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Do Bridges Affect Migrating Juvenile Salmon: Tracking Juvenile Salmon and Predator Fish Movements and Habitat Use Near the SR 520 Bridge in Lake Washington

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Project Description

Results of a two-year fish tracking study evaluating the behavior and habitat use by both outmigrating juvenile salmon and their predators in the vicinity of the SR 520 bridge on Lake Washington near Seattle, WA.

Abstract

Large anthropogenic infrastructure such as major bridges in and near waterways can influence the ecological dynamics of the nearby aquatic environment. These influences may affect behavior, habitat use, fitness, and survival of fishes. Chinook salmon (*Oncoryhnchus tshawytscha*) spawning in tributaries to Lake Washington typically spend three to five months rearing in Lake Washington before travelling through the Lake Washington Ship Canal to Puget Sound. Most salmon smolts in Lake Washington must pass beneath the SR520 Bridge en route to Puget Sound. Plans to replace the existing bridge have sparked interest in how smolts and potential predators behave around and use the bridge.

To address this interest, we tracked Chinook smolts, smallmouth bass and northern pikeminnow in a 17.2 ha area along a 560 m stretch of the SR520 bridge during June-July 2007 and 2008 using fine-scale acoustic tracking. During the 2007 tracking season a total of 171 smolts were released in three June release groups and 162 were successfully tracked in the study area. Repeating the study design in 2008, 181 smolts were released and 133 were successfully tracked in the study area during a total of four release groups occurring in June and July. Although this study focused on the SR 520 bridge, many fish were also observed at a downstream tracking station approximately 2-miles downstream allowing us to evaluate movements within and between sites. Different release groups appear to exhibit different behaviors, some release groups rapidly migrated through the SR 520 tracking area in < 3 h ("migrating"), while other release groups were often detected ≥ 2 days ("holding"). The bridge appeared to delay some migrating smolts. These delays were typically short in duration as salmon would move along the bridge – typically towards the shoreline – prior to migrating past the bridge. Many holding smolts used areas near the bridge extensively. Timing of migrational cues, physiological smolt status, water temperature and clarity, and macrophytes may have influenced movement timing and habitat use. During the same study periods small numbers of northern pikeminnow and smallmouth bass were also tracked. Bass preferred habitats under overwater structures, including the bridge – particularly near bridge columns. Pikeminnow preferred macrophytes and overwater structures other than the bridge. Predator diets and abundance were also evaluated in and near the study area.

These results suggest that the bridge in its current form may affect the movements of some Chinook smolts and may be preferred habitats for some salmon predators. The SR 520 Bridge Replacement Project is continuing to evaluate these results to help inform design of the proposed bridge replacement.

Introduction

Puget Sound Chinook salmon *Oncoryhnchus tshawytscha* (listed as threatened under the Endangered Species Act) are an important component of the Lake Washington ecosystem. Within this ecosystem, juvenile Chinook salmon primarily rear in the south end of the lake from January to May (Tabor et al. 2006), with migration throughout the lake, through the ship canal and into the marine environment occurring between May and July. The lake lies within an urbanized area and has been modified in many ways to suit human uses. Modifications to the lake that affect salmon include increases in impervious surface within the tributary systems that have decreased baseflows (Horner and May 1998) and increased flooding (Moscrip and Montgomery 1997), shoreline armoring that has replaced native vegetation and covers 81% of the shoreline combined with approximately 2700 residential piers (Toft 2001), and the construction of a ship canal connecting Lake Washington to marine waters (NOAA 2008). In 1916, drainage from Lake Washington into the Black River was blocked and the Ship Canal and Hiram M. Chittenden Locks were constructed to allow navigable passage between Puget Sound, Lake Union, and Lake Washington and provide better flushing in Lake Washington.

Furthermore, the timing of the natural hydrologic cycle has been reversed so that today lake elevations are at their highest in summer to support recreation activities and at their lowest in winter.

The existing State Route (SR) 520 bridge completely spans the lake connecting Seattle with its eastern suburbs including Bellevue and Redmond. The bridge location is a transition area between Lake Washington and the ship canal where Chinook salmon smolts are presumed to concentrate in large numbers during the outmigration period. Wild fish populations from the Cedar River at the south end of the lake must pass under the bridge to exit to salt water, and juvenile hatchery fish appear widely distributed in the lake and a substantial portion of them also likely pass under the bridge. The existing bridge was completed in 1963 and is nearing the end of its functional lifespan leading to plans for a replacement structure that would be less vulnerable to wind and wave storms, seismic events and improve movement of people and goods (WSDOT 2006). Following the release of the Draft Environmental Impact Statement (EIS) for the SR 520 Bridge Replacement and HOV Project (WSDOT 2006), resource agencies and tribes voiced concerns about potential impacts to fishery resources from the existing and proposed replacement for the SR 520 bridge. These concerns focused primarily on either the potential for the existing and future bridge to act as a barrier to migrating juvenile salmonids or the potential for the bridge and related structures to provide habitat for piscivorous fish, thereby potentially increasing predation rates on outmigrating juvenile salmon. Predation risk is an important factor influencing juvenile Chinook salmon which can cause changes in habitat use, movements, and behavior. Unlike other structures that juvenile Chinook can avoid by moving into deeper water away from the structure and predators, the bridge extends from shoreline to shoreline.

Important fish predators of juvenile salmon in Lake Washington include cutthroat trout (Nowak et al. 2004), northern pikeminnow (Olney 1975; Brocksmith 1999), and smallmouth bass (Tabor et al. 2007). Predaceous cutthroat trout inhabit the pelagic zone and are highly mobile (Nowak and Quinn 2002) and would therefore be difficult to study at the SR 520 bridge. Northern pikeminnow inhabit the littoral zone as water temperatures increase and may be abundant at our study site in response to increases in juvenile salmon abundances during outmigration. Pikeminnow have been shown to congregate in other areas in Lake Washington (Olney 1975) and in other systems (Collis et al. 1995) where prey is abundant. Little is known about their use of overwater structures as habitat or to ambush prey. They have been shown to congregate near structures at dams, but their presence is believed to be related to prey abundance or water velocity, not necessarily the structure.

In contrast to northern pikeminnow, smallmouth bass have been documented to use overwater structures. For example, Fresh et al. (2001) found 49% of all smallmouth bass observed in Lake Washington were within 2 m of an overwater structure. Other factors influencing smallmouth bass habitat use include substrate type with cobble and boulders being preferred over finer substrates (Fresh et al. 2001) and steep slopes (Hubert and Lackey 1980).

In efforts to improve bridge design and to respond to concerns from resource agencies, Washington State Department of Transportation (WSDOT) partnered with US Fish and Wildlife Service (USFWS) to develop and implement a study that uses a combination of fine-scale acoustic tracking system to monitor fish movements and habitat movements near the bridge with conventional field techniques to evaluate the interactions of fisheries with the existing bridge. The objectives of the study were to: 1) document juvenile Chinook salmon migration patterns near the existing bridge; and 2) determine the relationship in space and time between outmigrating juvenile Chinook salmon and piscivorous fishes. In developing this research project we created an initial conceptual model for fish activity near the SR 520 bridge. This conceptual model generated several expectations which guided the study design and formed testable hypotheses. With regard to Chinook salmon smolts, we predicted that the bridge would not influence movement or habitat use of tracked fish. We assumed that the intent of tagged fish to migrate through the study area and beyond the bridge would be clear, and that abrupt changes in direction of travel at the bridge would indicate a bridge effect. For both Chinook salmon smolts and predators we predicted that habitat selection would be similar in areas near and away from the bridge, and that areas near the bridge would not be selected any more or less than areas away from the bridge. Differences in habitat selection ratios between areas near the bridge compared with areas away from the bridge would suggest a bridge effect. Field research began in 2007 (Celedonia et al. 2008) and continued through the 2008 field season.

Methods

Fine-Scale Acoustic Tracking System

Tracking was performed using a fine-scale acoustic system developed by Hydroacoustic Technology, Inc. (HTI), Seattle, Washington. This system uses acoustic tag transmitters implanted within the study fish, and a fixed array of underwater listening devices - termed hydrophones - to track fish movements in a specific study area. Tag transmitters are programmed to periodically emit a signal, or ping. The system uses time differentials to triangulate a 3-dimensional position for the origin of each ping. Calculated positions are relatively accurate, estimated to be ± 0.5 m in the horizontal plane when the fish is within the perimeter of the hydrophone array. Accuracy declines outside the array perimeter, but has been estimated to be approximately ± 3 m in the horizontal plane at a distance of 1 array width from the array perimeter. In general, we accepted calculated fish positions from both within and outside the array perimeters.

Study Site

The study site was located on the western shore of Lake Washington and included an approximately 560 m stretch of the bridge (Figure 1). This general area comprises a transition between the 60 m-deep Lake Washington proper, and the much shallower 10-12 m-deep Union Bay and entrance to the LWSC. The shoreline within the study area changed abruptly from a north-south orientation to a west-east orientation at the opening to Union Bay. The study site had a gently sloping gradient extending north and east from the shoreline. On the east side of the site the gradient steepened considerably starting at ~ 10-12 m depth. Prominent features of the study area in addition to the bridge included: a large condominium building that extended over the water on the very southern edge of the site; two small boat docks along the southern shoreline; dense and abundant macrophytes (primarily the non-natives Brazilian elodea *Egeria densa* and Eurasian milfoil *Myriophyllum spicatum*) generally in most areas < 6 m deep and particularly on the south side of the bridge; and, an anomalous peninsula-like ledge with shallower water (4-6 m depth) extending northward from the bridge on the east side of the site. Substrate throughout the area appeared to consist largely of sand and silt, although we did not perform a formal substrate survey to verify this.

The SR 520 bridge is approximately 19 m (60 feet) wide. It generally runs east-west across Lake Washington; however, the portion contained within the study site had a slight east-southeast – west-northwest tilt. On the east side of the site depth contours were oriented perpendicular to the bridge. However, at the transition to Union Bay, depth contours were parallel with the bridge. The bridge at the very east end of the site included a high span approximately 20 m above the water surface. Moving west from this span, a gradual downward gradient brings the bridge closer to the water surface. At the west side of the site, the bridge was within 1-2 m of the water surface. Concrete columns served as support structures for the bridge and were located along the entire length of the bridge within the study area. Columns are approximately 1 m in diameter. Bents of six columns apiece ran perpendicular to the bridge at approximately 30-m (100 foot) intervals. Sixteen bents of columns were contained within the study site, totaling 96 columns

Water Quality, Aquatic Vegetation and Substrate

Aquatic vegetation and substrate were surveyed by collecting a large number point observation samples within and near the tracking area. Sample points were collected along transects at 20 m intervals perpendicular to shore, and survey points every 15 m along each transect. At each sampling point an underwater camera was lowered and the following data was collected: presence/absence of vegetation; density of vegetation; and total depth. Vegetation density, primarily aquatic macrophytes, was categorized according to coverage within the camera viewfinder: >95% cover was categorized as “very dense”; 75-95% as “dense”; 25-75% as “moderate”; 1-25% as “sparse.” Plant densities were collected at the end of the field season in both years, and during the second year growth was tracked along four transects during the study period. Substrate was collected using the same methods as the macrophyte survey and categorized into two categories – cobble and boulder or silt during the 2008 study year.

Water quality was periodically sampled throughout the tracking area during the study period. Six sample points were established on the south side of the bridge, and two points on the north side (figure 2). Sample point locations represent the variety of habitat types throughout the study area: shallow water and deep water; vegetated areas and unvegetated areas; nearshore and offshore; and areas near the bridge and not near the bridge. At each point Secchi depth, temperature, dissolved oxygen, conductivity, and salinity were collected. Where appropriate, parameters were sampled at 1 m depth and then 2-m depth intervals thereafter.

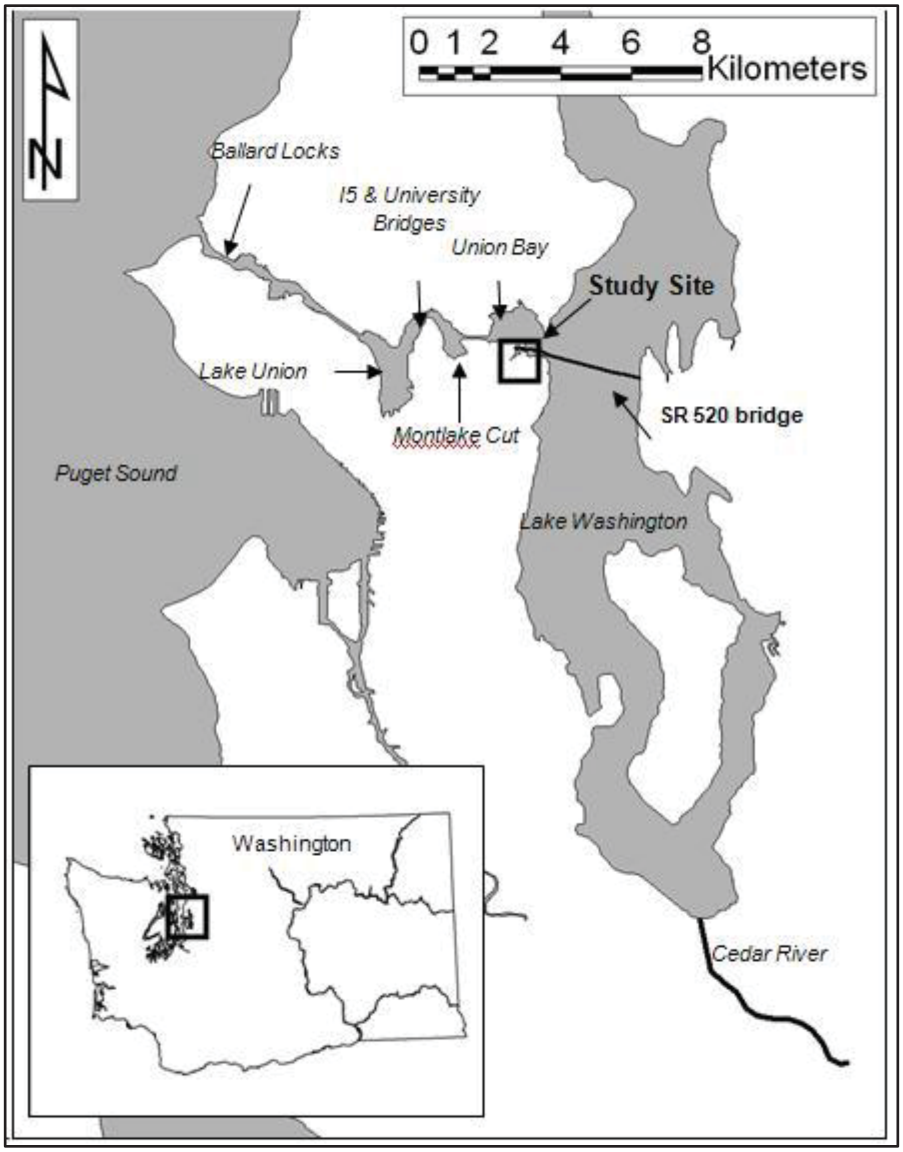

Figure 1. Map of Lake Washington showing 2008 study site location at the west end of the SR 520 bridge.

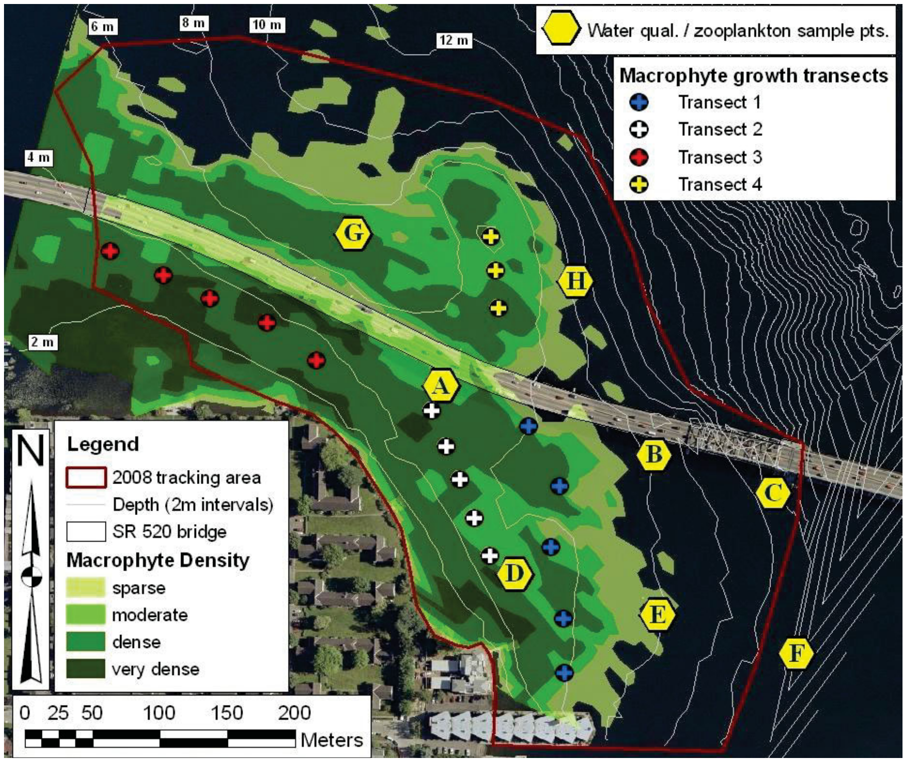

Figure 2. Sampling locations for water quality and zooplankton - May 31 - July 11, 2008.

Chinook Salmon Smolt Tagging and Tracking

Juvenile Chinook salmon from the Washington State Department of Fish and Wildlife's Issaquah hatchery were used in 2007 and 2008. In 2007 tags were turned on after surgery and immediately prior to release, whereas in 2008 Chinook salmon tags were programmed and switched on at the time of implant. We expected tag batteries to last approximately 12 days after the fish were released.

General behavioral patterns, movement times, residence times, and behaviors associated with the bridge were evaluated. Data were represented and evaluated with parametric or nonparametric statistics depending on the type of distribution observed (Zar 1999; Sheskin 2000). Unless otherwise noted, statistical significance was established at $\alpha = 0.05$.

Actual time fish spent in the tracking area (i.e., time spent on-site) was evaluated using the number of data points obtained for each fish as a surrogate for time. To correct data point observations for underestimates of the actual time spent on site, we randomly subsampled 166 fish days to calculate an equation for adjusting time estimates.

We used habitat selection equations described by Manly et al. (2002). These equations avoid take each animal as the experimental unit and evaluate each animal's proportional use of habitats and depths. Issues associated with pseudoreplication and serial correlation are therefore avoided regardless of which equations are used (Aebischer et al. 1993; Garton et al. 2001; Rogers and White 2007).

From Manly et al. (2002), the selection ratio for the *j*th fish and the *i*th habitat or depth category, was calculated as

$$\hat{w}_{ij} = (u_{ij} / u_{+j}) / \pi_i$$

where u_{ij} is the amount of time spent in habitat type (table 1) or depth category *i* by fish *j*, u_{+j} is the amount of time fish *j* was tracked across all habitat types or depth categories, and π_i is the proportion of available habitat or depth in category *i* relative to all available habitats or depths at the study site. For each release group of fish, a mean population-level selection ratio for each habitat or depth category was calculated as

$$\hat{w}_i^{'} = \sum_{j=1}^{n} \hat{w}_{ij} / n$$

where *n* is the number of fish tracked across all habitat types or depth categories.

Habitat type	Abbreviation	Description	Area (ha)	Percent
Near shore	NS	Unvegetated areas close to the shoreline.	0.17	1.06
Very dense vegetation	VDV	Area of very dense macrophytes not including areas in types OWS, CE, BR, NBR.	0.53	3.33
Dense vegetation	DV	Area of dense macrophytes not including areas in types OWS, CE, BR, NBR.	3.28	20.63
Moderately dense vegetation	MV	Area of moderately dense macrophytes not including areas in types OWS, CE, BR, NBR.	1.90	11.97
Sparsely dense vegetation plus offshore edge of vegetation	SV/VE	Area of sparsely dense macrophytes including 20 m from the offshore edge of macrophytes, not including areas in types OWS, CE, BR, NBR.	2.59	16.27
Open offshore area	OO	Open offshore area that is not within 20 m of macrophytes and does not include areas in types OWS, CE, BR, NBR.	3.69	23.21
Other overwater structures	OWS	Area that is directly under the Lakeshore West Condominiums and that is directly under or within 5 m of the boat docks at the Edgewater Apartments and Madison Point Condominiums.	0.26	1.64
Condo edge	CE	Area extending from the edge of the Lakeshore West Condominiums to 20 m from the edge.	0.23	1.43
SR 520 bridge	BR	Area that is directly beneath the SR 520 bridge.	1.07	6.71
Area near SR 520 bridge	NBR	Area extending from the edge of the bridge to 20 m from the edge of the bridge	2.19	13.76

Table 1. Ten habitat types used to determine habitat selection at the 15.9 ha SR 520 bridge study site.

Selection for a habitat or depth occurs if the lower confidence interval is > 1, and selection against a habitat or depth occurs if the upper confidence interval is < 1. Confidence intervals that include 1 indicate proportional distribution across that habitat type or depth category. That is, the habitat type or depth category is neither selected for nor selected against, but rather is used in proportion to its availability.

Northern Pikeminnow and Smallmouth Bass Acoustic Tracking

In 2007 and 2008, we primarily used sinking horizontal gill nets to collect predatory fishes. The gill nets were variable-mesh, monofilament nylon nets, which consisted of 2.5, 3.2, 3.8, 5.1, and 6.4-cm square-mesh panels. The nets were 38 m long and 2.4 m high. Two or three nets were set each sampling night. In addition to gill nets, we also tried to collect predatory fish through angling; however, catch rates were low.

After each fish was anesthetized, the weight (g) and fork length (mm) was measured. The same tagging procedures used with juvenile Chinook salmon were used for predatory fishes except we used larger suture material. Fish were allowed to recover before being released at their approximate capture location.

Data points for the first 24 h after release were not used to allow time for the fish to recover and start to behave naturally. Predator tracking data were separated into dawn, day, dusk, and night time periods to examine diel behavior. Selection for the SR 520 bridge structure and other habitat types was estimated by determining the number of data points observed in each habitat category. Habitat and depth selection were determined in a similar manner as that for Chinook salmon smolts.

Predator Field Sampling and Fish Processing

To determine the abundance and diet of northern pikeminnow and other predatory fishes, we set a series of gill nets at five locations: 1) SR 520 bridge, 2) Wolf Bay 3) Webster Point, 4) Madison Park North Beach, and 5) Seattle Tennis Club (Figure 3). Two sites were north of the bridge and two were south of the bridge. We set two nets at each site; both running parallel to the shore. Nets were placed along the 5 and 10 m depth contours. At the SR 520 bridge site, the nets were set directly under the bridge and perpendicular to the structure. Nets were deployed once each week for six weeks from May 29 to July 1, 2008. On the first sampling date, nets were deployed shortly before sunset and retrieved shortly after sunrise.

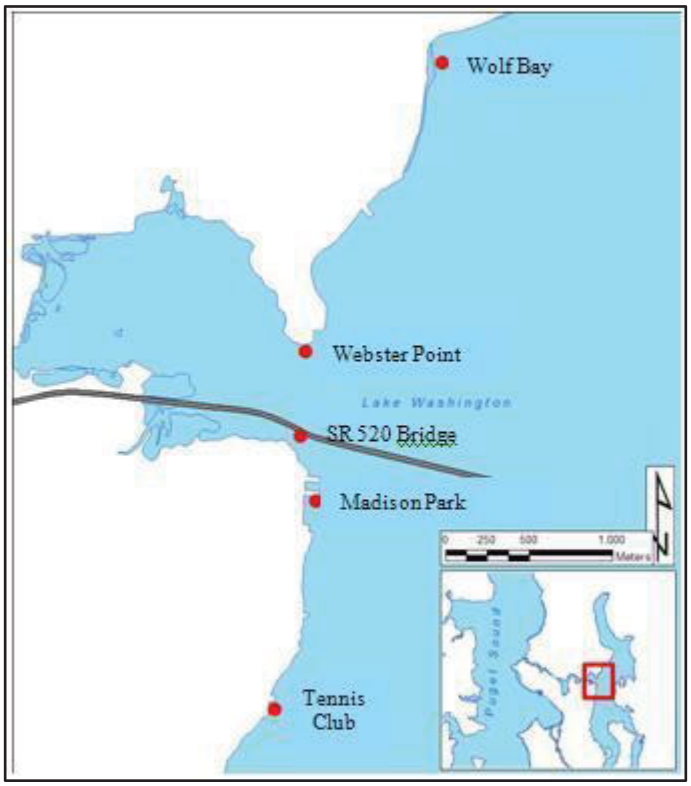

Figure 3. Map of central Lake Washington displaying the five gill-netting sites for piscivorous fish.

Laboratory Analysis

In the laboratory, each sample was thawed and placed under a dissecting microscope. Stomach contents were separated into major prey taxa. Insects and crustaceans were identified to order while other invertebrate prey items were identified to a convenient, major taxonomic group.

Results

Juvenile Salmon Tagging and Tracking

Hatchery fish were released in a total of seven release groups across two out-migration seasons (Table 2). The first release group of each season had fewer fish than later release groups because an insufficient number of fish had reached the minimum size necessary to tolerate tagging. Fish size was similar among release groups, however lengths and weights were not the statistically the same within release years based on single-factor analysis of variance (Zar 1999). In general later release groups included slightly longer and heavier fish.

Release date	Release time	No. fish released	Mean FL [SD] (mm)	Mean wt. [SD] (g)	% detected at 520 (no. fish)	% tracked at 520 (no. fish)	% detected in LWSC (no. fish)
				2007			
June 1	10:08	37	105.7 [3.1]	13.3 [1.0]	97% (36)	97% (36)	83% (31)
June 14	9:42	68	106.0 [2.7]	12.9 [0.9]	90% (61)	87% (59)	46% (31)
June 28	13:03	66	108.5 [4.9]	14.3 [2.2]	98% (65)	97% (64)	38% (25)
				2008			
June 12	9:06	27	101.6 [2.0]	11.4 [0.6]	89% (24)	85% (23)	17% (4)
June 26	9:28	50	103.0 [1.9]	11.3 [0.5]	80% (40)	78% (39)	60% (24)
July 3	9:33	53	105.5 [2.3]	12.5 [0.7]	79% (42)	75% (40)	69% (29)
July 10	9:08	51	109.3 [4.0]	13.6 [0.9]	84% (43)	80% (41)	30% (13)

Table 2. Seven groups of tagged Chinook salmon smolts released during June 2007 and June-July 2008 and tracked at the SR 520 study site, including percentage of tagged fish detected at the SR 520 bridge hydrophone arrays, the percentage of tagged fish that yielded tracks, and the percentage of fish detected at the SR 520 bridge that were also detected in the LWSC.

The substantial majority of tagged fish from all release groups were both detected (heard by at least one hydrophone) and tracked (heard by at least 3 hydrophones) at the SR 520 bridge arrays. Between 79% and 98% of tagged fish were detected at the SR 520 arrays and 75% to 97% of tagged fish yielded point location data (tracks). Between 17% and 83% of released fish were also detected at the University Bridge study site, approximately 2 miles further along the migration route to saltwater (table 2). No fish reached the University Bridge site without first being detected at the SR 520 bridge site.

Fish were typically detected at the study site the day of release. In general, fish traveled more quickly from release to the study site as the season progressed: median travel times were 10.2, 4.9, 3.7, and 1.5 h, respectively, for the June 12, June 26, July 3, and July 10, 2008 releases. Site area residence time (time between first and last detection) also shortened as the season progressed. Given the relatively short battery life of the tags, it is uncertain how many non-LWSC fish may have entered the LWSC after the tag battery died.

Juvenile Salmon Behavior and Habitat Selection

Generally, fish released during this study expressed one of two dominant behavioral types described here as type A (migrating) and type B (holding). Fish expressing these different behavioral types showed differences in their bridge approach, encounter, pass and post-pass behaviors. Type A behaviors would generally move in a direct line with little deviation or changes in speed during each phase of the bridge encounter and never be detected within the monitoring site after leaving the area. Type B behaviors would meander or mill within the site and may change direction and swim parallel to the bridge upon bridge encounter or travel underneath the bridge. Type B behavior also includes fish that might return to the study site on multiple days or multiple bridge passage events from south to north.

Spatial distribution, habitat selection, and depth selection were largely similar in release groups dominated by on-site holding behaviors (i.e., the June 12, June 26, and July 3 releases), and reflected similar patterns as those observed in 2007 (Celedonia et al. 2008). Highest frequencies of occurrence appeared: around the Lakeshore West Condominium (condo); in shallow water (< 6 m) with dense and moderately dense macrophytes that were not near the surface of the water; along the northern and southern edges of the bridge in areas with macrophytes and in deeper (> 6 m) open water areas without macrophytes; and, under the bridge in areas where the bridge was elevated above the surface of the water. These observations were reflected in habitat and depth selection calculations. The most common and consistently selected habitat was near the bridge (i.e., areas lying within 20 m of the edge of the bridge but not directly underneath) (Figure 4). The condo edge usually had the highest selection ratios, but extremely large confidence intervals precluded statistical significance in all but three occasions (Figure 4). Other habitats that were occasionally selected for included areas directly under the bridge, and dense vegetation. Habitat most often selected against included offshore open water areas, sparse vegetation and the offshore edge of vegetation, and unvegetated nearshore areas. Very dense vegetation, dense vegetation, moderately dense vegetation, and areas directly under the bridge were sometimes selected against depending on release date and diel period.

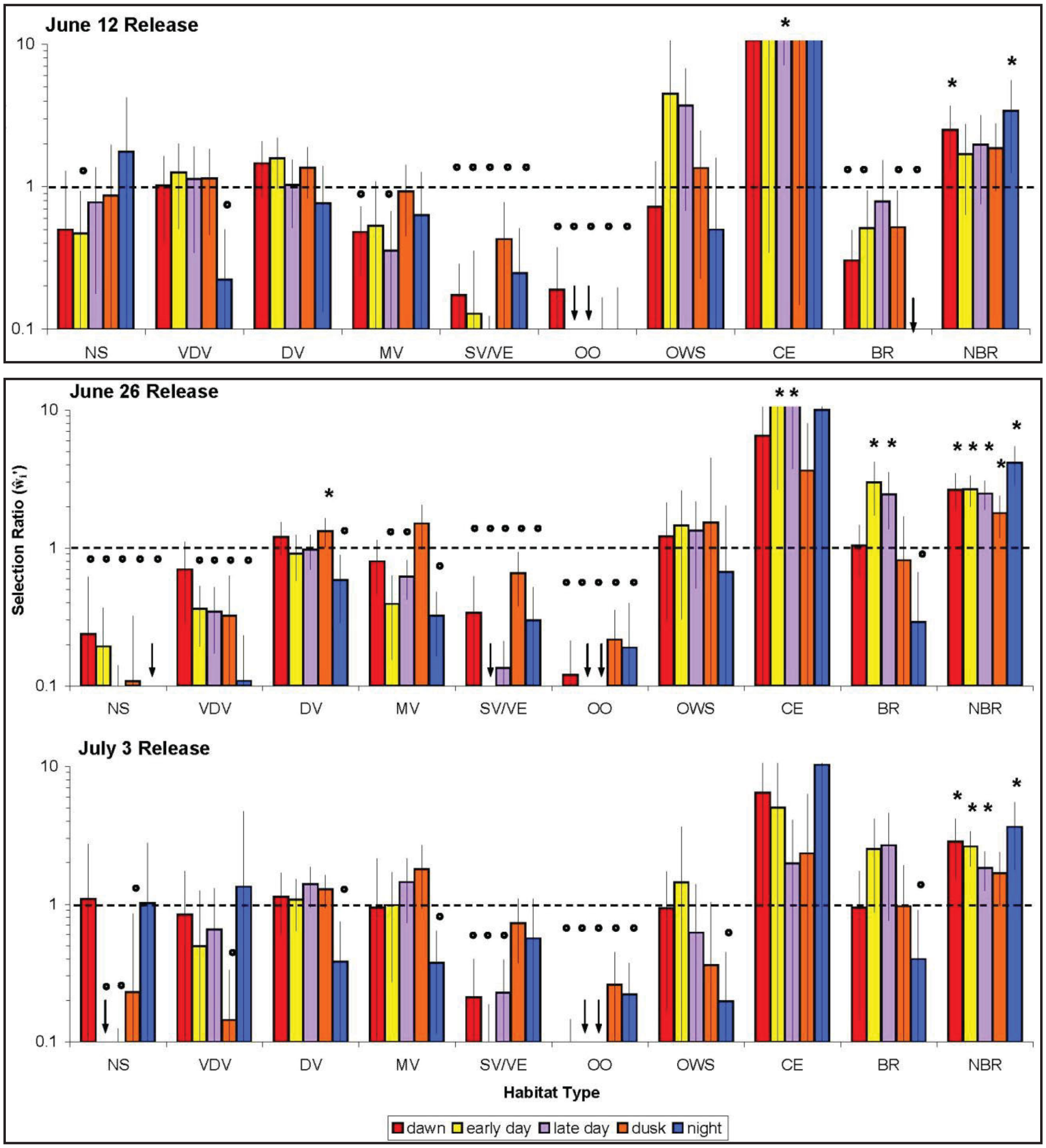

Figure 4. Diel habitat selection ($\hat{w}_i'$, selection ratio; log scale) of Chinook salmon in the SR 520 bridge tracking area, June-July, 2008. Error bars represent Bonferroni-adjusted 90% confidence intervals. Error bars indicate if selection for (>1) or against (<1) a habitat type occurred. An asterisk (*) denotes selection for a habitat and a circle (o) denotes selection against. Habitat types are described in Table 1.

Fish selected for deeper water when they were near or under the bridge or near the condo, particularly during the day. When fish were not near either structure, peak selection was observed for 2-5 m water column depth. Offshore sites, both north and south of the bridge, had higher abundances of zooplankton than nearshore sites (figure 5). Difference in depth selection relative to structure proximity was less pronounced or non-existent during crepuscular periods and at night. These corroborated similar observations in 2007, although the condo was not included in the 2007 analyses. A subtle yet noticeable shift to deeper water was also observable as the study period progressed. This was evident in both spatial frequency distribution plots and depth selection, and was observed throughout the site except near the condo.

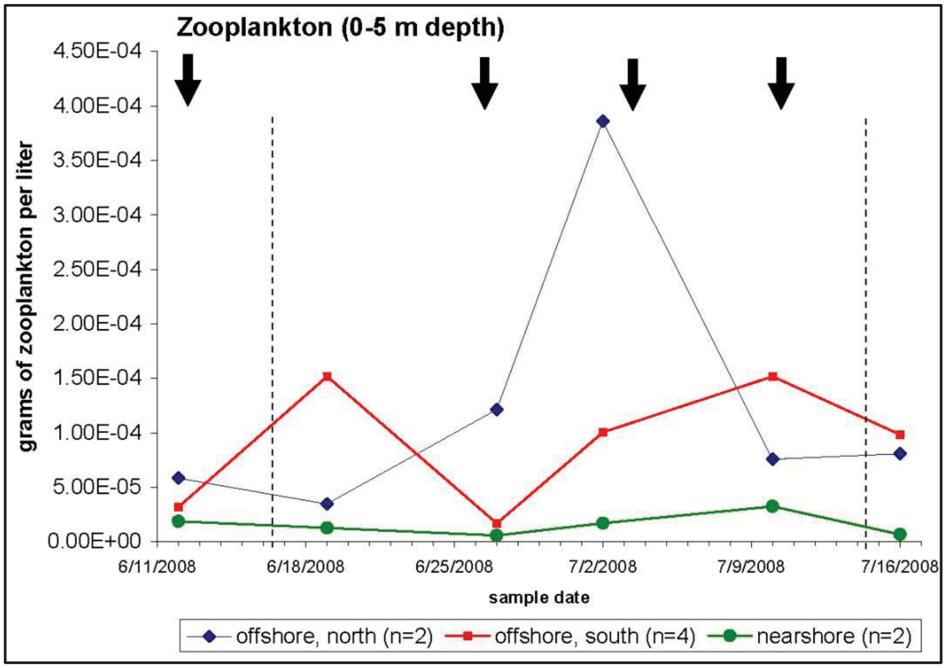

Figure 5. Mean zooplankton mass collected from 0-5 m water column depth at the SR 520 bridge study site, June 12 - July 16, 2008. Black arrows indicate when tagged Chinook salmon were released. Vertical black lines indicate moon apogee.

Most fish that were known to have passed beneath the bridge - 92% of seven release groups - were directly observed passing beneath the bridge within the study site (Table 3; Figure 6). Some fish in the multiple pass groupings may have been tracked moving from south to north on multiple occasions with no corresponding north to south movement observed. A small proportion from three releases were not directly observed passing beneath the bridge but were detected north of the bridge and/or in the LWSC, and were therefore known to have passed beneath the bridge outside of the tracking area. Three-quarters of the fish that passed under the bridge off-site did so to the west of the tracking area. These fish were initially tracked on-site on the south side of the bridge and were observed moving off-site to the west without first passing beneath the bridge. These fish were later observed on the north side of the bridge or in the LWSC.

The most common bridge passing behaviors suggested that most fish were not inhibited by the presence of the bridge. These behaviors included fish crossing beneath the bridge on multiple occasions (multiple passes), and fish milling directly beneath the bridge and/or travelling laterally beneath the bridge for distances of 10 m or more (table 3). In both years fish that were holding in and near the study area as opposed to actively migrating through often exhibited multiple and/or complex passes. In both 2007 and 2008 single, simple passes were often observed by actively migrating fish as well as by some holding fish.

Only that portion of study fish that actively migrated through the approach, encounter and pass portion of the study site were used to evaluate the effect of the bridge on migration. In 2008, only 11 observations fit this description, and of these 6 (55%) delayed by either paralleling or milling near the bridge. Those that delayed did so for an average of approximately 20 minutes. In 2007, 46 observations were used to evaluate migratory delay, and of those, 31 (67%) delayed by paralleling or milling near the bridge. Of those that delayed, the average delay was approximately 10 minutes (range of 14 s to 2774 s). Combined, these observations demonstrate that the bridge may create a delay in migration for some fish, however that delay is relatively short in duration, and for the 37 fish observed to delay, none did so for more than 47 minutes.

	Release group						
Observed bridge passing characteristics	June 1	June 14	June 28	June 12	June 26	July 3	July 10
Single, simple pass	0.72 (26)	0.12 (8)	0.26 (17)	0.07 (2)	0.10 (5)	0.08 (4)	0.40 (21)
Multiple and/or complex pass	0.14 (5)	0.59 (40)	0.57 (37)	0.41 (11)	0.60 (30)	0.57 (30)	0.38 (20)
Passed off-site							
West of site	0.11 (4)	0.06 (4)	0.02 (1)	0.11 (3)	0.04 (2)	0.04 (2)	0.00 (0)
East of site	0.00 (0)	0.03 (2)	0.05 (3)	0.00 (0)	0.00 (0)	0.00 (0)	0.00 (0)
Partial pass only	0.00 (0)	0.00 (0)	0.03 (2)	0.07 (2)	0.00 (0)	0.00 (0)	0.00 (0)
No known pass							
detected and/or tracked on-site	0.00 (0)	0.07 (5)	0.06 (4)	0.22 (6)	0.06 (3)	0.11 (6)	0.04 (2)
not detected on-site	0.03 (1)	0.13 (9)	0.02 (1)	0.11 (3)	0.20 (10)	0.21 (11)	0.15 (8)

Table 3. SR 520 bridge passing characteristics of tagged Chinook salmon, June 2007 and June-July 2008. Fish that were observed passing beneath the bridge only once without lingering beneath the bridge or crossing back to the south were labeled "single, simple pass." Fish that were observed passing beneath the bridge more than once and/or that were observed lingering or milling around directly under the bridge were labeled "multiple and/or complex pass." Fish that were observed directly beneath the bridge without ever crossing beyond the north edge of the bridge were labeled "partial pass." Fish that were never detected north of the bridge (i.e., in either the SR 520 or the LWSC arrays) were labeled "no known pass."

Fish Response to Roadway Lighting

During review of the 2008 study data, prominent groupings along the southern and northern edges of the bridge prompted further attention. Review of these data showed that they were night-time observation which led to an evaluation of the distribution of fish at night versus the location of street lights along the bridge. High concentration areas were on the same side of the bridge as the light. Areas on the opposite side of the bridge from the light usually did not show elevated fish usage. A weaker area of fish attraction appeared as a line of elevated fish usage running parallel with the bridge approximately 15-27 m from both the northern and southern edges. This appeared in both the June 12 and June 26 releases (Figure 28). This may be caused by lights on the opposite side of the bridge. Typical luminare mounting height is 40 feet from the roadway surface. Furthermore, 6 inches (height) by 13.5 inches (width) house/water-side shields are installed on the luminares mounted over water to reduce light spillage.

Review of tracking data found no evidence for a response to lighting by smallmouth bass, and density plots indicated northern pikeminnow may have a slight attraction to light or lighted areas may overlap with substrate types where pikeminnow preferentially prey at night (cobbles and boulders).

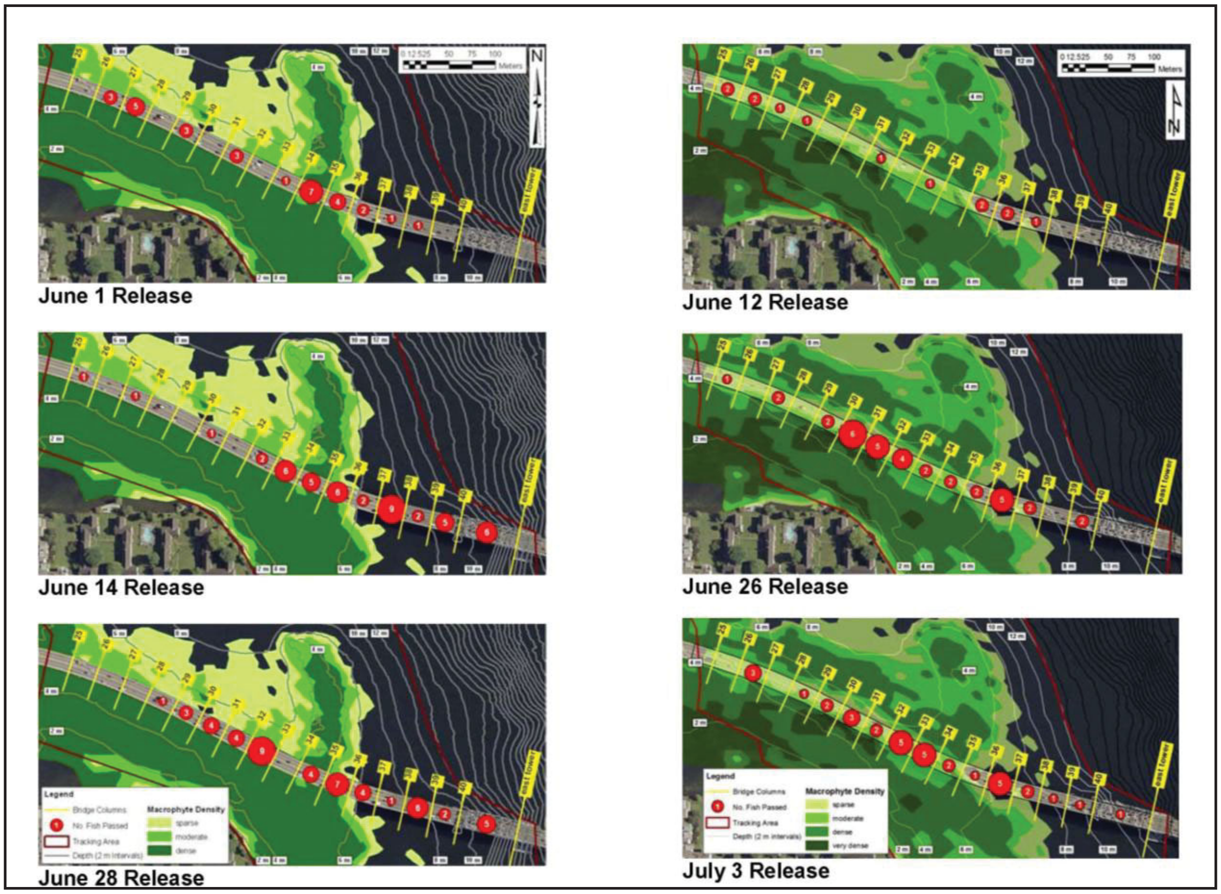

Figure 6. Locations where tagged Chinook salmon first crossed beneath the SR 520 bridge, June-July 2008. Bridge column locations are shown in yellow. Size of the red circle is relative to the number of fish that passed (white). The number of fish known to have initially passed beneath the bridge outside the tracking area is also shown: n_w and n_e are the numbers of fish that passed west and east of the site, respectively. Note that some fish passed beneath the bridge more than once (table 3). Additional passes are not shown here.

Predator Abundance and Diet Composition

A total of 337 fish were captured with gill nets, of which 135 (40%) were northern pikeminnow and 111 (33%) were peamouth (Mylocheilus caurinus). The highest mean catch per unit effort (CPUE) measured in fish per hour was observed at the Seattle Tennis Club site; however, CPUE was not statistically different between sites (Friedman test; T = 1.47; P = 0.83). Overall CPUE of smallmouth bass was much higher at the Webster Point site (0.32 fish/h); however catch and lengths were not significantly different between sites.

Diet composition for northern pikeminnow was similar between most sites (Figure 8) with fish comprising 71% of the overall diet. A large portion of the diet at Webster Point was composed of crayfish, while it made up a small proportion of the diet at Seattle Tennis Club and Wolf Bay with the other sites having intermediate abundances (Figure 9). Although the amount of food in the digestive tracts of northern pikeminnow varied widely among individuals, no there was significant differences in food per body weight between sites (Kruskal-Wallis test = 4.9; P = 0.30). All salmonids that were identifiable to species were Chinook salmon.

Overall, 50% of the smallmouth bass had an empty stomach, with sixty percent (6 of 10) from the SR 520 bridge having empty stomachs. Smallmouth bass diet was comprised primarily of either salmonids (50%), yellow perch (13.2%), crayfish (12.9%) or sculpin (9.2%). There was no apparent difference in diet between sites.

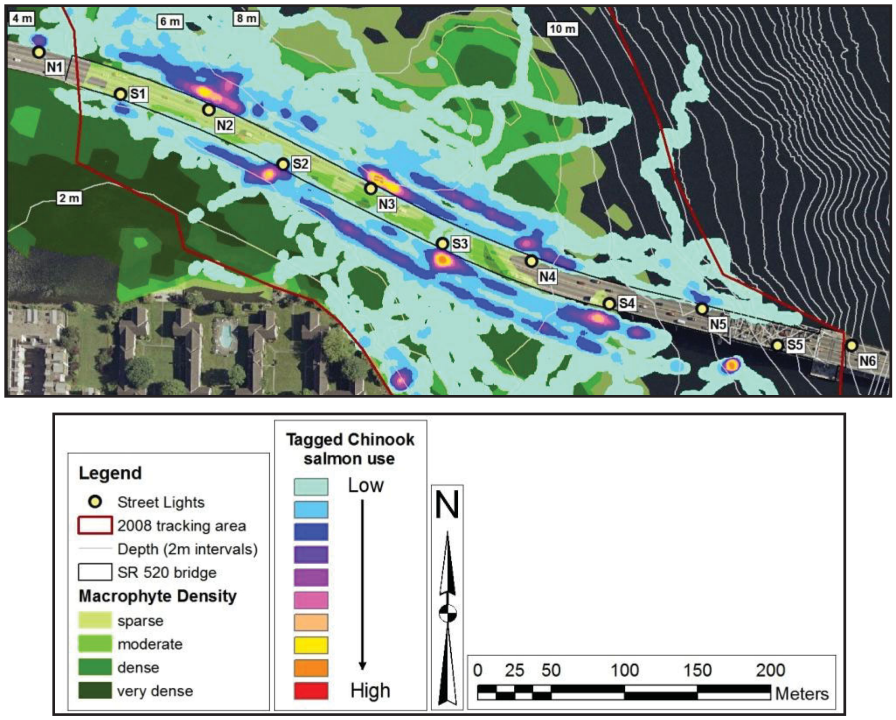

Figure 7. Night density plots of tagged Chinook salmon released on June 12 (similar patterns appear on June 26, and July 3, 2008) and tracked near the SR 520 bridge. Relative amount of time spent is indicated by the color bar, with red showing areas where fish spent the most amount of time, and blue the least. Locations of street lights on the bridge are also shown.

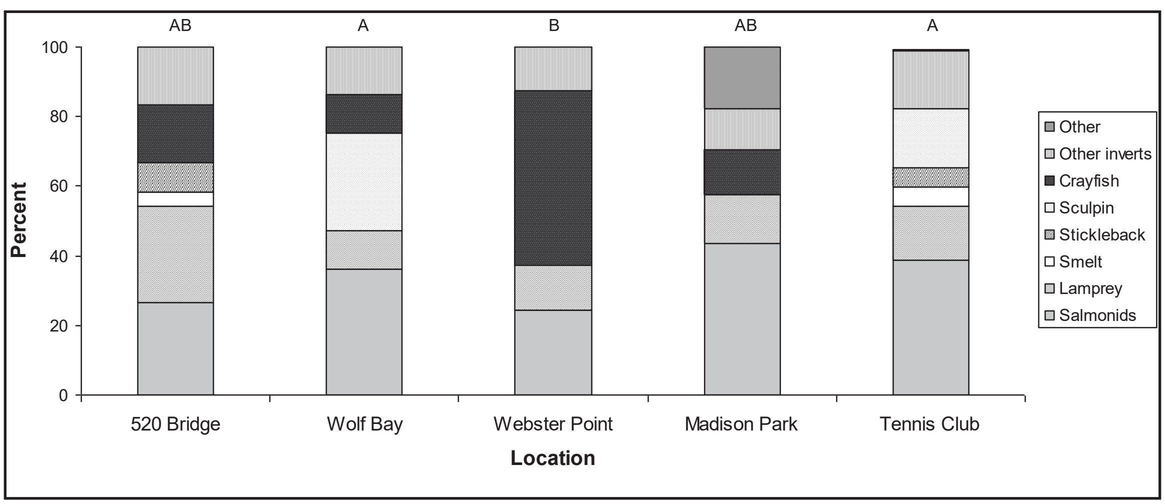

Figure 8. Mean proportion by weight (*%MWi*) of northern pikeminnow at five sites in central-west Lake Washington, May-July, 2008. All sample dates were combined. Groups of bars with different letters are significantly different (Schoener's diet overlap index, *C* < 0.6).

Discussion

Fine-scale acoustic tracking of juvenile Chinook salmon proved to be a useful tool for evaluating Chinook movements, behavior and habitat selection.

Bridge Delays to Migration

Prior to this study, it was suggested that migration delays could present a significant source of mortality by either causing outmigrating fish to miss opportunities to outmigrate when the water temperature and other factors are more favorable to fish survival and smoltification, or by encouraging fish to delay and concentration at locations that might either attract predatory fish or provide favorable habitat for predatory fish. These two years of inquiry demonstrate that while some fish do delay at their first encounter with the bridge, these delays are, on average, relatively short in duration and that the bridge does not pose a migratory barrier for juvenile Chinook salmon. It is unknown, though possible that fish behaviors may change slightly as additional bridges are encountered. For fish tracked in this study, the SR 520 bridge is their first encounter with a bridge, while wild fish migrating to this location will have already passed under at least one additional bridge, and will pass under several additional bridges with the Ship Canal prior to migrating to salt water. Furthermore, the bridge appears to be sited in an area that juvenile Chinook salmon use both for migratory and rearing behaviors. Those fish exhibiting rearing behavior may use the bridge as habitat for feeding opportunities or as cover to access habitats not otherwise accessible.

The study area represents a transition from the steeper shoreline areas to the south that provide relatively little area within the preferred depth range for juvenile salmonids, to a more gradual lake bottom gradient that provides a wider area for outmigrating salmonids to use. This habitat characteristic allows fish to use a larger area within the bridge study area than along other shorelines further south and appears to reduce the concentrations of outmigrants at any given location. The bridge does not interfere with this distribution of juvenile salmonids as even those fish that are delayed and initially parallel the bridge, frequently pass under the bridge at or near the location of initial encounter.

Only that portion of study fish that actively migrated through the approach, encounter and pass portion of the study site were used to evaluate the effect of the bridge on migration. In 2008, only 11 observations fit this description, and of these 6 (55%) delayed by either paralleling or milling near the bridge. Those that delayed did so for an average of approximately 20 minutes. In 2007, 46 observations were used to evaluate migratory delay, and of those, 31 (67%) delayed by paralleling or milling near the bridge. Of those that delayed, the average delay was approximately 10 minutes (range of 14 s to 2774 s). Combined, these observations demonstrate that the bridge may create a delay in migration for some fish, however that delay is relatively short in duration, and for the 37 fish observed to delay, none did so for more than 47 minutes.

Piscivorous Fishes at the SR 520 Bridge

We found no evidence that northern pikeminnow were congregated at the SR 520 bridge in comparison to four other nearby sites. Tracking data found pikeminnow have a diurnal pattern to their habitat selection for soft substrates preferred during daylight hours and cobble and boulder substrates preferred at night. While some individuals expressed habitat selection for overwater structures, that trend was driven by habitat selection related to a pier in the southern portion of the study area, not the SR 520 bridge. Diet composition of northern pikeminnow found at the SR 520 bridge suggests that northern pikeminnow appear to be feeding on juvenile salmonids at a similar rates at the bridge and other nearby areas. We found no evidence to support the hypothesis that juvenile salmonids are more vulnerable to pikeminnow predation due to the bridge structure. Similarly, Ward et al. (1994) found no difference in the frequency of occurrence of juvenile salmonids in northern pikeminnow between developed and undeveloped areas of the lower Willamette River.

In contrast, tracking data suggests that smallmouth bass do appear to use the bridge and in particular the bridge columns as preferred habitat. However, when five sites were evaluated for predator abundance, smallmouth bass abundance at the SR 520 bridge was not elevated over other sites, and a single site – Webster Point – accounted for nearly half the smallmouth bass that were caught. Smallmouth bass prefer steep slopes and large substrates such as cobble and boulders (Hubert and Lackey 1980; Fresh et al. 2001). Of the five sites, Webster Point has the steepest slope between 2 and 8 m deep.

Methods for Evaluating Habitat Selection

The methods used in this study for evaluating habitat selection - namely selection ratios, spatial frequency distributions, and density plots - provide useful information in determining which areas are used more often and by more fish. However, these results can easily be misinterpreted (Garshelis 2000; Alldredge and Griswold 2006). Selection for a particular habitat type does not necessarily mean that that habitat is essential or even preferred. Conversely, habitats apparently selected against may actually be quite important to fitness and survival. These issues may arise through differences in activity specific habitat use that are not accounted for in the study (Garshelis 2000; Alldredge and Griswold 2006). For example, a habitat critical for feeding may appear infrequently used relative to resting habitat. Furthermore, less preferred habitats may become frequently used if animals are forced into them due to external factors such as habitat configuration or predation risk. Thus, habitat selection itself does not necessarily indicate preference, nor does it provide an indicator of how various habitats contribute to overall fitness and survival.

Habitat selection results must be considered for their biological significance in the proper context. For example, selection ratios and spatial frequency distributions showed that actively migrating Chinook salmon smolts (e.g., most fish from the June 1, 2007 release) selected for overwater structures (other than the bridge). This appears to have arisen because the large overwater condo on the south edge of the site lay across the preferred migrational corridor for these fish. Migrating juvenile Chinook salmon are known to avoid overwater structures (Kemp et al. 2005; Celedonia et al. 2008; Tabor et al. 2006). Thus, most fish swam along the outside perimeter of the structure rather than moving underneath. These fish also spent little time on site, which inflated the relative amount of time spent along the structure. Thus, the statistically significant selection ratio that resulted was due to lack of preferred migrational conditions (i.e., shallow water with no overwater structure) caused by spatial configuration of the area (i.e., large structure) and concomitant avoidance behavior.

Effects of Replacement Bridge on Juvenile Salmon

Ultimately, this study helps inform the design of the future replacement bridge to minimize impacts juvenile Chinook salmon. Design of the future bridge is continuing to be evaluated through NEPA and several design options are still under consideration. However, all design options currently under evaluation share some commonalities within this study area. The future bridge will be approximately 115 feet wide in this part of the lake, nearly twice as wide as the current span, and will be situated to the north of the existing span (Figures 9 and 10). While design is ongoing, it is possible that the bridge profile will be slightly higher than the existing span and the bridge will be on two separate structures with a small (approximately 7 feet) gap between the structures. Span lengths will increase from 100 feet to approximately 200 feet, and while the total cross section area of shafts will increase slightly as the diameter of individual shafts increases, the total number of shafts will decrease with fewer shafts per bent and fewer total bents (Figure 10). Roadway lighting may ultimately be eliminated from portions of the bridge including the study area, and where lights are used they are likely to have shielding to limit the leakage of light to the lake.

The projected effects from the future bridge to salmon are difficult to extrapolate. Some effects may be indirect such responses to changes to macrophyte densities caused by bridge shading. Other effects may be more direct, as the wider bridge may create a wider, darker area for fish to migrate through, however the bridge may be higher and will have a gap between the structures which may offset those effects. Further effects may result from changes in the area and distribution of shafts. Of the species studied, only smallmouth bass appeared to respond directly to in-water structures, and it is unclear if the greater spacing between shaft and shaft bents or the greater size of individual shafts will generate a population level response from smallmouth bass. If lighting is reduced either because roadway lighting is not included in this portion of the bridge or because sound walls or shielding lessens light leakage to the lake, it is likely that aggregations of juvenile salmon observed during nighttime hours will be reduced or eliminated. It is unclear what, if any, difference shifting the bridge location slightly to the north may have. Actively migrating juvenile salmon appear to change the directionality of their movements somewhat to the north of the existing span, as they begin to move in a westerly direction. This could lead to some fish attempting to pass the bridge at an angle making the transit longer, whereas most actively migrating fish currently encounter the bridge perpendicular to the bridge and continue in that orientation to take the shortest possible route under the bridge.

While the permanent effects of the new bridge are uncertain, it is likely that construction effects will impact salmonids as construction lighting, pile driving, temporary work bridges, and other in-water work will occur in the project vicinity for several years. Impacts to juvenile salmonids will be minimized by timing in-water work to avoid active migration periods. Temporary and permanent impacts to fisheries will be offset through habitat mitigation efforts.

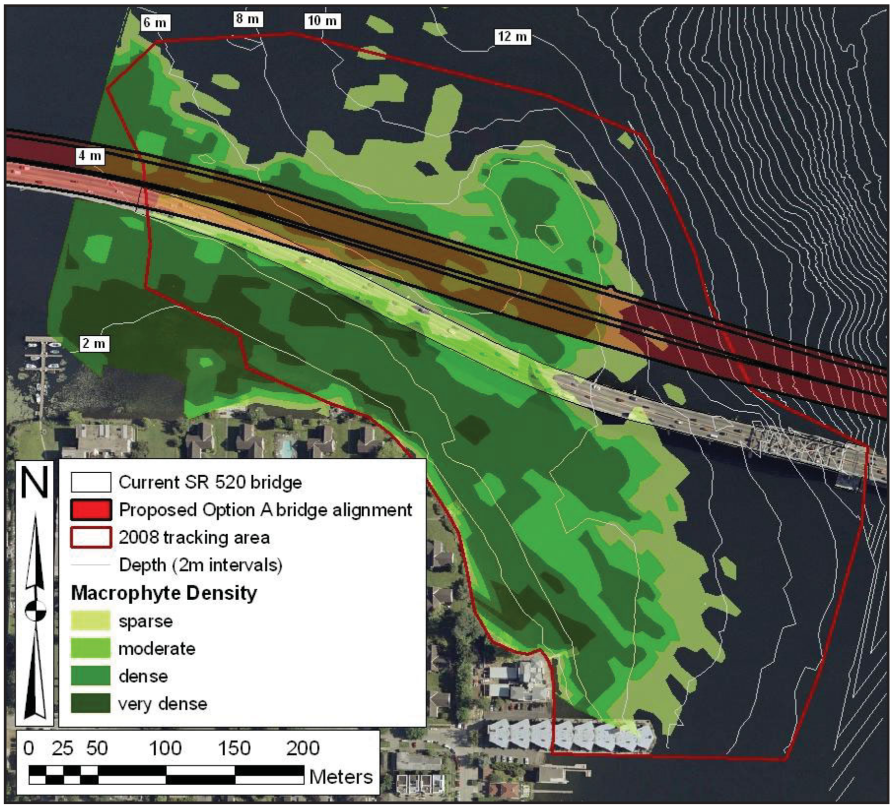

Figure 9. Proposed SR 520 bridge alignment relative to the current bridge.

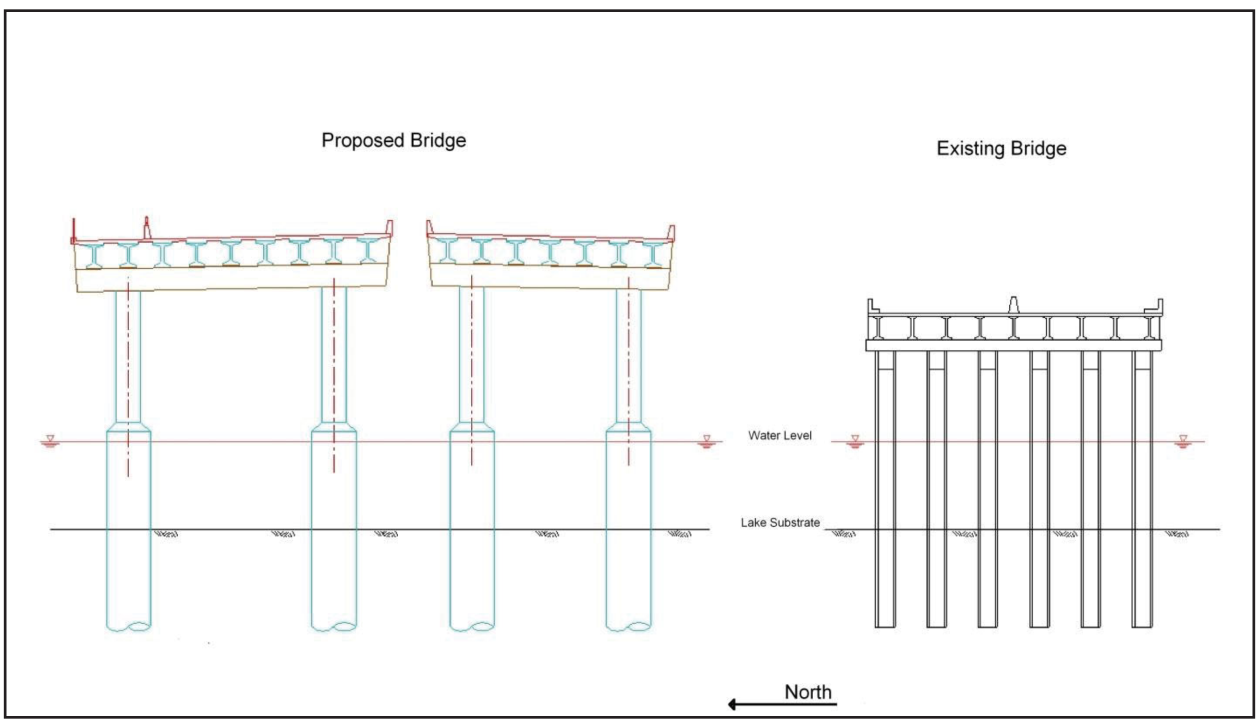

Figure 10. Cross section of existing and proposed bridge structures in study area.

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