NEARSHORE HABITAT USE BY JUVENILE CHINOOK SALMON IN LENTIC SYSTEMS OF THE LAKE WASHINGTON BASIN, ANNUAL REPORT, 2001

by

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ABSTRACT

Nearshore areas of Lake Washington, Lake Sammamish, and the Ship Canal/Lake Union area were surveyed for juvenile chinook salmon (*Oncoryhnchus tshawytscha*) during the winter and spring of 2001 to provide information on habitat use and its relationship to shoreline development. All three systems are highly altered environments with extensive development along the shoreline. 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 chinook salmon rarely occur in lakes throughout their natural distribution.

Data on chinook habitat use were collected primarily through snorkel surveys. Both day and night surveys were conducted. A variety of study elements were undertaken, which included: random transects in south Lake Washington, Gene Coulon foot surveys, Gene Coulon index sites, restoration site monitoring (Seward Park and Beer Sheva Park), woody debris surveys in Lake Sammamish, habitat manipulation experiments, and Ship Canal surveys.

Initially in February, numbers of juvenile chinook salmon were low in the nearshore areas of south Lake Washington but increased substantially in early March. Day and night random 100-m transects were sampled during two time periods, February-March and April-May; however, few fish were observed during April-May daytime surveys. Based on electivity indices, chinook salmon selected sand and gravel habitats during both day and night throughout the sampling period. During the February-March time period, chinook salmon appeared to commonly use overhead structure during the day but rarely used it at night. In April and May, chinook salmon did not appear to use overhead structures at night or during the day. During both time periods, day and night, the percent of chinook salmon along armored banks (bulkheads and rip rap) was relatively low compared to the percent of shoreline that had armored banks.

In addition to random daytime snorkel sampling, we also conducted foot surveys along a continuous section of shoreline in Gene Coulon Park to further document daytime habitat use as well as assess the effectiveness of daytime snorkeling. The addition of a shoreline observer greatly improved our ability to locate chinook salmon and gather habitat use information. Sand was strongly preferred and boulders rarely used in the Gene Coulon section, similar to what was seen in the randomly-selected sites around the south lake area. However, a slight positive selection for cobble was also observed. Unlike random daytime sampling, few juvenile chinook salmon were observed directly under overhead structures, instead most fish were in the open away from any overhead structure.

During the day, juvenile chinook salmon were usually observed in aggregations, commonly with juvenile sockeye salmon and often were actively feeding at the surface. At night, chinook salmon were no longer in an aggregation and were inactive. They were usually on the bottom in shallow water, close to shore.

Three index sites in Gene Coulon Park were repeatedly surveyed to examine temporal changes in juvenile chinook salmon abundance within the nearshore area. We used the same index sites as in 2000 sampling. In January and February, few chinook salmon were observed but in early March their abundance increased sharply. In late May, the number of juvenile

chinook salmon declined abruptly and few were present in June. Juvenile chinook salmon appeared to move into somewhat deeper water in May and June. Juvenile chinook salmon abundance at index sites was unexpectedly high given the low number of adult spawners in the Cedar River in the fall of 2000.

Baseline information was collected from April to June at two potential restoration sites, Seward Park and Beer Sheva Park. Sampling consisted primarily of nighttime snorkeling. During the first two nighttime surveys (April and early May) at Seward Park, most chinook salmon were observed along the west shoreline. Juvenile chinook appeared to be more evenly distributed across all sites during the last two survey dates in late May and June. Out of three survey dates, only two chinook salmon were ever observed at Beer Sheva Park

We conducted an assessment of the use of woody debris and overhanging vegetation in Lake Sammamish because there was little of these habitat types in south Lake Washington. Three sites with woody debris and overhanging vegetation were compared to three sites without any riparian vegetation. Sites were surveyed once in March and once in May. During the day, there was no significant difference between woody debris sites and open sites, however woody debris sites had a higher overall density of chinook salmon than open sites. At night, significantly more chinook salmon were in open sites than woody debris sites. Large numbers of juvenile coho salmon (*O. kisutch*) were also present in Lake Sammamish, unlike south Lake Washington. During the day, coho salmon had a much stronger affinity towards woody debris than chinook salmon. At night, coho salmon inhabited open sites and were not closely associated with woody debris or overhanging vegetation.

Nighttime scuba diving was done once on May 1 to check deeper waters areas of the nearshore area for the occurrence of juvenile chinook salmon. Results indicated the vast majority of chinook salmon were in water less than a meter deep. Preliminary daytime observations indicated juvenile chinook salmon use water less than a meter deep in March and April but use increasingly deeper water in May and June.

Preliminary habitat manipulation tests were conducted in Gene Coulon Park to experimentally test the use of woody debris and overhead structures. Experiments were conducted in April and May in areas where chinook salmon were known to be abundant. Two sites with structure added were compared to two control sites where no structures were added. Overall, there was no difference between woody debris and control sections during the day or night. However, during the first three dates these sites were monitored during the day, substantially more chinook salmon were present in woody debris sites than in control sites. Chinook salmon appeared to avoid overhead structures during the day and night. Habitat manipulation experiments allowed us to examine some habitat characteristics of juvenile chinook salmon under more controlled conditions and should be considered for future investigations.

Six sites were surveyed in June in the Ship Canal area to determine the effectiveness of snorkeling to gather habitat use information in this area. Few chinook salmon were observed considering the large number of migrating fish. Overall, snorkeling did not appear to be effective in determining chinook habitat use in the Ship Canal.

Table of Contents

List of Tables

List of Figures

List of Photos

INTRODUCTION

Across their natural distribution, chinook salmon (*Oncorhynchus tshawytscha*) primarily occur in large rivers and coastal streams (Meehan and Bjornn 1991) and their use of lakes is relatively rare. Within the Lake Washington basin, an important, wild run of chinook salmon spawns in the Cedar River but a considerable amount of rearing often occurs in Lake Washington. Shortly after emerging from their redds, many juvenile chinook salmon fry migrate to Lake Washington in February and March where they may inhabit the lake environment for 4 to 5 months. Other juvenile chinook salmon remain in the riverine environment and migrate to the lake in May and June and probably spend a relatively short period of time in Lake Washington. Both groups migrate to the Puget Sound as smolts in June and July. Because juvenile chinook salmon rarely inhabit lakes throughout their range, relatively little is known about their ecology in lakes. Recent work indicated that juvenile chinook salmon in Lake Washington are primarily restricted to the littoral zone (Fresh 2000). However, within this area little is known about their habitat use.

The shoreline of Lake Washington is extensively developed (Weitkamp and Ruggerone 2000; Toft 2001). Land use along the lake is mostly residential (Photos 1 and 2), but also includes some recreational and industrial areas. To reduce erosion and improve access, shorelines are commonly armored with rip rap (Photo 1) or bulkheads resulting in steep slopes (Kahler et al. 2000) and little shallow water area (< 1 meter (m) deep). Overhead structures (docks, boat houses, houses, and decks) that shade nearshore areas are common along the shoreline (Photo 2). The few "undeveloped" shoreline areas are relatively small (most <250 m in length) and separated by long distances. Little is known about the relationship between shoreline development and juvenile chinook salmon habitat use.

In 2000, we conducted a preliminary study to determine the feasibility of using nighttime snorkeling and to collect some initial data on juvenile chinook salmon habitat use in south Lake Washington (Piaskowski and Tabor 2001). Results indicated that nighttime snorkeling was an easy and effective method of determining juvenile chinook habitat use. Juvenile chinook salmon were found primarily on low gradient shorelines with small substrates such as sand and gravel. They were concentrated in very shallow water, approximately 0.4 m depth. Preliminary data also indicated that they avoided overhead structures (piers and docks) as well as rip rap and bulkheads. However, sample sizes were small and further data were needed. Additionally, information on the daytime habitat use and habitat use in other areas of the lake was needed.

In 2001, a more intensive study was undertaken to examine the habitat use of juvenile chinook salmon. Habitat use was determined primarily by snorkeling surveys, daytime and nighttime. A variety of study objectives were selected to better understand juvenile chinook salmon habitat use and its relationship to shoreline development.

Study objectives:

1)   Document daytime and nighttime habitat use and examine its relationship to shoreline development.

2)   Examine temporal changes in chinook salmon abundance at index sites and compare 2001 results to 2000 results.

3)   Collect baseline information at potential restoration sites.

4)   Examine the use of woody debris and overhanging vegetation by juvenile chinook salmon.

5)   Document the water depths used by juvenile chinook salmon.

6)   Examine the potential for using artificial structures to conduct controlled field experiments.

7)   Conduct preliminary snorkel surveys in the Ship Canal and Lake Union to assess snorkeling as a survey technique.

STUDY SITE

We examined habitat use of juvenile chinook salmon in Lake Washington, Lake Sammamish, and the Ship Canal. 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 stratifies from June through October. Surface water temperatures range from 4-6°C in winter to over 20°C in summer. Over 78% of the shoreline is comprised of residential land use. 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 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, controls the lake level.

The major tributary to Lake Washington is the Cedar River which enters the lake at the south end. The river originates at approximately 1,220 m elevation and over its 80-km course falls 1,180 m. The lower 35.1 km are accessible to anadromous salmonids. Landsburg Dam, a water diversion structure, prevents fish from migrating upstream of river kilometer 35.1. A fish ladder is planned to be constructed at Landsburg Dam in 2003, which will allow access to an additional 20 km of the Cedar River.

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 Ship Canal. These activities changed fish migration routes and environmental conditions encountered by migrants.

Today, the largest run of wild chinook salmon in the Lake Washington basin occurs in the Cedar River. Adults 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 Cedar River from Lake Washington in September and continue until November. Spawning in the Cedar River occurs from October to December with peak spawning activity usually in November. Fry emerge from their redds from January to March and migrate to Lake Washington from January to July. Juveniles migrate past the Chittenden Locks from May to September. Juveniles migrate to the ocean in their first year, and thus Cedar River chinook salmon are considered "ocean-type" fish.

We surveyed chinook salmon along the shoreline in southern Lake Washington (Figure 1). Our study area extended from the mouth of the Cedar River to the I-90 bridge on the west shore and to the outlet of May Creek on the east shore. The shoreline was highly developed with industrial and residential structures. Residential homes with private docks and other shoreline structures are present south of Seward Park along the west shore and in part of the east shore. Renton Airport, Boeing plants, and a power plant are located on the south shoreline and several cement, steel, and wooden bulkheads and overhead structures are present. Much of the east shore study area was contained within Gene Coulon Memorial Beach Park. Part of the park contains large wooden booms and docks; however, much of the shoreline is relatively undeveloped. From the south end of Seward Park north to the I-90 bridge, most of the shoreline is City of Seattle parks. The park shoreline has some bank armoring and few piers and docks.

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. A Washington Department of Fish and Wildlife salmon hatchery is located at river kilometer 4.8. Adult chinook salmon return to the hatchery in September through November. Chinook salmon also spawn below the hatchery and other adults are allowed to migrate upstream of the hatchery if the hatchery production goal of returning adults is met. Juvenile chinook salmon are released from the hatchery the following May. Large numbers enter Lake Sammamish a few hours after release (Brian Footen, Muckleshoot Indian Tribe, personal communication).

The Ship Canal is a 13.8-km artificial waterway that is located between Lake Washington and Puget Sound. The Ship Canal consists of five sections, Montlake Cut, Portage Bay, Lake Union, Fremont Cut, and the Salmon Bay waterway. The largest part of the Ship Canal is Lake Union which is 235 hectares in size and has a mean depth of 9.8 m. We surveyed chinook salmon along the shoreline of Portage Bay, Fremont Cut, and the south end of Lake Union. The shorelines of Portage Bay and Lake Union are highly developed with numerous marinas, commercial shipyards, and house boat communities. The Fremont Cut is a steep rip rap channel that connects Lake Union to Salmon Bay.

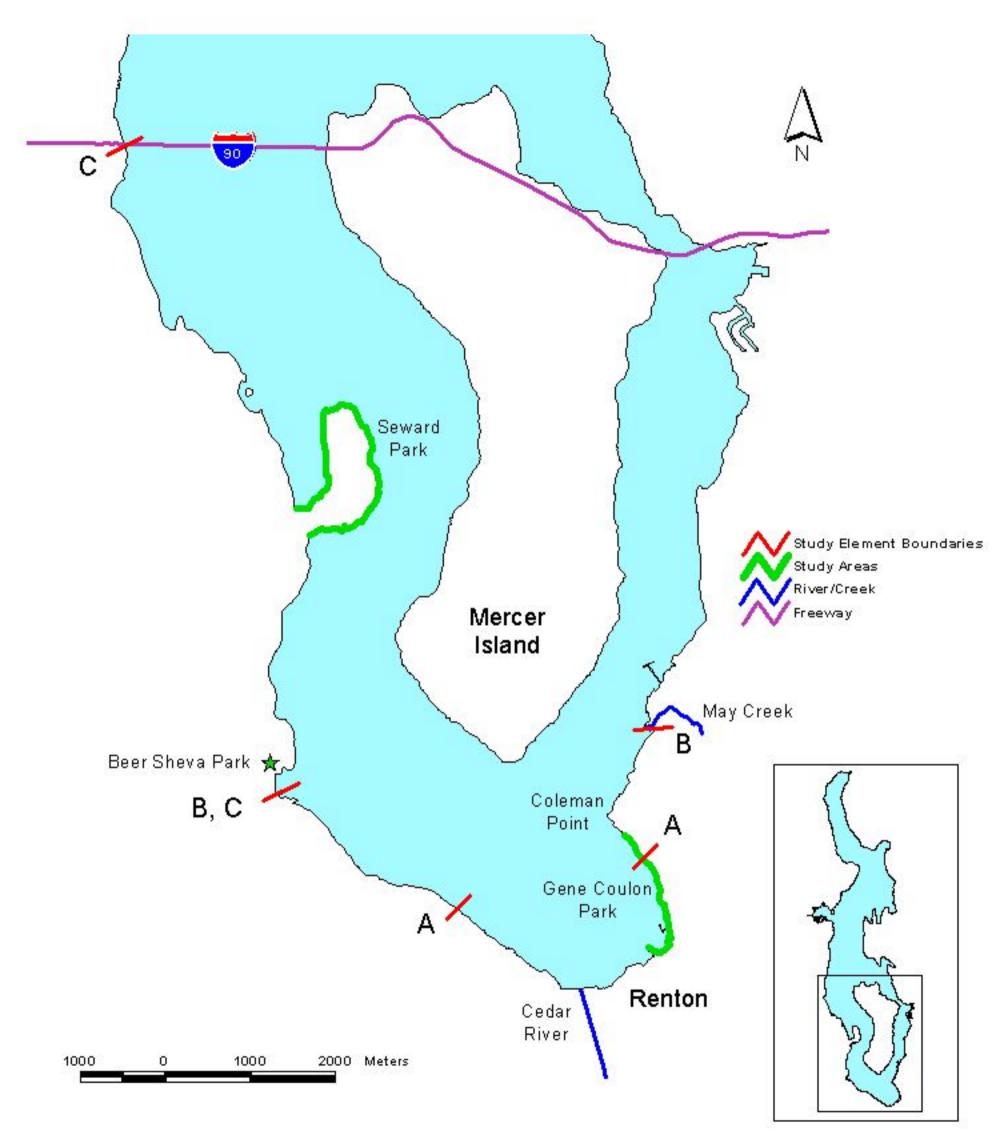Figure 1. - Map of south Lake Washington and location of study areas. Letters represent the boundaries of the sample areas used for random daytime and nighttime surveys. Different letters represent different phases of random sampling; A = south shore, February-March; B = south shore, April-May; and C = west shore, May-June. Restoration monitoring locations (Seward Park and Beer Sheva Park) are also shown.

METHODS

RANDOM TRANSECTS

To determine the selectivity of substrate type and use of shoreline structures, we surveyed random transects in south Lake Washington. We conducted snorkel surveys along the shoreline (Photo 3) and measured chinook salmon microhabitat use. After snorkel surveys were completed, we measured the habitat surveyed to relate habitat availability to the actual habitat used by chinook salmon. The study area included the east shoreline from May Creek south to the mouth of the Cedar River and the west shoreline from I-90 Bridge south to the Cedar River (Figure 1). Three study components (Table 1) were undertaken: 1) south shoreline - early-time period (February-March), 2) south shoreline - late-time period (April -May), and 3) middle-west shoreline (May-June). The south shoreline surveys were conducted during two time periods to examine seasonal differences in nearshore habitat use. In February and March, surveys were conducted within 2 km of the Cedar River mouth because the vast majority of chinook salmon were expected to be in this area. Given the expected low number of juvenile chinook salmon emigrating from the Cedar River during the study season, few chinook salmon would be present in more northern areas. Random transects in April and May were chosen from a larger area of southern Lake Washington: from Beer-Sheva Park south on the west shore, and from May Creek south on the east shore. Surveys in the middle-west shoreline area were conducted during May and June because juvenile chinook salmon were expected to be rare in the area before May. These surveys were conducted from Beer-Sheva Park north to the I-90 Bridge. Daytime and nighttime surveys were done at the south shoreline sites. The same transects were used for daytime and nighttime surveys. Only nighttime surveys were conducted at the middle-west sites because of the difficulty in locating fish during the day.

Aerial photos were used to divide the south Lake Washington area into 100-m transects and each transect was assigned a number in sequential order, starting from the northwest corner of the sample area. The south shoreline was divided into 98 transects. Three transects along the Boeing facility were not used because of safety considerations caused by an unknown effluent. The early-time period sampling was done within the closest 44 transects to the mouth of the Cedar River. The late-time period sampling was done within the entire 98 transects. The middle-west area was divided into 130 transects. Random numbers were obtained from a computer spreadsheet program and transects were then surveyed in the same order they were selected. Aerial photos were used in the field to find the transect start and ending point. In some cases, the actual transect length was slightly shorter or longer than 100 m. The nighttime surveys began at least one hour after sunset. Snorkelers swam parallel to shore along the 0.4 m depth contour or within 0.5-1.5 m from shore if the depth was greater than 0.4 m at the shoreline. Snorkelers carried an underwater flashlight and identified and counted all fish observed.

Table 1.-- Summary of the different types of snorkel surveys completed in Lake Washington, January-June 2001 and in the Lake Washington Ship Canal, June 2001. The number of fish surveys is total number of surveys at all sites regardless if sites were repeated. At those sites where more than one depth contour was surveyed, we combined them into one survey.

Sampling Type	Start Date	End Date	Number of survey dates		Number of fish surveys		Total # of chinook	
			Day	Night	Day	Night	Day	Night
A. Random Sites	Feb. 22	June 7	6	18	31	81	152	571
1. South shoreline - early	Feb. 22	March 27	3	6	24	28	149	155
2. South shoreline - late	April 25	May 23	3	6	7	32	3	360
3. West shoreline	May 15	June 7	0	6	0	21	--	28
B. Gene Coulon Park - daytime	March 20	April 4	3	0	26	0	896	--
C. Index sites-Gene Coulon Park	Jan. 24	June 20	0	9	0	27	--	858
D. Restoration site monitoring	April 11	June 5	1	5	6	30	0	62
1. Seward Park	April 11	June 5	1	4	6	24	0	60
2. Beer Sheva Park	April 18	May 31	0	3	0	6	--	2
E. Lake Sammamish - woody debris	March 22	May 11	2	2	12	11	846	268
F. Depth selection- South lake and Lake Sammamish	May 1	June 19	3	1	4	1	80	98
G. Habitat Manipulation Experiments- Gene Coulon Park	April 3	May 15	17	10	84	56	715	2132
1. Woody debris	April 3	May 9	15	9	60	36	598	1884
a. Swim beach	April 3	April 10	4	3	16	12	1	1098
b. North Gene Coulon	April 11	May 9	11	6	44	24	597	786
2. Overhead structure	April 24	May 9	5	4	20	16	115	179
3. Combination (1 and 2)	May 9	May 15	2	1	8	4	2	69
H. Ship Canal	June 13	June 27	0	3	0	13	--	32

We used a single transect along the 0.4 depth contour because earlier sampling indicated that juvenile chinook salmon were concentrated at this depth. Given the depth contour used and the effective sample width of approximately 3.75 m (Piaskowski and Tabor 2001), we felt we observed a large percentage of chinook salmon in the nearshore area. Obviously, some chinook salmon were overlooked by snorkelers or were outside of the transect area. We assume that the habitat use of these juvenile chinook salmon was similar to those chinook salmon that we did observe. At steep sloping banks (> 20%), we usually could effectively sample the entire nearshore area (0-1 m). However, in moderate to gradual sloping banks, we could only sample a proportion of the nearshore area. Therefore, there may have been a small bias for steep sloping banks. Overall, we felt our habitat survey techniques gave a good picture of the habitat use of juvenile chinook salmon within the nearshore area.

Micro-habitat use was measured for all individual chinook salmon by marking their locations with weighted flags where they were first encountered. If more than one chinook was seen within 0.5 m of each other and fish were within the same microhabitat conditions, only one flag was used to mark the location of those fish. Microhabitat variables measured at flagged chinook salmon locations were water depth, dominant and subdominant substrate that the fish was associated with, distance to cover, type of cover, and distance to shore. Substrate categories were: sand (<5 millimeters (mm), gravel (5-49 mm), cobble (50-249 mm), boulder (>250 mm), and other (e.g., organic, wood, metal). Distances to cover and shore were measured along the water surface. Cover was broadly defined as any in-water or overhead structure that a fish may use to obscure its visibility, and included large wood, boulders, submerged vegetation, overhanging vegetation, and artificial structures.

Habitat measurements were made at the site- and at the microhabitat level after snorkeling each site. Lake levels were unchanged between the time a site was snorkeled and when habitat was measured. It is important to note, however, that habitat at a particular site could change with changes in lake levels; possibly affecting fish use in particular nearshore areas. Site-level variables measured included: transect length; substrate composition; mean slope; the number and size of docks or other overhead structures; and the presence, type, and depth of shoreline armoring. Substrate and slope were measured systematically. A measurement was taken every 10 m and the starting point was randomly chosen within the first 10 m. For substrate, we visually estimated the percentage of six pre-defined size categories within 1-m-diameter circles. The mean slope of each site was estimated by measuring the distance from the shoreline out to a water depth of 1 m. Slope was determined as 1 / [distance from shoreline], and then averaged for each site.

Differences between day and night chinook salmon abundance at the same sites were tested with a sign test. The percent of chinook salmon associated with armored banks or overhead structure was calculated for each transect and compared to the percent of the shoreline length made up of those habitat features. Comparisons were also made with a sign test.

To evaluate preference of each substrate type, we calculated electivity indices which are commonly used to measure the use of food types or habitat types in relation to their abundance or availability in the environment. We used Vanderploeg and Scavia's (1979) E because it was recommended by Lechowicz (1982) in a review of electivity indices. The E index has the convenient property of a zero value for random selection and a possible range of plus and minus

one (Lechowicz 1982). Also, the index is unaffected by the relative abundance of habitat types which allows for meaningful between-sample comparisons, if the other samples have the same food or habitat types.   The disadvantage of the E index is that it is not conducive to parametric statistical analyses. Also, as the number of food or habitat types increases, the index becomes more vulnerable to sampling error for food or habitats that are rarely used and rare to moderately common in the environment. According to Lechowicz (1982), there is no one index that satisfies all the desirable criteria: however, the E index provides the best, but not perfect, electivity index. The E index is calculated as follows:

$$E_i = [W_i - (1/n)] / [W_i + (1/n)]$$
where,
$$W_i = [r_i/p_i] / [\sum r_i/p_i]$$
and,

r_i = relative utilization of substrate type i
p_i = relative availability of substrate type i.

GENE COULON PARK DAYTIME FOOT SURVEYS

In addition to random daytime sampling, we also conducted foot surveys along a continuous section of shoreline in Gene Coulon Park (Figure 2). Juvenile salmonids and other fish were initially located by an observer who slowly walked along the shore. When fish were located, one or two snorkelers entered the water a short distance away and slowly moved towards the fish to count and identify them (Photo 4). The shore observer remained on shore and helped guide the snorkelers to the fish. Snorkelers also surveyed under some overhead structures if the shoreline observer had difficulty observing fish. This type of survey could only be done on completely calm days when there was no surface turbulence. Also this type of survey was best done early in the year (February-April) when chinook salmon are small, close to shore, and easily approached by an observer from shore. The number of fish, depth, and substrate type were estimated for each group of salmonids. Habitat measurements were taken where the fish were first observed. Analysis of substrate use, overhead structure, and armored banks was done the same as random site surveys.

INDEX SITES

Three index sites were repeatedly surveyed to examine temporal changes in juvenile chinook salmon abundance within the nearshore area. We used the same index sites from 2000 sampling (Piaskowski and Tabor 2001). All sites were in Gene Coulon Park (Figure 2) and thus were easily accessible and could be done routinely within a minimal amount of time. The most northerly site (Cove, 66 m long) was at a small cove that was one of the same beach seining sites used by Fresh (2000); the middle site (Ivar's, 75 m long) was just north of Ivar's Restaurant (Photo 4); and the southern site (Swim beach, 60 m long) was along the park's swimming beach. Each site had either a predominately sand, gravel, or gravel/cobble substrate. Surveys were done at night,
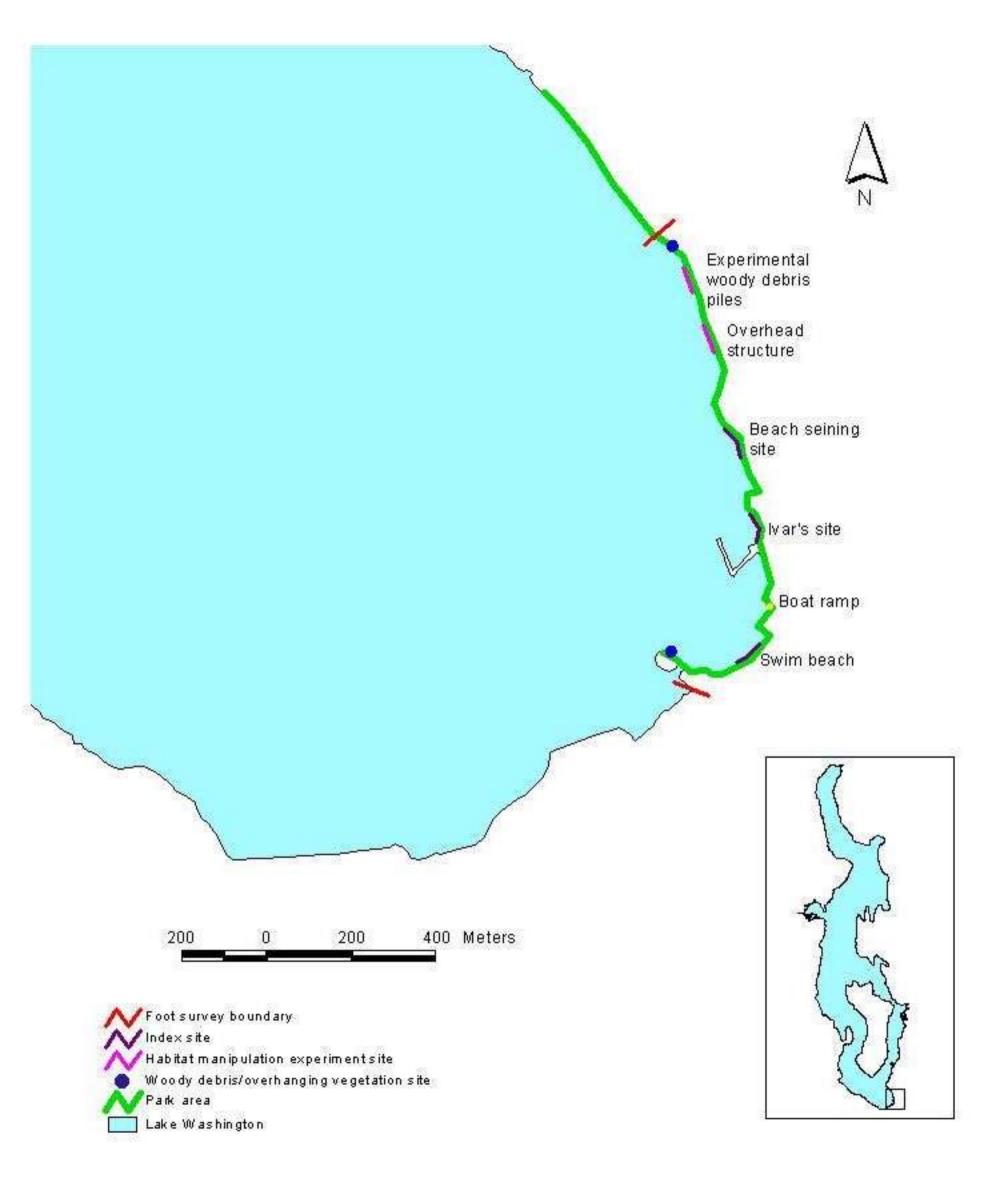
Figure 2. - Map of Gene Coulon Park. Locations for various study elements are shown. Red lines indicate the northern and southern boundaries of daytime foot surveys.

similarly to 2000. Two snorkelers were used at each site, one swimming along the 0.4 m depth contour and the other along the 0.7 m depth contour. Snorkelers swam parallel to shore with an underwater flashlight, identifying and counting fish observed as they swam along the transect.
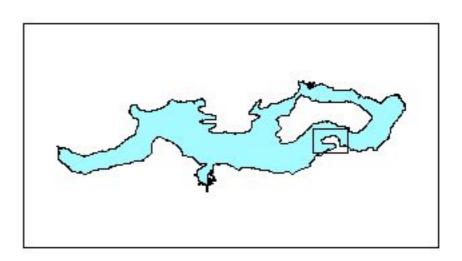
RESTORATION PROJECT MONITORING

The City of Seattle has proposed to undertake some habitat modifications in 2001 and 2002 to help determine if lake shoreline habitat can be improved for chinook rearing. Monitoring of these sites was done in 2001 to collect baseline data.

Seward Park. We used the same six Seward Park sites (Figure 3) as Paron and Nelson (2001) except we expanded their transect length from 50 m to 100 m. We followed the same protocols we used in other south Lake Washington surveys and did not follow the exact snorkeling procedures of Paron and Nelson (2001), however the techniques were similar. We surveyed along one depth contour, 0.4 m depth. Paron and Nelson (2001) used two transects, approximately 3.75 and 11.25 m from shore, regardless of depth. Substrate and other site characteristics were taken from Paron and Nelson (2001). We conducted four nighttime surveys and one daytime survey. To help locate juvenile salmonids during the daytime survey, a shoreline observer was also used, similarly to Gene Coulon daytime foot surveys.

Beer Sheva Park. The Beer Sheva Park study area was divided into two study sites, a southwest site and a northeast site. Beer Sheva Park occurs within a small cove where fine soft sediments (silt/mud) predominate. The southern boundary of the southwest site was 10 m north of the boat ramps and was 62 m in length. The site was along a gravel shoreline with little riparian vegetation except a grass lawn. Close to shore the substrate is gravel but a short distance offshore the substrate is silt and mud. The average distance to one meter depth was 12.1 m. The other site started at the chain-link fence at the edge of the park lawn and extended 35 m to the east. This site had abundant riparian vegetation. The slope was very gradual, the average distance to one meter depth was 15 m. The entire area was silt and mud. The Beer Sheva Park sites were sampled three times from April to May. Only nighttime surveys were conducted.

WOOD AND VEGETATED SHORELINE SURVEYS

Because there was little woody debris and overhanging vegetation (WD/OHV) in south Lake Washington, we conducted most of our assessment of the use of these habitat types by chinook salmon in Lake Sammamish. Surveys were conducted along the shoreline of the Lake Sammamish State Park. All surveys were just to the west of the mouth of Issaquah Creek. The study area was divided into six shoreline sections, three with WD/OHV and three open sections (Figure 4). Two of the open sections were swimming beaches and the other was a sandy shoreline adjacent to the Issaquah Creek delta. Along the WD/OHV sections, there was abundant riparian vegetation that provided shade as well as several pieces of small woody debris (< 10-cm diameter) and a few pieces of large woody debris (> 10-cm diameter) that provided structural complexity within the water column. Shoreline surveys were conducted once in March (day sample, March 23; night sample, March 28) and once in May (day sample, May 11; night sample, May 8). All surveys were done before any planned releases of juvenile chinook salmon from the WDFW Issaquah

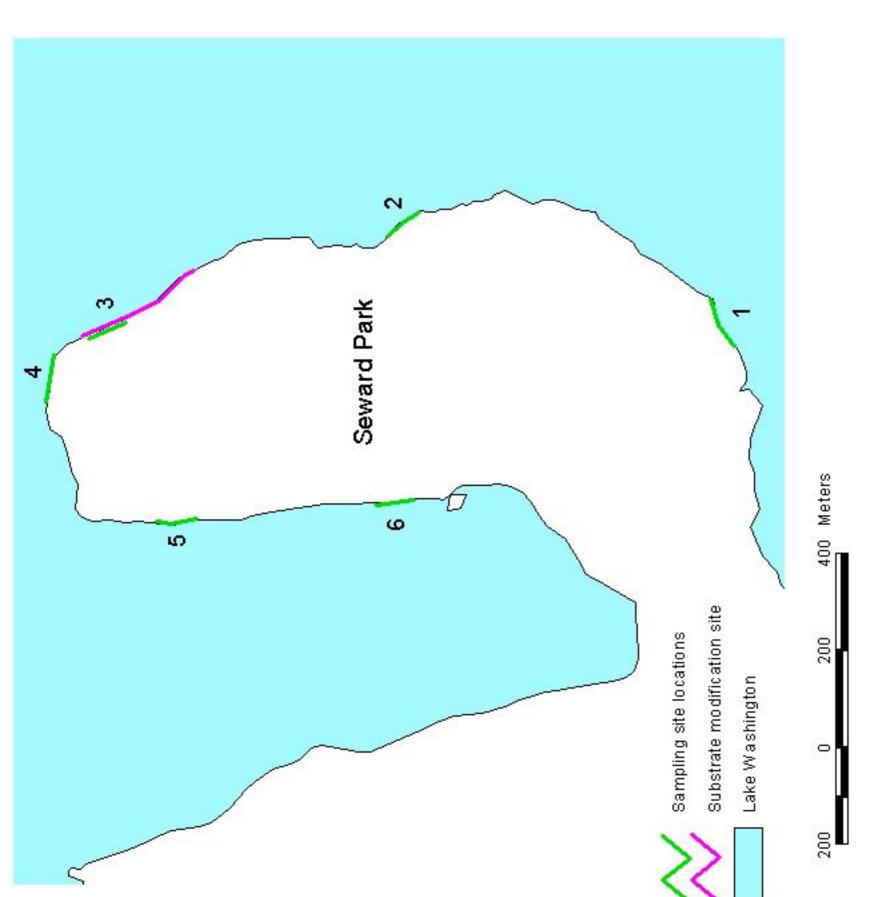Figure 3. – Map of Seward Park. Locations of snorkel transects are indicated. The location of the December 2001 substrate modification project is also shown.
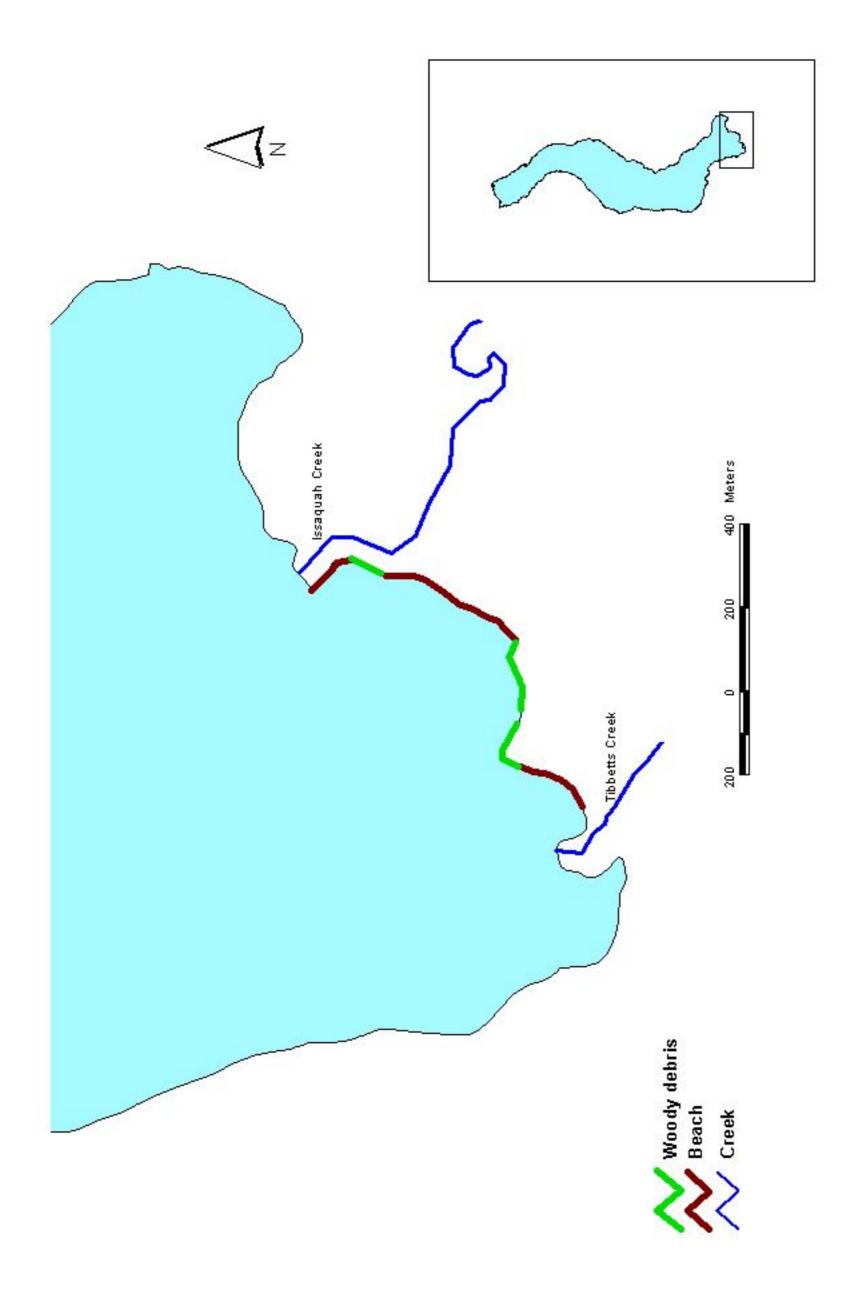
Figure 4. - Map of the south end of Lake Sammamish. Snorkel transects of woody debris-overhanging vegetation sites (green lines) and open, sandy beaches (brown lines) are indicated. Location of study area within Lake Sammamish is also shown.

Hatchery. Therefore, the juvenile chinook salmon were most likely naturally produced from Issaquah Creek. In addition to analyzing chinook salmon counts, we also compared the numbers of coho salmon (*O. kisutch*). Juvenile coho salmon were abundant along the shore of south Lake Sammamish, presumably because 1.7 million fry had been released earlier (March 1-12) from WDFW Issaquah Hatchery (L. Klube, WDFW, personal communication). Fish counts for both species were converted to fish/m of shoreline based on the length of each transect. Differences between site type and month for chinook and coho salmon abundance were analyzed with a two-way analysis of variance (ANOVA). Data were log transformed because the data was multiplicative rather than additive (Zar 1984).

Although we were unable to conduct extensive WD/OHV observations in Lake Washington, we did periodically monitor two small sites in Gene Coulon Park that had woody debris with overhanging vegetation. The first site was on the east side of a small island in the southwest corner of Gene Coulon Park. The other site was in the north end of Gene Coulon Park. Both sites were essentially a large shrub with branches that provided overhanging vegetation and a few branches that were in the water and provided woody debris. Both sites were snorkeled periodically from February to May.

DEPTH SELECTION

Earlier nighttime sampling in 2000 (Piaskowski and Tabor 2001) indicated that juvenile chinook salmon use shallow water; however, we only examined two depths, 0.4 and 0.7 m, because of the limitations of snorkeling. In 2001 we examined slightly deeper waters with the aid of scuba equipment. Four 50-m transects (0.5, 1.0, 1.5, and 2.5 m depth contours) were established on the Gene Coulon swim beach (Figure 2). Scuba equipment was used on all transects in case the fish responded differently between a scuba diver and a snorkeler. Earlier in the day, a nylon rope was placed along each transect. One diver swam on the inside of the line and the other diver swam on the outside. Divers swam just off of the bottom and only counted fish on their side of the line. Nighttime scuba diving transects were done on one night, May 1.

Preliminary observations on daytime depth use were also collected in 2001. Juvenile chinook salmon were located visually while walking the shoreline. Fish were observed as they were feeding at the surface. Observations could only be done on a very calm day when the lake surface was flat. After fish were located, one or two snorkelers attempted to get close to the fish and identify them. The fish generally stayed close to the snorkelers at the same depth. Water depths were taken where the fish were first observed. A depth profile was also taken along a line perpendicular to shore. The distance to shore was recorded with a range finder. Preliminary daytime depth information was collected in March at Gene Coulon Park (Lake Washington), May-June at Lake Sammamish State Park (Lake Sammamish), and June at Stan Sayres Park (Lake Washington).

DAWN OBSERVATIONS

We also collected some information on the behavior of juvenile chinook salmon during the changeover from night to day. Snorkel observations were all done near the Gene Coulon Park swim beach. Juvenile chinook salmon were selected and then continuously observed from full darkness (just before sunrise) to daylight. Light level measurements were taken once every minute with an International Light Inc. model IL1400A radiometer/photometer. Snorkelers located individual chinook salmon and noted their behavior (e.g., depth, response when approached, level of movement, association with other fishes) and associated time observed.   Observations were done on three dates, twice in March and once in April.

HABITAT MANIPULATION EXPERIMENTS

Preliminary habitat manipulation tests were conducted to experimentally test the use of woody debris and overhead structures. All habitat manipulation experiments were done at Gene Coulon Park. We selected two areas of the park with no structures, the shoreline was relatively uniform for over 100 m, and juvenile chinook salmon were abundant. The two areas selected were the swimming beach and a gravel/cobble shoreline in the northern part of the park (Figure 2). For each experimental trial, the shoreline was broken into four sections, two with structures added and two controls without structures. Snorkel surveys were conducted within each shoreline section during both day and night. Most surveys were only done along the 0.4 m depth contour; however, on some occasions 0.4 and 0.7 m depth contours were surveyed. 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 towards 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 done with 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.

Since the precise location of the fish could be observed at night, we separated fish that were directly within the structure and those that were outside of the structure but still in the sample section. During the day, the precise location could not be determined because fish were active and may have moved somewhat in response to the snorkeler. Therefore, only one fish count was taken for each shoreline section. Furthermore, only wooded or shaded sections of treatment sites were surveyed during the day to avoid influencing fish behavior and location.

Differences between treated (woody debris or overhead structure) shoreline sections and control sections were analyzed with a repeated measures ANOVA. The repeated measure was the counts of chinook salmon taken over several days.

Woody debris. We examined the use of small woody debris piles at both the swimming beach and the north Gene Coulon site. The shoreline at each location was divided into four 25-m

shoreline sections: two with woody debris and two without. The woody debris was 15 m long and located in the middle of the shoreline section. The woody debris consisted of branches and old Christmas trees placed in two rows parallel to shore (Photo 5). 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. At the swimming beach, woody debris was placed along 0.3 and 0.7 m depth contours. At the north site, woody debris was placed in slightly deeper water, 0.5 and 1.0 m depth contours. The woody debris was tied together and anchored with sand bags. Woody debris piles were placed along the swimming beach on April 3 and then removed on April 10 and moved to the north Gene Coulon site, where they were monitored from April 10 to May 9.

In addition to snorkeling, beach seining was conducted on two separate occasions during daylight hours (Photo 6). Beach seining was done to confirm snorkeling results and get some preliminary information on the effectiveness of beach seining in and around structures. On each date beach seining was conducted, we sampled one woody debris section and one control. Different sections were used for each date. Each beach seine set sampled an area extending 15 m along the shoreline and offshore 7-8 m. Within the woody debris section, the beach seine completely encircled the woody debris. At each section, two beach seines were used, a large net and a smaller net. The large net was 23 m long and 2.4 m deep with a 2.5-mm mesh. The smaller net was 8.8 m long and 1.6 m deep with a 3-mm stretch mesh and a 1.5 m deep by 1.8 m long bag in the middle. The two nets were deployed from opposite ends of the area sampled. Each net was deployed from shore by wading or swimming. At first, the two nets were pulled straight offshore 7-8 meters. The large net was then pulled parallel to shore along the outside perimeter of the sample area and pulled along the entire shoreline length. The smaller net was next pulled inside of the large net 2 to 3 meters. After placing the nets completely around the sample area, two snorkelers swam through the netted area, herding fish towards the end with the smaller net. As snorkelers approached the smaller net, the outside end of the smaller net was brought to shore to encircle the fish. At the control sections, we were also able to bring the large seine into shore to check if any fish were missed by herding the fish. Fish caught by the larger net indicated most prickly sculpin (*Cottus asper*) and several three-spine stickleback (*Gasterosteus aculeatus*) were missed, but no salmonids were missed. Thus, herding fish appeared to be effective in moving salmonids into a seine where they could be encircled. Collected fish were anesthetized, identified to species, and counted. Additionally, chinook salmon were measured for weight (nearest tenth of a gram) and length (nearest mm).

Overhead structure. Two overhead structures were installed along the shoreline, just south of the woody debris piles in the northern part of Gene Coulon Park (Figure 2). The shoreline was divided into four 20-m shoreline sections. The overhead structures were placed on the middle of two sections and the other two sections served as controls. Each overhead structure was 10 m long (shoreline length) and 5 m wide (distance from shore). The structure consisted of vinyl tarps spread out over a wooden frame (Photo 7). The structure was supported above the water by three floats. The inside edge was anchored on the shore with sand bags and cinder blocks. At the outer edge of the structure the water depth was 0.6 to 0.7 m. The structure was approximately 0.3 to 0.4 m above the water surface, which allowed snorkelers to swim
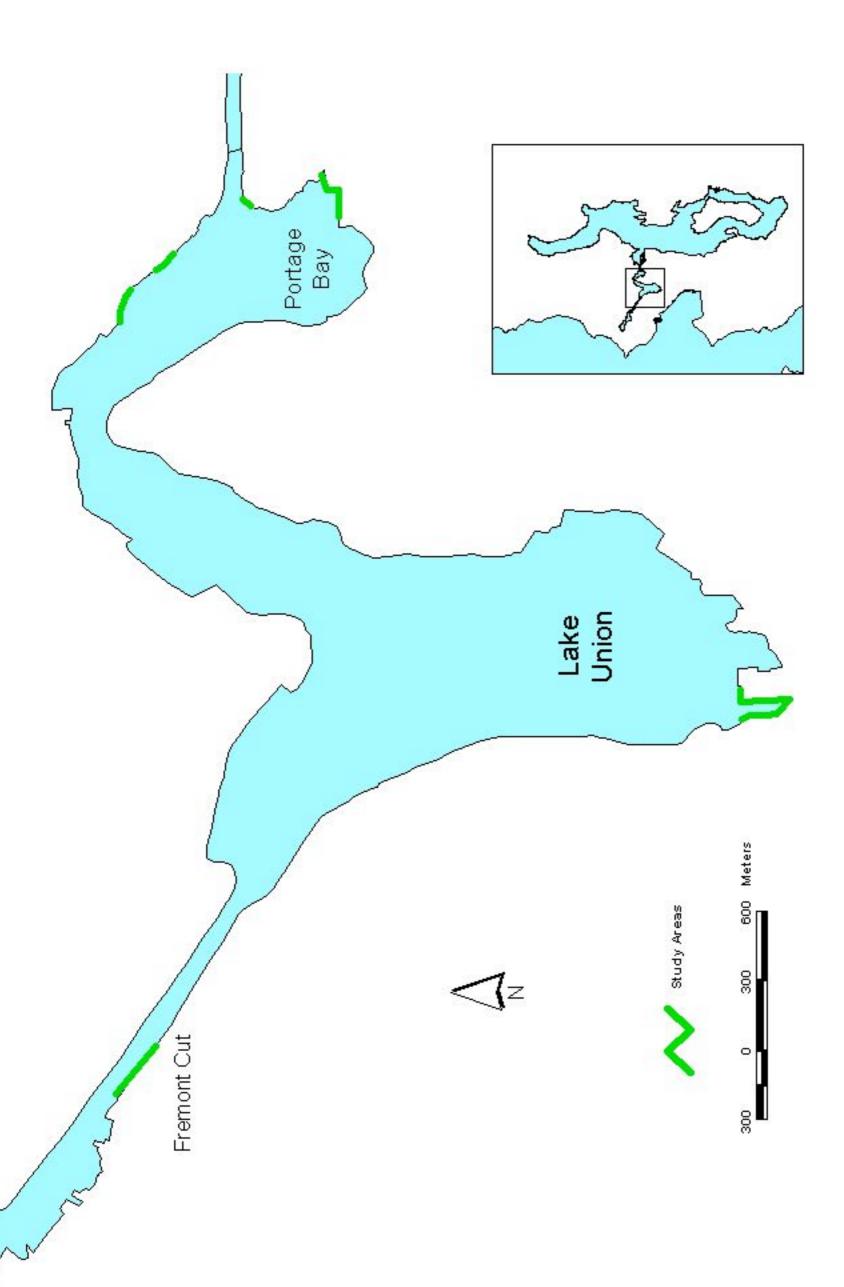
Figure 5. - Map of the Lake Washington Ship Canal. Locations of snorkel transects are indicated.

underneath. In order to not cause fish to move under the structures during the day, snorkelers began at edge of the structures and swam to the middle. Therefore, during the day, snorkelers swam 10 m in the structure sections and 20 m in the control sections. At night the entire 20 m was surveyed for each section. Overhead structures were installed on April 24 and removed on May 9.

Combination. On May 9, the woody debris piles and overhead structures were combined. The overhead structures were removed from their original locations and placed on top of the woody debris piles. The overhead structures were turned 90°, such that the shoreline length was 5 m and distance offshore was 10 m. The structures were turned to cover part of both rows of woody debris. The water depth at the offshore edge was 1.3 m.

SHIP CANAL/LAKE UNION SURVEYS

Surveys were conducted in the Ship Canal/Lake Union area to determine the effectiveness of snorkeling to gather habitat use information in this area. We established six study sites within the Ship Canal/Lake Union area, four in Portage Bay, one in Lake Union, and one in the Fremont Cut (Figure 5). Sites were selected that had a wide range of habitat types and were easily accessible. The two sites along the University of Washington shoreline each had a large dock that snorkelers could swim under as well as an adjacent open area without any overhead structure. In Lake Union, we snorkeled the south shoreline at the old Naval Reserve building, a City of Seattle restoration site. Three nighttime snorkel surveys of all sites were conducted in June.

RESULTS

RANDOM TRANSECTS

South shore, nighttime surveys.– Electivity indices demonstrated that chinook salmon preferred sand and gravel substrates during both February-March and April-May time periods (Figure 6; Photo 8). Chinook salmon occasionally used cobble and boulder substrates but the percent of chinook salmon that used these substrates was much lower than the percent of these substrates available along the nearshore area. Electivity indices did not change appreciably between the February-March and April-May time periods.
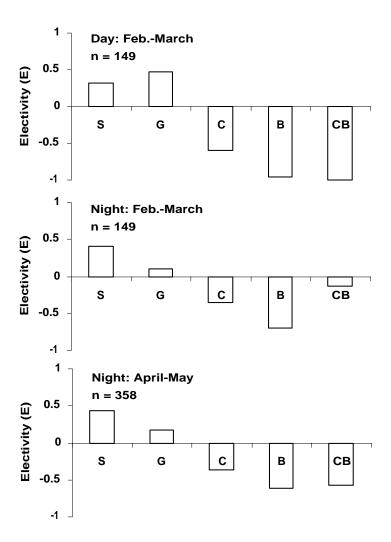
Figure 6.– Electivity index values (E; Vanderploeg and Scavia 1979) for substrate use by juvenile chinook salmon in nearshore areas of south Lake Washington during February-March and April-May time periods, 2001. Few chinook salmon were observed during the day, April-May time period and are not shown. Positive index values indicate a preference. The number of chinook salmon measured for substrate use is also indicated. S = sand, G = gravel, C = cobble, B = boulder, CB = cement/wooden bulkhead.

Overall, the occurrence of chinook salmon under overhead structures at night was rare. Of the 60 transects surveyed (199 total structures) that had chinook salmon, we only observed chinook salmon under an overhead structure on four transects (four different structures) (Figure 7). Three of the structures had one chinook salmon. However, 22 chinook salmon were observed under the other overhead structure. This structure was a walking bridge at a small island in the southwest corner of Gene Coulon Park. The use of this site may have been related to nearby artificial lighting which increased light intensity under the structure as well as surrounding areas. If all sites are combined, the percent of chinook salmon under structures

(14.8%) and the percent of shoreline covered by structures (15.4%) were similar in February and March, primarily because of this one site. However, the percent of chinook under docks and piers per transect was significantly lower than the percent of each transect covered by docks and piers (sign test; $P < 0.001$). In the April-May time period, the results were also significantly different (sign test; $P < 0.001$); only 0.5% of the chinook salmon were under docks, whereas 17% of the shoreline was covered by overhead structures.
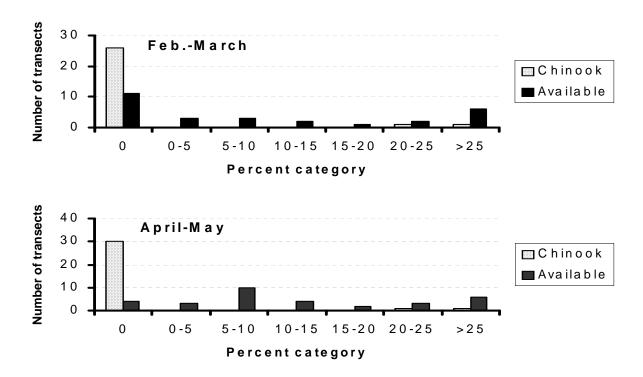

Figure 7.-- Number of transects with various percentages of chinook salmon observed under overhead structures at night compared to the number of transects with various percentages of the shoreline that were covered by overhead structures (available), south Lake Washington, 2001.

Armored banks comprised 72% of the shoreline surveyed in February and March and 80% in April and May. During February to March surveys, only 26% (39 out of 149) of the chinook salmon were along an armored bank and only 29% (106 out of 360) during April to May surveys (Figure 8). For both time periods, the percent of chinook salmon along armored banks for each transect was significantly lower than the percent of each transect shoreline that had armored banks (sign test; Feb.-March, $P < 0.001$; April-May, $P < 0.001$). Of the fish that were associated with armored banks, most were found where the wetted depth of the bank was relatively shallow. For both time periods, the armored bank wetted depth along the shoreline was significantly deeper than the armored banks used by chinook salmon (Mann-Whitney U tests; Feb.-March, $P < 0.001$; April-May, $P < 0.001$). In the February-March time period, the mean armored-bank wetted depth was 0.98 m; whereas, chinook salmon were observed along armored banks that averaged 0.38 m deep. In the April to May time period, the mean armored depth of the shoreline sampled was 0.94 m and the average depth of the armored bank where

chinook salmon were observed was 0.61 m.

In February to March, most chinook salmon that occurred along armored banks were along bulkheads and few were observed with rip rap (Figure 8). The opposite was observed in the April-May time period, most were along rip rap banks. The ratio of the rip rap shoreline to bulkhead shoreline was similar between time periods.
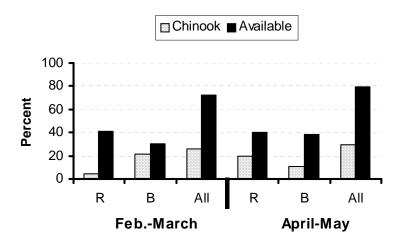

Figure 8.-- Percent of juvenile chinook salmon associated with armored banks at night compared to the percent of the shoreline comprised of armored banks (available) for two time periods, south Lake Washington, 2001. R = rip rap; B = bulkhead; All = rip rap and bulkheads combined. In the February-March sampling, 149 chinook salmon were observed along 2783 m of shoreline (28 transects) and 360 chinook salmon were observed along 3295 m of shoreline (32 transects) in April-May sampling.

South shore, daytime surveys.- From March 19 to 27, 24 daytime transects were completed. Chinook salmon were observed in only 5 transects. Significantly more chinook salmon were observed along the same transects at night (sign test; $P = 0.004$). At night, 21 of the 24 transects had chinook salmon. Daytime and nighttime transects were done during slightly different time periods. Nighttime surveys were conducted from February 22 to March 13 and, based on other snorkel counts, we had expected to see higher overall counts from March 19 to 27 than late February and early March.

During daytime, juvenile chinook salmon were active and were mostly in small schools (Photo 9) as compared to night when they were spread out from each other and were inactive. Juvenile chinook salmon were only observed at nine locations. On two occasions a single chinook salmon was observed and they were not associated with any other fish. During the other seven occasions, chinook salmon were either in an aggregation of just chinook salmon (29%) or were in a mixed group with juvenile sockeye salmon (*O. nerka*; 71%). Group size ranged from 10 to 120 fish and the percentage of chinook salmon within the group ranged from 3 to 100%.

Similar to night observations, chinook salmon appeared to strongly prefer sand and gravel substrate and rarely used boulders (Figure 6). Because chinook were often grouped together in small schools, the number of observations on substrate use was relatively small and

thus the accuracy of the data is questionable. Although a total of 149 chinook salmon were observed, chinook salmon were only observed on 9 occasions. Chinook regularly moved parallel to shore when approached, thus making microhabitat measurements difficult. Further daytime substrate observations are needed to get a better picture of chinook salmon substrate preferences.

All chinook salmon were within 3 m of an overhead structure such as a dock, walking bridge, or overhanging vegetation and 52% were directly under an overhead structure. All but two of the 44 chinook salmon observed on the west shoreline were directly under an overhead structure. Within the entire area sampled, 34% of the shoreline length was within 3 m of an overhead structure and they directly covered 17% of the overall shoreline length. Thirty percent of the chinook salmon occurred along armored banks (bulkheads and rip rap). Of the shoreline length surveyed, 63% was comprised of either bulkhead or rip rap.

Seven daytime transects were completed in late April and early May. No chinook salmon were observed along six of the transects and only three were observed on the other transect. Unlike earlier sampling, no chinook salmon were found under any overhead structure or close to it. Significantly more chinook salmon were observed along the same transects at night during the same time period (sign test; $P = 0.016$). A total of 126 chinook were observed along these transects at night.   Further sampling in May was not done due to the difficulty in finding fish.

Middle-west shore, May and June. - We completed 21 nighttime transects along the middle-west shoreline between Beer Sheva Park and the I-90 bridge. Chinook salmon were only observed on eight (38%) of the transects surveyed. A total of 28 chinook salmon were observed and 57% of those were from the two most southern transects near Pritchett Beach Park. The highest concentration was at the swimming beach within Pritchett Beach Park where 12 chinook salmon were observed. Within Seward Park, nine chinook salmon were observed from a total of seven transects.   Along the middle-west shore, north of the Seward Park entrance, only 3 chinook salmon were observed from 12 transects surveyed.

GENE COULON PARK DAYTIME FOOT SURVEYS

Foot surveys of Gene Coulon Park were conducted on two dates, March 22 and April 4. Large numbers of juvenile chinook salmon were observed during daytime foot surveys in Gene Coulon Park, in contrast to the abundance observed at random daytime sites around south Lake Washington. Between the two dates, 896 chinook salmon were observed along 2,256 m of shoreline surveyed (0.40 chinook/m). Along random, daytime sites (March 19-27), we only saw 149 chinook salmon over 2,303 m surveyed (0.06 chinook/m), and of those random sites that were in Gene Coulon Park, we observed 105 chinook salmon along 874 m of shoreline surveyed (0.12 chinook/m). Using a shoreline observer to help snorkelers find fish appeared to substantially increase our ability to locate juvenile chinook salmon.

When chinook salmon were located, they were usually in a small aggregation and then schooled tightly together as a snorkeler approached them. On only two occasions was a single chinook salmon observed. The size of the aggregations ranged in size from 2 to 100 chinook

salmon. Forty-one percent of the time when a group of chinook was located, it was also associated with juvenile sockeye salmon. In these mixed aggregations, chinook salmon were usually as abundant or more abundant than sockeye salmon. Sockeye salmon were generally smaller and were often in shallower water and closer to shore than chinook salmon, whether they were in mixed schools with chinook salmon or in sockeye-only schools.

Similarly to random-site substrate selection, sand was strongly preferred and boulders were rarely used (Figure 9). However, a slight positive selection for cobble was also observed. Unlike random daytime sampling along the west shore, few juvenile chinook salmon were directly under docks; however, docks were relatively rare in Gene Coulon Park (Figure 10). Docks comprised 1.9% of the shoreline sampled and 1.1% of the chinook salmon were under docks. Although few chinook salmon were under docks, many chinook salmon were a short distance from a dock or other structure. Twenty-three percent of the chinook salmon were within 5 m of a dock or other structure. The length of the shoreline that was within 5 m of a dock or other structure was 15% of the total shoreline length. An additional 5.4% of the chinook salmon were under overhanging vegetation which comprised only 1% of the shoreline. The majority of chinook salmon occurred along open shorelines and were more than 20 m away from any type of cover.
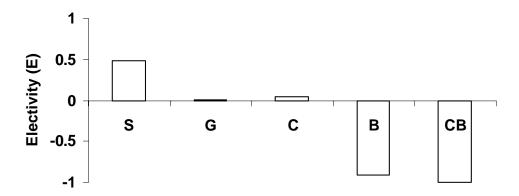

Figure 9.– Electivity index values (E; Vanderploeg and Scavia 1979) for substrate use by juvenile chinook salmon (n = 711) in the daytime at Gene Coulon Park, March, 2001. Data were collected during foot and snorkel surveys. Positive index values indicate a preference. S = sand, G = gravel, C = cobble, B = boulder, CB = cement/wooden bulkhead.

Few chinook salmon were associated with armored banks (Figure 11). Of the shoreline length surveyed, 45% was comprised of either bulkhead or rip rap. An additional 2.5 % was boat ramps. Only 6.6% of the chinook salmon were associated with armored banks (excluding boat ramps). If boat ramps are included in the calculation, then 17.1% of the fish were associated with armored banks. A large number (50-80) of juvenile chinook salmon were often observed at the Gene Coulon Park boat ramps in March and April.
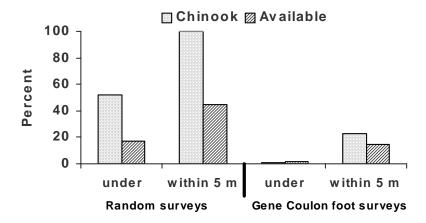

Figure 10.-- Percent of juvenile chinook salmon during the daytime under and within 5 m of an overhead structure compared to the percent of the shoreline covered by or within 5 m of an overhead structure, February-April, south Lake Washington, 2001.   Overhead structures include piers and docks as well as overhanging vegetation.
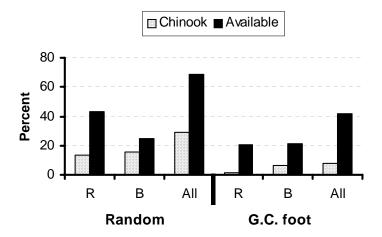
Figure 11.-- Percent of juvenile chinook salmon associated with armored banks compared to the percent of the shoreline comprised of armored banks (available) for two daytime survey methods, south Lake Washington, February-April, 2001. R = rip rap; B = bulkhead; All = rip rap and bulkheads combined. G.C. = Gene Coulon Park. In the random sampling, 149 chinook salmon were observed along 2411 m of shoreline (24 transects) and 711 chinook salmon were observed along 1550 m of shoreline (17 transects) during Gene Coulon foot surveys.

INDEX SITES

In January and February, few juvenile chinook salmon were observed at the three Gene Coulon index sites; however, in early March their abundance rose dramatically (Figure 12). From March to early May, the number of chinook for all three sites combined remained relatively high. In late-May, the number of juvenile chinook salmon declined abruptly and by June 20 only 4 chinook salmon were present amongst all index sites combined.
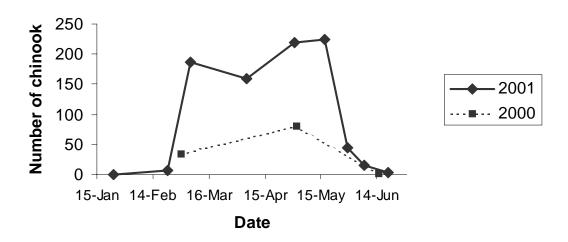
Figure 12.-- Number of juvenile chinook salmon observed at night by snorkelers at index sites in Gene Coulon Park, south Lake Washington, 2000 and 2001. The number of chinook is the combined total of two depth contours, 0.4 and 0.7 m, at three sites (total shoreline length surveyed for each date was 201 m).

In May and June, similar to nighttime observations in 2000, juvenile chinook salmon

appeared to move into somewhat deeper water. In March and April, 81% of all the chinook salmon observed in the index sites were along the 0.4 m depth (Figure 13). However, in May and June only 42% were found along the 0.4 m depth contour.

During February, March, and April surveys, most of the juvenile chinook salmon were in the swim beach site, the site with the smallest substrates (Figure 14). In May, chinook salmon densities were highest at the Ivar's site which had primarily gravel/cobble substrate. However, because the swim beach site is much wider than the other sites, the estimated overall abundance to 1 m depth was higher at the swim beach for all survey dates except June 7.
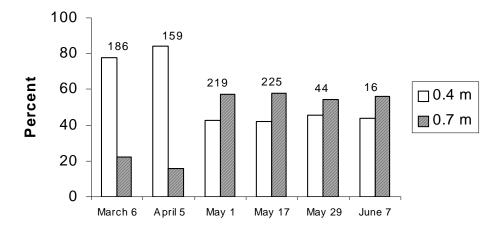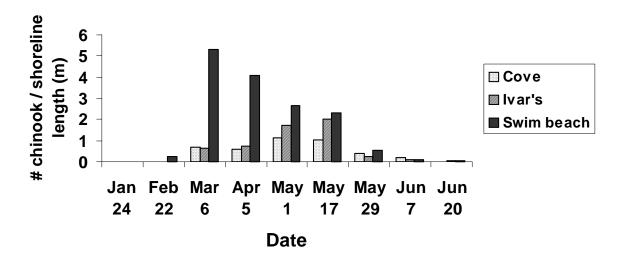
  Figure 13.-- Percent of juvenile chinook salmon observed at night along two depth contours, 0.4 and 0.7 m, for the combined three index sites in Gene Coulon Park, south Lake Washington, 2001.   Only dates with at least 15 chinook salmon observed were included in the graph. The total number of chinook salmon observed for each date is indicated above each pair of bars.
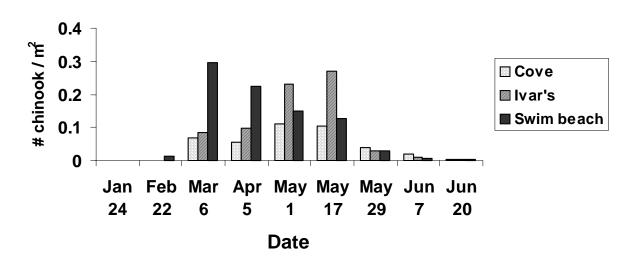
Figure 14.-- Number of juvenile chinook salmon per shoreline length (# / m of shoreline) and density of chinook salmon (# chinook / m^2) observed at night by snorkelers at three index sites in Gene Coulon Park, south Lake Washington, 2001. Abundance estimates were obtained from two depth contours, 0.4 and 0.7 m, at each site (total shoreline surveyed was 201 m). Number per shoreline length is the estimated abundance between the shore and the depth of 1 m.

RESTORATION PROJECT MONITORING

Seward Park sites were surveyed five times: one daytime survey, April 11, and four nighttime surveys, April 18, May 8, May 29, and June 5. No juvenile chinook salmon were observed at any site during the one daytime survey. During the first two nighttime surveys, 36 of 37 chinook were observed along the west shoreline, either at site 5 or 6 (Figure 15). Juvenile chinook appeared to be more evenly distributed across all sites during the last two survey dates.

During the three Beer Sheva Park surveys (April 18, May 8, and May 31), only two juvenile chinook salmon were observed. Both fish were observed at the northeast site (vegetated shoreline) on May 8.

As part of the nighttime random sites, we also sampled a 100-m shoreline section on May 9 that was mostly within Beer Sheva Park. The northern boundary of the transect was the middle of the southwest site and extended south to 10 m south of the boat ramps. Between the middle of the southwest site and the boat ramps, 11 chinook salmon were observed. An additional 25 chinook were observed on the boat ramps. On the south side of the boat ramps, three chinook salmon was observed.

One species that was relative common at Beer Sheva Park but uncommon at other south Lake Washington sites was brown bullhead (*Ameiurus nebulosus*). The brown bullhead observed were juveniles and were found primarily at the northwest site. Brown bullhead are often characteristic of areas of the lake with low gradient slopes and silt/mud substrate (Imamura 1975; R. Tabor, unpublished data) such as the northwest site.
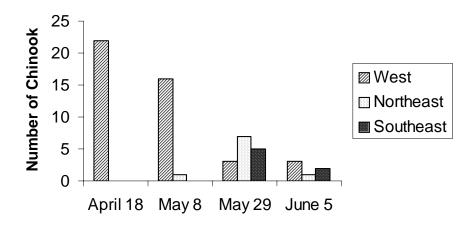

Figure 15.-- Number of juvenile chinook salmon observed at night along three shoreline areas of Seward Park, south Lake Washington, 2001. Two 100-m transects were surveyed in each shoreline area.

WOOD AND VEGETATED SHORELINE SURVEYS- LAKE SAMMAMISH

There was no significant difference in the daytime density of juvenile chinook salmon between shoreline with WD/OHV and open shoreline areas (Figure 16; two-way ANOVA, F = 1.23, P = 0.30). However, the overall abundance in March and May was higher in the WD/OHV sections than the open areas. This was mostly due to the large number of chinook that inhabited the section closest to Issaquah Creek. This site had sand substrate while the other two sites had primarily silt substrate with some sand.
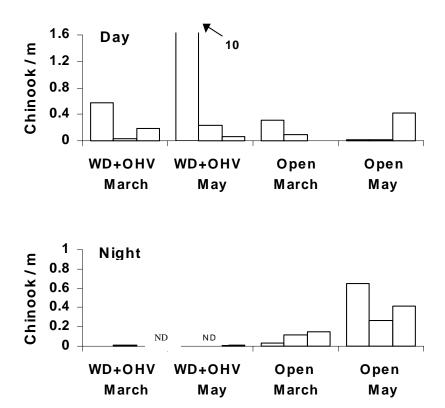
Figure 16.-- Number of juvenile chinook salmon per meter of shoreline during the day and night at six sites in the south end of Lake Sammamish, March and May, 2001. Three sites had woody debris and overhanging vegetation (WD + OHV) and three sites were open, sandy beaches (Open). Sites were done once in March and once in May. ND = no data.

Juvenile chinook salmon were often together in loose aggregations and showed more pronounced schooling behavior as they were approached by snorkelers. Most chinook salmon were in mixed-species groups with juvenile coho salmon and occasionally juvenile sockeye salmon or small minnows (eight of the minnows were collected with dip nets for identification; all were adult fathead minnows, *Pimephales promelas*, an exotic species not previously known in

Lake Sammamish (E. Warner, Muckleshoot Indian Tribe, personal communication) but has been present in the Lake Washington basin since at least the early 1980's (B. Pfeifer, Parametrix, Inc, personal communication).

Predators were also observed to influence the daytime chinook salmon behavior and habitat use. At the first WD/OHV site, we estimated 600 juvenile chinook salmon were present along the transect on May 11 (Figure 16). When we swam the first half of the transect, we observed 26 juvenile chinook salmon mixed with juvenile coho salmon and fathead minnows. After surveying this first section, we observed a large school of fish, 550-600 juvenile chinook salmon and 20 coho salmon smolts, move into the woody debris from the open offshore area. Two mergansers were observed approximately 10 m behind the large school and appeared to be pursuing the school of fish. Prior to surveying the transect, we had observed a large number of fish (presumably juvenile chinook salmon) feeding at the surface, approximately 20 m offshore. Therefore, the mergansers appeared to cause these fish to move inshore and seek refuge in the woody debris.

The daytime use of the WD/OHV sections was far more apparent for juvenile coho salmon than juvenile chinook salmon. The daytime densities of coho salmon were significantly different between the two types of shoreline (Figure 17; two-way ANOVA, F = 20.3, $P = 0.002$). All three WD/OHV sections had higher densities of juvenile coho salmon than the open sections on both daytime sampling dates (Figure 17). The mean abundance of the three WD/OHV sites was 7.7 coho salmon/m of shoreline in March and 11.3 coho salmon/m in May; whereas at open sites it was 0.1 coho salmon/m in March and 0.0 in May. Juvenile coho salmon were often very abundant in WD/OHV sites and difficult to accurately count.

In addition to the WD/OHV transects, we also swam two supplemental daytime transects through water lilies (195 m length, 0.9 and 1.6 m depth contours), just offshore of the middle WD/OHV transect (25 and 35 m offshore). No juvenile chinook salmon were observed in this habitat. Except for one juvenile coho salmon, the only fish observed were large adult fish, which included 2 largemouth bass (*Micropterus salmoides*), 10 common carp (*Cyprinus carpio*), and 50 suckers (*Catostomus sp.*).

At night, significantly more chinook salmon were in the open habitat than in the WD/OHV habitats (two-way ANOVA, F = 13.7, $P = 0.003$). The open habitats represented 65% of the shoreline length surveyed but 99% of the chinook observed at night (Figure 16). Only three chinook salmon were ever observed within the WD/OHV sections. Within the open shoreline sections, chinook salmon tended to be in the middle part of each transect and thus were often 50-100 m from any WD/OHV.

At night, most juvenile coho salmon had moved away from locations with WD/OHV and into open areas (Figure 17). However, unlike chinook salmon, they were usually located only a short distance from WD/OHV (approximately 1-15 m). At the swimming beaches, juvenile coho salmon were primarily located at the ends of the transect adjacent to the WD/OHV sections and rare in the middle part of the transect. The nighttime densities of coho salmon were significantly different between the two types shoreline (two-way ANOVA, F = 11.2, $P = 0.012$). Of the coho

salmon that were within WD/OHV sites, most were in small patches of open, sandy areas within the sites. Few coho salmon were actually observed to be using WD/OHV at night. In contrast, the vast majority of juvenile coho salmon were in close association with WD/OHV during the day.
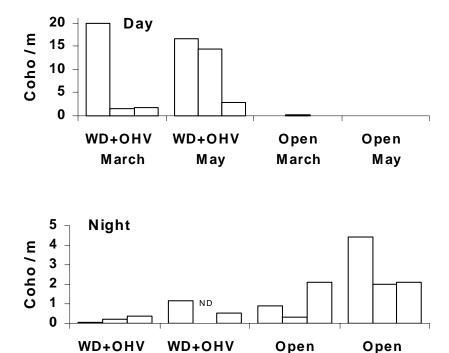
Figure 17.-- Number of juvenile coho salmon per meter of shoreline (day and night) at six sites in the south end of Lake Sammamish, March and May, 2001. Three sites had woody debris and overhanging vegetation (WD + OHV) and three sites were open, sandy beaches (Open). Sites were done once in March and once in May. ND = no data.

        Monitoring of two WD/OHV sites (8 m, total length of shoreline) in Lake Washington also indicated that juvenile chinook salmon use this habitat type, particularly when they are small (Figure 18). In February and March, juvenile chinook salmon were usually abundant at these sites and in close association with the woody debris. At the smaller, shallower site in north Gene Coulon Park, in February and March, chinook salmon were either directly under the structure or within three meters. During the next two observations in April and May, chinook salmon were present but were several meters away and none were under the structure. During the last two observations in May, no chinook salmon were present. At the larger, deeper site at the small island, if chinook salmon were present they were always located within the woody debris. There was either a large school of 30 to 50 chinook salmon present or no chinook salmon were present at all. On one occasion when no chinook salmon were present, an adult largemouth bass was present, which probably influenced the use of this site by chinook salmon.
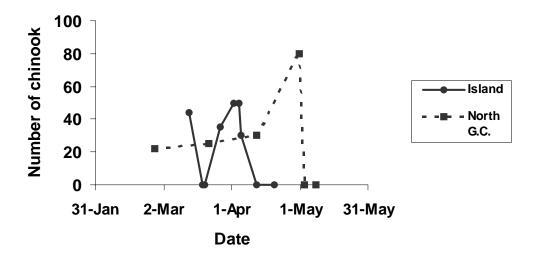
Figure 18.-- Number of juvenile chinook salmon observed during the day at two woody debris-overhanging vegetation sites in Gene Coulon Park, south Lake Washington, 2001. North G.C. = north Gene Coulon Park site. At the island site, chinook salmon were always directly under the overhanging vegetation, whereas at the north Gene Coulon Park site most chinook salmon were a few meters away.

DEPTH SELECTION

Four nighttime scuba diving transects were completed on May 1, 2001. Ninety percent of the juvenile chinook salmon were observed in the shallowest transect, 0.5 m (Figure 19). Additionally, within the 0.5 m transect, the inside diver observed 56 juvenile chinook salmon while the outside diver observed 32 juvenile chinook salmon. No juvenile chinook salmon were observed along the deepest transect (2.5 m). Juvenile chinook salmon were scattered along each transect and were always close to the substrate.

Daytime observations indicated juvenile chinook salmon use shallow water in March and then move to deeper waters and further from shore in May and June (Figure 20). At Gene Coulon Park in March, juvenile chinook salmon used areas that were 0.2-1.3 m deep (mean, 0.55 m) and were 1 to 8 m from shore (mean, 4.5 m). In Lake Sammamish State Park, daytime observations in May and June indicated chinook salmon were in water that was 1.1 to 3.3 m deep and were 18-55 m from shore. On June 19 in Lake Washington, chinook salmon were found in water that was 4 to 5.7 m deep at one site (25-35 m from shore) and 3 to 6 m deep at another site (13-17 m from shore). In both Lake Sammamish and Lake Washington, juvenile chinook salmon were usually observed during the day within the upper two thirds of the water column. Occasionally, we observed them making short foraging runs to the water surface.

Some additional daytime observations were made at a dock (3 m wide and extended 32 m out from shore) in Stan Sayres Park. On the morning of June 19, we observed 14 schools of juvenile salmonids swim past the dock. Each school was approximately 50 to 75 fish and all

were swimming in the same northerly direction at a similar speed. They appeared to be juvenile chinook but we were unable to get close enough to positively identify them. As each school approached the dock, they were swimming parallel to shore in water that was approximately 2.1 to 2.8 m deep and 18 to 25 m from shore. When they got to within 4 to 5 meters of the dock, they all turned 90° and swam around the dock where the water was approximately 3.1 m deep and 32 to 35 m from shore. No fish were observed to go under the docks. The dock structure had skirting on its side that extended part way down into the water column. Fish could easily swim under the dock but it was substantially darker under the dock than surrounding areas. Unlike other daytime observations, no foraging activity was noted in these schools.
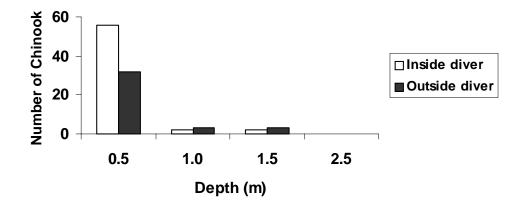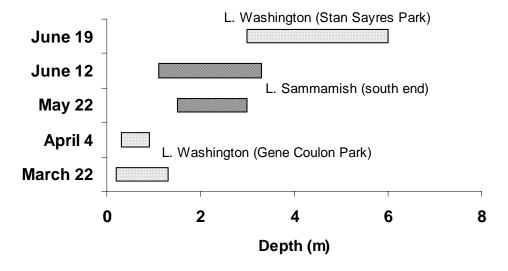
Figure 19.--Number of juvenile chinook salmon observed by scuba divers along four transects at the Gene Coulon Park swim beach, south Lake Washington, May 1, 2001. Transect lines were set parallel to shore; the inside diver swam along the shoreward side of the line and the outside diver swam along the offshore side of the line.
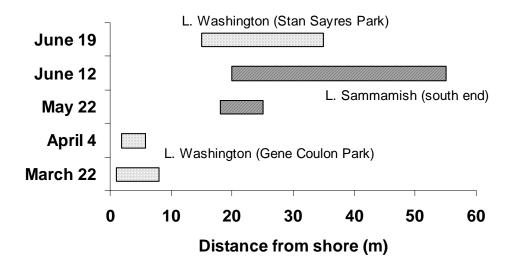
Figure 20.-- Preliminary data on the range of water column depths and distance to shore used by juvenile chinook salmon in Lake Washington and Lake Sammamish, 2001. The depths are the entire water column depth where the fish were located. Fish were first located by a shoreline observer; shortly afterwards snorkelers identified the fish and took depth and distance to shore measurements.

DAWN OBSERVATIONS

Dawn snorkel observations were done on three dates at the Gene Coulon swim beach. We made observations on a total of 28 chinook salmon. Observations began at night at approximately 0540 h when light intensity levels ranged from 0.3 to 0.6 lumens/m². Night light intensity levels at the swim beach were higher than many other shoreline areas because of nearby artificial lighting. Chinook salmon were close to the bottom and lacked group association at night. Chinook salmon became active at approximately 0550 to 0605 h when light intensity levels were 0.8 to 2.1 lumens/m². They moved off the bottom and were schooled with other chinook salmon. In some cases, the schools included juvenile sockeye salmon. We continued snorkeling until 0630 h when light intensity levels were 120 (cloudy day) to 740 (sunny day) lumens/m². However, as light intensity increased between 22 and 65 lumens/m², we had difficulty finding chinook salmon. Either they moved further offshore or they avoided the snorkelers.

HABITAT MANIPULATION EXPERIMENTS

Woody debris. Woody debris piles were present in the swim beach nearshore area for seven days, from April 3 to April 10. During the day, the shoreline sections were surveyed four times and only one juvenile chinook salmon was ever observed. Several juvenile sockeye salmon were observed during the day but none were directly associated with the woody debris.

At night, chinook salmon were abundant in all shoreline sections except the first woody debris section which was the closest section to a wooden bulkhead that was perpendicular to shore (Figure 21). There was no significant difference between woody debris sections and control sections (repeated measures ANOVA, F = 0.0, P = 0.98). Within woody sections, there was no significant difference between the abundance within the woody debris and those on the outside edges.
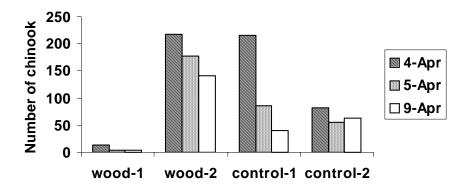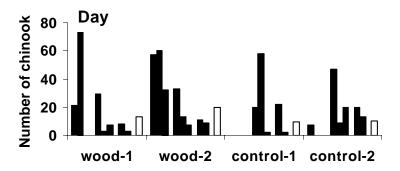

Figure 21.-- Number of juvenile chinook salmon at night at four experimental sites along the shoreline at the swim beach in Gene Coulon Park, south Lake Washington, April, 2001. Woody debris piles were added at two sites and two other sites served as controls. Woody debris was installed on April 3, 2001.

At the north Gene Coulon Park site, woody debris piles were in place for 29 days, from April 10 to May 9. Daytime observations were collected on 11 dates. Overall, there was no significant difference between woody debris and control sections (repeated measures ANOVA, $F = 3.7$, $P = 0.19$). However, there was a significant interaction effect between treatment (woody debris) and time (days from start of experiment)(repeated measures ANOVA, $F = 4.4$, $P = 0.009$). This was because of the large number of chinook salmon observed on the first three survey dates. On April 11, 18, and 19, 245 juvenile chinook salmon were observed around the woody debris while only 7 chinook salmon were observed in the control sections (Figure 22). In later survey dates (April 25-May 9), there was no apparent difference between woody debris and control shoreline sections. On three survey dates, no chinook salmon were observed in any of the shoreline sections. If the water surface was calm, we often observed fish jumping at the surface about 12-20 m offshore. We assumed these fish were chinook salmon.
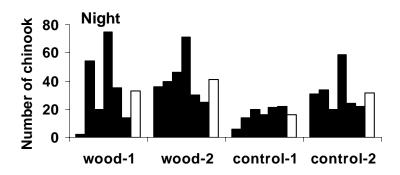
Figure 22.– Number of juvenile chinook salmon at four experimental woody debris sites along the shoreline at the north Gene Coulon Park site, south Lake Washington, April-May, 2001. Woody debris piles were added at two sites and two other sites served as controls. Woody debris was installed on April 10, 2001. Eleven daytime and six nighttime surveys were conducted from April 11 to May 9, 2001. Shaded bars represent the number of chinook salmon on a survey date. Bars are in chronological order. Open bars are the mean number of chinook salmon for all survey dates.

Preliminary beach seining done on May 3 and 8 produced similar results as snorkeling, there was no difference in chinook salmon abundance between woody debris and control sections. The technique of using two seines and herding fish appeared to be effective in sampling around structures. In all cases, more chinook salmon were collected with beach seines than were observed while snorkeling (Figure 23). The area surveyed by snorkelers was similar to the area beach seined. Therefore, differences between the two techniques suggest that chinook salmon are better able to avoid detection by snorkelers than they are able to avoid being encircled by beach seines. Overall, beach seining appeared to provide a more reliable method of estimating chinook salmon abundance during the daytime. The disadvantage with beach seining was that it was much more labor intensive than snorkeling.
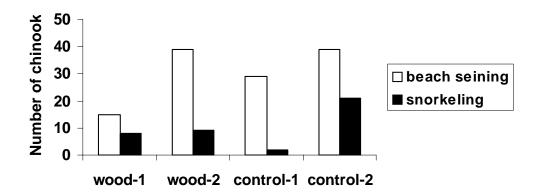

Figure 23.-- Comparison of two sampling types at four experimental woody debris sites, north Gene Coulon Park site, south Lake Washington, May 8 and 11, 2001. The beach seining number is the number of juvenile chinook salmon caught in one set. The snorkeling number is the number of chinook salmon observed along the 0.4 m depth contour. Each site was done once with the two sample types. Snorkeling surveys were conducted prior to beach seining.

At night, there was also no significant difference between shoreline sections with and without woody debris (repeated measures ANOVA, F = 2.4, $P = 0.26$).

Other fish species, such as three-spine stickleback, yellow perch (*Perca flavescens*) and peamouth (*Mylocheilus cauridnus*), tended to be more abundant in the woody debris sections than the control sections. All adult yellow perch (N =17) observed were in woody debris piles. The woody debris also appeared to provide a suitable spawning site for yellow perch as all three perch egg masses observed were directly on the woody debris.

Overhead structure. No juvenile chinook salmon were observed under the structures during five daytime sample dates. In contrast, juvenile chinook salmon were present 70% of the time a control section was sampled (Figure 24). A total of 110 chinook salmon were observed in the two control sections, however, 93% were observed in the furthest north section.
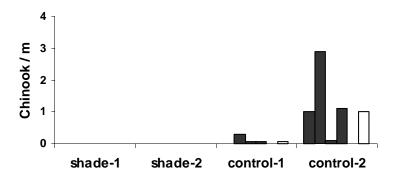
Figure 24. Number of juvenile chinook salmon observed during the day at four experimental overhead-structure sites at the north Gene Coulon Park site, south Lake Washington, April-May, 2001. Overheaded structures (shade) were added at two sites and two other sites served as controls. At shade sites, we only counted fish directly under the overhead. Five surveys were conducted from April 24 to May 9, 2001. Shaded bars represent the number of chinook salmon on a survey date. Bars are in chronological order. Open bars are the mean number of chinook salmon for all survey dates.

The only fish species that was routinely seen under the during the day was juvenile smallmouth bass (< 150 mm; *M. dolomieui*). During the day, they were present 70% of the time a overhead structures was sampled; whereas, they were only present 15% of the time a control section was sampled. Most of the time a bass was observed, only one was present and it was located close to the edge of the structure. Overall, 0.09 bass/m were observed in the overhead structures and 0.015 bass/m were in the control sections.

On all four sample nights, juvenile chinook salmon appeared to strongly avoid overhead cover (Figure 25). The overhead structures represented 25% of shoreline length sampled but only 1.1 % (2 of 179) of the juvenile chinook were under the structures at night. The only two chinook salmon observed under the structures were located close to the edge of the structure. Comparison of chinook salmon abundance between open areas and areas directly under the structures indicated there was a significant difference (repeated measures ANOVA, F = 16.7, P = 0.015). Within each overhead structure (treatment) section there was two areas surveyed, an area directly under the structure and an area within 5 m of the structure, along the shore. If we compare the overall abundance of control and overhead structure sections (both open and shaded areas), we find that there was no significant difference (repeated measures ANOVA, F = 1.8, P = 0.31). This indicates that chinook salmon were often close to the overhead structure but rarely directly under them.
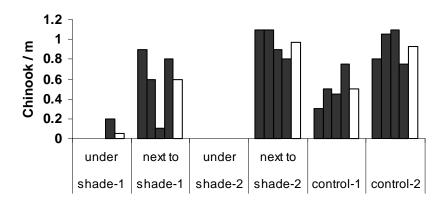
Figure 25. Number of juvenile chinook salmon observed at night at four experimental overhead-structure sites at the north Gene Coulon Park site, south Lake Washington, April-May, 2001. Overhead structures (shade) were added at two sites and two other sites served as controls. Sites with overhead structure were divided into two segments, the area directly under the structure and the shoreline area that was within 5 m of the structure. Four surveys were conducted from April 24 to May 9, 2001. Shaded bars represent the number of chinook salmon on a survey date. Bars are in chronological order. Open bars are the mean number of chinook salmon for all survey dates.

Combination. The combination woody debris and shade structures were installed on May 9, but then removed on May 15 because of an approaching storm. We were only able to complete one nighttime survey and two daytime surveys. Several juvenile chinook were observed during the nighttime survey in all experimental sites. As with earlier experiments, chinook salmon were present in open, unshaded areas but none were directly under the shade structures. During the day, few juvenile chinook salmon were observed in the study area. Other fish (three-spine stickleback, yellow perch, smallmouth bass, and crappie (*Pomoxis sp.*)) however were more abundant in the combination sites than control sites. On the two survey dates, adult yellow perch were observed in both combination sites while they were never observed in the control sites. A total of 14 juvenile smallmouth bass were observed in the combination sites and only one was observed in the control sites. Additionally, two adult crappie were observed in one of the combination sites.

SHIP CANAL SURVEYS

Nighttime shoreline surveys were conducted on three days in June, from June 13 to June 27. Only 32 chinook salmon were observed from all surveys. Thirteen transects were surveyed for a total of 2.5 km of shoreline sampled. Ninety-four percent (N = 30) of the chinook salmon observed were from the first sample date, June 13. On the second sample date, June 20, some sites were not done due to poor visibility, presumably due to heavy boat traffic earlier in the evening. On June 27, visibility was good yet only one chinook observed from five sites surveyed. Besides chinook salmon, few other salmonid smolts were seen. Only 10 juvenile coho salmon were observed.

DISCUSSION

Random daytime surveys and Gene Coulon daytime surveys produced contrasting results. In Gene Coulon Park, most chinook salmon were in the open, away from any cover, whereas during random surveys, chinook salmon were always close to some type of structure such as docks or overhanging vegetation. Some of the discrepancy may have been due to differences in sampling dates. Random surveys were done from February 22 to March 13 and Gene Coulon surveys were done from March 20 to April 4. Most likely though differences were due to the use of a shoreline observer during Gene Coulon surveys who helped snorkelers locate fish. Because water visibility is usually less than 3 m, a snorkeler had difficulty getting close enough to chinook salmon before they moved away and were probably often undetected. In contrast, the shoreline observer could locate fish from a much further distance and then could get within 5-8 m of the fish without disturbing them. During random surveys, the snorkelers may have had more difficulty observing chinook salmon in open areas because the distance at which fish first fled from snorkelers (reactive distance) was much greater than for fish close to cover. Grant and Noakes (1987) found that the reactive distance for brook trout (*Salvelinus fontinalis*) was significantly shorter when fish were close to cover than when they were away from cover.

The addition of a shoreline observer greatly improved our ability to locate chinook salmon and gather habitat use information. However, the use of a shoreline observer had two major limitations: 1) it could only be done effectively on calm days when there was no surface turbulence, and; 2) the fish must be close enough to shore for the observer to see them. At very gradual sloping shores, such as Gene Coulon swim beach, chinook salmon may be in shallow water but still too far offshore for an observer to effectively see them. Outside of the swim beach, an observer could effectively locate chinook salmon along Gene Coulon Park shoreline. Additionally, as chinook salmon move further offshore in April and May, they will be more difficult to locate by an observer. The use of a step ladder and binoculars could help locate chinook salmon. Another important limitation of future foot surveys could be the difficulty in getting shoreline access on private property. We did all of our foot surveys in Gene Coulon Park because we could easily walk the shoreline over a long distance. However, to better understand the daytime use of docks and bulkheads, foot surveys along residential shorelines would be desirable.

Even with a shoreline observer, the use of daytime snorkeling to collect habitat use information was not as effective as night snorkeling. At night, chinook salmon were not active and could easily be approached by a snorkeler. During the day, chinook salmon were active, usually in an aggregation, and swam away from snorkelers. At night, however, chinook salmon were no longer associated with any other fish and were motionless, close to the bottom. This type of behavior pattern, diurnally active and nocturnally inactive, is common in many other freshwater fishes (Emery 1973; Helfman 1978).

After mid-May, juvenile chinook salmon were present in the littoral zone but were no longer as close to shore as they were in March and April. Fresh (2000) found that, after mid-May, chinook salmon were no longer exclusively found in the littoral zone but were also found in surface limnetic area. Chinook salmon appear to progressively move into deeper waters as they increase in size. Ontogenetic habitat shifts from nearshore nursery areas to offshore areas have

been reported for other juvenile fish including bluegill (*Lepomis macrochirus*; Werner and Hall 1988) and rainbow trout (*O. mykiss*; Wurtsbaugh and Tabor 1988; Post et al. 1998). Juvenile bluegill move to offshore areas when they are 50 to 80 mm FL and rainbow trout move offshore when they are 100 to 120 mm FL. Chinook salmon appeared to move offshore when they are 80 to 100 mm FL (Fresh 2000). Researchers have suggested that juvenile fish move offshore when they reach a size that they are no longer vulnerable to most fish predators (Jackson 1961; Werner 1986).   Additionally, Werner and Hall (1988) found that the size that juvenile bluegill moved offshore was correlated with predator densities.

After mid-May, snorkeling does not appear to be the best method of collecting data on chinook salmon habitat use, day or night. Fewer chinook salmon were present in nearshore areas and those that were present appeared to be more wary and thus more difficult to count accurately. In winter and early spring, a snorkeler at night could easily approach within 10-20 cm of the fish but after mid-May it was difficult to get within 70-100 cm of them. Grant and Noakes (1987) found that large fish were more wary than small fish. After mid-May, other sample techniques need to be used to accurately assess the daytime and nighttime habitat use of juvenile chinook salmon. Techniques such as hydroacoustics in combination with some type of netting (beach seines, purse seine, or pop-up nets) need to be investigated. Some scuba diving transects may also be beneficial.

We saw few chinook salmon in the Ship Canal considering the large number that migrate through that area. We were also somewhat surprised to see so few other salmonid smolts such as coho salmon smolts. Large numbers of chinook salmon were captured by WDFW with beach seines at West Montlake Park and Gas Works Park during the same time period we sampled. Earlier shoreline sampling in 1999 with an electrofishing boat indicated large numbers of chinook salmon and other salmonids are often located close to the shore at night (R. Tabor, unpublished data). At steep sloping shoreline, the area snorkeled would have been part of the area electrofished because were able to maneuver the boat close to shore. However, in more gradual sloping banks, the area snorkeled would have been closer to shore than the area electrofished. One possible reason for the difference between the two years was possible differences in flow rates that caused smolts to migrate faster in 2001 than in 1999.   However, chinook salmon were most likely slightly offshore and rapidly moved away from snorkelers, similarly to what we observed in Lake Washington after mid-May.

Chinook salmon abundance at index sites in Gene Coulon Park was unexpectedly high given the low spawner abundance. Data from the Cedar River fry enumeration trap indicated chinook abundance was low in 2001 and substantially lower than 2000 (D. Seiler, WDFW, personal communication). The vast majority of chinook salmon in south Lake Washington should have originated in the Cedar River. Our data indicated that the chinook salmon abundance at the index sites was higher in 2001 than 2000, however, we only sampled the index sites three times in 2000 and thus we were unable to make a powerful comparison between years. We did not, however, find any evidence that juvenile chinook salmon abundance was lower in 2001 than 2000. Additionally, results of beach seines catches by WDFW also did not indicate any reduction in chinook salmon abundance (K. Fresh, WDFW, personal communication). Chinook salmon abundance in south Lake Washington could have been high if there was a high egg to fry survival rate and a large percent of the chinook salmon migrated to the lake as fry in February and March.

Peak flows were low in 2000-2001 which probably resulted in little redd scour and thus egg to fry survival rates should have been high. The sharp increase in index counts in early March occurred shortly after the earthquake on February 28, and thus the earthquake and an associated landslide may have caused an unusually high percentage of the fry to migrate to the lake. Reasons why index counts do not match fry trap data are unclear. The fry trap could have missed some chinook salmon shortly after the earthquake or a high number of chinook migrated close to shore and were missed by the fry trap which samples the thalweg. An additional possible explanation is that the distribution of chinook salmon within the lake varies from year to year. However, comparisons of 2000 and 2001 snorkeling data do not indicate any major shift in chinook distribution.

Of the three woody debris/overhanging vegetation sites in Lake Sammamish, the furthest east site had a substantially higher density of juvenile chinook salmon and coho salmon than the other two sites. Several factors may help explain the differences between the sites. The east site was the closest to Issaquah Creek, where most of the fish probably originated. Other possible explanations include the proximity of the east site to open shoreline areas as well as to open offshore areas. In other words, the east site may have the best edge habitat of the three sites. The east site was the shortest site and open sandy beaches were a short distance away on both sides of the site and thus fish have easy access to open shoreline areas which may be more preferred nighttime resting habitat and daytime foraging habitat. At the other two sites, the adjacent offshore habitat is a long, wide strip of water lilies. Juvenile salmonids do not appear to use this habitat, which was instead inhabited by a few adult largemouth bass, a potential predator. No water lilies are present at the east site. Other differences between the sites included substrate type and undercut banks. The east site had primarily sand substrate while the other two sites had primarily mud/silt substrate with some patches of sand. Two large black cottonwoods were along the shore at the east site. These trees had a large root system along the shore which created complex undercut banks along most of the site shoreline. No such habitat was present at the other two sites.

The use of fine substrate, such as silt and mud, by juvenile chinook salmon is unclear. Preliminary evidence indicates that they may not use this habitat type in relation to its availability. Large areas with fine substrates were not common in the south part of Lake Washington and thus it was difficult to assess its preference by juvenile chinook salmon. However, at Lake Sammamish State Park, chinook salmon appeared to avoid areas with fine substrates in comparison to nearby areas that had sand and gravel substrates. Further sampling is needed to determine if this relationship is correct.

Both boat ramp locations (Gene Coulon Park and Beer Sheva Park) in south Lake Washington had high concentrations of chinook salmon in comparison to adjacent areas. Although the boat ramps are a type of armored bank, they have a substantially gentler slope than a bulkhead or rip rap. To some degree, boat ramps may simulate a sandy beach, a gentle sloping area with very small interstitial spaces in the substrate. Additionally, juvenile chinook salmon may be attracted to boat ramps due to the docks in between the boat ramps which may provide some overhead cover. In Gene Coulon Park, juvenile chinook salmon appeared to use the boat ramps extensively in March and progressively used them less and less in April and May. This pattern is similar to the pattern we observed for chinook salmon use of overhead cover.

Alternatively, increased boat traffic in April and May could have caused the chinook salmon to move to other locations.

Although chinook salmon did not appear to strongly prefer woody debris, it may be beneficial as a refuge from predators and may only be used for brief periods of time. Thus, to determine the importance of woody debris, we may need to include fish from a larger area, particularly fish that are a little ways offshore. In Lake Sammamish and woody debris experiments at Gene Coulon Park, we measured the habitat selection at the mesohabitat scale; however, a larger scale may have been more appropriate. When we observed a merganser pursuing juvenile chinook salmon and coho salmon smolts in Lake Sammamish, the fish appeared to move from 20 m offshore and seek cover along the shoreline. For example, we may need to compare shorelines (with and without woody debris) that are ≥ 100 m long and count chinook salmon that are inshore and offshore. Peters (1996) found that, at a large habitat scale, juvenile coho salmon in the Clearwater River strongly selected woody debris habitats but at a fine habitat scale it was not preferred. Selecting the appropriate habitat scale may be especially important for active fish species which can quickly move a long distance to a different habitat type to escape predators.

Besides refuge from predators, woody debris may also be used as a daytime resting area. When juvenile chinook salmon are actively foraging, they may move offshore where prey may be more abundant and when resting they may move back to the woody debris. Peters (1996) found that foraging juvenile coho salmon were further from woody debris than resting fish. At Lake Sammamish woody debris sites, there appeared to be two groups of chinook salmon, a small group that was inshore in the woody debris and did not appear to be foraging and a larger group that foraged offshore. Thus, the use of woody debris may also be related to feeding activity and the time of day.

Woody debris and overhanging vegetation appeared to be commonly used by chinook salmon in March and April but in May and June its use seemed to get progressively reduced. In May, juvenile chinook salmon move into deeper water and thus their use of riparian vegetation would be expected to be reduced. Additionally at this time, smallmouth bass and other potential predators appear to move into the shallow waters and often inhabit woody debris. Weidel et al. (2000) found that smallmouth bass > 50 mm were common at woody debris sites and bass > 300 mm were only found at woody debris sites. During our habitat manipulation experiments and other surveys, we observed that smallmouth bass became progressively more abundant in May and June and were usually found associated with some type of overhead structure including overhanging vegetation. Smallmouth bass were rarely observed in the nearshore area until late April. We observed adult yellow perch spawning in woody debris in late April and May which may also influence the use of woody debris by chinook salmon. Also, on one occasion we observed an adult largemouth bass at a WD/OHV site. No chinook salmon were present; whereas, on other days when no bass were present, chinook salmon were commonly observed.

At night, chinook salmon appear to avoid the darkest areas such as locations with overhead structures or overhanging vegetation. In Lake Sammamish, juvenile chinook salmon and coho salmon inhabited woody debris/overhanging vegetation habitats during the day but strongly avoided them at night. Instead, both species inhabited open areas (lacking structural

complexity) at night. In the habitat manipulation experiments, chinook salmon strongly avoided overhead structures at night but were often present in woody debris. The light intensity levels below the overhead structures appeared to be much lower than surrounding areas; whereas light levels under the woody debris were probably similar to surrounding areas. Most likely, chinook salmon avoid areas with very low light at night to avoid nocturnal predators such as large prickly sculpin which may be more abundant in complex habitats (Tabor, Chan, and Hager 1998). Also, chinook salmon may be more vulnerable to sculpin under very low light conditions as has been observed with juvenile sockeye salmon and sculpin (Tabor, Brown, and Luiting 1998).

Habitat manipulation experiments provided valuable information on the habitat use of juvenile chinook salmon. In habitat surveys of the shoreline, many of the habitat variables are often correlated and thus it is often difficult to understand which are the important variables affecting habitat use. For example, the shoreline under docks is often more armored than the surrounding shoreline and the avoidance of these habitats by chinook salmon could be due to the overhead structure or possibly the armoring. In our experiments, we tested the avoidance of overhead structure. There was no armoring in the control or overhead structure sections and thus we were able to better isolate the effect of the overhead structure. The experiments clearly showed that chinook salmon avoid overhead structures during April and May. Additional experiments would be useful to test the relationship between chinook salmon habitat use and other types of shoreline modifications, such as various dock designs. Also, additional experiments need to be conducted in March because our experiments were only conducted in April and May. The major limitations of these experiments is finding a suitable site and having sufficient funds to construct the habitat modification. Our sites in Gene Coulon Park worked well because we found a long shoreline with little structure and chinook salmon were known to be abundant. Other potential sites include the open beaches in the south end of Lake Sammamish.

Conclusions

A summary table is presented below which lists various habitat variables and displays conclusions about each variable for three time periods (Table 2).

1) Based on observations at the Gene Coulon index sites, Seward Park, middle-west shoreline sites, and the Ship Canal, juvenile chinook salmon do not appear to make extensive use of the nearshore area during the day or night after mid-May.

2) After the middle of May the use of snorkeling to survey juvenile chinook salmon appears to be problematic. Juvenile chinook salmon appear to primarily inhabit other areas beside the nearshore area in Lake Washington and the Ship Canal/Lake Union area and other techniques are needed to determine their habitat use.

3) Daytime snorkeling in February-April can be useful in determining chinook habitat use if done with a shoreline observer or in combination with other sampling techniques such as netting and hydroacoustics.

4) Chinook salmon selected sand and gravel habitats during both day and night throughout the sampling period.

5) During the day, juvenile chinook salmon were active and often were feeding at the surface. They were usually in some type of aggregation, either a chinook-only group or a mixed group with juvenile sockeye salmon. At night, chinook salmon were inactive, rested on the bottom, were close to shore, and were no longer associated with each other.

6) In February and March, chinook salmon were found using overhead structures (piers, docks, and overhanging vegetation) during the day but in April and May, no chinook salmon were ever observed using overhead structures. At night, chinook salmon rarely used overhead structures.

7) During both time periods, day and night, the percent of chinook salmon along armored banks (bulkheads and rip rap) was lower than the percent of shoreline that had armored banks. If chinook salmon were present along armored banks, they were along armored banks that were relatively short.

8) In February and March, chinook salmon appeared to use woody debris during the day but as they grew they used it less and less. In May and June, woody debris was probably not used extensively but may still have served as a refuge from predators.

9) Our results demonstrated that day and night habitats can be dramatically different and managers should consider both day and night habitat requirements when designing restoration projects. Results also suggest the need to have a diverse shoreline with open areas as well as areas with woody debris.

10) Habitat manipulation experiments were beneficial because we were able to examine some habitat characteristics of juvenile chinook salmon under more controlled conditions. Additional experiments would be useful to test the relationship between chinook salmon habitat use and other types of shoreline modifications.

Table 2.-- Summary table of juvenile chinook salmon habitat use during three time periods in Lake Washington, Lake Sammamish, and the Ship Canal/Lake Union area. Summary designations are based on 2000 (Piaskowski and Tabor 2001) and 2001 results. + 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.

| Habitat variable | February - March | | April - mid-May | | mid-May - June | |
	Day	Night	Day	Night	Day	Night
Water column depth (m)	0.2-1.3	0.1-0.7	??	0.3-0.9	(?)1-6	??
Location in water column	entire column	bottom	middle to top	bottom	middle to top	(?) bottom
Behavior	schooled, feeding	solitary, resting	schooled, feeding	solitary, resting	schooled, feeding	(?)solitary, resting
Distance from shore (m)	1-12	1-12	??	1-12	(?)12-55	(?)12-55
Substrate	sand/gr.	sand/gr.	??	sand/gr.	??	??
Slope	< 20%	< 20%	< 20%	< 20%	??	??
Small woody debris	+	=	(?) +	=	??	??
Large woody debris	??	(?) -	??	(?) -	??	??
Overhanging vegetation	+	- -	(?) +	- -	??	??
Overhead structures	+	- -	-	- -	??	(?) -
Bulkheads	-	-	??	- -	??	??
Rip rap	- -	- -	??	-	??	??

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