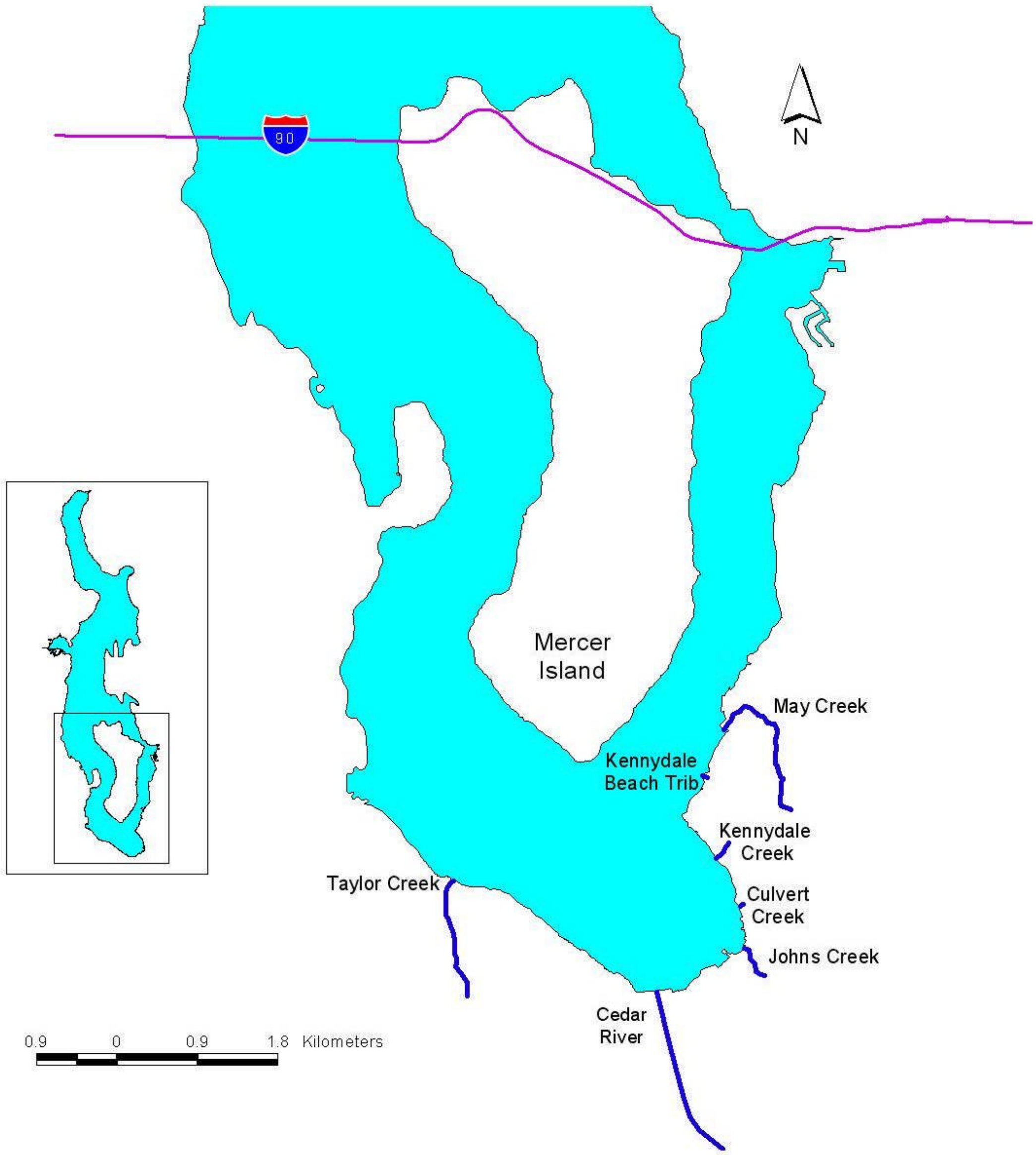


FIGURE 28.—Location of four south Lake Washington tributaries (Taylor Creek, May Creek, Kennydale Creek, and Kennydale Beach tributary) studied to examine the diet of juvenile Chinook salmon at tributary mouths. Also shown are two nonnatal tributaries (Johns Creek and Culvert Creek) that were also studied to determine their use by juvenile Chinook salmon (Chapter 6). The Cedar River, a major spawning tributary for Chinook salmon, is also shown.

TABLE 3. —Streamflow conditions (cfs) at six tributaries used to determine the abundance and diet of Chinook salmon at the tributary mouths in south Lake Washington and south Lake Sammamish. Streamflow was measured shortly after fish were sampled. Fish were sampled once during base flow conditions and again under high flow conditions if possible.

Lake		Streamflow (cfs)	
Tributary	Year	Base flow	High flow
Lake Washington			
Kennydale Cr.	2003	0.51	4.80
	2004	0.47	ND
Kennydale Beach trib.	2003	0.01	ND
May Cr.	2003	30.43	ND
	2004	12.86	39.20
Taylor Cr.	2003	2.12	ND
	2004	0.94	4.58
Lake Sammamish			
Laughing Jacobs Cr.	2003	8.27	ND
Tibbetts Cr.	2003	19.24	ND

Chinook salmon were collected primarily with beach seines (Figure 29). At the small tributaries, Kennydale Beach tributary and Kennydale Creek (Figure 29), one beach seine set was conducted, whereas at the other larger tributaries, 3 to 4 sets were usually done to cover the entire delta area. In 2003, we used two seines depending on the size of the fish. When Chinook salmon were less than 60 mm FL, we used a small seine that was 5.7 m long and 1.2 m deep with a 2-mm stretch mesh and had no bag in the middle. The larger net, used when Chinook salmon were > 60 mm FL, was 9.1 m long and 1.6 m deep and a 1.5-m deep by 1.8-m long bag in the middle. The entire net had 6-mm stretch mesh. In 2004, only one seine was used because it was effective in sampling various sizes of Chinook salmon. The net was 9.1 m long and 1.8 m deep with a 1.8- m deep by 1.8- m long bag in the middle. The mesh size in the wings was 6-mm stretch mesh while the bag was 2-mm stretch mesh. In the event that few Chinook salmon could be collected at a particular site, we collected additional Chinook salmon for diet analysis with small dip nets while snorkeling at night.

Captured fish were identified and counted and 10 Chinook salmon were randomly-selected for diet analysis. The 10 Chinook salmon were anaesthetized with MS-222, the fork length was measured, and their stomach contents were removed through gastric lavage. Stomach contents were put in plastic bags, placed on ice, and later froze.

In the laboratory, stomach samples were thawed, examined under a dissecting scope, and divided into major prey taxa. Aquatic insects and crustaceans were identified to family, while other prey items were identified to major taxonomic groups. Prey groups were counted and then the wet weight was measured. Each group was blotted by placing the sample on tissue paper for approximately 10 seconds and weighed to the nearest 0.0001 g.

FIGURE 29.—Photos of sites used to collect juvenile Chinook salmon to examine the diet at tributary mouths and lakeshore sites. The upper photo is of the mouth of Kennydale Creek and the lower photo is of the beach seine being deployed at the lakeshore reference site for Kennydale Creek. At the mouth of Kennydale Creek, a small delta was present, which was used to seine juvenile Chinook salmon.

To describe the diet of juvenile Chinook salmon, we followed the procedures of Cortés (1997) and Liao et al. (2001). For each prey group in each sample, we determined the percent weight (%W), percent number (%N), and percent occurrence (%O). A percent index of relative importance (%IRI) was then developed for each prey group:

$$IRI = \%O_i(\%W_i + \%N_i) \quad \text{and,} \quad \%IRI = 100 \cdot \frac{IRI_i}{\sum_{i=1}^{n} IRI_i}$$

To help compare the diet between samples, we also calculated Schoener's diet overlap index (Schoener 1971):

$$Cxy = 1 - 0.5\left(\sum \left| p_{xi} - p_{yi} \right|\right)$$

where C_{xy} is the index value, p_{xi} is the proportion of food type *i* used by Chinook salmon at site *x* and p_{yi} is the proportion of food type *i* used by Chinook salmon at site *y*. Researchers commonly use an overlap index level of 0.6 or less to indicate a significant difference in diet (Zaret and Rand 1971; Johnson 1981). Comparisons were made between tributary mouths and lakeshore reference sites, as well as between high and base streamflow conditions at each tributary mouth.

A diet breadth index (*B*; Levins 1968) was also calculated to determine if Chinook salmon utilize a wider variety of prey types at the tributary mouths in comparison to the lake shore:

$$B = \frac{1}{\sum p_i^{\,2}}$$

where p_i is the proportion of the diet represented by food type i. Diet breadth index values range from 1 (no diet breadth: only one prey type in the diet) to infinity. Values less than 2 indicate little diet breadth.

Results

Catch. —In 2003, beach seine catch rates of juvenile Chinook salmon at tributary mouths and lakeshore sites were extremely variable between sites and between day and night. During the day, we were able to catch Chinook salmon at some tributary mouths but not at lakeshore reference sites. At some lakeshore sites, we could visually observe Chinook salmon but they could easily avoid the beach seine. At tributary mouths, they could be collected more easily, likely because the water was turbid or they retreated to the tributary mouth where they could be easily encircled with the seine. Because of the difficulty of collecting Chinook salmon at most lakeshore sites during the day, we collected Chinook salmon in 2004 at one site in Gene Coulon Park where they were known to be abundant.

Nighttime sampling was conducted at a few tributary mouths. Although night sampling was logistically more difficult, it appeared to be less variable than daytime sampling. At night, Chinook salmon were collected at each sampling location; however not enough sampling was conducted to make any meaningful comparison between tributary mouth and lakeshore sites.

During high flow conditions, the number of Chinook salmon caught at the mouth of May Creek in 2004 was substantially higher than during base flow conditions. Additionally, nine cutthroat trout (range, 147-190 mm FL) were caught during the high flow event while none were caught during the base flow condition. In contrast to May Creek, more Chinook salmon were caught under base flow conditions than during high flow conditions at the mouth of Taylor Creek (Figure 30). Different types of seine nets were used at Kennydale Creek in 2003 and thus catch rates could not be compared between streamflow conditions.

Diet.—In 2003, monthly samples (February to June) were collected at Kennydale Creek and a lakeshore reference site in Gene Coulon Park. Chironomid pupae and adults were the most important prey item for each sample date at both sites (Table 4). Other than chironomid pupae and adults, little else was present in the lakeshore diet for February to May, making up at least 89% of the diet by weight. The same was observed in the April and May diet at the mouth of Kennydale Creek. The March diet sample included a large seed pod that probably offered little nutritional value. If the seed pod is excluded from the analysis, chironomid pupae and adults made of 87% of the diet by weight. The March sample at the mouth of Kennydale Creek was taken during a high flow event yet there was no significant difference in the diet between the lakeshore sample on the same date and between the base flow sample taken in April (Table 5). In February, a large number of springtails (Collembola; 43% of the diet by number and 19% by weight) were present in diet at the tributary mouth but were absent in the lakeshore diet. Springtails are primarily inhabitants of soil and moist vegetation but some species inhabit the neuston of lentic systems (Christiansen 1996). Streams may act as a dispersal mechanism. Because springtails were absent from the lakeshore diet, it indicates Chinook salmon may have been feeding on prey items that originated from the creek watershed. Besides chironomid pupae and adults, the June tributary mouth sample included a large number of emerging mayflies (Caenidae; 38% by weight) and the lakeshore sample included large numbers of chironomid larvae.

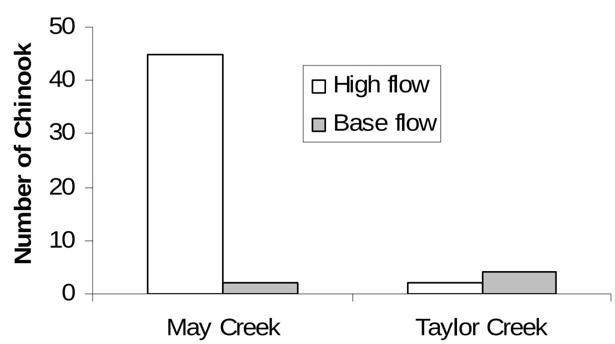


FIGURE 30. —Total number of Chinook salmon caught with a beach seine at the mouth of three tributaries of south Lake Washington, 2004. Each bar represents the number caught on one sampling effort; at May Creek three sets were conducted during each flow condition, and four at Taylor Creek.

TABLE 4. —Diet composition of juvenile Chinook salmon at the mouth of Kennydale Creek, 2003. Samples from March 12 were collected under high streamflow conditions. The other dates were collected under base streamflow conditions. n = number of stomach samples analyzed; the range of Chinook salmon lengths is also given; %N = percent number; %O = percent occurrence; %W = percent weight; %IRI = percent index of relative importance. Samples on February 19 were combined together in the field and %O and %IRI could not be calculated.

	February 19				March 12				April 3				May 8				June 3			
	n = 6, range = 38-43 mm FL				n = 6, range = 41-52 mm FL				n = 10, range = 45-54 mm FL				n = 10, range = 57-76 mm FL				n = 10, range = 85-103 mm FL			
Prey group	%N	%O	%W	%IRI	%N	%O	%W	%IRI	%N	%O	%W	%IRI	%N	%O	%W	%IRI	%N	%O	%W	%IRI
Insecta																				
Diptera																				
Chironomid pupae and adults	53.4	-	77.3	-	87.2	83	71.3	84.6	98.3	100	97.4	99.6	73.7	100	97.6	87.4	46.4	90	52.3	50.6
Chironomid larvae	1.1	-	0.9	-	1.2	17	0.1	0.1	0	0	0	0	0.6	10	0.1	0.04	3.1	80	1.5	2.1
Other aquatic diptera	0.5	-	0.5	-	3.5	50	2.8	2.0	0	0	0	0	0.5	20	0.2	0.1	1.4	50	1.2	0.7
Ephemeroptera	0.5	-	1.4	-	0	0	0	0	0	0	0	0	0.1	10	0.05	0.01	24.0	90	38.4	31.9
Collembola	43.4	-	18.6	-	0	0	0	0	0.6	10	0.1	0.03	0.1	10	0.01	0.01	0	0	0	0
Other aquatic insects	0	-	0	-	0	0	0	0	0	0	0	0	0.1	10	0.1	0.01	0.1	10	0.4	0.03
Homoptera (Aphididae)	0	-	0	-	0	0	0	0	0	0	0	0	0.4	30	0.2	0.1	0.4	10	0.2	0.03
Other terrestrial insects	1.1	-	1.4	-	1.2	17	0.1	0.1	0	0	0	0	1.5	60	0.9	0.7	1.1	50	0.9	0.6
Crustacea																				
Cladocera - Daphnia	0	-	0	-	0	0	0	0	0	0	0	0	0	0	0	0	0.2	10	0.0	0.01
Other crustaceans	0	-	0	-	2.3	17	0.2	0.3	0	0	0	0	1.0	50	0.4	0.4	4.4	90	0.2	2.4
Hydrachnida	0	-	0	-	0	0	0	0	0	0	0	0	21.8	100	0.4	11.3	18.1	90	0.1	9.4
Oligochaeta	0	-	0	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Other	0	-	0	-	4.7	67	25.5	12.9	1.1	20	2.5	0.4	0.2	10	0.1	0.01	0.9	70	4.9	2.3

TABLE 5. —Diet overlap indices (C) and diet breadth indices (B) of the mouth of Kennydale Creek and a lakeshore reference site, Lake Washington, 2003. Streamflow data were collected close to the mouth of the creek. ND = no data. Diet overlap index less than 0.6 indicates a significant difference. Diet breadth index values can range from 1 (no diet breadth) to infinity. Values less than 2 indicate little diet breadth.

	Streamflow	Diet overlap index (*C*)	Diet breadth index (*B*)	
Date	(cfs)	trib. mouth and lake shore	tributary mouth	lake shore
February 19	0.55	0.78	1.58	1.02
March 12	4.80	0.74	1.97	1.25
April 3	0.51	0.94	1.05	1.14
May 8	0.20	0.98	1.05	1.05
June 3	ND	0.70	2.37	3.17

Three other tributary mouths in Lake Washington were sampled in 2003, which included Kennydale Beach tributary, May Creek, and Taylor Creek; however, we were only able to survey each site under base streamflow conditions. Chironomid pupae and adults were the most important prey item for each tributary mouth as well as the lakeshore reference sites (Table 6). Chironomid larvae and terrestrial insects were more important in the diet at each tributary mouth than at the lakeshore reference sites. However, there was no significant difference in the diet between the tributary mouths and lakeshore sites (Table 7). The diet breadth index was higher at the tributary mouths than the lakeshore (Table 8).

In Lake Sammamish, the mouths of Tibbetts Creek and Laughing Jacobs Creek were sampled in April 2003. Chinook salmon were also collected at one lakeshore reference site, Lake Sammamish State Park boat ramps. Similar to Lake Washington, the diet of Chinook salmon in all Lake Sammamish sites was dominated by chironomid pupae and adults. In contrast to Lake Washington, *Daphnia* made up a substantial portion of the diet of Chinook salmon in Lake Sammamish sites (Table 9). In Lake Washington, *Daphnia* usually does not become an important prey item until June (Koehler 2002). The diet at the mouth of Tibbetts Creek was somewhat different than the lake shore (overlap index = 0.68 and a higher diet breadth index). The diet at the creek mouth included several chironomid larvae, mayfly nymphs (Ephemeroptera), oligochaetes, and terrestrial insects. The diet at the mouth of Laughing Jacobs Creek was similar to the lakeshore (Tables 7 and 8).

Several water mites (Hydrachnida) were often found in stomach samples, especially in samples collected in May and June. At the mouth of Kennydale Creek (May and June), they represented about 20% of the prey by number and %IRI was approximately 10%. Ingested water mites were quite small and were generally much smaller than any other prey item. They were probably larval water mites, which are parasites of aquatic insects, especially larval dipterans such as chironomids (Smith et al. 2001). Therefore, they probably were not a true prey item of Chinook salmon.

TABLE 6. —Diet composition of juvenile Chinook salmon along the shoreline of Lake Washington and at three tributary mouths of Lake Washington, April 2003. n = number of stomach samples analyzed; the range of Chinook salmon lengths is also given; %N = percent number; %O = percent occurrence; %W = percent weight; %IRI = percent index of relative importance.

	Lake shoreline n = 20, range = 45-84 mm FL				Kennydale Beach trib. n = 6, range = 59-73 mm FL				May Cr. n = 11, range = 56-74 mm FL				Taylor Cr. n = 10, range = 44-62 mm FL			
Prey group	%N	%O	%W	%IRI	%N	%O	%W	%IRI	%N	%O	%W	%IRI	%N	%O	%W	%IRI
Insecta																
Diptera																
Chironomid pupae and adults	93.4	95	92.9	97.3	92.7	100	74.7	92.2	73.3	90.9	65.1	75.8	76.8	80	82.0	88.8
Chironomid larvae	2.7	55	0.7	1.0	5.7	50.0	14.7	5.6	8.5	90.9	17.1	14.0	10.5	60	2.6	5.5
Other aquatic diptera	0.1	5	0.05	0.01	0	0	0	0	0.8	27.3	1.4	0.4	0	0	0	0
Ephemeroptera	0	0	0	0	0	0	0	0	3.7	54.5	4.0	2.5	1.1	10	1.1	0.1
Collembola	0.4	15	0.1	0.0	0.5	33.3	0.3	0.1	2.7	36.4	1.3	0.9	2.1	10	0.2	0.2
Other aquatic insects	0.1	5	0.02	0.01	0	0	0	0	2.4	36.4	1.6	0.9	0	0	0	0
Homoptera (Aphididae)	0	0	0	0	0.5	33.3	1.0	0.3	0	0	0	0	0	0	0	0
Other terrestrial insects	1.1	15	0.6	0.1	0.3	33.3	8.9	1.7	2.1	36.4	2.0	0.9	4.2	30	6.5	2.2
Crustacea																
Cladocera - Daphnia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Other crustaceans	0.2	10	0.7	0.05	0.2	16.7	0.4	0.05	0.3	9.1	0.5	0.04	0	0	0	0
Hydrachnida	1.0	25	0.3	0.2	0	0	0	0	0.8	18.2	0.01	0.1	1.1	10	1.4	0.2
Oligochaeta	0	0	0	0	0	0	0	0	0.3	9.1	0.2	0.02	0	0	0	0
Other	1.0	40	4.6	1.2	0	0	0	0	5.1	63.6	6.6	4.5	4.2	40	6.3	2.9

TABLE 7. —Diet overlap indices (C) of tributary mouths in Lake Washington and Lake Sammamish. Comparisons were made between two different streamflow conditions and between a lakeshore reference site and the two flow conditions. Samples were collected in either March or April in 2003 and 2004. Diet overlap index numbers in bold indicate a significant difference in diet ($C < 0.6$). ND = no data.

		Diet overlap index (*C*)		
Lake Tributary	Year	Base flow and lake shore	High flow and lake shore	Base flow and high flow
Lake Washington				
Kennydale Cr.	2003	0.80	0.74	0.71
	2004	0.70	ND	ND
Kennydale Beach trib.	2003	0.76	ND	ND
May Cr.	2003	0.66	ND	ND
	2004	0.82	0.69	0.67
Taylor Cr.	2003	0.90	ND	ND
	2004	0.74	**0.34**	**0.45**
Lake Sammamish				
Laughing Jacobs Cr.	2003	0.87	ND	ND
Tibbetts Cr.	2003	0.68	ND	ND

TABLE 8. —Diet breadth indices (B) of tributary mouths and lakeshore reference site in Lake Washington and Lake Sammamish. Samples were collected in either March or April. ND = no data. Diet breadth index values can range from 1 (no diet breadth) to infinity. Values less than 2 indicate little diet breadth.

		Diet breadth index (*B*)			
Lake		Base flow		High flow	
Tributary	Year	tributary mouth	lake shore	tributary mouth	lake shore
Lake Washington					
Kennydale Cr.	2003	1.05	1.14	1.97	1.50
	2004	2.49	1.42	ND	ND
Kennydale Beach trib.	2003	1.70	1.12	ND	ND
May Cr.	2003	2.17	1.12	ND	ND
	2004	1.55	1.35	2.45	1.47
Taylor Cr.	2003	1.47	1.26	ND	ND
	2004	1.74	1.35	4.09	1.47
Lake Sammamish					
Laughing Jacobs Cr.	2003	1.65	2.01	ND	ND
Tibbetts Cr.	2003	2.88	2.01	ND	ND

TABLE 9. —Diet composition of juvenile Chinook salmon at three locations (one shoreline site and two sites at the mouths of tributaries) in south Lake Sammamish, April 16 to 21, 2003. n = the number of stomach samples analyzed; the range of Chinook salmon lengths is also given; %N = percent number; %O = percent occurrence (%); %W = percent weight; %IRI = percent index of relative importance.

	Lake shoreline n = 10, range = 60-85 mm FL				Laughing Jacobs Cr. n = 10, range = 52-80 mm FL				Tibbetts Cr. n = 11, range = 53-74 mm FL			
Prey group	%N	%O	%W	%IRI	%N	%O	%W	%IRI	%N	%O	%W	%IRI
Insecta												
Diptera												
Chironomid pupae and adults	69.7	90	67.1	81.3	65.8	100	76.5	81.6	48.9	100	56.3	70.6
Chironomid larvae	4.1	50	0.9	1.6	4.8	100	3.1	4.5	19.1	63.6	2.7	9.3
Other aquatic diptera	0	0	0	0	0.1	10	0.02	0.01	2.1	18.2	0.2	0.3
Ephemeroptera	0.1	10	0.2	0.02	0	0	0	0	8.5	45.5	8.0	5.0
Collembola	0.4	20	0.1	0.1	0	0	0	0	0	0	0	0
Other aquatic insects	0	0	0	0	0	0	0	0	3.2	18.2	5.4	1.0
Homoptera (Aphididae)	0	0	0	0	0	0	0	0	0	0	0	0
Other terrestrial insects	0	0	0	0	0.2	20	0.1	0.03	4.3	36.4	10.8	3.7
Crustacea												
Cladocera - Daphnia	16.6	40	19.3	9.5	27.2	50	8.2	10.1	1.1	9.1	0.04	0.1
Other crustaceans	5.5	40	0.7	1.6	0.4	20	0.6	0.1	0	0	0	0
Hydrachnida	2.5	50	0.1	0.9	1.1	30	0.2	0.2	3.2	18.2	0.1	0.4
Oligochaeta	0.3	10	0.01	0.02	0	0	0	0	0	0	0	0
Other	0.8	60	11.7	4.9	0.4	50	11.3	3.4	9.6	54.5	16.6	9.6

In 2004, two tributaries, May Creek and Taylor Creek, were surveyed under high streamflow conditions as well as base streamflow conditions. During high streamflow conditions at May Creek, the percent of the diet of chironomids pupae and adults decreased from base flow conditions, while the percent of chironomid larvae, oligochaetes, and mayflies increased (Table 10). The diet at May Creek during high flow conditions also included some prey items that are usually only found in flowing waters. These prey items included the immature stages of rhyacophilid caddisflies, black flies (Simuliidae), and heptagenid mayflies. Diet breadth was approximately 60% higher than at the lakeshore and base flow condition (Table 8); however, the diet overlap index was not significantly different (lakeshore, 0.69; base flow, 0.67). Cutthroat trout (n = 9) at the mouth of May Creek during the high flow event were foraging primarily on terrestrial prey items, which included terrestrial isopods or sow bugs (36% by weight), oligochaetes (28%) and insects (4%).

Several larval longfin smelt (*Spirinchus thaleichthys*) were consumed by Chinook salmon at the mouth of May Creek on April 1 (baseflow conditions), which represented 8% of the diet by weight. Much of the consumption of larval smelt was observed in one individual (64 mm FL), which had consumed 29 smelt. Adult longfin smelt have been documented to spawn in May Creek (Moulton 1974; Martz et al. 1996).

TABLE 10. —Diet composition of juvenile Chinook salmon at the mouth of May Creek, 2004 under two streamflow conditions. Base streamflow samples were collected on March 31 and April 1 and the high streamflow samples were collected on March 26. n = the number of stomach samples analyzed; the range of Chinook salmon lengths is also given; %N = percent number; %O = percent occurrence; %W = percent weight; %IRI = percent index of relative importance.

	Base flow				High flow			
	n = 10, range = 40-64 mm FL				n = 10, range = 51-62 mm FL			
Prey group	%N	%O	%W	%IRI	%N	%O	%W	%IRI
Insecta								
Diptera								
Chironomid pupae and adults	62.7	100	79.7	85.6	56.7	100	61.2	70.1
Chironomid larvae	3.7	40	1.6	1.3	17.9	70	16.0	14.1
Other aquatic diptera	0	0	0	0	2.2	30	1.8	0.7
Ephemeroptera	1.5	20	1.0	0.3	5.2	50	4.6	2.9
Collembola	4.5	30	0.8	1.0	2.2	20	0.5	0.3
Other aquatic insects	0.7	10	4.6	0.3	3.0	30	4.3	1.3
Homoptera (Aphididae)	0	0	0	0	0.7	10	0.8	0.1
Other terrestrial insects	0	0	0	0	0	0	0	0
Crustacea								
Cladocera - Daphnia	0	0	0	0	0	0	0	0
Other crustaceans	0.7	10	0.3	0.1	0.7	10	0.2	0.1
Hydrachnida	0	0	0	0	0	0	0	0
Oligochaeta	0	0	0	0	8.2	90	6.1	7.7
Other	26.1	50	11.9	11.4	3.0	60	4.4	2.7

The diet at the mouth of Taylor Creek during high streamflow conditions was significantly different than the lakeshore on the same date as well as Taylor Creek during base flow conditions (Table 11). Chironomid larvae were the most important prey item and represented approximately half of the prey items consumed. Other prey items included chironomid pupae and adults, oligochaetes, springtails, and mayflies. The diet breath index was 4.09, which was higher than any other creek mouth or lake sample.

Supplemental surveys of Kennydale Creek and Taylor Creek were conducted on April 20, 2004. Chinook salmon were also collected at a lakeshore reference site, north Gene Coulon Park. At the mouth of Taylor Creek, little else was present in the diet except chironomid pupae and adults (97% by weight). Chironomid pupae and adults were also the dominant prey item at the mouth of Kennydale Creek (58% by weight) and the lakeshore reference site (83% by weight). However unlike Taylor Creek, aphids made up a substantial part of the diet (Kennydale Creek, 25% by weight; lakeshore, 7% by weight).

TABLE 11. —Diet composition of juvenile Chinook salmon at the mouth of Taylor Creek, March 2004 under two streamflow conditions. Base streamflow samples were collected on March 30 and the high streamflow samples were collected on March 25. n = number of stomach samples analyzed; the range of Chinook salmon lengths is also given; %N = percent number; %O = percent occurrence; %W = percent weight; %IRI = percent index of relative importance.

	Base flow n = 5, range = 47-61 mm FL				High flow n = 2, range = 42-57 mm FL			
Prey group	%N	%O	%W	%IRI	%N	%O	%W	%IRI
Insecta								
Diptera								
Chironomid pupae and adults	65.0	100	73.2	72.3	31.6	100	24.9	30.1
Chironomid larvae	32.5	100	18.3	26.6	48.7	100	37.5	45.9
Other aquatic diptera	0.6	20	0.1	0.1	0	0	0	0
Ephemeroptera	0.6	20	6.1	0.7	3.9	50	11.9	4.2
Collembola	0	0	0	0	9.2	100	4.5	7.3
Other aquatic insects	0	0	0	0	0	0	0	0
Homoptera (Aphididae)	0.6	20	0.1	0.1	0	0	0	0
Other terrestrial insects	0.6	20	0.2	0.1	1.3	50	1.1	0.6
Crustacea								
Cladocera - Daphnia	0	0	0	0	0	0	0	0
Other crustaceans	0	0	0	0	0	0	0	0
Hydrachnida	0	0	0	0	0	0	0	0
Oligochaeta	0	0	0	0	3.9	100	15.3	10.2
Other	0	20	2.0	0.2	1.3	50	4.7	1.6

Discussion

Although differences in the diet between the lake shore and the tributary mouth were not pronounced, Chinook salmon at tributary mouths do appear to utilize prey from the tributary. At tributary mouths, benthic insects (chironomid larvae and mayfly nymphs) and terrestrial insects were more prevalent in the diet than at lakeshore sites. Occasionally, some prey types (i.e., larval black flies and rhyacophilid caddisflies) are consumed that should have only come from a stream. Consumption of larval longfin smelt was also documented at May Creek. Longfin smelt are known to spawn in the lower reaches of rivers and large streams of Lake Washington. There is no evidence of lake spawning by smelt. Longfin smelt eggs have been observed in Cedar River, May Creek, Coal Creek, Juanita Creek, and McAleer Creek (Moulton 1970; Martz et al. 1996) and therefore, juvenile Chinook salmon may be able to take advantage of this prey source at the mouths of these streams. The diet breadth was usually broader at the tributary mouths than along the lakeshore. Using all baseflow samples (2003 and 2004), the diet breadth was significantly higher at tributary mouths than the lakeshore (Wilcoxon test, $n = 9$, $P = 0.038$).

The lack of a large difference between the diet of lakeshore and tributary mouth fish may be because chironomid pupae and adults are an important dietary item regardless of location. Even in an upstream location of Johns Creek, chironomid pupae and adults were the most important prey item (Chapter 6). The high composition of chironomids in the diet of juvenile Chinook salmon has been observed in both lentic (Johnson 1983; Koehler 2002) and riverine systems (Becker 1973; Merz and Vanicek 1996; Martin and Saiki 2001; Petrusso and Hayes 2001; Sommer et al. 2001). To determine the origin of ingested chironomids from Lake Washington Chinook salmon, we may need to identify them to genus or species to determine if they are largely lake dwelling or stream dwelling prey. Samples of stream drift would also add information on the types and sizes of potential prey entering the lake from the stream.

In general, juvenile Chinook salmon appear to be opportunistic feeders. They consume a wide variety of prey items and probably can quickly switch to a locally abundant prey source. Chironomids are extremely abundant in the nearshore areas of Lake Washington (Koehler 2002) and it's not surprising they are important in the diet of juvenile Chinook salmon. As other prey items become abundant, Chinook salmon continue to feed on chironomids but also prey on these other prey items. For example, Chinook salmon did not feed heavily on mayflies of the family Caenidae until June when the mayflies were emerging. In Lake Ontario, Johnson (1983) found that subyearling Chinook salmon fed predominantly on fish eggs when emerald shiners (*Notropis atherinoides*) were spawning; however, in another year, Chinook salmon were collected prior to spawning of emerald shiners and they preyed predominantly on chironomids. Because juvenile Chinook salmon are opportunistic feeders, they can forage at the mouths of tributaries and take advantage of a wide variety of prey types from both the lake and tributary.

In 2002, we found strong differences in the diet between Kennydale Creek mouth and lakeshore (Tabor et al. 2004b). The diet overlap index was 0.17 and diet breadth was much higher at the tributary mouth (B = 9.0) than the lakeshore (B = 1.2). In contrast, differences between tributary mouth and lakeshore samples were generally small in 2003 and 2004 except during high flow events. The sample collected at Kennydale Creek in 2002 did not appear to be during a high flow event. Also, weather records do not indicate any measurable precipitation during the 2 days before the sample was taken. In 2002, Chinook salmon at the mouth of Kennydale Creek were collected at night with small dip nets on the interior part of the delta, close to the tributary mouth. Samples in 2003 and 2004 were collected primarily during the day with a beach seine, which sampled the entire delta area. Therefore, Chinook salmon that are closer to the tributary may be feeding to a larger extent on prey from the tributary and fish on the outer part of the delta may be feeding primarily on prey that originated in the lake. Additionally, Chinook salmon collected at night near the mouth may include some fish that were foraging in the stream (convergence pool) during the day and then moved downstream to rest in quiet waters of the delta. In the Cedar River, small Chinook salmon appear to move to low velocity sites at night and rest near the bottom (R. Peters, USFWS, unpublished data).

Tributary mouths appear to be especially valuable habitat for Chinook salmon during high streamflow conditions. Chinook salmon appear to respond both functionally (change in diet) and numerically (change in abundance) to increased streamflow. At all three tributary mouths, the diet breadth was higher at high streamflow than at base streamflow conditions. A large percentage of the diet during high streamflow conditions consisted of benthic prey such as chironomid larvae and oligochaetes. These prey items may become more available due to streambed scour and prey are displaced downstream. At May Creek, we found the abundance of Chinook salmon can increase during a high flow event. An increase in prey availability as well as flow may attract Chinook salmon and other salmonids such as cutthroat trout. At Taylor Creek, we were unable to demonstrate an increase in Chinook salmon abundance due to an increase in streamflow. Taylor Creek is much smaller than May Creek and thus the amount of prey and attraction flow is most likely less. Also, May Creek may have been easier to sample with a small beach seine than Taylor Creek because the delta of May Creek is confined between two riprap banks and fish may be easily encircled with a beach seine.

CHAPTER 6. USE OF NONNATAL TRIBUTARIES

Introduction and Methods

The lower reaches of several nonnatal tributaries were surveyed in 2002. Juvenile Chinook salmon commonly used the tributary delta areas within the lake but they were only found in the lotic environments of a few tributaries (Tabor et al. 2004b). Nonnatal tributaries that had a high abundance of juvenile Chinook salmon were small- to medium-sized streams, which had a low gradient and were close to the mouth of the natal system. In 2003 and 2004, we surveyed Johns Creek and Culvert Creek to collect additional information on the use of nonnatal tributaries. Johns Creek was surveyed to determine if the tributary is used extensively from year to year and to collect some information on Chinook salmon habitat use that could be used to design restoration projects of other nonnatal tributaries. For example, the City of Seattle has proposed to daylight the mouth and lower 100 m of Mapes Creek (currently in a culvert and enters the lake a few meters below the lake surface), yet little information is available on what type of habitat conditions would be best for Chinook salmon. In 2004, we also surveyed Culvert Creek because it is also a small, low-gradient creek that is close to the mouth of the Cedar River; however, the creek is located entirely within a culvert. The creek is located approximately 0.65 km north of Johns Creek.

Johns Creek. — Johns Creek is located in Gene Coulon Park in the southeast corner of Lake Washington, 1.5 km from the mouth of the Cedar River. Typical winter streamflow is about 0.8 cfs (Tabor et al. 2004b). Juvenile Chinook salmon use the lower 460 m of the stream (Tabor et al. 2004b). Upstream of this, there are two equal-sized streams that appear to be completely in culverts.

In 2003 and 2004, we repeatedly surveyed the same 260-m long reach that was surveyed in 2002 (Tabor et al. 2004b). The downstream end of the study reach was the lake. There was no developed delta unlike other tributaries to Lake Washington. The upstream end was a large culvert near the entrance to Gene Coulon Park. The study reach was delineated into habitat units, which were either classified as a convergence pool, scour pool, glide, or riffle. The convergence pool was the lower 61 to 136 m of the index reach that the water level was directly influenced by the lake level (Figure 31). As the lake rose from February to June, the convergence pool grew progressively larger. Scour pools were other pools upstream of the convergence pool that had a maximum depth > 0.35 m. Glides or shallow pools were other slow water habitats that had a maximum depth < 0.35 m (Figure 31). The maximum pool depth of 0.35 m was adapted from Timber-Fish-Wildlife (TFW) stream ambient monitoring methodology (Pleus et al. 1999). For a stream the size of Johns Creek (5- to- 10-m bankfull stream width), the authors recommended pools have a residual pool depth of 0.25 m (residual pool depth = max. pool depth – outlet pool depth). Because the outlet depth of pools was approximately 0.1 m deep, we used a maximum pool depth as > 0.35 m. Riffles were areas that had noticeable surface turbulence with increased water velocities. Length and width was measured for each habitat unit. The maximum depth and average depth was also determined for each habitat unit.

FIGURE 31.—Photos of glide habitat (upper photo) and the convergence pool (lower photo) of Johns Creek, Gene Coulon Park. In the background of the convergence pool photo is Lake Washington.

Fish surveys of Johns Creek were conducted during the day primarily by a snorkeler who slowly moved upstream and counted fish. In small- and medium-sized streams, juvenile Chinook salmon appear to be easily observed and counted during the daytime. At night, the snorkeler's light is usually close to the fish and often causes fish to scatter, thus making it difficult to count the fish. Pools and most glides were surveyed by snorkelers. In 2003, shallow habitat units (riffles and some glides) that were too shallow to snorkel were surveyed through surface observations by walking slowly along the stream bank. Because fish are often difficult to observe in riffles when using surface observations, we used electrofishing equipment to sample this habitat in 2004. The number of Chinook salmon and other fish were recorded for each habitat unit. At the location of individual or groups of Chinook salmon, we also measured the water column depth (surface to bottom). In 2003, surveys of Johns Creek were done once every 2 weeks from March to June while in 2004, surveys were conducted once every 3 weeks from February to May.

Stomach samples of Chinook salmon from Johns Creek were also collected in 2003 to compare their diet to Chinook salmon collected from the lakeshore. Chinook salmon in Johns Creek were collected with a small beach seine. Lakeshore fish were collected at a site in the north end of Gene Coulon Park, approximately 1 km from the mouth of Johns Creek. Stomach samples were taken once a month from the end of February to the end of May. Fish processing, laboratory analysis, and data analyses for stomach samples were done the same as tributary mouth sampling (see Chapter 5).

<u>Culvert Creek</u>**.** **—**In addition to Johns Creek, we also surveyed a small unnamed creek or seep in Gene Coulon Park (Figure 27). It begins on the east side of the railroad tracks about 100 m from Lake Washington. Except for a section under the railroad tracks, the upper 35 m are daylighted. Sixty-five meters from the lake, the creek runs through a small drain and drops 2.1 m into a culvert. The lower 65 m was available to juvenile Chinook salmon and was located entirely in a culvert (Figure 32), thus we referred to this creek as Culvert Creek. The outlet of the creek is along a riprap bank (Figure 32). The creek has a small sandy delta. The delta has a steep gradient similar to the riprap bank. In the summer and fall, the creek is usually dry. During the winter and spring, base streamflows appear to be approximately 0.04 cfs.

Snorkel surveys were conducted along four transects at this location: 1) creek (entirely inside culvert), 2) delta (4 m long by 3 m wide), 3) an adjacent 18-m-long riprap shoreline and, 4) a 14-m-long gravel beach 40 m north of the creek's mouth. The length of the creek that we were able to snorkel varied with lake level. In February, the lake level was low and the lower end of the culvert was perched above the lake level and the creek was one long riffle. We assumed no Chinook salmon could use the creek during this time period. As the lake rose, water was backed up in the culvert and we were able to snorkel inside the culvert. Transects were surveyed four times, approximately once every three weeks from March to May.

FIGURE 32. — Outlet of Culvert Creek, Gene Coulon Park, Lake Washington, April 2003.

Results

Johns Creek. —In both 2003 and 2004, large numbers of juvenile Chinook salmon were present in the index reach of Johns Creek in February and March (Figure 33). Peak abundance was 632 Chinook salmon on March 5, 2003. Numbers gradually decreased from late March through May and few Chinook salmon were present by the beginning of June. In February, the mean length of juvenile Chinook salmon in Johns Creek was approximately 40 mm FL and by the end of May they averaged 74 mm FL (Figure 34). As they grew they used progressively deeper areas of the creek, from 0.28 m in February to approximately 0.5 m in May (Figure 35).

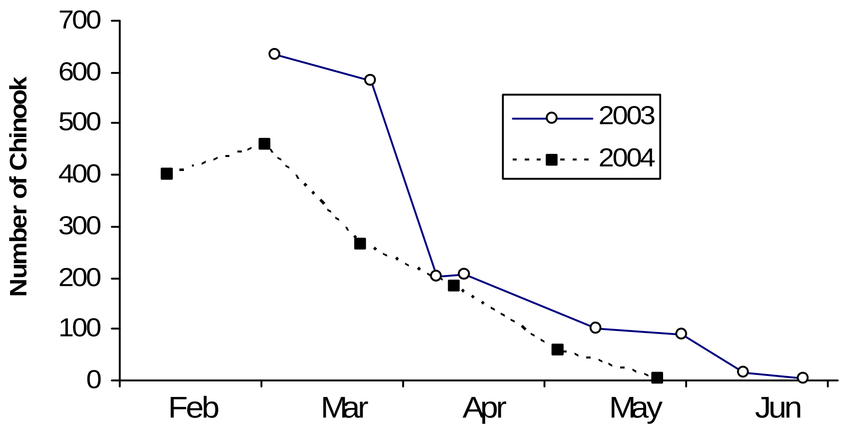


FIGURE 33. —Number of juvenile Chinook salmon observed in the lower 260 m of Johns Creek in 2003 and 2004. Data are based primarily on snorkel counts. Habitats that were too shallow to snorkel were surveyed with surface observations or electrofishing surveys

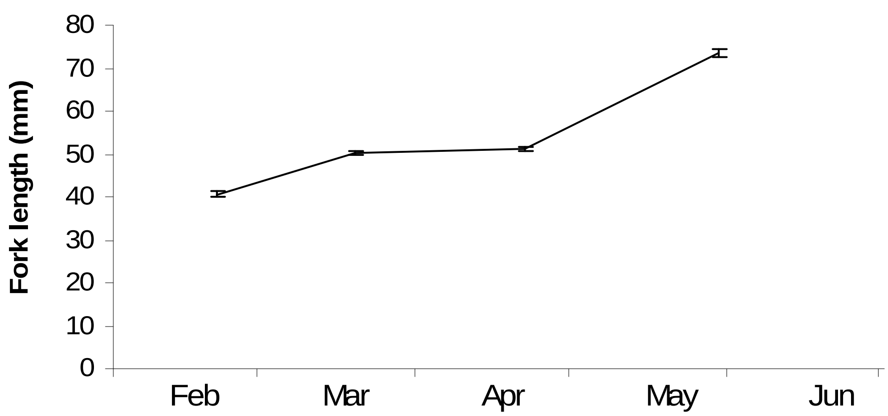


FIGURE 34. —Mean fork length (mm, ± 2 SE) of juvenile Chinook salmon in the lower 260 m of Johns Creek, 2003. Fish were collected with beach seines.

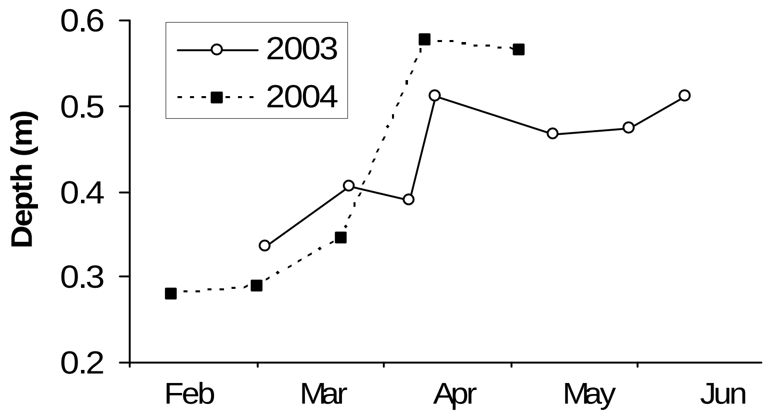
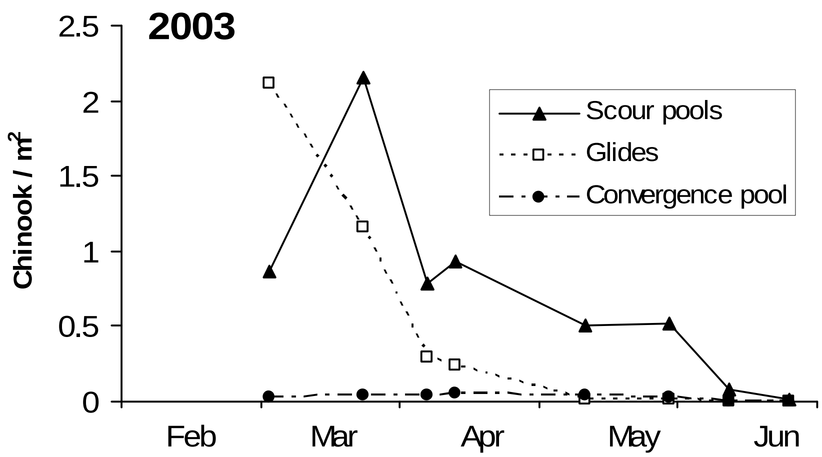


FIGURE 35. —Mean water column depth (m) where juvenile Chinook salmon were located in the index reach of Johns Creek, 2003 and 2004. Figure only includes dates when at least 10 Chinook salmon were observed.

A total of only six Chinook salmon were collected in riffles (only sampled in 2004). They were collected in February and early March and were located in small pocket water behind boulders. Juvenile Chinook salmon density was highest in glides in February and early March. In both 2003 and 2004, the density in the beginning of March was about twice as high in glides than scour pools. The density in glides declined dramatically in late March and after the beginning of April, few Chinook salmon were present in glides and those that were present were almost always under overhanging vegetation. In April and May, the density in scour pools was 3 to 65 times higher than in glides. Juvenile Chinook salmon were present in scour pools throughout the study period (Figure 36). In February, they were located in shallow areas of the pool such as the edges and tailouts. After February, they were found in deeper water and by the end of March they were usually in the deepest part of the pool (Figures 37 and 38).

Similarly to scour pools, Chinook salmon were present in the convergence pool throughout the study period, albeit at a much lower density (Figure 39). Chinook salmon in the convergence pool were usually close to the edge and associated with shoreline vegetation. One notable exception was in February, 2004 when most Chinook salmon in the convergence pool were located under the footpath bridge. Large numbers of juvenile Chinook salmon were also observed under the bridge in 2002. The March and April abundance of Chinook salmon in the convergence pool was higher in 2004 than 2003, even though the abundance in all habitats combined was higher in 2003. To compare the use of the convergence pool to the rest of the index reach, we calculated the number per stream length because the convergence pool is wide and Chinook salmon do not appear to use the large area in the middle of the stream channel. The number of Chinook salmon per stream length was 3 to 26 times lower in the convergence pool than the rest of the stream in 2003; however, in 2004 it was only 2 to 7 times lower (Figure 36). The water column depth used by Chinook salmon in the convergence pool was similar to the average depth available. The deep areas (> 0.9 m deep) of the convergence pool did not appear to be used extensively by Chinook salmon. Instead these areas were often inhabited by large trout or largemouth bass (*Micropterus salmoides*), which may have influenced the distribution of juvenile Chinook salmon.



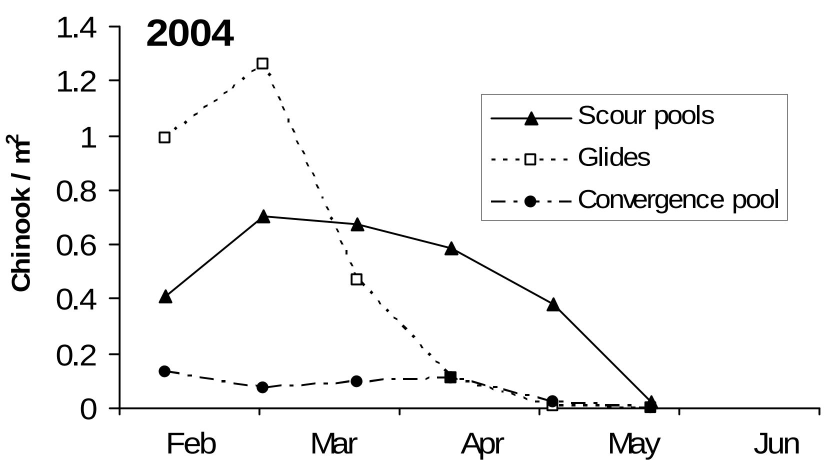


FIGURE 36. —Density (number /m^2) of juvenile Chinook salmon in three habitat types in the lower 260 m of Johns Creek, 2003 and 2004. Density in riffles is not shown because few fish were observed. Note different scales between years.

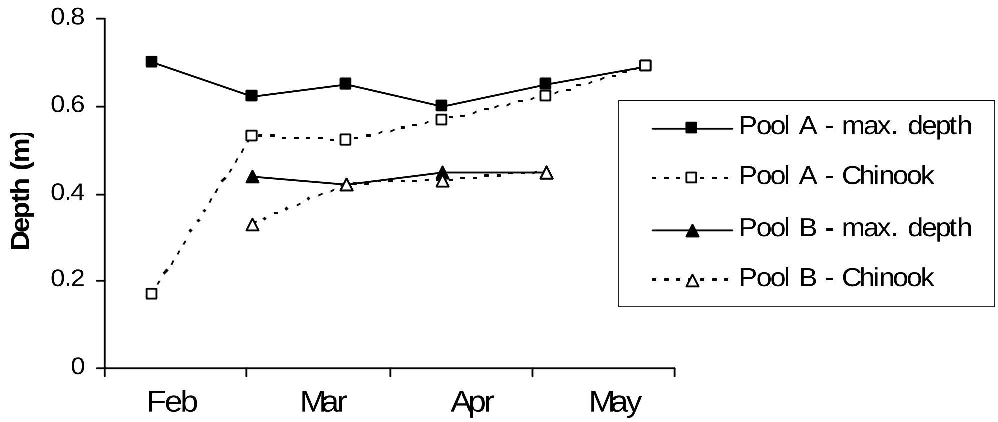


FIGURE 37. —Water column depth (m) where juvenile Chinook salmon were located and maximum depth of two scour pools in the index reach of Johns Creek, February – May, 2004. max. depth = maximum depth.

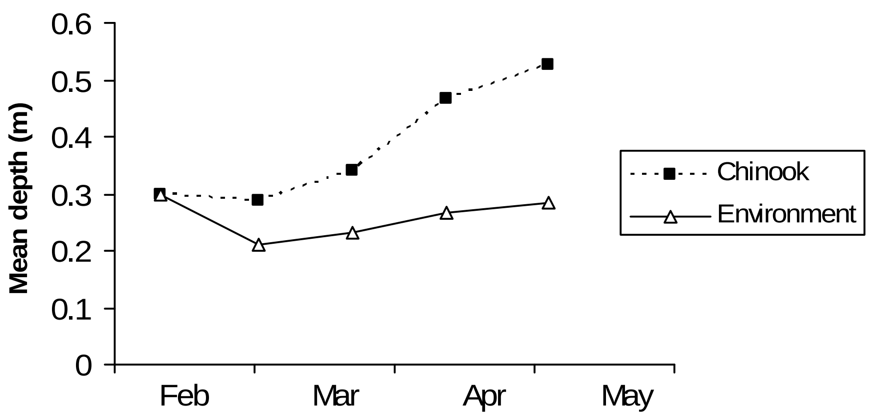


FIGURE 38. —Mean water column depth (m) in scour pools and glides (environment) and the mean water column depth where juvenile Chinook salmon were located in those habitats, lower Johns Creek, February-May, 2004. Figure only includes dates when at least 10 Chinook salmon were observed.

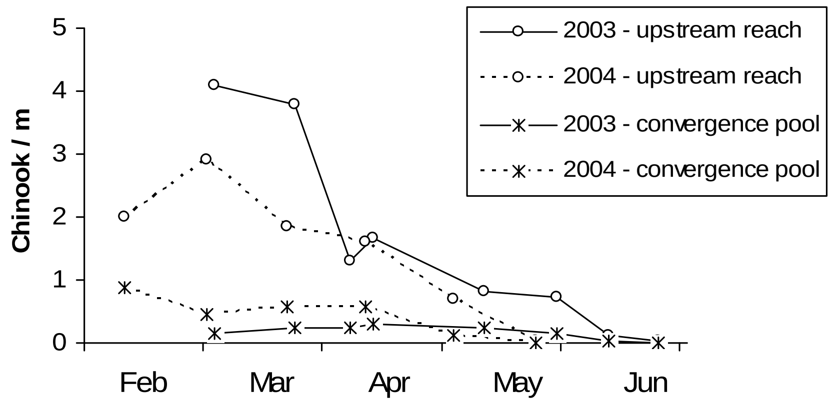


FIGURE 39. —Number of juvenile Chinook salmon in Johns Creek per stream length in the convergence pool and the stream reach immediately upstream of the convergence pool. The length of the convergence pool and upstream reach varied depending on lake level. The entire stream reach was 260 m. The upstream reach included riffles, glides, and scour pools.

Other salmonids in Johns Creek consisted primarily of sockeye salmon fry. Other fish observed in Johns Creek included trout, prickly sculpin, coastrange sculpin (*C. aleuticus*), threespine stickleback, juvenile brown bullhead (*Ameiurus nebulosus*), juvenile suckers (*Catostomus* sp.), juvenile sunfish (*Lepomis* sp.), juvenile peamouth (*Mylocheilus caurinus*), and largemouth bass. Salmonids and sculpins were found throughout the index reach and throughout the study period; whereas, the other fish species were observed primarily in the convergence pool in May and June.

In general, the diet of juvenile Chinook salmon in Johns Creek was similar to the diet from Lake Washington. Chironomid pupae and adults had the highest %IRI on each sampling date in both Johns Creek and the lakeshore (Table 12). However, on two of the four dates (March 20 and April 22), the diet in Johns Creek was substantially different than the lake shore at north Gene Coulon Park (Table 12). In Johns Creek, chironomid pupae and adult made up less than 30% of the diet by weight on both dates, whereas they made up over 80% of the diet from the lake shore during that time period. On March 20, oligochaetes were the most important prey item by weight and on April 22 other terrestrial invertebrates (centipedes, isopods, and gastropods) made up over half of the diet by weight. The diet breadth index was also much higher for Johns Creek fish than the lakeshore fish on these two dates (Table 13).

TABLE 12. —Diet composition of juvenile Chinook salmon in Johns Creek, 2003. n = number of stomach samples analyzed; the range of Chinook salmon lengths is also given; %N = percent number; %O = percent occurrence; %W = percent weight; %IRI = percent index of relative importance. Samples on February 21 were combined together in the field and %O and %IRI could not be calculated.

	February 21 n = 10, range = 37-45 mm FL				March 20 n = 11, range = 47-54 mm FL				April 22 n = 10, range = 48-54 mm FL				May 30 n = 10, range = 72-81 mm FL			
Prey group	%N	%O	%W	%IRI	%N	%O	%W	%IRI	%N	%O	%W	%IRI	%N	%O	%W	%IRI
Insecta																
Diptera																
Chironomid pupae and adults	63.9	-	47.0	-	36.8	90.9	18.6	39.3	67.3	80	26.8	57.8	58.5	100	75.8	71.7
Chironomid larvae	11.5	-	4.0	-	8.8	45.5	3.6	4.4	3.6	10	0.3	0.3	30.8	100	6.2	19.7
Other aquatic diptera	0	-	0	-	0	0	0	0	0	0	0	0	0	0	0	0
Ephemeroptera	0	-	0	-	0	0	0	0	0	0	0	0	0	0	0	0
Collemba	11.5	-	5.0	-	16.7	72.7	1.5	10.3	1.8	10	0.1	0.2	0.5	20	0.5	0.1
Other aquatic insects	0	-	0	-	0	0	0	0	0	0	0	0	0.8	10	5.9	0.4
Homoptera (Aphididae)	0	-	0	-	0	0	0	0	0	0	0	0	1.8	60	1.1	0.9
Other terrestrial insects	6.6	-	4.0	-	0.9	9.7	0.3	0.1	3.6	20	5.0	1.3	5.8	90	6.7	6.0
Crustacea																
Cladocera - Daphnia	0	-	0	-	0	0	0	0	0	0	0	0	0	0	0	0
Other crustaceans	0	-	0	-	0	0	0	0	0	0	0	0	0.5	10	0.0	0.03
Acarina	0	-	0	-	1.8	9.1	0.1	0.1	0	0	0	0	0.3	10	0.0	0.01
Oligochaeta	0	-	0	-	24.6	45.5	46.7	25.3	0	0	0	0	0	0	0	0
Other terrestrial invertebrates	0	-	0	-	0.9	9.1	7.9	0.6	12.7	60	55.9	31.6	0	10	4	0.2
Other	6.6	-	40.0	-	9.6	81.8	21.3	19.8	10.9	50	11.9	8.7	1.0	40	3.7	1.0

TABLE 13. —Diet overlap index (C) and diet breadth index (B) of juvenile Chinook salmon from Johns Creek and Lake Washington, 2003. Lake Washington Chinook salmon were collected in the north part of Gene Coulon Park, approximately 1 km from Johns Creek. Diet overlap index numbers in bold indicate a significant difference in diet ($C < 0.6$). Diet breadth index values can range from 1 (no diet breadth) to infinity. Values less than 2 indicate little diet breadth.

	Diet overlap index (*C*)	Diet breadth index (*B*)	
Date	Johns Cr. and lake shore	Johns Cr.	lake shore
February 21	0.70	1.98	1.02
March 20	**0.21**	3.39	1.25
April 22	**0.29**	5.03	1.05
May 30	0.62	1.71	3.17

Culvert Creek. —A total of only five Chinook salmon were observed in Culvert Creek (inside the culvert); however, the amount of available habitat was relatively small. The few Chinook salmon observed inside the culvert were located close to the downstream end of the culvert (mouth of the creek), presumably because light levels at the mouth were higher and more conducive for foraging. Few other fish were observed inside the culvert. Out of four surveys, only one sockeye salmon fry, one small trout, and three sculpin were observed. No Chinook salmon were ever observed on the creek delta. Instead other fish, such as largemouth bass, prickly sculpin, pumpkinseed (*Lepomis gibbosus*), and small trout, were usually present. Few Chinook salmon were observed along the riprap transect. On three of the four surveys, large adult bass (either largemouth bass or smallmouth bass *M. dolomieu*) were present. Other fish observed included trout, pumpkinseed, and large prickly sculpin. The highest abundance of Chinook salmon (#/m) was observed along the gravel beach transect (Figure 40). Except for some small sculpin, few other fish were observed along this transect.

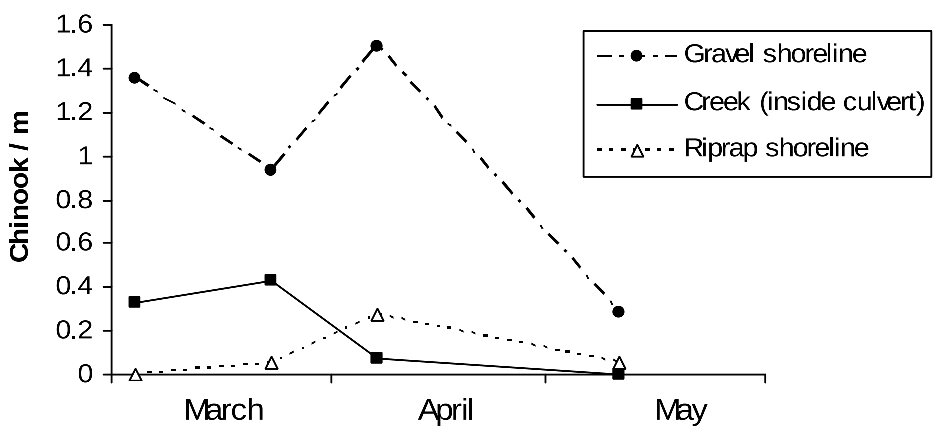


FIGURE 40. —Abundance (number per m) of juvenile Chinook salmon in Culvert Creek (inside culvert) and at two nearby shoreline transects in Lake Washington, 2004.

Discussion

Johns Creek.— Results from Johns Creek indicated that Chinook salmon extensively use this nonnatal tributary from year to year. Several nonnatal tributaries of Lake Washington and Lake Sammamish were surveyed in 2002 and the number of Chinook salmon found in Johns Creek was higher than all the other tributaries combined. Johns Creek appears to be an ideal nonnatal tributary because it has a low gradient, is a small- to medium-sized stream, and is close to the natal system, the Cedar River. Preliminary results from Lake Quinault in 2004 indicate there are also several nonnatal streams that are used by juvenile Chinook salmon. We plan to conduct additional surveys of these streams in 2005 to identify important factors that influence their use of these streams. In the lower part of the Fraser River, British Columbia, juvenile Chinook salmon used nonnatal tributaries that had low gradients and had no fish barriers such as waterfalls, culverts, bridge footings, or flood control gates (Murray and Rosenau 1989). The use of the lower reaches of nonnatal tributaries by juvenile Chinook salmon has also been documented in the upper Fraser River system in British Columbia (Scrivener et al. 1994), the Taku River system in Alaska (Murphy et al. 1989) and the Umpqua River system in Oregon (Scarnecchia and Roper 2000).

Based on the habitat use patterns of Johns Creek, a suitable stream for juvenile Chinook salmon should have a wide variety of habitat features, which would take into account the change in habitat use of Chinook salmon as they grow. Shallow, slow water habitats (< 0.35-m depth) or glides were used extensively in February and early March. We also observed small Chinook salmon in pocket water of riffles, thus using cobbles and small boulders in riffles might provide additional rearing habitat. After late March, Chinook salmon were usually in deeper pools but we did not observe them in pools greater than 0.9 m depth. Throughout the study period, juvenile Chinook salmon appeared to often use overhead cover.

The density of Chinook salmon in the convergence pool was considerably lower than in the upstream reach. Low density in the convergence pool may be due to a combination of suboptimal habitat conditions and presence of other fish species. Much of the convergence pool had riprap banks and there was little woody debris and little riparian vegetation to provide overhanging cover. Potential predators of Chinook salmon, such as largemouth bass, smallmouth bass, large trout, and prickly sculpin, were commonly observed in the convergence pool, thus Chinook salmon may avoid this area. Besides predators, the convergence pool also had large numbers of potential competitors (juvenile peamouth, juvenile sunfish, threespine stickleback, and prickly sculpin), which could reduce the food available for Chinook salmon. In the upstream reach, few other fish species were present and the habitat conditions appeared to be better than the convergence pool.

Culvert Creek.— Although few Chinook salmon were present at Culvert Creek, it does provide evidence that small creeks or seeps could be potential Chinook salmon rearing habitat. The number observed at Culvert Creek in 2004 was higher than the number observed in 2002 in much larger tributaries such as May Creek (Tabor et al. 2004b). Use of these small tributaries has not been well documented; however, in the Nooksack River system, Chinook salmon fry were frequently caught in several spring seeps and small tributaries but not along the river edge

(P. Castle, WDFW, unpublished data). Use of these small tributaries in Lake Washington is probably most beneficial for newly emerged fry. These tributaries would provide shallow water habitat and large predatory fish would most likely be absent. As they grow and move into deeper habitats their use of these small tributaries would be greatly reduced.

The number of juvenile Chinook salmon in Culvert Creek may actually be high considering the poor condition of the habitat. The creek could be significantly improved if it was daylighted and riparian vegetation was planted. Additionally, the creek delta was adjacent to riprap and the abundance of predatory fishes (bass and large sculpin) appeared to be much higher than at other tributary deltas. Any stream restoration project would probably also need to include removing the riprap. If the creek was restored, perhaps it could support as many as 50 juvenile Chinook salmon (based on densities observed in Johns Creek).

CHAPTER 7. WOODY DEBRIS AND OVERHANGING VEGETATION EXPERIMENT

Introduction

In 2001 and 2002, habitat manipulation experiments were conducted in Gene Coulon Park to test the use of small woody debris (SWD) by juvenile Chinook salmon. In all experimental tests, no preference for SWD was found (Tabor and Piaskowski 2002, Tabor et al. 2004b). However during snorkel surveys, juvenile Chinook salmon were found to extensively use natural small woody debris when associated with overhanging vegetation (OHV) in south Lake Washington and Lake Sammamish. Since no preference was shown for SWD by itself during experimental tests, then OHV may be an important element of preferred habitat for juvenile Chinook salmon. In 2003, we conducted the final phase of our habitat manipulation experiments by examining the use of OHV in combination with SWD.

Methods

We used the same site in Gene Coulon Park that we used in 2001 and 2002 (Figure 14). The shoreline was divided into six 15-m shoreline sections: two with SWD, two with OHV/SWD and two with no structure of any kind. The structures within the SWD only sections and OHV/SWD sections were 8 m long and located in the middle of the 15-m shoreline section. In the sections with OHV, we placed four fence posts in the water at a 0.3 m depth and then a rope was tied between them, approximately 0.4 meter above the water. Scotch broom (*Cytisus scoparius*) cuttings (1.5 to 2 m long) were then laid down such that the base of each cutting was close to the edge of the shore and the top part of the cutting rested on the rope (Figure 41). The cuttings were anchored with sand bags on shore and cable ties along the rope. The small woody debris consisted of tree branches placed in two rows parallel to shore. Each row was approximately 1 to 2 m wide. The rows were approximately 1.5 m apart, which allowed room for a snorkeler to swim between the rows. Small woody debris was placed along 0.4 and 0.7 m depth contours and was tied together and anchored with sand bags. Snorkel surveys were conducted within each shoreline section. Surveys were done during both day and night. Surveys were done along the 0.4 m depth contour. At the beginning of each snorkel survey, the temperature (^oC) and light intensity (lumens/ft^2) was measured. Light intensity measurements were taken at the water surface with an International Light Inc., model IL1400A radiometer/photometer.

During the day, Chinook salmon were active and often moved away from snorkelers. To get a more accurate count and insure that snorkelers did not push fish into an adjoining section, two snorkelers slowly swam toward each other from the outer edges of each shoreline section. After surveying each section, snorkelers compared notes on fish observed and adjusted fish counts to reduce the likelihood that fish were double counted. At night, shoreline sections could be surveyed by one snorkeler. Fish were inactive and usually did not react to the snorkeler. Occasionally, a Chinook salmon was startled but usually only swam away a short distance in any direction. Therefore, it was possible for a fish to have moved into an adjoining section, but we considered this number to be insignificant in comparison to the total number of fish observed. Within each shoreline section with structure, we also estimated the number of Chinook salmon

FIGURE 41.—Placement of Scotch broom used to experimentally test the use of overhanging vegetation by juvenile Chinook salmon. Small woody debris was also placed next to the Scotch broom on the lake side.

that were closely associated with OHV or SWD or were located on the periphery of the structure (3.5-m shoreline length on each side of the structure).

We conducted the experiment during two time periods, an early period (March 24 to April 9) and a late period (May 2 to 16). To compare between treatments, we used a one-way analysis of variance test (ANOVA).

Results

A total of ten daytime surveys were conducted during the early time period between March 24 and April 9. On each survey date, both the OHV/SWD sections had a substantially higher number of Chinook salmon than any other section. The daytime abundance of Chinook salmon was significantly different between shoreline types (Figure 42; ANOVA, $F = 87.7$, df = 2,3, $P = 0.002$). Results from a post hoc Fisher's LSD test showed a significantly higher abundance in the OHV/SWD sections than either the SWD sections or open sections. No difference was detected between SWD and open sections. Large numbers of Chinook salmon were often observed directly under OHV (Figure 43). On average, 86.7% of the Chinook salmon within the OHV/SWD sections were most closely associated with the OHV part of the structure, while 6.3% were associated with the SWD and 6.8% were in the open on the periphery of the structure. Three nighttime surveys were conducted during the early time period. There was no significant difference in nighttime Chinook salmon abundance between shoreline types

(ANOVA, $F = 5.6$, df = 2,3, $P = 0.098$). However, 46% of all the Chinook salmon were present in the open sections and 65% of those within sections with structure (OHV/SWD and SWD) were located in the open, away from the structure.

During the late time period (May 2–16), seven daytime and four nighttime snorkel surveys were conducted. There was no significant difference in Chinook salmon abundance between shoreline types during either the daytime (Figure 42; ANOVA, $F = 0.02$, df = 2,3, $P = 0.98$) or nighttime (ANOVA, $F = 6.0$, df = 2,3, $P = 0.089$). Unlike the early time period, few Chinook salmon used OHV during the daytime of the late time period. On average, only 7.2% of the Chinook salmon within the OHV/SWD sections were most closely associated with the OHV while 30.2% were associated with the SWD and 62.6% were in the open on the periphery of the structure. During the early time period, only 17% more Chinook salmon were observed at night than during the day; however, twice as many were observed at night as during the day during the late time period. This suggests that either snorkelers were less able to observe the Chinook salmon during the day of the late time period or many of the Chinook salmon were further offshore during the day of the late time period and not close to snorkelers.

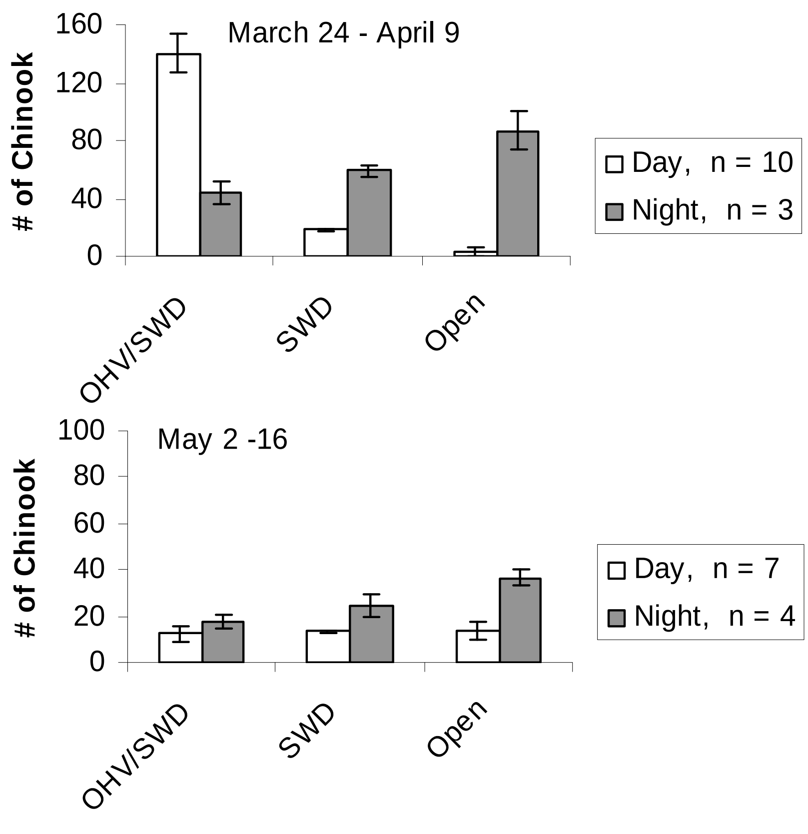


FIGURE 42. —Mean number (±range) of juvenile Chinook salmon observed in three habitat types during an early and late time period, Gene Coulon Park , south Lake Washington (2003). Bars represent the mean of two replicates. n = the number of snorkel surveys used to calculate the mean number observed for each replicate. OHV = overhanging vegetation; SWD = small woody debris.

FIGURE 43.—Photo of a group of juvenile Chinook salmon within a overhanging vegetation/small woody debris (OHV/SWD) structure, March 27, 2003. Within this structure, Chinook salmon were more closely associated with the OHV.

Discussion

A variety of different surveys from Lake Washington, Lake Sammamish, and Lake Quinault have indicated that overhead cover (alone or in combination with small woody debris) is an important habitat feature for small Chinook salmon. In March 2001, small Chinook salmon were often found under south Lake Washington docks during the day (Tabor and Piaskowski 2002). No SWD was present under these docks. Surveys of natural OHV/SWD sites in Lake Washington and Lake Sammamish found large numbers of small Chinook salmon were often present (Tabor and Piaskowski 2002; Tabor et al. 2004b). In Lake Quinault, we also found Chinook salmon directly under LWD and OHV. In 2004, we undertook a field experiment to test its importance, and results clearly showed that large numbers of Chinook salmon use sites with overhead cover. Use of overhead cover by juvenile Chinook salmon has also been observed in Cedar River (R. Peters, USFWS, unpublished data). Brusven et al. (1986) used an artificial stream channel to test the importance of overhead cover and found it was an important habitat component for juvenile Chinook salmon. Meehan et al. (1987) covered sections of a side-channel of the South Fork Salmon River and found the number of juvenile Chinook salmon was substantially higher in the covered sections than open sections.

The use of overhead cover has also been documented for other juvenile salmonids. Juvenile Atlantic salmon preferred overhead cover when light levels were greater than 300 ft-c (Gibson and Keenleyside 1966). Fausch (1993) found juvenile steelhead selected habitat structures that provided overhead cover; however, juvenile coho salmon did not select overhead cover. The use of overhead cover has also observed in adult salmonids such as brown trout, rainbow trout, and brook trout (Gibson and Keenleyside 1966; Butler and Hawthorne 1968).

The main function of overhead cover for juvenile Chinook salmon was most likely predator avoidance. It would seem unlikely that Chinook salmon selected the overhanging vegetation because of food availability. In our experiments, we used freshly-cut scotch broom and it's doubtful if there was any increase in prey abundance. Besides, there probably would not be enough food production for the large number of Chinook salmon in such a small area. Chinook salmon associated with the overhead cover were inactive and did not appear to be actively foraging. In contrast, fish in open areas were often observed foraging. The overhead cover probably provides a visual refuge from avian predators as well as fish predators. Helfman (1981) proposed that fish utilize overhead cover because they are better able to see approaching predators and it is hard for predators to see into the shade.

Similar to 2002 results, no significant difference was detected between experimental SWD sites and open sites. Overall, there was fives times as many fish in the SWD sites as the open sites; however, there was large variability between survey dates. For example, on seven occasions, there were no fish in a SWD section but on four occasions were more than 30 fish. Small woody debris does not appear to provide resting habitat like OHV/SWD but still may be important as a refuge from predators. Chinook salmon may retreat to the SWD if a predator approaches and only use the SWD for a short period of time until the predator has moved away. The addition of SWD adds structural complexity and may reduce the foraging ability of predators (Glass 1971).

In May, juvenile Chinook salmon were rarely found associated with OHV or SWD. Previous work in Lake Washington also indicated Chinook salmon do not appear to extensively use cover as they increase in size (Tabor et al. 2004b). In the Cedar River, juvenile Chinook salmon were located further from cover as they became larger (R. Peters, USFWS, unpublished data). Allen (2000) also found that juvenile Chinook salmon in the Yakima River were further away from instream cover as they grew larger. As Chinook salmon grow they inhabit deeper waters and may not need to use cover. Deeper water may act a visual barrier from some predators such as avian predators. Gibson and Power (1975) found that juvenile Atlantic salmon used overhead cover in shallow water but if they were in deeper water it was not used. Additionally, juvenile Chinook salmon may not need to use cover because they will have much faster burst swimming speed as they increase in size (Webb 1976) and thus can quickly move away from some types of predators. Alternatively, juvenile Chinook salmon may be further away from cover in May but complex structures such as OHV and SWD may still be important as a refuge from predators. As Chinook salmon increase in size and have faster burst swimming speed, they can move further from cover and still be able to retreat to cover if a predator approaches. For example, in 2001 we observed a large school of juvenile Chinook salmon feeding offshore in the open but later they quickly moved to OHV/SWD that was close to shore when they were pursued by two mergansers (Tabor and Piaskowski 2002).

CHAPTER 8. LAKE QUINAULT SURVEYS

Introduction

Some habitat features such as LWD and emergent vegetation are difficult to study along the highly developed shorelines of Lake Washington and Lake Sammamish because they are rare. Outside of the Lake Washington basin, the only other major run of ocean-type Chinook salmon that spawn above a large lake in the State of Washington occurs in the Quinault River above Lake Quinault. In 2003, we conducted a preliminary investigation of Lake Quinault to determine if the lake could be used to study the habitat features that are rare in the Lake Washington basin. A few day and night snorkel surveys were conducted in April and July. Large numbers of Chinook salmon were found along the lake shoreline and the lake had large areas with LWD and emergent vegetation. Additionally, the shoreline is relatively undeveloped and the only introduced fish species is common carp, which do not appear to be abundant. Therefore, the lake appeared to be an excellent site to study juvenile Chinook salmon habitat use in a pristine lentic environment and examine some habitat features not found in the Lake Washington basin.

Methods

Chinook salmon habitat use was studied during two periods in 2004; one in late April and another in late June. The nearshore area was divided in one of five habitat types (Figure 44): open beach (gentle slope) with small substrate (sand and gravel), bedrock and large substrate (steep slope), emergent vegetation (Figure 45), LWD (Figure 45), or tributary mouths. Except for deltas of some small tributaries, we only used nearshore areas where the shoreline habitat was the same for at least 50 m.

The maximum transect length was 120 m. Only one area of the lake had bedrock and three transects were established at this location (Figure 44). These transects were surveyed on each study period during both day and night. Seven tributary mouths were chosen, three (Gatton Creek, Falls Creek, and Willaby Creek) are spawning streams for Chinook salmon, the other four tributaries are considered nonnatal streams. For the other three habitat types, we used a stratified random sampling design to select transects to survey. Sampling consisted of both day and night snorkel surveys. We tried to survey the same transects on each study period during both day and night; however, we were not able to survey a few transects due to time constraints or weather issues. On low to moderate sloping shorelines, two depth contours (0.4- and 0.7-m depth) were surveyed, while on steep sloping shorelines only one depth contour (0.4- m depth) was surveyed. Chinook salmon (separated into those greater than and less than 60 mm FL) and other fish were counted along each transect. A habitat survey was also done at each transect. Information collected included: substrate type, length, slope, and amount of structure (woody debris or emergent vegetation).

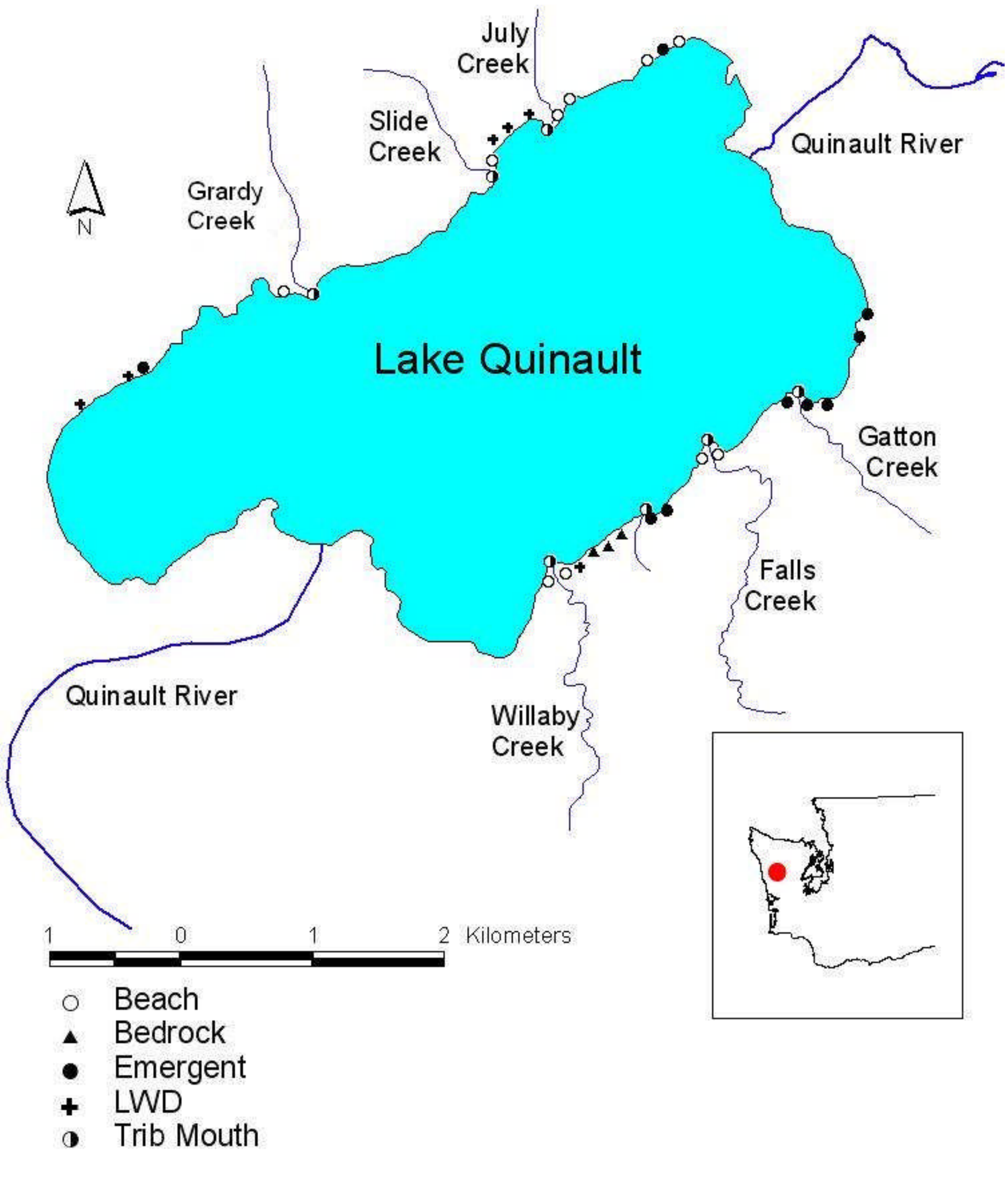


FIGURE 44. —Location of nearshore transects used to study habitat use of juvenile Chinook salmon in Lake Quinault, 2004.

FIGURE 45. — Photos of large woody debris habitat (upper photo) and emergent vegetation habitat (lower photo) of Lake Quinault.

We compared day and night Chinook salmon counts with a sign rank test. The abundance of fish at each site was calculated two separate ways; 1) nearshore abundance (number of fish per 100 m of shoreline), and 2) shoreline density (number of fish per m^2). The nearshore abundance is the estimated number of fish to 1-m depth and is based on fish counts along one or two transects (depending on the bottom slope) and then expanded based on the distance from the shoreline to 1-m depth. The shoreline density is the number of fish along the 0.4-m transect. We used a transect width of 2.5 m for the 0.4 contour depth and 2 m for the 0.7-

m depth contour, which are the same widths used for index sites in Lake Washington (Chapter 1). Abundance of fish in different habitat types for April and June were compared with an one-way ANOVA and Fisher's LSD test. Separate tests were performed for the nearshore abundance (#/100 m of shoreline) and shoreline density (#/m^2).

Results

In April 2004, large numbers of juvenile Chinook salmon were observed during both day and night. Comparison of sites that were surveyed day and night (n = 12) indicated there was no difference in the number of Chinook salmon (sign rank test, $P = 0.39$). Of all day and night transects in April (n = 47), there was only one day transect where no Chinook salmon were observed. In June, few Chinook salmon were observed during the day except at tributary mouths. Overall, significantly more Chinook salmon were observed at night than during the day in June (sign rank test, $P = 0.002$). No Chinook salmon were observed along 11 of the 25 (44%) day transects. In contrast, Chinook salmon were observed along every night transect (n = 26).

Both daytime nearshore abundance (number/100 m of shoreline) and daytime shoreline density (#/m^2) of juvenile Chinook salmon in April was significantly different between habitat types (Figure 46; ANOVA, df = 3,7; #/100 m, $F = 4.2$, $P = 0.008$; #/m^2, $F = 6.6$, $P = 0.001$). Results of a post-hoc Fisher's LSD test indicated that tributary mouths generally had higher numbers of Chinook salmon than the other habitat types and bedrock sites often had a lower number (Figure 46). Beach, emergent vegetation, and LWD sites were not significantly different from each other. The abundance of Chinook salmon in emergent vegetation sites was highly variable, which appeared to be due to differences in the type of emergent habitats. Sites with soft, silty sediments and a gentle slope tended to have a lower abundance than sites with a sand/gravel substrate and a moderate slope. If emergent sites are removed from the ANOVA model, the nearshore abundance at LWD sites becomes significantly higher than at beach sites as well as bedrock sites. Within LWD sites, juvenile Chinook salmon were often resting directly under a large piece of LWD.

Only 12 transects were snorkeled at night in April. No significant differences were detected between habitat types for either number/100 m of shoreline (ANOVA, $F = 3.1$, df = 3,7, $P = 0.099$) or shoreline density (ANOVA, $F = 2.1$, df = 3,7, $P = 0.19$). However, the average number/100 m of shoreline at bedrock sites was considerably lower than the other habitat types.

Ninety percent of Chinook salmon observed during the day in June were at tributary mouths. The number of Chinook salmon/m was 1.14 at the tributary mouths; whereas it was only 0.02 at the other sites. Chinook salmon were observed at all tributary mouth sites (n = 6) but only observed at 5 of 19 (28%) other sites. Because no Chinook salmon were observed at most sites except at the tributary mouths, no statistical test was preformed. At tributary mouth sites, most Chinook salmon were located directly in the current, close to where the stream enters the lake.

The nighttime nearshore abundance (#/ 100 m of shoreline) of Chinook salmon in June was not significantly different between habitat types (ANOVA, $F = 7.4$, df = 4,21, $P = 0.001$).

Similar to April surveys, the nearshore abundance in emergent sites was also highly variable between sites. If emergent sites are removed from the ANOVA model, abundance at beach sites and tributary mouths becomes significantly higher than at bedrock sites. The June nighttime shoreline density ($\#/m^2$) was significantly different between habitat types (ANOVA, $F = 3.1$, df = 3,7, $P = 0.099$). Results of a post-hoc Fisher's LSD test indicated that tributary mouths generally had higher shoreline densities than the other habitat types and bedrock sites had lower shoreline densities than beach sites (Figure 47).

Chinook salmon observed in June were a wide range of sizes. There appeared to be two distinct groups, a group of large individuals that were approximately 70-90 mm FL and a group of smaller individuals (45-60 mm FL). We made separate counts for each group. We divided them into two size categories (less than and greater than 60 mm FL). During the day, Chinook salmon were mostly observed at tributary mouths and 68% were large Chinook salmon. The large Chinook salmon were located in the current of the tributary and slightly offshore, while the small Chinook salmon were located close to shore on the periphery of the delta. The few Chinook salmon observed at the other habitat types during the day were all small. At night, 69% of the Chinook salmon were small and there was no large difference in the ratio of small to large Chinook salmon between the habitat types.

At many sites, we also observed large numbers of juvenile coho salmon. Small juvenile coho salmon and coho salmon presmolts were observed in April, while in June only juvenile coho salmon were observed. Most juvenile coho salmon appeared to be smaller than Chinook salmon and were more closely associated with LWD, especially during the day. During the day in April, the number of juvenile coho salmon per shoreline length was 0.63 fish/m for LWD sites, whereas it was 0.23 fish/m for beach, bedrock, and emergent sites, combined. No coho salmon were observed at the seven tributary mouth sites. At night in April, the highest abundance of coho salmon was observed in beach sites, 0.91 fish/m. Coho salmon presmolts were observed primarily at night at beach and tributary mouth sites. Sixty-six percent of all coho salmon observed during the day in June were in LWD sites. The abundance of coho salmon at LWD sites was 1.0 fish/m; however, at the other sites combined it was only 0.14 fish/m. At night in June, good numbers of juvenile coho salmon were observed in each habitat type. The highest abundances were observed in LWD (0.88 fish/m) and tributary mouth sites (0.80 fish/m).

Besides juvenile Chinook salmon and coho salmon, other fish commonly observed included speckled dace (*Rhinichthys cataractae*), threespine stickleback, prickly sculpin, trout, and suckers. Speckled dace were especially abundant at night. During the day, they appeared to usually be closely associated with some type of cover such as woody debris or emergent vegetation; while at night, they were in the open areas of each habitat type. Large numbers of threespine stickleback were observed in emergent vegetation sites as well as beach and tributary mouth sites. A few small sculpin (< 75 mm TL) were observed during the day; while at night, large numbers of small and large (> 75 mm TL) sculpin were observed in all habitat types. Trout were observed primarily at night. The only place we observed large trout (> 150 mm) during the day was at tributary mouths. Adult suckers were observed primarily at tributary mouths (day and night) and juvenile suckers were observed at night primarily at beach and emergent sites.

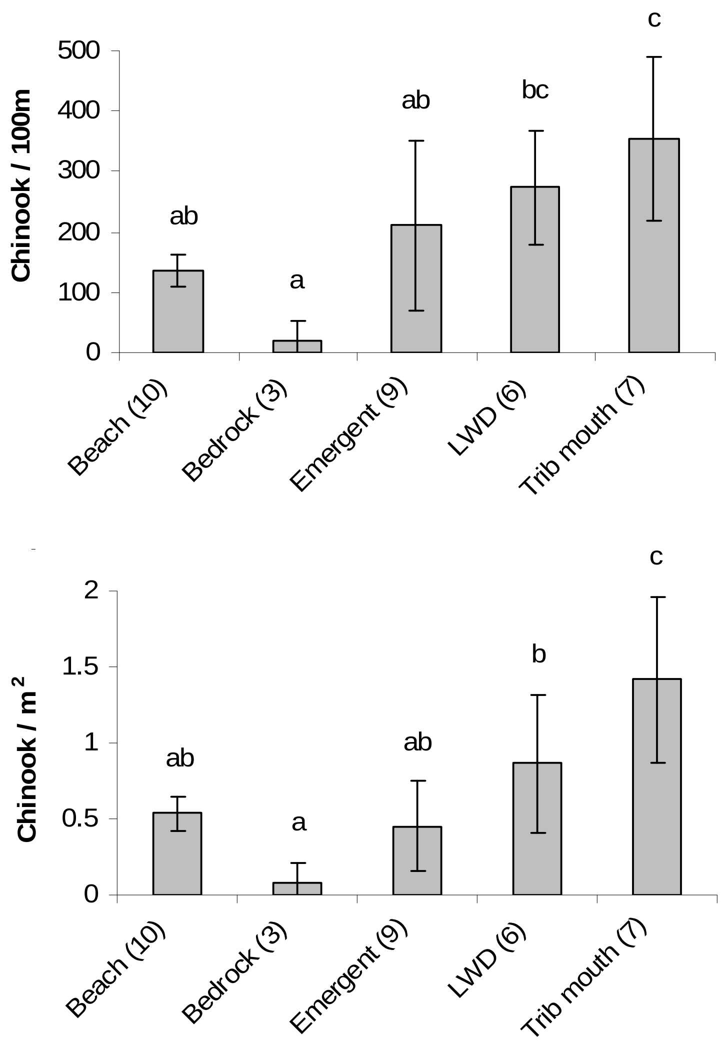


FIGURE 46. —April daytime nearshore abundance to 1 m depth (mean ± 2SE; top panel) and shoreline density (mean ± 2SE; lower panel) of juvenile Chinook salmon in Lake Quinault, 2004. Bars with different letters are significantly different (ANOVA and Fisher's LSD; $P < 0.05$). Numbers in parentheses indicate the number of replicates.

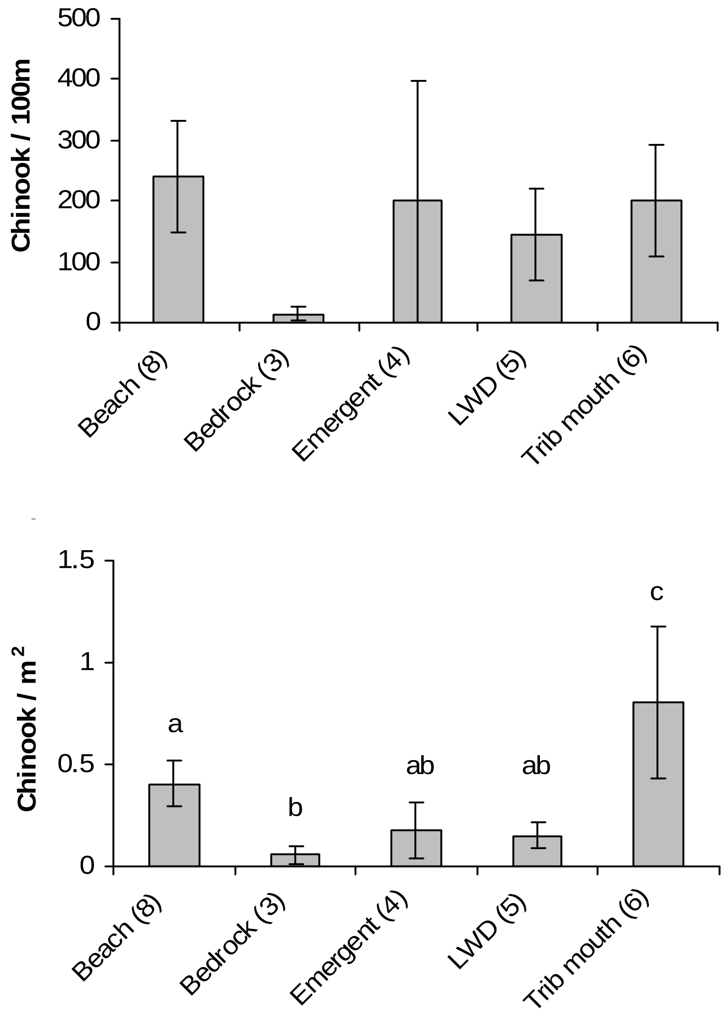


FIGURE 47. —June nighttime nearshore abundance to 1 m depth (mean ± 2SE; top panel) and shoreline density (mean ± 2SE; lower panel) of juvenile Chinook salmon in Lake Quinault, 2004. Bars with different letters are significantly different (ANOVA and Fisher's LSD; $P < 0.05$). The ANOVA test was not significant for the nearshore abundance (top panel). Numbers in parentheses indicate the number of replicates.

Discussion

Except for tributary mouths, few significant differences were observed in the use of different habitat types in Lake Quinault. Lack of pronounced differences may have been due to small sample sizes and high variability in Chinook salmon abundance between sites. There is little bedrock shoreline in Lake Quinault and only three bedrock sites were established. The abundance of Chinook salmon at bedrock sites was substantially lower than other habitat types, yet we detected few significant differences between bedrock sites and other habitat types.

High variability in the April surveys may have been due to differences in the distance to natal streams. For example, sites in the northeast corner of the lake near the mouth of Quinault River appeared to have a higher abundance of Chinook salmon than other sites. Adjusting the counts of Chinook salmon based on distance to natal streams would be difficult because there are several natal streams spread around the east and south shoreline of the lake. In June, Chinook salmon were probably well distributed around the lake and distance to the natal stream probably had little influence on their abundance.

The abundance of Chinook salmon at emergent vegetation sites was highly variable. Much of the variability appeared to be due to the substrate type and bottom slope. Sites with sand and gravel substrates (hard substrates) tended to have a higher abundance (1.5 times higher in April and 21 times higher in June) than emergent sites with silt and mud (soft substrates). Areas with soft substrates also had a more gradual slope than areas with hard substrates. In 2001 and 2002, we made some preliminary observations on the use of soft substrates (silt and mud) by juvenile Chinook salmon in Lake Washington (Tabor and Piaskowski 2002; Tabor et al. 2004b), which suggested that they tend to avoid this substrate type. Results from surveys at Beer Sheva Park provided further evidence that Chinook salmon do not extensively use soft substrates. The reasons why soft substrates are avoided is unclear. We hypothesized that Chinook salmon may avoid soft substrates in Lake Washington because these areas may have a higher density of predators such as largemouth bass and brown bullhead. However, in Lake Quinault these predators do not occur. Soft substrates also appear to have a higher density of macrophytes than other substrate types and Chinook salmon may prefer a more open environment. Other possible explanations include competition with threespine stickleback, which were predominantly found in emergent vegetation sites with soft substrate. Other potential competitors, including speckled dace and juvenile coho salmon, were also common in these sites. Also, the soft substrate sites appear to often have higher turbidity than other sites which could reduce foraging success of juvenile Chinook salmon.

In comparing fish abundance, we assumed that Chinook salmon could be observed equally between the different habitat types. However, it is certainly possible that there was some degree of bias. The distance at which a fish will react to a potential predator (reactive distance) may be much longer in open areas than in complex habitats such as LWD and emergent vegetation sites (Grant and Noakes 1987). Alternatively, fish can be difficult to observe in complex habitats because they can easily hide from the observer. Additionally, emergent vegetation sites with soft substrates appeared to have higher turbidity from wave action and/or common carp activity, which may also have reduced our ability to observe juvenile Chinook salmon. Some additional sampling techniques such as beach seining could be employed to confirm the results but other techniques may also have some bias between habitats types.

Although we did not document a strong preference for LWD or emergent vegetation in Lake Quinault, these habitats may still be more beneficial than open beach habitat if survival rates are higher in structurally complex habitats. The addition of LWD or emergent vegetation adds structural complexity and reduces the foraging ability of predators (Glass 1971). Research in warm-water systems has been found that structural complexity is important for survival of many species of juvenile freshwater fishes (Savino and Stein 1982; Werner and Hall 1988).

Tabor and Wurtsbaugh (1991) concluded that nearshore structural complexity improved the survival of juvenile rainbow trout in reservoirs because trout strongly selected this habitat feature and improved survival was demonstrated in a pond experiment.

The benefit of LWD in Lake Washington and Lake Sammamish has been debated because it may provide valuable salmonid habitat but it may also be used extensively by smallmouth bass and other introduced predatory fish. Fresh et al. (2001) found that smallmouth bass occurred primarily in areas with cobble and were usually near some type of structure such as a dock. Smallmouth bass generally prefer areas with a steep sloping bottom (Hubert and Lackey 1980). Therefore, LWD could be placed in areas with fine substrates and a gentle slope, which is what juvenile Chinook salmon prefer. However, LWD sites with a gentle slope could also be used by largemouth bass. At a natural OHV/SWD site (gentle slope with sand substrate) in Lake Washington we observed juvenile Chinook salmon for a few weeks until an adult largemouth bass was observed. Another possible management scenario would be to only have LWD placed in the south end of the lake. From February to mid-May, juvenile Chinook salmon are located primarily in the south end of the lake. Smallmouth bass and largemouth bass do not appear to become very active until May when water temperatures are greater than 10^{o}C and by then many of the juvenile Chinook salmon have moved into deeper waters. Also, by only having the LWD in the south end, the total population of bass in Lake Washington may not increase substantially.

Experiments in Lake Washington in 2001 (Tabor and Piaskowski 2002), 2002 (Tabor et al. 2004b), and 2003 (Chapter 7) indicated SWD is not preferred habitat for juvenile Chinook salmon. Similarly, LWD was not strongly preferred over open beach areas in Lake Quinault. It is difficult to make comparisons between the SWD and LWD because they were not directly compared in the same study. However within LWD sites, juvenile Chinook salmon were commonly located directly under pieces of LWD that had a large diameter. Therefore in Lake Quinault, LWD may be more beneficial than SWD because it provides more overhead cover. Small woody debris provides some structural complexity but provides little overhead cover. Ideally, a study of different diameter woody debris would be valuable to determine the best size of woody debris to use in restoration projects. A simpler approach would be to measure the diameter of the piece of woody debris that Chinook salmon were associated with and compare to the sizes of woody debris available.

CHAPTER 9. SURFACE OBSERVATIONS OF MIGRATING JUVENILE CHINOOK SALMON IN LAKE WASHINGTON

Introduction and Methods

On June 19, 2001, several schools of Chinook salmon were observed migrating along the Seattle shoreline of Lake Washington (Tabor and Piaskowski 2002). Observations were made from a pier at Stan Sayres Park. These schools were observed swimming north in approximately 2.1- to 2.5-m deep water and as they approached the pier they moved to deeper water (3.1-m deep water) and swam around the pier. Occasionally, we looked for migrating Chinook salmon at this pier and other piers during the months of May and June in 2002 but no Chinook salmon were seen. In 2003 and 2004, we undertook a more systematic sampling approach to determine when they can be observed migrating along the shore. Additionally, we wanted to collect additional information on their behavior in relation to piers. In 2003, weekly observations (May-July) were conducted at one site, a public pier near McClellan Street. This site was selected because no other piers were nearby to alter the fishes' behavior and the offshore end of the pier was relatively deep (9.5 m) compared to other piers. The pier is perpendicular to the shoreline and is 42 m long, 2.4 m wide, and 0.45 m above the water surface. There were few aquatic macrophytes at this site. Additional observations were also taken on June 26, 2003 at Mt. Baker Park and Stan Sayres Park when juvenile Chinook salmon appeared to be abundant. In 2004, the McClellan Street pier was again monitored weekly in May through July. In addition, several other piers (Table 14; Figure 48) were surveyed within a few days of the moon apogee when we expected juvenile Chinook salmon would be abundant (DeVries et al. 2004).

TABLE 14. —Dates surveyed and general habitat conditions of south Lake Washington piers used to observe migrating juvenile Chinook salmon in June 2004. Percent slope was measured from the toe of the shoreline armoring to the offshore end of the pier. Milfoil density is a description of the density of Eurasian milfoil; A = abundant; R = rare or absent.

Shoreline Site	Dates surveyed	Length (m)	Distance from shore (m)	Width (m)	Maximum depth (m)	Slope (%)	Milfoil density
West shore							
Beer Sheva boat ramp	June 17	12	12	1.9	1.9	15.7	A
Island Drive	June 17	20	20	1.5	3.5	15.7	R
Seward Park	June 18	26	19	2.4	4.2	22.1	A
Stan Sayres Park	June 17	32	32	2.5	2.6	7.7	A
Mt. Baker Park	June 16,17,18	74	50	1.8	7.5	15.0	A
Jefferson Street	June 15,17	59	42	2.4	7.5	18.0	A
Madison Park	June 17,18	25	25	3.7	3.0	10.4	R
Edgewater Apartments	June 17	9	9	9.0	2.1	11.7	A
East Shoreline							
Chism Park	June 18	39	34	2.4	3.5	8.2	R
Mercer Island							
Groveland Park - A	June 18	65	32	1.8	7.3	22.8	A
Groveland Park - B	June 18	28	19	2.8	3.0	12.9	A

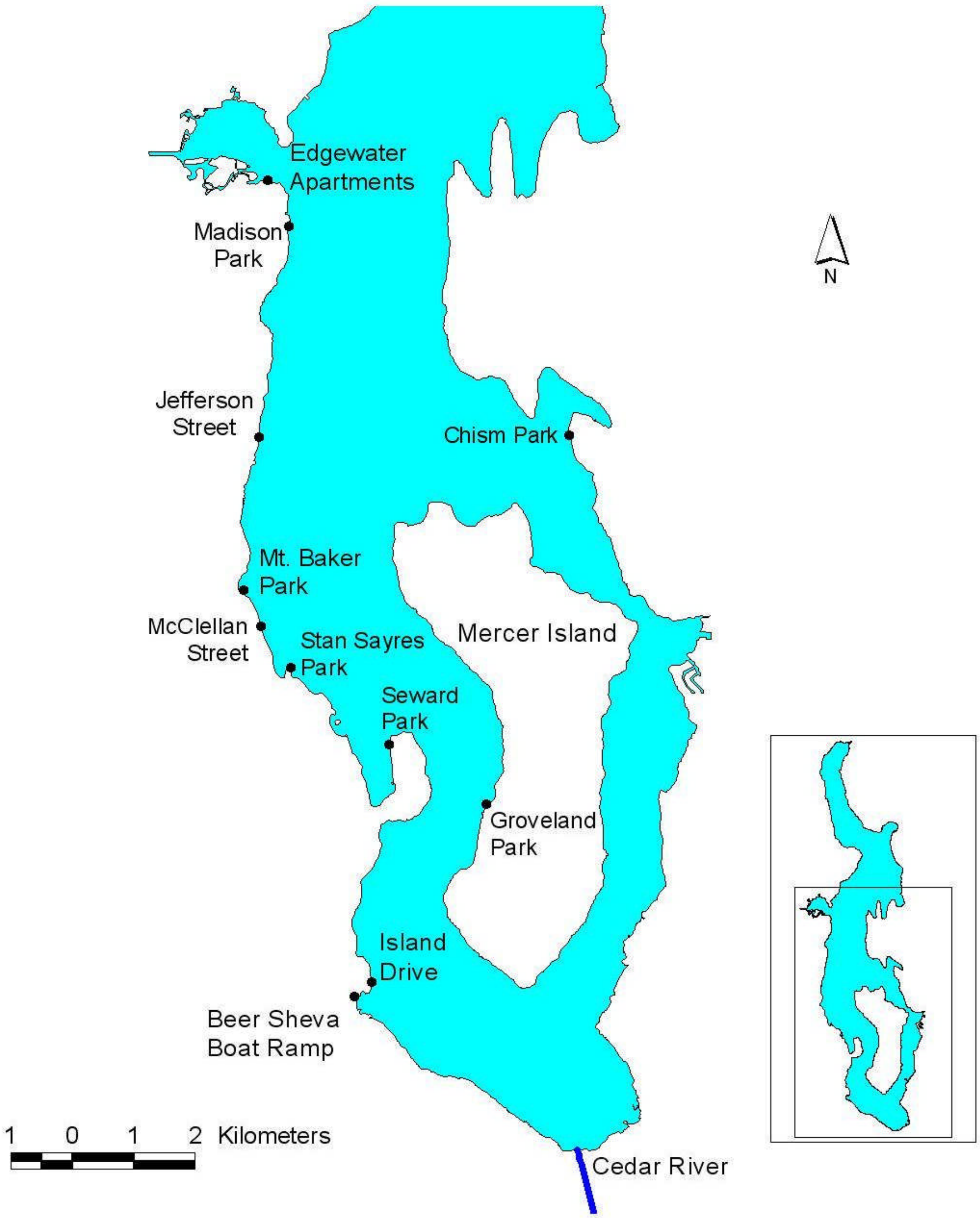


FIGURE 48.—Location of south Lake Washington piers used to conduct visual observations of migrating Chinook salmon. The McClellan Street pier was surveyed weekly from May to July, 2003 and 2004. The other piers were only surveyed during the peak migration period in June.

Observations were conducted primarily in the morning when the water was calm and fish could be easily observed. On windy days, no observations could be conducted. Observations were made by standing on the pier and observing schools of Chinook salmon as they swam near the pier (Figure 49). The time each school was observed and the direction they are swimming was noted. The size of each school of Chinook salmon was categorized as either small (< 50 fish), medium (50-100 fish), large (100-200 fish) or very large (> 200 fish). How Chinook salmon responded to the pier was determined by estimating the depth of each school as the approached the pier and the depth they were at as they past under or around the pier.

Results

Surface observations at the McClellan Pier were conducted once a week from May 21 to July 3 in 2003 and May 19 to July 9 in 2004. During the first five surveys in 2003 (May 21 to June 18), few juvenile salmonids were observed and no obvious movements were seen. Similarly in 2004, few Chinook salmon were observed until June 16. On June 26, 2003 and June 16, 2004, large numbers of salmonids were observed moving along the shoreline. Based on fish size and date, we assumed they were juvenile Chinook salmon. Snorkel surveys conducted in 2004 also indicated they were Chinook salmon. To better understand fish movements, we conducted additional surface surveys during the period when Chinook salmon were abundant. The timing of the migration appeared to coincide with the moon apogee, which has been also suggested to be related to the passage of Chinook salmon smolts at the Ballard Locks (DeVries et al. 2004).

When Chinook salmon were abundant at McClellan Pier, we took extended observations to collect additional information on migrating Chinook salmon. In 2003, extended observations were conducted twice (June 26 and July 1) and in 2004 they were conducted three times (June 16 to 18). On all five dates, observations were conducted from at least 0730 h to 1100 h (Figure 50). Peak number of schools was observed between 0800 h and 0830 h and the lowest abundance was at the end of the survey between 1030 h and 1100 h. However, results of an ANOVA test indicated there was no significant difference in abundance for any half hour period between 0730 h and 1100 h. Additional observations were conducted if weather conditions and personnel schedules permitted. On one date, June 16, 2004, we were able to make observations from 0600 h to 1200 h (Figure 51). On this date, few schools of Chinook salmon were observed before 0730 h and after 1100 h. Observations on other dates showed the same general trend; little activity before 0700 h and a reduction in activity after 1100 h or 1200 h.

FIGURE 49.—Conducting visual observations of migrating Chinook salmon at the McClellan Street pier, Lake Washington.

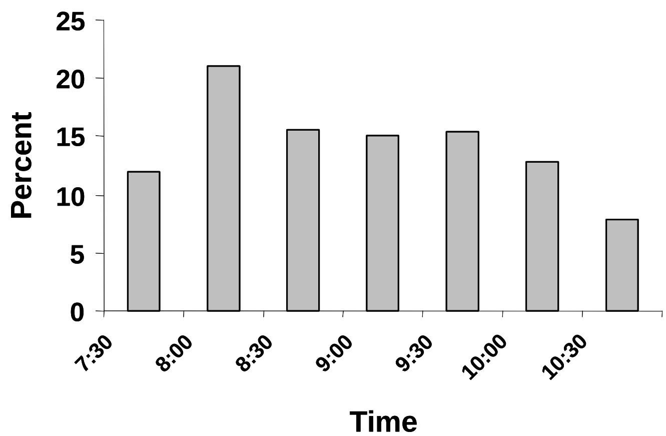


FIGURE 50. —Percent of Chinook salmon schools occurring in half hour intervals between 0730 h and 1100 h, McClellan Pier, Lake Washington. Bars represent the mean percent of five dates, June 26, 2003, July 1, 2003 and June 16 to 18, 2003.

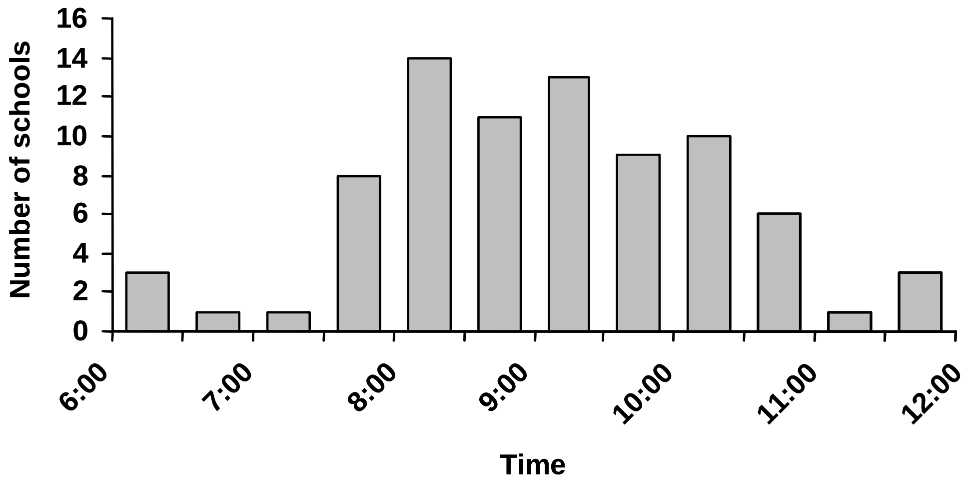


FIGURE 51. — Number of Chinook salmon schools observed on June 16, 2004 between 0600 h and 1200 h at McClellan Pier, Lake Washington.

At McClellan Pier, Chinook salmon were observed moving along the shore in both a northerly and southerly direction. In 2003, we observed 64% of the schools moving in a northerly direction; whereas, in 2004 we observed 85% moving north. Combined (2003 and 2004), 47% of the schools were small (0 to 50 fish), 36% were medium-sized (50 to100 fish), 16% were large (100-200 fish) and 1% were very large schools (> 200 fish).

As Chinook salmon approached McClellan Pier they were typically in water that was 1.5 to 2 m deep (Figure 52) and 12 to15 m from the shore. When they got to within 3 to 4 m of the pier, they swam to deeper water and usually swam under the pier where the water depth was about 2.1 to 4.5 m deep. On a few rare occasions, fish did not go under the pier but headed into deeper waters and appear to turn around and head in the opposite direction. After most fish swam under the pier, they usually swam back towards shore and returned to the same depth as they were before encountering the pier. On some occasions, Chinook salmon continued to move to deeper water after they past under the pier. We could not tell if they eventually returned to the shoreline.

FIGURE 52.—Photo of a group of juvenile Chinook salmon moving along the shore at McClellan Pier, Lake Washington, June 2003. Water depth at this location was about 1.7 to 2 m deep.

Besides McClellan Pier, we surveyed 11 other piers. They were all surveyed close to the moon apogee, the time period (2003 and 2004) when Chinook salmon were abundant at McClellan Pier. The location of juvenile Chinook salmon appeared to be related to the presence of Eurasian milfoil (*Myriophyllum spicatum*). If milfoil was present, Chinook salmon were in deeper water and further from shore; however, the depth of Chinook salmon above the milfoil appear to be similar as the total water column depth if the milfoil was absent (i.e., McClellan Pier). Therefore the top of the milfoil appeared to act as the bottom of the water column to Chinook salmon. Milfoil was absent or rare at four locations, McClellan Pier, Beer Sheva Park, Island Drive, and Madison Park, and the mean water column depth of Chinook salmon before encountering the pier was 2.1 m. In contrast, the mean water column depth of Chinook salmon at piers with milfoil was 4.0 m. At Edgewater Apartments and Stan Sayres Park, the top of the milfoil was close to the water surface along the entire length of the dock and few Chinook salmon were observed. At Groveland Park, Jefferson Street, and Seward Park, milfoil was close to the water surface along the length of the dock except at the offshore end of the pier and therefore Chinook salmon were only seen at the end of the dock and they did not appear to change their behavior in response to the pier. Movement of Chinook salmon to deeper water as they approached the pier was observed at Mt Baker and Madison Park piers. At the Island Drive pier, Chinook salmon were observed moving closer to shore as they approached the dock. This was probably caused by other nearby docks, which may have caused Chinook salmon to be further from shore.

Discussion

When migrating Chinook salmon approach a pier they appear to move to slightly deeper water and either pass directly under the structure or swim around the pier. Most likely they move to deeper water as a way of reducing their predation risk. Both smallmouth bass (Fresh et al. 2001) and largemouth bass (Colle et al. 1989) can be found directly under piers. As Chinook salmon approach the pier, they probably have a difficult time seeing under the structure and bass may be better able to see approaching prey fish (Helfman 1981). In deeper water, Chinook salmon will probably have more space to avoid a bass predator. Also, Chinook salmon may move to a greater water column depth and will be further away from the pier and thus there may be more ambient light to help detect the presence of a predator.

Our results appear to support work by DeVries et al. (2004), who found that Chinook salmon smolt emigration past the Ballard Locks was related to the moon apogee. However, in 2003 we only detected movements on or shortly after the June 25 apogee. In contrast, DeVries et al. (2004) observed most Chinook salmon emigrated shortly after the May 28 apogee and little movement was observed after June 25. Taken together, these results suggest that there was a large movement of Chinook salmon following the May apogee and then a much smaller migration following the June apogee. Why we did not observe any Chinook salmon activity on or shortly after the May apogee in unclear. Water temperatures were cooler in May and Chinook salmon may have behaved differently and selected deeper water and were further offshore.

Although visual observations of migrating Chinook salmon can provide useful information, it does have several limitations. Observations can only be conducted when the water surface is calm; this usually means surveys can only be conducted in the morning hours. Only a small area near the shore can be effectively surveyed. Fish in deeper waters are hard to observe. There also may be large differences between observers. The observer may also have some influence on the behavior of Chinook salmon. To get a more complete picture of the behavior of migrating Chinook salmon other techniques are needed. Tracking fish with acoustic tags and obtaining accurate positions appears to be the most promising technique. Efforts in 2005 will focus on this technique.

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