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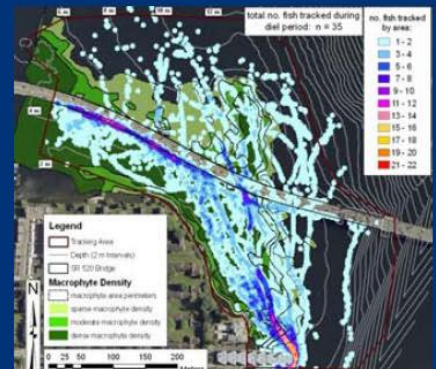
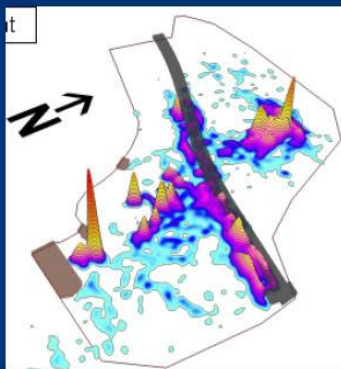
Movement and Habitat Use of Chinook Salmon Smolts, Northern Pikeminnow, and Smallmouth Bass Near the SR 520 Bridge

2008 Acoustic Tracking Study

December 2011

By Mark T. Celedonia, Roger A. Tabor, Steve Damm, Daniel W. Lantz, Terence M. Lee, Zhuozhuo Li, Benjamin E. Price, William Gale, Kenneth Ostrand

U.S. Fish and Wildlife Service
Washington Fish and Wildlife Office
Lacey, Washington



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NORTHERN PIKEMINNOW, AND SMALLMOUTH BASS NEAR THE
SR 520 BRIDGE**

2008 ACOUSTIC TRACKING STUDY

by

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EXECUTIVE SUMMARY

This study continued and extended research performed in 2007 by the Washington State Department of Transportation (WSDOT) and the U.S. Fish and Wildlife Service (USFWS) to evaluate influence of the SR 520 bridge (the bridge) on behavior and habitat use of Chinook salmon *Oncorhynchus tshawytscha* smolts and piscivorous fish. Results obtained in 2007 suggested that the bridge was having some influence on migration, movement, and habitat use of Chinook salmon, and that at least one potential predator - smallmouth bass *Micropterus dolomieu* - often used the bridge as selected habitat. Further study was needed due to high variability in Chinook salmon behavior, uncertainty with regard to important causal factors, and low sample sizes of predators (namely northern pikeminnow *Ptychocheilus oregonensis*). Results will help guide design and construction of the new bridge to minimize impacts to Chinook salmon.

The primary objectives of the 2008 study were to: 1) increase the sample size of Chinook salmon used for evaluating migrational delay at the bridge; 2) evaluate interannual variability in fish behavior relative to the bridge; 3) collect additional ancillary data to help understand observed fish behavior patterns; 4) increase sample sizes of tagged northern pikeminnow and smallmouth bass; and, 5) explore potential predation consequences of the bridge on Chinook salmon. In order to meet these objectives, the 2008 study largely replicated the 2007 acoustic tracking study design. Components added for 2008 included: 1) Chinook salmon smoltification (gill Na^+ , K^+ ATPase) sampling; 2) zooplankton sampling; 3) predator abundance and diet sampling.

Four groups of 27-53 tagged Chinook salmon smolts were released between June 12 and July 10, 2008, and 75-85% of tagged fish were tracked at the study site. Overarching patterns in Chinook salmon smolt behavior were similar to those observed in 2007. Behaviors were generally similar within release groups and varied considerably between release groups. The first three release groups primarily exhibited holding behaviors at and near the study site. The fourth release group represented a unique case: most fish (93%) actively migrated through the site in one of two schools.

As in 2007, fish response to the bridge was at least partially dependent upon whether fish were actively migrating or holding. Behaviors of actively migrating fish were similar in both years, although few independent observations were obtained in 2008 ($n=11$). Combining both years ($n=57$), 35% of actively migrating smolts showed minimal or no response to the bridge, 42% paralleled the bridge before passing underneath, and 23% paralleled the bridge and milled near the bridge before passing underneath. Median delay was 63 seconds (range 6 seconds to 19 minutes) for paralleling fish, and 22 minutes (range 3-46 minutes) for paralleling and milling fish.

The bridge appeared to attract some Chinook salmon that exhibited a holding behavior. Holding fish spent 2 hours to 11 days on and near the study site, and median 51% of this time was spent on-site. When on-site, fish most commonly selected for areas near the bridge (within 20 m of the bridge edge) and the condo on the south side of the site. Of secondary importance were areas directly beneath the bridge and areas with moderately dense to dense vegetation not

near the bridge. During the day, fish selected more offshore areas when near the bridge (5-7 m bottom depth) or condo (7-8 m bottom depth) than when they were not near either structure (2-5 m bottom depth). Similar observations were made in 2007. Data suggested that the bridge may provide a source of nearby cover and thus function as a corridor to deeper water where there is a better foraging base and occasionally more favorable water temperatures.

At night, Chinook salmon were attracted to areas where street lamps on the bridge cast light into the water. A reevaluation of 2007 data found that it occurred then also. Bridge lighting thus appears at least partially responsible for the nighttime selection of near bridge areas by Chinook salmon. Neither smallmouth bass nor northern pikeminnow appeared particularly attracted to the lights. Other studies suggest that predation rate may be higher in lighted areas even if predators on the whole do not select for these areas. Any potentially negative consequences to Chinook salmon might be minimized by reducing the intensity of light reaching the water surface.

We tagged 21 northern pikeminnow and 10 smallmouth bass at the study site, and obtained extensive tracking results on 8 northern pikeminnow and 7 smallmouth bass. Results for both species were similar in 2007 and 2008; therefore, data were combined to provide more robust analyses. This yielded sample sizes of 15 northern pikeminnow and 19 smallmouth bass (> 240 mm FL).

Northern pikeminnow were primarily concentrated at 4-6 m depth during all diel periods. Moderately dense vegetation, which occurs at 4-6 m depth, was the most commonly used habitat type. The small pier at the Madison Point Condominiums was used extensively. During each diel period, less than 50% of northern pikeminnow showed positive selection for the bridge or areas near the bridge. Overall, we did not document a strong affinity for the bridge. Instead, the bridge was generally used in proportion to its availability.

Smallmouth bass showed a strong affinity for overwater structures, including the bridge. Smallmouth bass were often closely associated with bridge columns. At dawn, they often moved into sparse vegetation and the offshore edge of vegetation. These movements are probably indicative of foraging activity. Additionally, they occasionally used dense and moderately dense vegetation, primarily at dusk and night. In both years, smallmouth bass were primarily concentrated in water 4-8 m deep during all diel periods.

We set a series of gill nets at five locations (the bridge, two sites north of the bridge, and two sites south of the bridge) on a weekly basis during the study period to determine the relative abundance and diet of northern pikeminnow and smallmouth bass. We collected a total of 135 northern pikeminnow and found no evidence that northern pikeminnow were congregated at the SR 520 bridge in comparison to four nearby sites. Additionally, there was no evidence to suggest that juvenile salmonids were preyed upon at a higher rate by northern pikeminnow near the bridge. Juvenile salmonids (Chinook salmon and unidentified salmonids) made up 35% of the overall diet of all sites combined. One important observation was the prevalence of river lamprey *Lampetra ayresi* in the diet of northern pikeminnow. Previous studies of northern pikeminnow in Lake Washington have rarely found river lamprey in their diet.

Catch rates of smallmouth bass were substantially higher at the Webster Point site. Of the five sites, Webster Point has the steepest slope between 2 and 8 m deep, where smallmouth bass are typically found. Half of the overall diet of smallmouth bass was composed of juvenile salmonids. There was no strong difference in the diet composition between the five sites.

Design and siting of the new bridge were considered for effects on Chinook salmon, northern pikeminnow, and smallmouth bass. A higher bridge may lessen delay of actively migrating smolts; however, any potential benefits of a higher bridge might be offset by the increased bridge width. With regard to holding smolts and their daytime attraction to the bridge, we believe that the new higher bridge will either have minimal change from existing conditions or will lessen their attraction. Consequences of any diminished daytime attraction are uncertain but may include shorter area residence times of holding fish and lower proportions of time spent on site. These effects may have positive (e.g., reduced predation rate, quicker entrance into the LWSC, less residualism), negative (e.g., reduced growth, less resting and energy capture along migration route), or negligible consequences to Chinook salmon fitness and survival. The new higher bridge may also reduce the quality of habitat conditions for northern pikeminnow and smallmouth bass.

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INTRODUCTION

In 2007, the Washington State Department of Transportation (WSDOT) and the U.S. Fish and Wildlife Service (USFWS) conducted an acoustic tracking study of Chinook salmon *Oncorhynchus tshawytscha* smolts and piscivorous fish behavior and habitat use near the SR 520 bridge (Celedonia et al. 2008a). The intent was to evaluate fish behavior at the existing structure in order to minimize any deleterious impacts to Chinook salmon associated with the design and construction of a new SR 520 bridge proposed to be built in 2012. Specific objectives of the 2007 study were: 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 two piscivorous fishes – northern pikeminnow *Ptychocheilus oregonensis* and smallmouth bass *Micropterus dolomieu*. Null hypotheses were: 1) the bridge would not inhibit migration nor influence movement or habitat use of tagged Chinook salmon smolts; and 2) habitat selection of predators 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. These null hypotheses were rejected in whole or in part as study results showed that the bridge was having some influence on migration, movement, and habitat use of Chinook salmon, and that smallmouth bass often used the bridge as selected habitat. Northern pikeminnow were not shown to select for the bridge, although the sample size was small and results less conclusive.

Based on 2007 results, WSDOT and USFWS concluded that further study was warranted in order to: 1) increase the sample size of Chinook salmon smolts used for evaluating migrational delay at the SR 520 bridge; 2) evaluate interannual variability in fish movement and habitat use relative to the bridge; 3) collect additional ancillary data to help understand observed fish movement and habitat use patterns; 4) increase sample sizes of tagged northern pikeminnow and smallmouth bass; and, 5) explore potential predation consequences of the bridge on Chinook salmon. In order to meet these objectives, the 2008 study largely replicated the 2007 study design with regard to acoustic tracking. Acoustic tracking methods, array placement and operation, fish capture and tagging, and other aspects of the 2007 acoustic tracking study were generally the same in 2008 with some minor modifications. Water quality monitoring and aquatic macrophyte mapping were also similar. Components added for the 2008 study included: 1) Chinook salmon smoltification (gill Na^+ , K^+ ATPase) sampling; 2) zooplankton sampling; 3) predator abundance and diet sampling near the bridge and at nearby reference locations; 4) substrate mapping; and, 5) macrophyte growth monitoring.

In 2007, we observed two overarching behavioral patterns relative to migrational phase in Chinook salmon smolts, and each phase was associated with unique behaviors with regard to the bridge. One was an active migration phase where fish moved quickly from release, through the study site, and into the Lake Washington Ship Canal (LWSC). These fish generally moved through the study site in a rapid, direct, and linear fashion with little to no milling and no major movements in directions not toward Puget Sound. The other pattern was a holding phase where fish often spent 1-3 days or more on and near the study site. These fish appeared paused in their migration and were often observed milling throughout the site and in localized areas of the site. Holding fish often entered and exited the site repeatedly, suggesting that the study site was part of a larger area that fish were using while holding. Individual expression of one migrational

phase or the other appeared consistent within release groups, suggesting that fish were responding to common exogenous factors and/or experiencing similar physiological (e.g., smoltification) states. For example, moon apogee can be a strong migrational cue for Lake Washington Chinook salmon (DeVries et al. 2004), although this is not always the case (DeVries et al. 2007). Some but not all of the migrational patterns observed in 2007 appeared to be influenced by moon apogee. Ancillary data was also insufficient to provide satisfactory context for understanding migrational phase expression. The smoltification and zooplankton sampling added in 2008 were therefore intended to provide a fuller context for understanding these patterns.

The 2007 study found that both smallmouth bass and northern pikeminnow used areas near the bridge. Smallmouth bass showed significant selection for areas beneath the bridge, and most northern pikeminnow individuals showed some positive selection for areas under and near the bridge. The implications of these habitat usage patterns to predation on Chinook salmon smolts could not be discerned from the study. Therefore, in 2008 we performed a comparative abundance and diet evaluation of areas at the bridge with reference areas that were also in the central-west part of Lake Washington. Our goal was to determine if smallmouth bass or northern pikeminnow have a numerical response (change in abundance) or functional response (change in feeding behavior) as a result of the SR 520 Bridge. Our null hypotheses were that the relative abundance of piscivorous fishes would not be influenced by proximity to the bridge and that predation rates on juvenile Chinook salmon by piscivorous fishes would also not be influenced by proximity to the bridge.

Substrate and cover are important characteristics of preferred smallmouth bass habitat (Hubert and Lackey 1980; Fresh et al. 2001). Specifically, smallmouth bass prefer cobble and rocky-type substrate with abundant cover (e.g., boulders, submerged trees), and generally avoid areas dominated by mud or silt. Anecdotal observations at the study site in 2007 suggested that silt comprised a majority of the substrate, but that cobble was also present in some areas. Similar observations found miscellaneous structural features (e.g., boulders, construction debris) sporadically distributed throughout the site. In 2008 we mapped substrate types and structural components throughout the site in order to provide additional information for understanding smallmouth bass behavioral and habitat use patterns.

The 2007 study and other studies in Lake Washington (e.g., Tabor et al. 2006; Celedonia et al. 2008b) have observed Chinook salmon smolts migrating through and using areas with abundant aquatic macrophytes. Macrophytes may serve as a source of cover and may also allow fish to utilize deeper water areas they would not otherwise use by functioning as a false bottom and shortening the perceived water column depth (Tabor et al. 2006). Conversely, macrophytes growing too near to the water surface may inhibit Chinook salmon use by creating conditions that are too shallow. In 2007, we mapped aquatic macrophyte distribution and density throughout the study site in order to consider this factor in our analysis. However, the mapping survey was conducted shortly after the tracking study concluded, and thus any changes in macrophyte density and vertical growth that occurred during the study period were not captured. Therefore, we implemented a macrophyte growth monitoring survey in order to evaluate how these parameters change during the study period and how such changes may influence Chinook salmon smolt and predator behavioral patterns.

STUDY SITE

The study site was the same as 2007, described by Celedonia et al. (2008a) (Figure 1).

METHODS

Acoustic tracking equipment

Acoustic tracking equipment used in 2008 was identical to that used in 2007. Array configuration and testing were similar to that in 2007 with some minor variations. In 2008, hydrophones on the south side of the bridge were positioned in essentially the same locations as 2007 (Figure 2). On the north side of the bridge, the five hydrophones in open water (i.e., not along the bridge edge) were positioned closer to the edge of the bridge in 2008. This was done to improve coverage on the north side of the bridge because in 2007 coverage gaps were observed in this area. System testing was also similar, except that in 2008 we did not release any tagged fish solely for testing. The effective tracking area measured 15.9 ha, a slight decline from the 17.2 ha covered in 2007. Despite the minor loss in coverage area, the length of bridge included in the tracking area remained the same at 560 m.

Water quality, aquatic macrophytes, and substrate

Aquatic macrophytes, substrate, and water column depth were surveyed from July 28 to August 12, 2008 using similar methods as those used in 2007 (Celedonia et al. 2008a). We surveyed a total of 1,044 points in the study area (Figure 3). Macrophyte density categorization was refined in 2008 to include a “very high density” category equivalent to ocular coverage > 95%. Substrate was surveyed simultaneously with macrophyte density. Substrate was categorized as follows: silt, gravel, cobble, and boulder. The proportion of each substrate category was visually estimated at each survey point. Any structural components were also noted (e.g., woody debris, tires, etc.). For both macrophyte density and substrate, ArcGIS 9.2 was used to generate a Triangulated Irregular Network (TIN) based on data recorded at each point. This TIN was then used to generate macrophyte density and substrate maps.

Macrophyte growth and water column depth to the top of macrophytes were monitored throughout the study period at four transects (Figure 4). Transects were positioned to represent unique areas of the site based on anecdotal observation and macrophyte mapping conducted in 2007. Transect 1 was intended to represent offshore sparse vegetation; transect 2, nearshore dense vegetation; transect 3, very dense vegetation close to the water surface on the southwest side of the site; and, transect 4, dense vegetation on the shallow ridge north of the bridge. Depth to the top of the vegetation and macrophyte density were monitored at five sample points on each transect, except for transect 4 which had only three points. Monitoring was performed on the same days as water quality and zooplankton sampling.

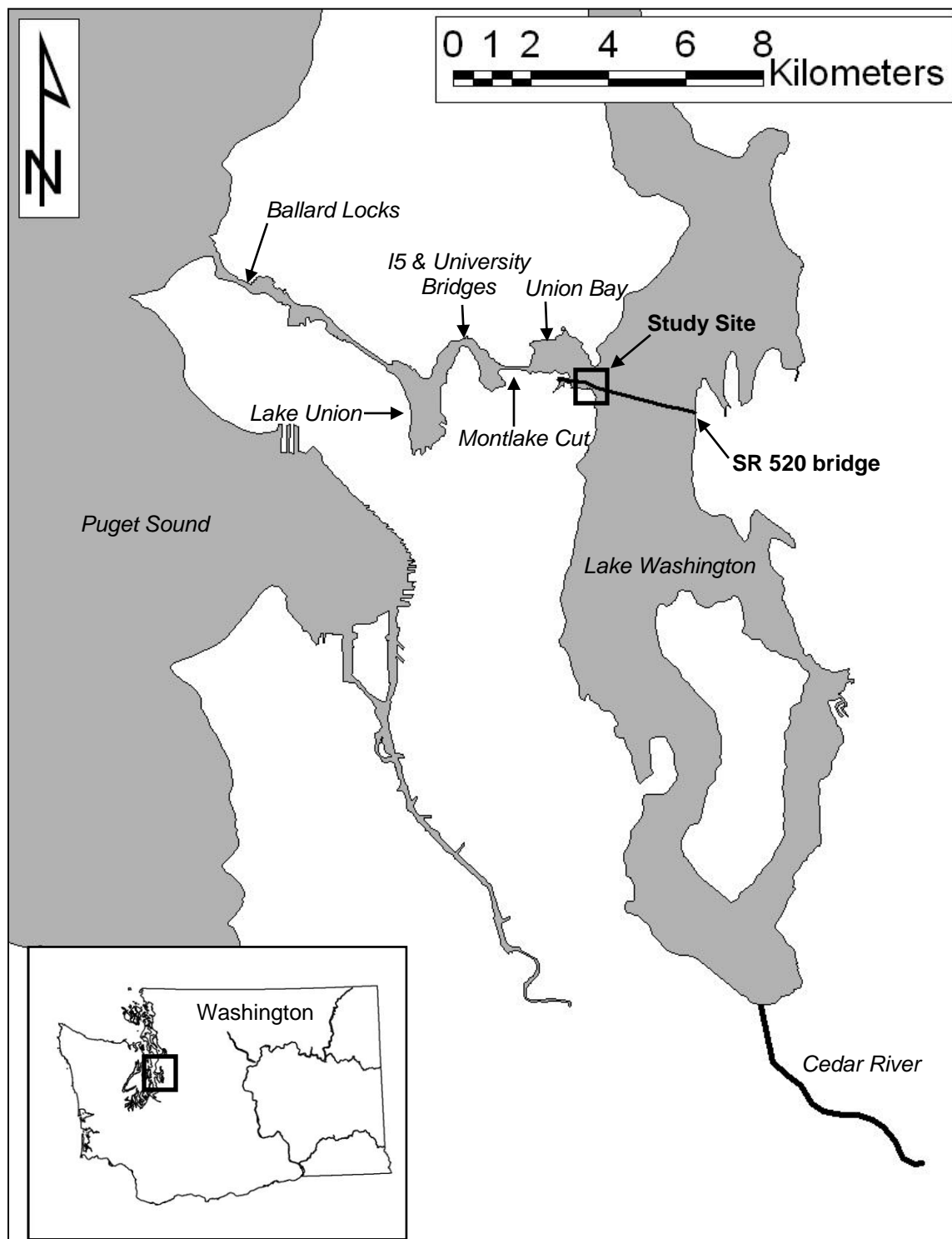


FIGURE 1. Map of Lake Washington showing 2008 study site location at the west end of the SR 520 bridge.

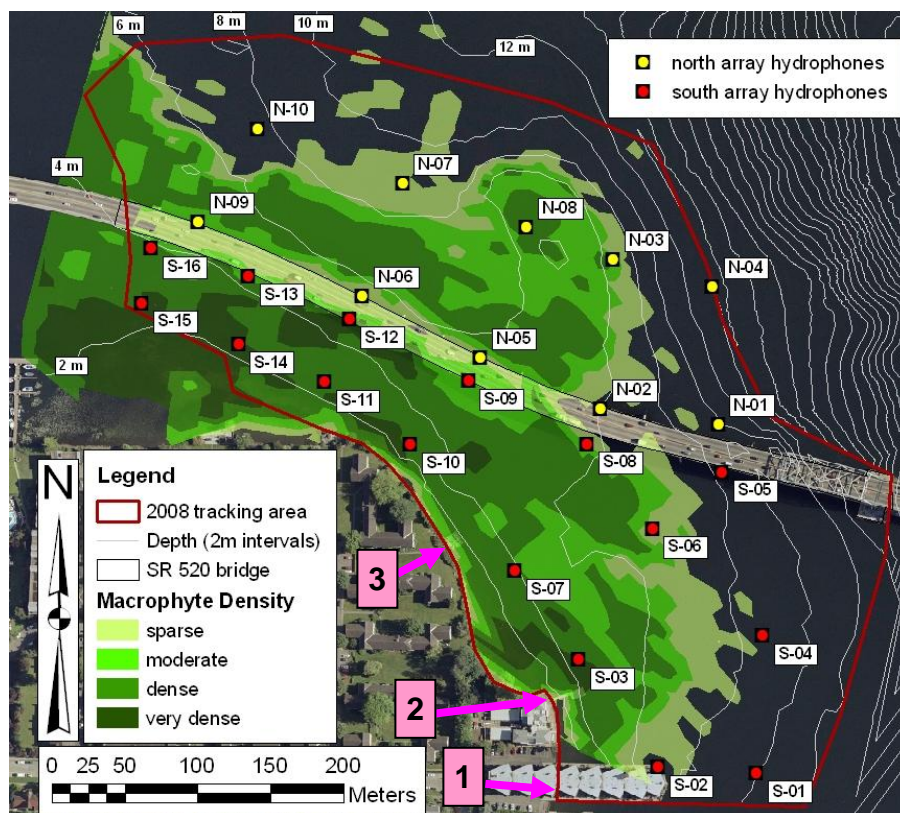


FIGURE 2. Map of SR 520 bridge study site, May-August 2008, including locations of acoustic hydrophones, effective tracking area, and locations of overwater structures other than the SR 520 bridge. Hydrophones on the south (red) and north (yellow) sides of the bridge were connected to separate receivers. Thus, each array functioned independently of the other. Overwater structure names are: #1- Lakeshore West Condominiums, #2 - small pier at the Madison Point Condominiums, and #3 - small pier at the Edgewater Apartments.

Water quality was sampled once each week during the study period, commencing the week of the first release of tagged Chinook salmon, and concluding the week after the last release. Six locations were sampled on the south side of the bridge, and two points on the north side (Figure 4). Sample point locations were selected to 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. The following water quality parameters were sampled at each point: Secchi depth, temperature, dissolved oxygen, conductivity, and salinity. The latter four parameters were sampled at 1 m depth and then 2-m depth intervals thereafter to within 1 m of the substrate.

Zooplankton sampling

Zooplankton was sampled simultaneously with water quality (i.e., sampled at the same points and same time). To obtain an index of prey availability, we collected zooplankton samples at each water quality site (Figure 4). Zooplankton was collected with a 50-cm-diameter by 2-m high net with 500- μ m mesh. We used a large-mesh net to eliminate small zooplankton that

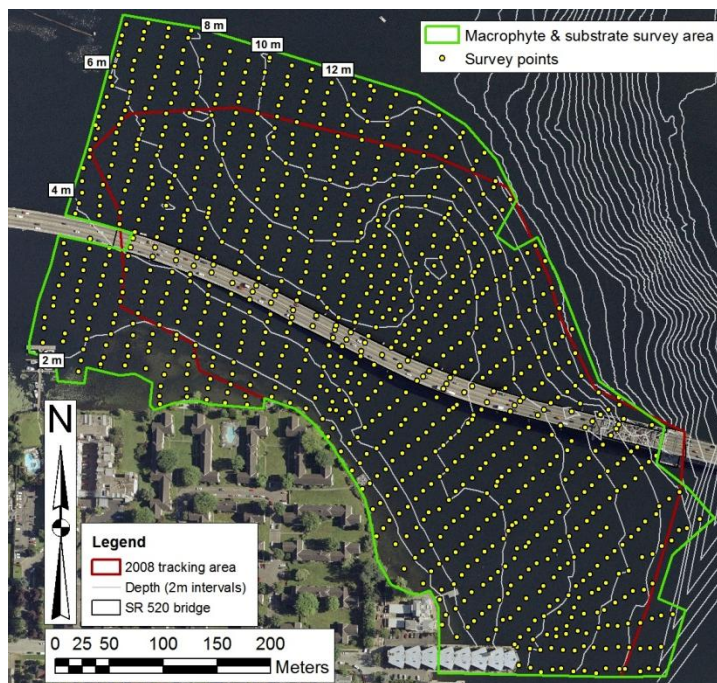


FIGURE 3. Aquatic macrophyte survey area and survey points at the SR 520 tracking site, July 23 - August 1, 2008. An underwater camera was lowered from a boat to determine macrophyte presence/absence, species present, macrophyte density, depth to top of macrophytes, and total water column depth at each survey point. Survey point locations were recorded using a GPS unit.

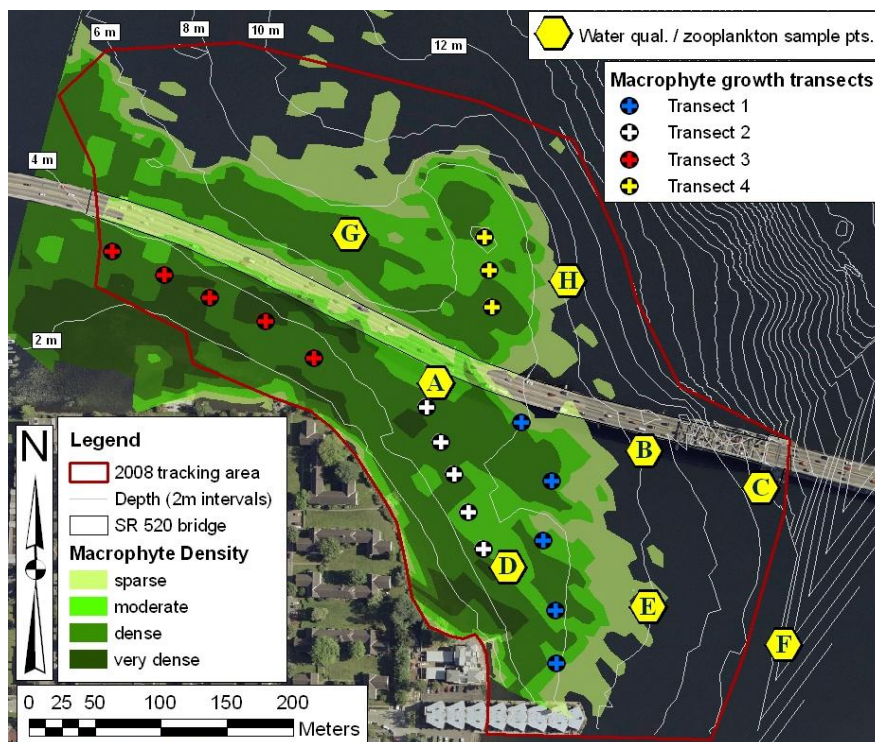


FIGURE 4. Map showing sample point locations where water quality and zooplankton were sampled, and transects used to monitor growth of aquatic macrophytes, May 31 - July 11, 2008.

typically are not consumed by juvenile Chinook salmon (Craddock et al. 1976; Rondorf et al. 1990). At each site, we took one vertical sample of the upper 5 m. At deep sites, we collected an additional sample of the upper 10 m. After lowering the net to the desired depth, it was slowly raised by hand to the surface. No estimate of net efficiency was made but we assumed it was the same between samples. Each sample was placed in a sample jar and preserved with 10% formalin. Zooplankton samples were collected on the same dates as water quality sampling.

In the lab, each sample was rinsed with tap water for a few minutes to remove as much formalin as possible. Samples were then examined under a dissecting microscope; all material that was not zooplankton including algae, insects, other plant material, etc. was removed. Visual examination of each sample under the dissecting microscope indicated more than 99% (by number) of the zooplankton was *Daphnia* spp. Samples were placed in a weighing tray and dried in a desiccation oven for 24 h at 110°C. Afterwards, samples were removed and weighed to the nearest 0.0001 g. The number of dried grams of zooplankton per liter of water sampled was calculated for each sample. On six samples, we also measured zooplankton lengths to determine if zooplankton sizes in our sample were similar to sizes typically consumed by juvenile Chinook salmon (Rondorf et al 1990). The first 50 zooplankters encountered for each sample were measured to the nearest 0.06 mm with an ocular micrometer. All measured zooplankters were cladocerans, which were measured from the top of their heads to the base of their tail spine. The six samples included both shallow water and deep water; and areas near the bridge and away from the bridge.

Chinook salmon smolt tagging and tracking

Juvenile Chinook salmon from the Washington Department of Fish and Wildlife's (WDFW) Issaquah Creek Fish Hatchery were used. Tagging methods were similar as those implemented in 2007 except that in 2008 we did not use the in-situ tag programmer. Instead, Chinook salmon tags were programmed and switched on at the time of implant. Tag battery life was therefore "lost" during the post-implant/pre-release recovery period. As a result, we expected tag batteries to last approximately 12 days after the fish were released. Salmonid tags were programmed with ping rates of 2.6-3.6 s.

General behavioral patterns, movement times, residence times, and behaviors associated with the bridge were evaluated using similar methods as those used in 2007. Results obtained in 2007 suggested that overarching behaviors and habitat use were unique within each release group. We therefore took each 2008 release group as a discrete analytical unit and evaluated behaviors and habitat use independently for each release group of fish. Data were represented and evaluated with parametric or nonparametric statistics depending on the type of distribution observed (Zar 1999; Sheskin 2000). Minimally-skewed data (e.g., fish lengths and weights) were evaluated with a pooled-variance t-test or single-factor between-subjects analysis of variance (ANOVA). More strongly skewed data (e.g., travel and residence times, gill NKA activity) were evaluated with a Mann-Whitney U test or Kruskal-Wallis one-way analysis of variance. Unless otherwise noted, statistical significance was established at $\alpha = 0.05$. Multiple and/or complex comparisons were performed using Tukey's HSD (simple comparisons with equal sample sizes) or the Scheffé test (simple comparisons with unequal sample sizes and complex comparisons) for significant ANOVA's, and the Bonferroni-adjusted Mann-Whitney U test for significant

Kruskal-Wallis tests (Sheskin 2000). The familywise error rate used for multiple and complex comparisons was $\alpha_{FW} = 0.05$ except for Scheffé tests for which we used $\alpha_{FW} = 0.10$. Sheskin (2000) notes that the larger α_{FW} is appropriate because of the highly conservative nature of this test (Sheskin 2000).

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. For example, 1,000 data points obtained from a fish with a ping rate of 3,602 ms would represent (1,000 data points * 3.602 s/data point) = 3,602 s or 60 minutes of time tracked. This will almost always yield an underestimate of actual time spent on site because few if any fish yield a continuous unbroken string of data points (i.e., a data point for every ping). This can arise from a variety of factors including but not limited to periodic excessive noise (e.g., from boats), signal dampening or complete blockage caused by localized obstructions (e.g., aquatic macrophytes, pilings, submerged logs, “hilly” bathymetry), or tag position and orientation relative to hydrophone position and orientation (i.e., emitted tag signal strength is not uniform around the tag, and hydrophone detection efficiency is not uniform around the hydrophone). We randomly subsampled 166 fish days to calculate an equation for adjusting time estimates. For each fish and day selected, we determined the actual amount of time the fish spent on site by performing a detailed evaluation of the plotted track in GIS, and compared this value to the ping rate-based time estimate. A best-fit second order polynomial was then calculated, yielding the equation

$$t_{est} = -0.052 * t_{raw}^2 + 2.213 * t_{raw}$$

where t_{raw} is the (no. data points * ping rate) estimate. This had $R^2 = 0.8572$. Time on site for all fish was then calculated with this equation.

Habitat and depth selection calculations performed in 2008 were similar to those used in 2007 with some important differences. We refined habitat types and depth categories used for evaluating selection in 2008 based on observations of Chinook salmon behavior, spatial distribution, and habitat and depth selection from 2007. The following changes were made to habitat typing for 2008: 1) a condo edge habitat, a very dense vegetation habitat, and a nearshore unvegetated habitat were added; 2) the offshore edge of vegetation habitat was combined with the sparsely dense vegetation habitat; 3) the SR 520 bridge habitat excluded areas within 5 m of the edge of the bridge and included only areas directly beneath the bridge; and, 4) the near bridge habitat included areas from the edge of the bridge to 20 m from the edge of the bridge (Table 1). In addition to these refinements, a separate evaluation was performed exclusively for areas near the bridge. Selection for specific areas near or under the bridge was evaluated using nine habitat types based on proximity to bridge (under, north, south) and latitudinal position (west, center, east) (Figure 5). Latitudinal categories were selected to represent specific features: the west was characterized by abundant vegetation; the east by unvegetated deeper open water; and the center was a transitional area between the two.

TABLE 1. Ten habitat types used to determine habitat selection at the SR 520 bridge study site, May-August 2008. The total tracking area was 15.9 ha.

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 outwards from the edge, on both the north and south sides of the bridge.	2.19	13.76

Depth selection was refined in two ways. First, bathymetry data used for depth selection analyses and graphical representations were based entirely on our 2008 macrophyte and substrate survey. Second, bottom depths from 4-8 m (i.e., the 4-6 m and 6-8 m units used for 2007 analyses) were split into 1-m increments instead of the 2-m increments used in 2007. These depths were most selected for by Chinook salmon in 2007, and we felt that subdividing depths into 1 m increments would provide a greater level of detail with regard to Chinook salmon depth selection in these areas. Other 2007 bottom depth categories (i.e., 0-2 m, 2-4 m, 8-10 m, and > 10 m) were maintained as-is in 2008.

We also utilized a different set of habitat selection equations than those used in 2007. Both sets of equations - those used in 2007 and 2008 - are offered by Manly et al. (2002). Manly et al. (2002) suggests that the decision of which set of equations to use can be difficult and depends on the specific research questions involved and nature of the data collected. Manly et al. (2002) also indicates that the two methods often yield similar results. After careful consideration, we

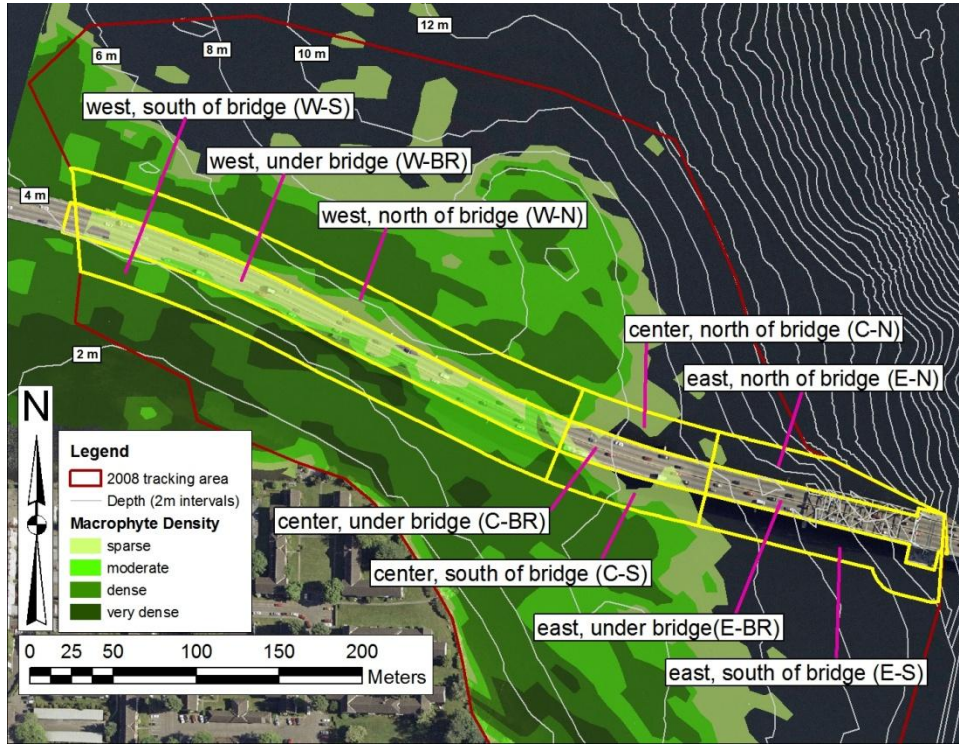


FIGURE 5. Map showing near-bridge habitat types used for evaluating habitat selection near the SR 520 bridge.

decided that the equations selected for 2008 were more appropriate and were worth the sacrifice in consistency between 2007 and 2008. Both sets of equations are similar in that they 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 set of equations are used (Aebischer et al. 1993; Garton et al. 2001; Manly et al. 2002; 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 or bottom 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 bottom 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 bottom depth categories.

To determine if there was significant selection among a release group of fish for a particular habitat type or bottom depth category, simultaneous Bonferroni 90% confidence intervals were calculated as

$$\hat{w}_i' \pm z_{\alpha(2I)} SE(\hat{w}_i')$$

where I is the number of habitat types or bottom depth categories, and

$$SE(\hat{w}_i') = \sqrt{\frac{1}{n(n-1)} \sum_{j=1}^n (\hat{w}_{ij} - \hat{w}_i')^2}$$

Selection for a habitat or bottom depth interval 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.

Gill Na^+ , K^+ ATPase sampling

Gill Na^+ , K^+ ATPase (NKA) activity of Issaquah Creek Hatchery juvenile Chinook salmon was sampled ($n=35$ fish / sample date) prior to and during the tracking period. Fish sampled prior to the tracking period were randomly selected from the group of fish being held at the hatchery for our study. Fish sampled during the tracking period were also taken from this group, and were handled similarly as tagged fish: they were transported to the King County Environmental Laboratory where they were held and acclimated to lake temperature similarly to tagged fish. On the day of release of tagged fish, a subsample ($n = 35$ fish / sample date) of untagged fish were sampled for gill NKA activity. All fish were anesthetized with MS-222 (0.1 g/L), fork length and weight recorded and a small gill biopsy collected. Gill tissue was placed into 0.1 ml ice cold SEI buffer (250 mM Sucrose, 10 mM $\text{Na}_2\text{-EDTA}$, 50 mM Imidazole; pH = 7.3) and rapidly frozen on dry ice. Samples were stored at -80°C . Gill NKA activity was determined using the method of McCormick (1993). Data was analyzed using a one-way analysis of variance test after appropriate transformations. Differences between groups were determined using an ANOVA and Tukey's HSD multiple comparison test.

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. Nets were set 1.5 to 2 h before sunrise and then retrieved shortly after sunrise. Nets were set in approximately 5 to 10 m deep water and set parallel to shore and perpendicular to the bridge. Nets were mostly set directly under the bridge. Occasionally a net was set just south of the bridge. To minimize stress to fish, we slowly brought the nets to the

boat. When we observed a predatory fish in the net, we left the net in the water and put a landing net under the fish. The gill net mesh around the fish was then cut to free the fish. The fish was then placed in an aerated cooler and transported 20 min back to the University of Washington (UW) pier where it was tagged. In addition to gill nets, we also tried to collect predatory fish through angling; however, catch rates were low.

All fish were brought to the UW pier for tagging. 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.

We used HTI Model 795E tags (20 day; 1.5 g) to tag small-sized bass (< 200 mm FL). For larger bass and northern pikeminnow, we primarily used HTI Model 795G tags (60 day; 4.4 g). In 2008, a couple of smallmouth bass were tagged with HTI Model 795M tags (12 day; 0.75 g) because other tags were not available. The tag weight to body weight ratio was less than 2% for all fish (Winter 1996). In 2007, tags were single-pulsed; whereas, in 2008 they were double-pulsed. Double-pulsing the tags reduces the battery life approximately 30-40% but allows data files to be processed reliably with the autotracking option in HTI MarkTags software which significantly reduces data processing time. Data files for single-pulse tags generally need to be processed manually, especially for an area like Lake Washington that has a large amount of background noise due to boating activity. To increase our sample size of smallmouth bass, we also included fish that were tagged and released in the LWSC (as part of our research with Seattle Public Utilities [SPU]) and later migrated to the SR 520 study site. These fish were collected primarily by angling at either north Lake Union (near Gas Works Park), near the I-5 or University Bridges, or at the west end of Montlake Cut at West Montlake Park (Figure 1). With the HTI autotracking software we were able to easily search SR 520 raw data files for presence of any smallmouth bass tagged in the LWSC in 2008. However, in 2007, we only searched for smallmouth bass that were double-tagged with Vemco acoustic tags. Instead of manually searching through numerous HTI data files to determine when fish were present, the Vemco tags allowed us to quickly determine when a particular double-tagged fish was in the vicinity of the SR 520 study site through a Vemco receiver mounted at the Lakeshore West Condominiums.

Predator habitat, depth, and substrate selection was determined in a different manner than that of Chinook salmon smolts. Because of small predator sample sizes for each year, we combined 2007 and 2008 results to provide a more robust analysis. Because the coverage area was slightly different between years, some of the analyses were different than those used for juvenile Chinook salmon data. Similar habitat types and water column depth categories used for Chinook salmon were used except some rarely-used habitat types were combined with other habitat types to simplify the analysis. Selection ratios were calculated for each fish. Differences in use between habitat and depth categories were compared with a non-parametric Friedman test and multiple comparisons procedure (Conover 1999). Individual fish were used as the blocking variable. This statistical test allowed us to combine results of 2007 and 2008 (different habitat availability). We only included fish that were present for more than one day and had more than 1,000 total data points. For each diel period, we included the results from these fish if there were more than 200 data points. 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.

We used two categories to determine substrate selection (silt and cobble/boulder; Figure 6). Cobble/boulder was defined as having more than 10% cobble or boulder, combined. There did not appear to be any difference in the use of various levels of cobble/boulder and thus they were combined into one category. To test the difference in the two substrate categories, we only included areas where the depth was 2-10 m deep; both smallmouth bass and northern pikeminnow were rarely in areas outside of this depth interval. We also did not include areas near overwater structures, which would likely confound the results. Selection ratios were calculated for each fish and differences were compared with a sign test.

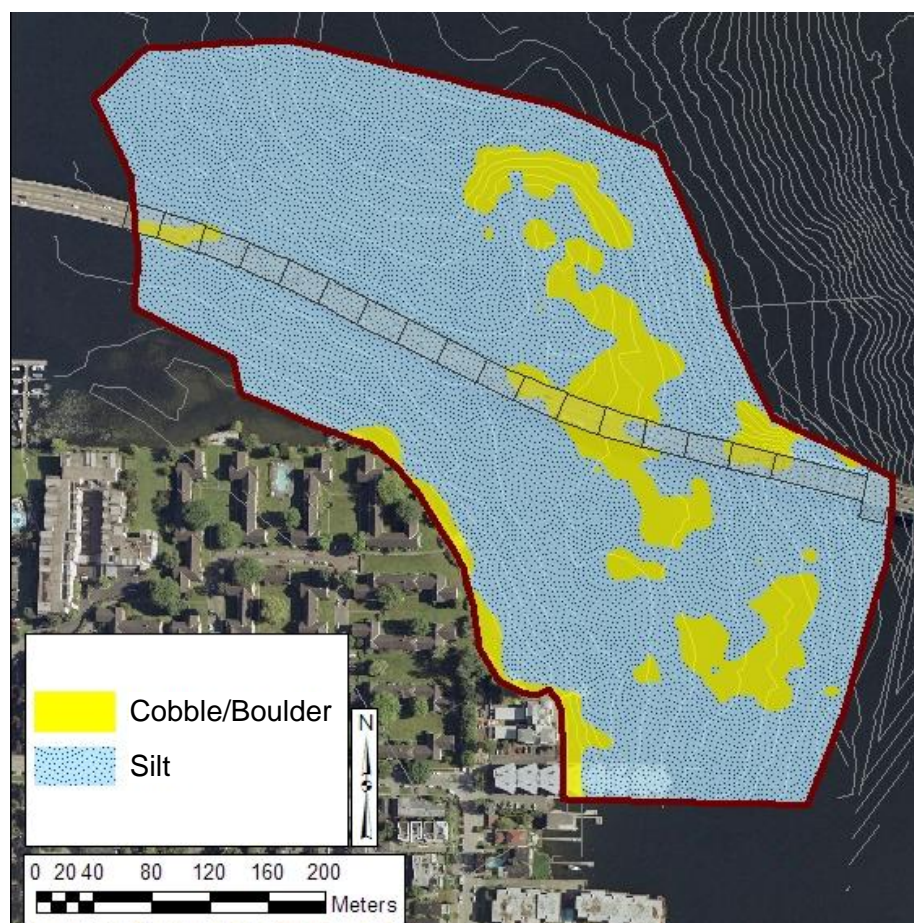


FIGURE 6. Two substrate categories used to determine substrate selection of northern pikeminnow and smallmouth bass at the SR 520 bridge tracking site, May-August 2008. The cobble/boulder is any area where there is more than 10% cobble or boulder, combined. The dark red line is the coverage area of the hydrophone array. White lines are depth contours in 2-m intervals.

Relative abundance and diet of piscivorous fishes at the SR 520 bridge site

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 7). 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. When the two nets were completely deployed, they extended a short distance away from the bridge on the north side. Gill nets were variable-mesh, monofilament nylon nets that were each 38-m long and 2.4-m high and consisted of five 7.6-m long panels: two panels had 5.1-cm square-mesh and the other three panels consisted of 3.2, 3.8, and 6.4-cm square-mesh, respectively. 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. To reduce bycatch and reduce the likelihood of capturing tagged predatory fish on the other sample dates, we deployed the nets 3 to 4 h before sunrise and then retrieved them shortly after sunrise. Gill nets were retrieved in the same order that they were deployed to minimize the difference in the amount the time they were fished between sites.

As the nets were being retrieved into the boat, we recorded the number of each fish species captured in each panel. Fish species that had a low likelihood of consuming smolts were immediately discarded. Other fish were placed in a bucket with fish from the same net. Some fish, such as smallmouth bass, that were in good condition were placed in an aerated holding tank (portable cooler). Shortly after all nets had been retrieved, fish were processed. Fish were identified and the length (nearest mm) and weight (nearest g) was measured. Because northern pikeminnow do not have a true stomach, each pikeminnow was sacrificed and the entire digestive tract was removed and stripped of its contents (Ward et al. 1995). The sex of northern pikeminnow was also recorded. Fish that were kept alive were sampled through gastric lavage. The remaining fish were dissected and the stomach contents removed. Diet samples were immediately placed on dry ice and later brought back to the laboratory for processing. To increase our sample size, we also took stomach samples from smallmouth bass that were caught at the SR 520 bridge for tracking purposes. These fish were all collected in June with gill nets set in roughly the same location and set during the same time of day as the regular gill net sampling.

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. Each prey group was enumerated and then blotted for ten seconds on a paper towel and weighed to the nearest 0.0001 g. Prey fish that are slightly digested were identified to species. Fishes in more advanced stages of digestion were identified to family, genus, or species from

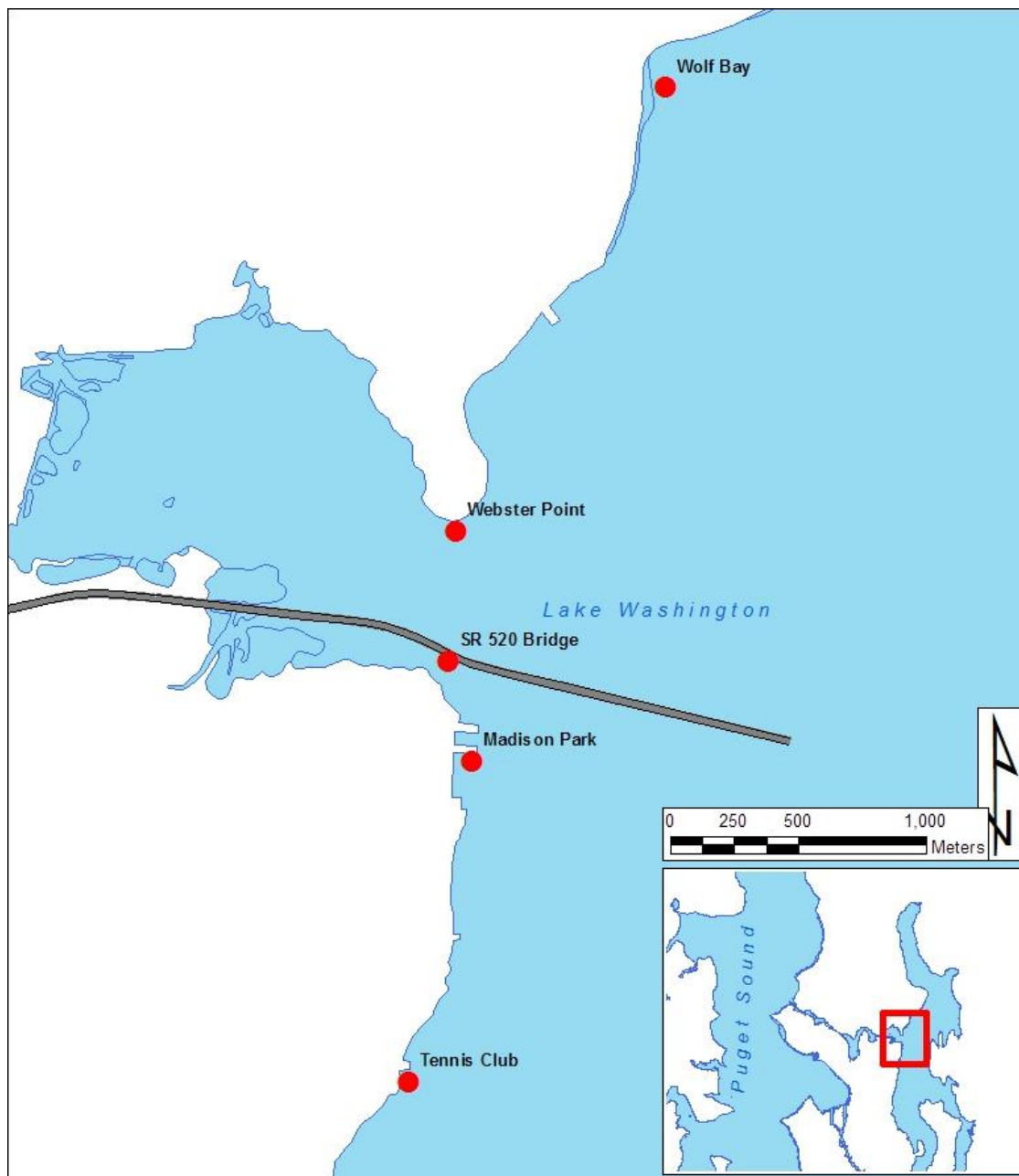


FIGURE 7. Map of central Lake Washington displaying the five gill-netting sites used to collect piscivorous fishes, May-July, 2008. Two gill nets (5-m and 10-m depth contours) were fished once a week for six weeks at each site.

diagnostic bones, gill raker counts, pyloric caeca counts, or vertebral columns. The fork length of each prey fish was measured to the nearest mm. If a fork length could not be taken, the original fork lengths of prey fish were estimated from measurements of standard length, nape-to-tail length (Vigg et al. 1991), or diagnostic bones (Hansel et al. 1988; Nowak et al. 2004; Tabor et al. 2007). Prey fish were individually weighed to the nearest 0.0001 g.

Data analysis

Differences in catch-per-unit effort (CPUE) between sites were compared with a non-parametric Friedman test (Conover 1999), with sample date used as a blocking variable. CPUE was defined as the number of fish caught in both nets (5-m and 10-m depth contours) per hour for each sampling date. Differences in fish length (all dates combined) between sites were compared with a one-way ANOVA and a post hoc Tukey's Honestly Significant Difference (HSD) test (SYSTAT 2007).

To describe the diet of northern pikeminnow and other fishes, we followed the procedures of Cortés (1997) and Liao et al. (2001). For each prey group in each sample, we determined the percent mean proportion by weight (% MW_i), percent number (% N_i), and percent occurrence (% O_i) (Chipps and Garvey 2007). Percent mean proportion by weight (% MW_i) was used instead of percent by weight because MW_i uses each fish as a sampling unit, minimizes the effect of fish size, and produces less volatile estimates of diet composition (Beauchamp et al. 2007b). A percent index of relative importance (% IRI) was then calculated for each prey group:

$$\%MN_i = \frac{1}{P} \sum_{j=1}^P \left(\frac{W_{ij}}{\sum_{i=1}^Q W_{ij}} \right) 100,$$

$$\%N = \frac{N_i}{\sum_{i=1}^Q N_i} 100,$$

$$\%O_i = \frac{J_i}{P} 100,$$

where P is the number of fish with food in their gut, W is the weight of food type i, Q is the number of prey types, N is the number of food type i, and J is the number of fish containing food type i. A percent index of relative importance (% IRI) was then calculated for each prey group:

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

Mean proportion of body weight (MBW_i) was also calculated to determine if there were any large differences in feeding activity between sites.

$$MBW_i = \frac{1}{P} \sum_{j=1}^P \left(\frac{W_{ij}}{F_j} \right),$$

where F is weight of predator j . Differences in percent body weight between sites were compared with a nonparametric Kruskal-Wallis test (more than two groups) or a Mann-Whitney U test (two groups). To help compare the diet between sites, we also calculated Schoener's diet overlap index (Schoener 1971):

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

where C_{xy} is the index value, p_{xi} is the proportion of food type i used by piscivorous fish at site x and p_{yi} is the proportion of food type i used by piscivorous fish at site y . Researchers commonly use an overlap index level of 0.6 or less to indicate a significant difference in diet (Zaret and Rand 1971; Johnson 1981). Comparisons were made between each site.

RESULTS

Site Ecology

Surface water temperature showed a gradual increase during the study period (Figure 8). At 2 m depth, temperature increased from about 12.5°C at the beginning of the study to about 22 °C toward the end, leveling off at about the time the last group of tagged Chinook salmon smolts were released. Temperature at 8 m depth showed a similar albeit more erratic increase from about 12.5°C at the beginning to about 19°C several days after the third group of tagged Chinook salmon were released. From this time to about the time the last group of tagged Chinook salmon were released temperature fluctuated several times between 11.5-20°C. After this, temperature gradually increased from 14.5°C to 20°C during the 10 days following release of the last group of tagged Chinook salmon. These patterns were considerably different than those observed in 2007 (Figure 8). In 2007, water was warmer earlier and was largely stable during most of the study period.

Water clarity generally ranged from 5.0-7.0 m Secchi depth during the study period, and showed a slight increase at the beginning of the study and a slight decline at the end (Figure 9). This pattern was different from that observed in 2007, which had lower clarity throughout the study period (3.0-5.0 m Secchi depth) and clarity gradually increased from the beginning of the study to the end.

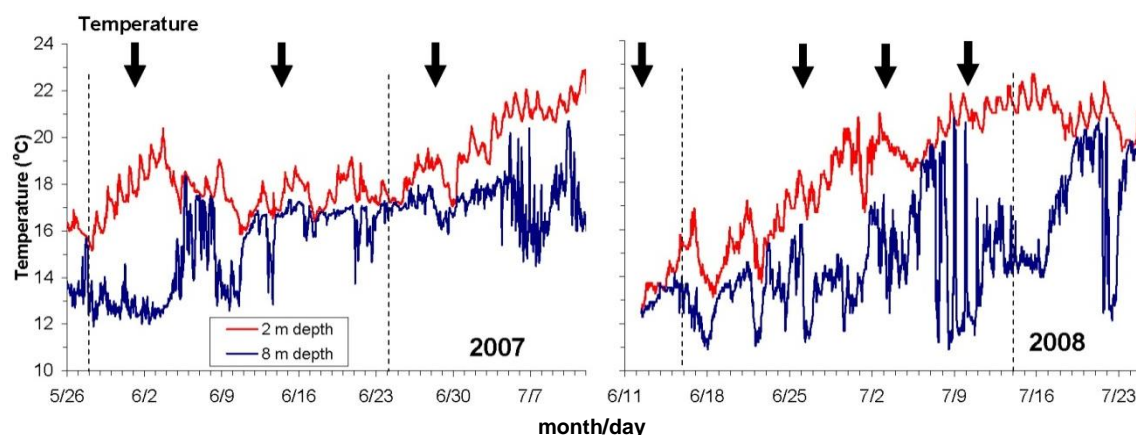


FIGURE 8. Water temperature at 2 m depth (red) and 8 m depth (blue) at the SR 520 tracking site, May 26 - July 12, 2007 and June 12 - July 25, 2008. Water temperature was recorded at 30 min intervals using TidbiT temperature loggers attached to hydrophone mounts. Temperature at 2 m depth is represented by hydrophone S-05, and temperature at 8 m depth is represented by hydrophone S-01 (see Figure 2 for hydrophone locations). Black arrows indicate when tagged Chinook salmon were released. Vertical dashed lines indicate moon apogee.

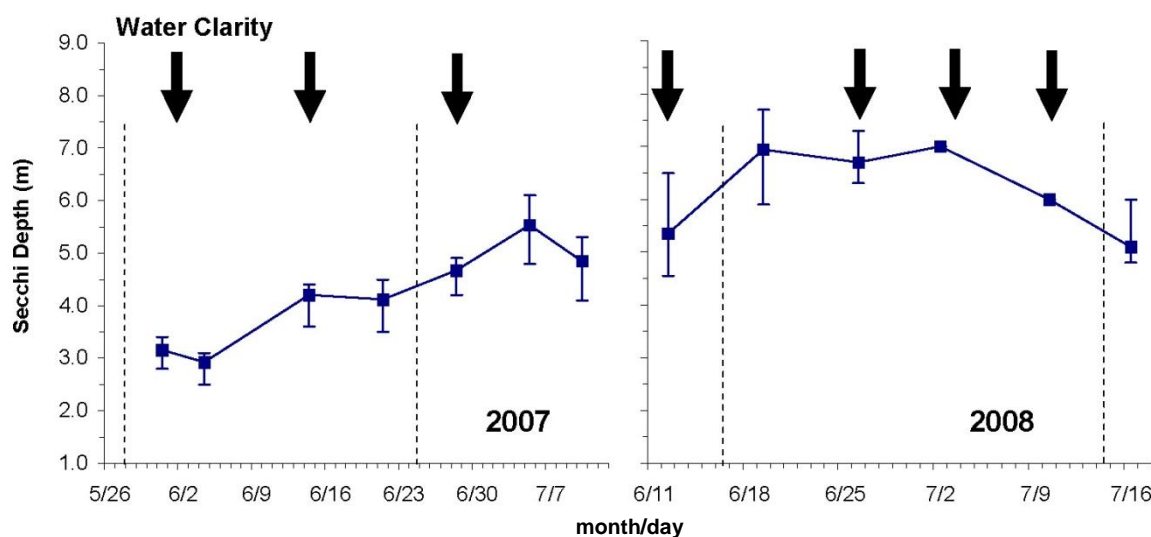


FIGURE 9. Water clarity (Secchi depth, m) at the SR 520 tracking area as measured with a Secchi disk, May 31 - July 11, 2007 and June 12 - July 16, 2008. Mean Secchi depth for all sampling points are shown (see Figure 8 for 2008 sample point locations). Error bars represent the minimum and maximum measurements. Black arrows indicate when tagged Chinook salmon were released. Vertical dashed lines indicate moon apogee.

Aquatic macrophytes were 0.5-1.5 m closer to the surface of the water at the end of the study than at the start of the study (Figure 10). Macrophytes on the southwestern part of the site (transect 3) were close to the water surface at the beginning of the study period (1.0 m below the surface), and were only about 0.5 m below the surface for the latter three releases of tagged Chinook salmon. Depth to macrophytes along the other three transects was deeper, and

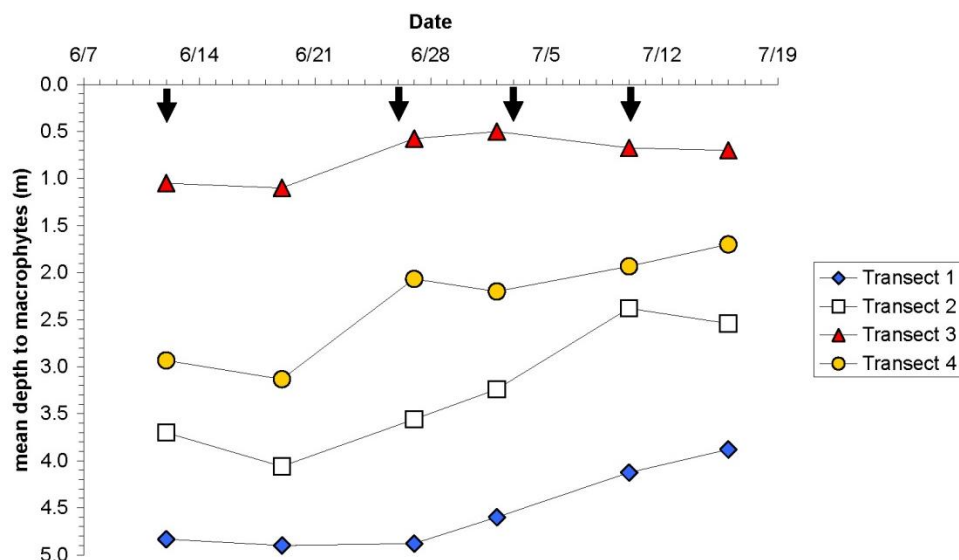


FIGURE 10. Growth of aquatic macrophytes as represented by mean depth to top of vegetation measured along four transects at the SR 520 tracking area, June 12 - July 16, 2008. Transect 1-3 had five sample points each, and transect 4 had three points. See Figure 4 for transect and sample point locations. Black arrows indicate when tagged Chinook salmon were released.

macrophytes here showed continual growth throughout the study period and grew more (1.0-1.5 m) than those along transect 3. There was no discernable change in macrophyte density during the study period at any of the transects.

Zooplankton mass was similar near the bridge and away from the bridge (Figure 11). Nearshore sampling locations consistently had the lowest zooplankton mass. Offshore areas had 2-23 times (median 5 times) greater zooplankton mass than nearshore areas. Patterns in zooplankton mass were strikingly different on the north and south sides of the bridge. Particularly intriguing was a large spike on the north side of the bridge on July 2, and a sharp decline on the south side of the bridge on June 27 at a time when mass on the north side of the bridge appeared to be increasing (Figure 11). Informal subsampling of zooplankton samples confirmed that *Daphnia* spp. made up the overwhelming majority of specimens.

The mean length of *Daphnia* in six samples ranged 1.23 to 1.76 mm (overall mean, 1.53 mm). Ninety-eight percent of all *Daphnia* were greater than 1.0 mm and 40% were greater than 1.65 mm. Rondorf et al. (1990) found juvenile Chinook salmon showed a positive selection for *Daphnia* greater than 1.0 and a strong positive selection for those greater than 1.65 mm. Therefore, we felt our zooplankton samples provided a reasonable estimate of zooplankton biomass available to juvenile Chinook salmon.

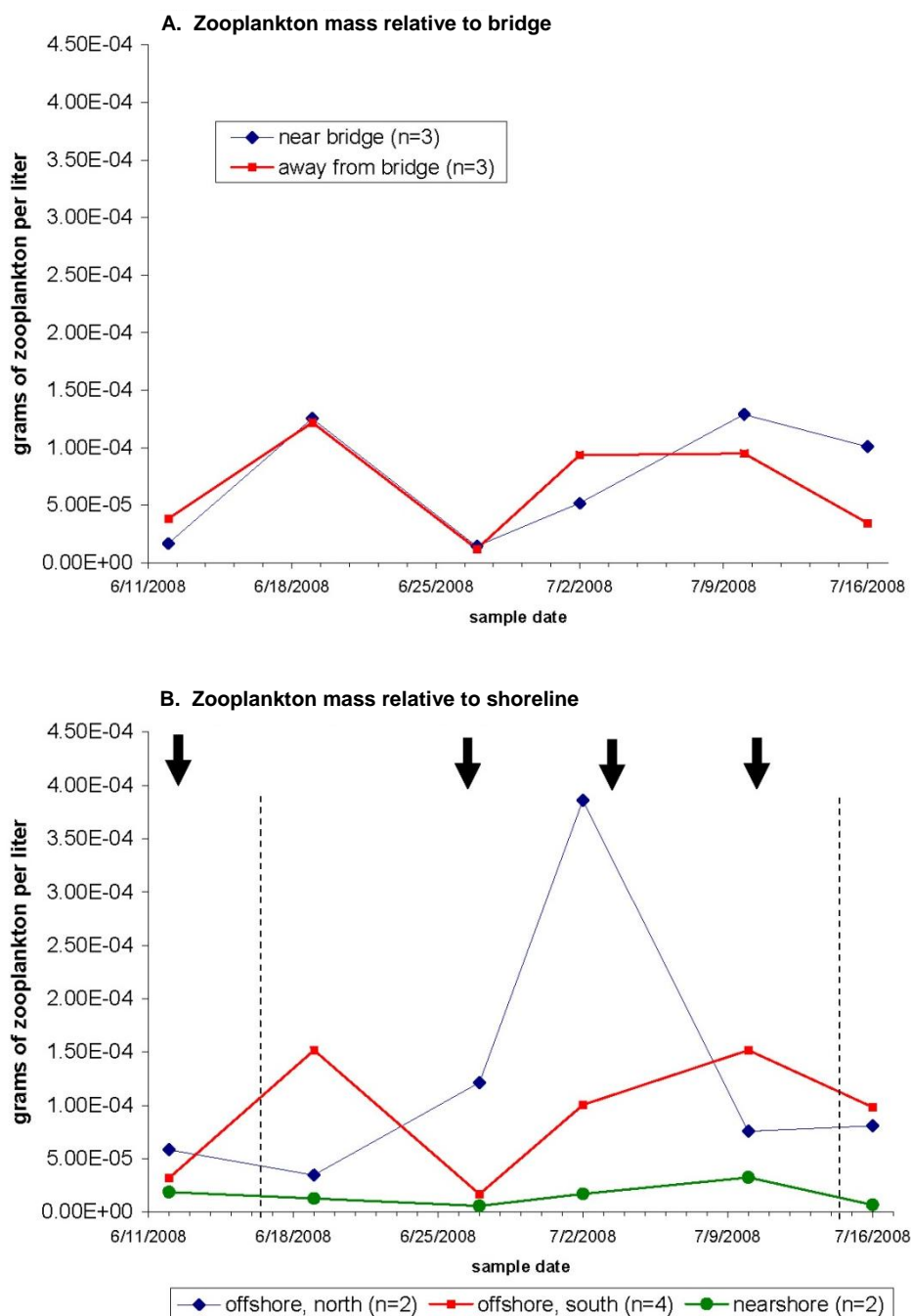


FIGURE 11. Mean zooplankton mass (g/l) collected from 0-5 m water column depth at the SR 520 bridge study site, June 12 - July 16, 2008. The following bridge/shoreline categorizations and corresponding sample point locations and were used: near bridge – A,B,C; away from bridge – D,E,F; near shore – A,D; offshore, south – B,C,E,F; offshore, north – G,H (see Figure 4 for sample point locations). Black arrows indicate when tagged Chinook salmon were released. Vertical dashed lines indicate moon apogee.

Chinook salmon smolts

Tagging and release

Four groups of tagged Chinook salmon smolts were released in 2008, one each on June 12, June 26, July 3, and July 10. The June 12 release group had fewer fish than the others because not enough fish were sufficiently large enough to tag. Fish size was generally comparable between release groups (Table 2; Figure 12); however, an ANOVA test (Zar 1999) suggested that lengths and weights were not statistically the same (length: $P < 0.01$; weight: $P < 0.01$).

TABLE 2. Four groups of tagged Chinook salmon smolts released during 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.

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)
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)

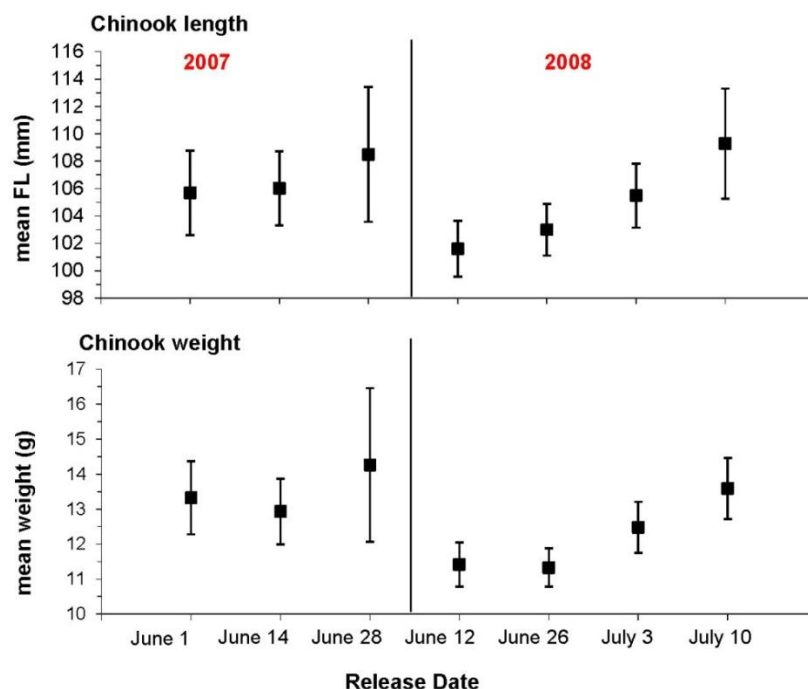


FIGURE 12. Mean fork length and weight (\pm one standard deviation) of tagged Chinook salmon smolts released during June-July, 2007-2008.

Subsequent Scheffé multiple comparison tests showed that lengths and weights were not significantly different between the June 12 and June 26 releases (length: $P = 0.219$; weight: $P = 0.969$). The July 3 and July 10 releases were both different from the June releases and from one another (length: $P < 0.01$; weight: $P < 0.01$).

Smoltification

The fork length (ANOVA, $P < 0.001$) and condition factor (ANOVA, $P < 0.001$) of fish collected during hatchery rearing and at the day of release varied significantly between sample dates (Figure 13) and location. There was a consistent trend of decreasing condition factor during hatchery rearing, with the April mean (\pm SE) condition factor ($1.21 \times 10^{-5} \pm 2 \times 10^{-7}$) decreasing to a mean (\pm SE) of $1.04 \times 10^{-5} (\pm 1 \times 10^{-7})$ at the release conducted on June 26. Condition factor varied significantly between the fish sampled at the four release dates. Fish collected at the first release date (June 12) had a significantly higher condition factor than fish from the other three release dates.

Gill NKA activities (Figure 14) did not vary by sample date (Kruskal-Wallis test, $P = 0.071$). Furthermore, NKA activity of fish sampled during rearing at the Issaquah Creek Fish Hatchery did not differ from fish sampled at the King County Environmental Lab just prior to release (Mann-Whitney U test, $P = 0.15$).

Chinook salmon tracking

The substantial majority of tagged fish from all release groups were both detected and tracked at the SR 520 bridge arrays. Between 79% and 89% of tagged fish were detected at the SR 520 arrays, and 75-85% of tagged fish yielded point location data (tracks) (Table 2). The proportion of fish detected at the study site that were also detected in the LWSC at the University Bridge varied considerably between release groups and ranged from 17% to 69% (Table 2). Fish size was not a consistent factor in whether fish were detected at the study site or at the University Bridge. For the latter 3 releases, fish lengths and weights were not significantly different between fish that were detected at neither site, those that were detected only at SR 520, and those detected at both sites (single-factor between-subjects analysis of variance, June 26: $P_{FL} = 0.52$, $P_{weight} = 0.34$; July 3: $P_{FL} = 0.85$, $P_{weight} = 0.90$; July 10: $P_{FL} = 0.24$, $P_{weight} = 0.40$) (Figure 15). A size bias was evident in the June 12 release (single-factor between-subjects analysis of variance, $P_{FL} = 0.039$, $P_{weight} = 0.007$): fish eventually detected in the LWSC were significantly larger than fish that were not (Scheffé complex comparison, $P_{FL} = 0.054$, $P_{weight} = 0.026$), although only 4 fish were detected in the LWSC.

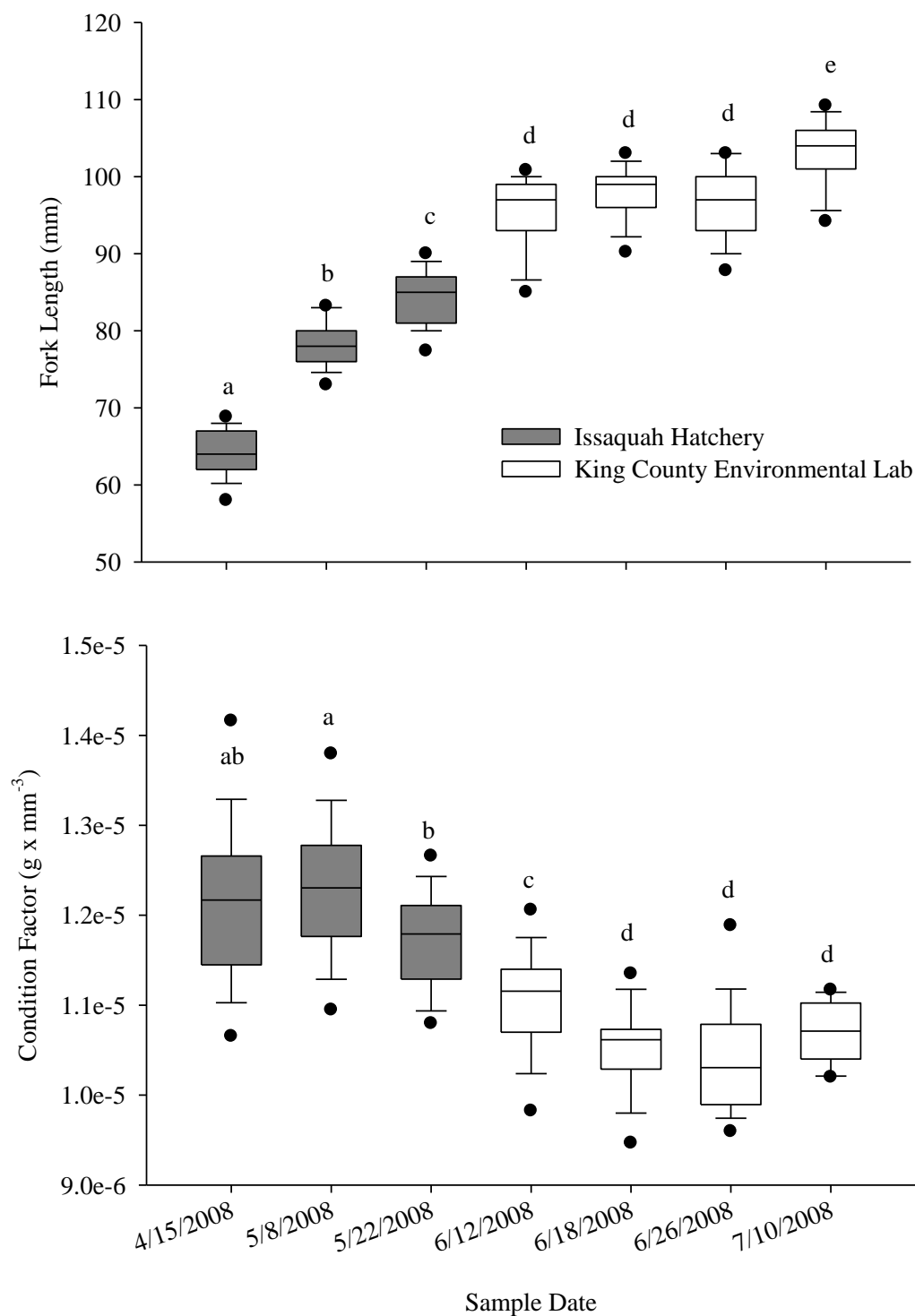


FIGURE 13. Box plots (dots – 2.5 and 97.5 percentiles; error bars – 5 and 95 percentiles; box – 25%, 50% [median], and 75% quartiles) of fork length and condition factor of juvenile Chinook salmon ($n = 35$ fish / sample date) sampled during hatchery rearing (WDFW Issaquah Creek Fish Hatchery) and just prior to release into Lake Washington (King County Environmental Lab), April 15 – July 10, 2008. Groups of bars with different letters are significantly different (ANOVA and Tukey's HSD; $P < 0.05$). Fish were not sampled for the July 3 release group and fish for June 18 were only released into the LWSC as part of different study (Celedonia et al. 2011).

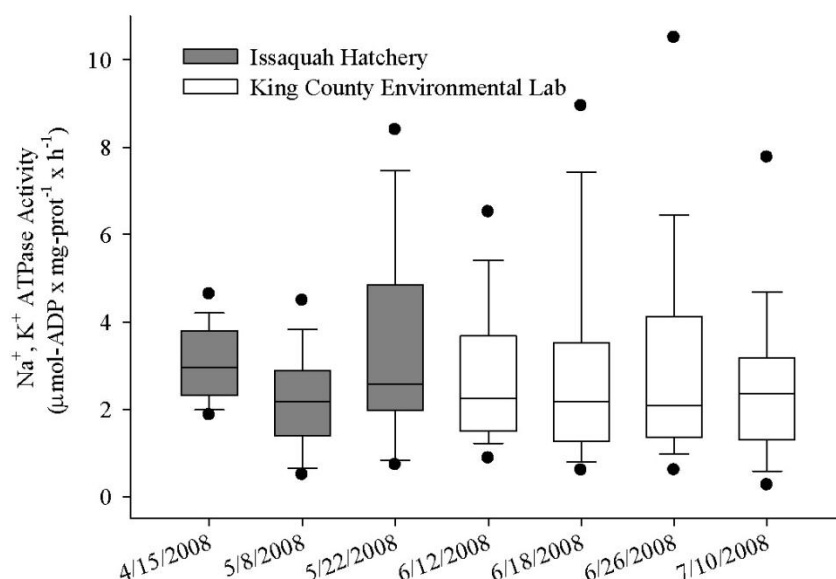


FIGURE 14. Box plots (dots – 2.5 and 97.5 percentiles; error bars – 5 and 95 percentiles; box – 25%, 50% [median], and 75% quartiles) of gill Na^+ , K^+ ATPase activity in juvenile Chinook salmon ($n = 35$ fish / sample date) sampled during hatchery rearing (WDFW Issaquah Creek Fish Hatchery) and just prior to release into Lake Washington (King County Environmental Lab), April 15 – July 10, 2008. Fish were not sampled for the July 3 release group and fish for June 18 were only released into the LWSC as part of different study (Celedonia et al. 2011).

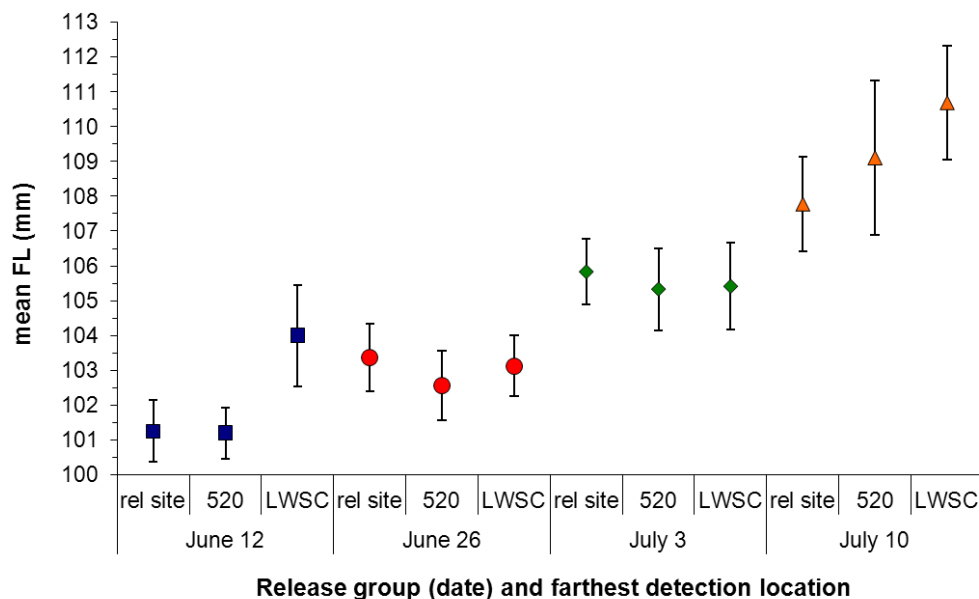


FIGURE 15. Mean fork length (\pm one standard deviation) of tagged Chinook salmon smolts by farthest known location from release site, June-July 2008. Rel site = fish that were released but not detected at either the SR 520 or University Bridge arrays. 520 = fish that were detected at the SR 520 array but not at the University Bridge array. LWSC = fish that were detected at both the SR 520 and University Bridge arrays. Note that no tagged fish were detected at the University Bridge without first being detected at SR 520.

As in 2007, we observed considerable variability in fish travel and residence times, habitat and depth selection, and behaviors near and under the bridge. Despite this variability, general patterns were evident particularly within each release group. Most fish were detected at the study site the day of release (Table 3; Figure 13). In general, fish traveled more quickly from release to the study site as the season progressed (Table 3; Figure 16): 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 releases. These differences were statistically significant except for the June 26-July 3 pair (Table 4). General site area residence time also shortened as the season progressed (Table 3; Figure 16). June releases were similar to one another (Table 4) and had median residence times of 141-170 h (Table 3). July releases were also similar to one another (Table 4) and had median residence times of 9.3-11.3 h (Table 3). Each June release was significantly different from each July release (Table 4). Despite the relatively short residence times of the July fish, a considerable proportion of fish from each release had residence times > 24 h (Figure 16). Travel time from the study site to the University Bridge in the LWSC also appeared to shorten from June to July (Table 3; Figure 16); however, these differences were not statistically significant (Table 4).

Overall travel time from release to the University Bridge in the LWSC was compared between the latter three releases. The June 12 release was excluded because only 4 fish from this group were detected at the University Bridge. Median travel times varied sharply - 178, 18.3, and 58.4 h for the June 26, July 3, and July 10 releases, respectively (Table 3). Despite the magnitude of differences, only one pair of releases - June 26 and July 3 - were statistically different from one another (Table 4). Interestingly, the July 10 group on the whole appeared intermediate between the June 26 and July 3 releases (Figure 16). This was curious because the July 10 group traveled as quick or quicker than the other groups in the preceding analyses. One reason for the apparent discrepancy may lie in possible differences between fish that were tracked both at the SR 520 bridge site and in the LWSC (LWSC fish) versus those that were only tracked at the SR 520 site and were never observed in the LWSC (non-LWSC fish). Some release groups showed an apparent difference between LWSC and non-LWSC fish in travel time from release to the study site and in site area residence time (Table 3; Figure 17), though not all apparent differences were statistically significant (Table 4). Thus, travel and residence time results may differ depending on whether all fish (both LWSC and non-LWSC fish) are collectively evaluated or whether they are evaluated separately. For example, when all fish were evaluated together, SR 520 area residence times for the June 26 and July 10 groups were median 141 and 11.3 h, respectively (Table 3), a difference that was statistically significant (Table 4). However, median residence times of LWSC fish only were 93.4 and 31.6 h, respectively (Table 3), a narrower difference that failed significance testing.

In general, site area residence times were shorter for LWSC fish than for 520 fish (Table 3; Figure 17). Given the relatively short battery life of the tags, it is uncertain how many non-LWSC fish entered the LWSC after the tag battery died. Nonetheless, these results suggest that many non-LWSC fish were holding in the general area rather than vacating the area altogether and moving to some other part of the lake. The exception was the July 10 group, where many non-LWSC fish had substantially shorter area residence times than LWSC fish (Table 3; Figure 17): many non-LWSC fish had residence times < 2 h, whereas most LWSC fish had residence

TABLE 3. Travel and residence times of tagged Chinook salmon after release, 2008. Median time (in hours) are shown for: time from release to first detection at the SR 520 array; area residence time^a at 520; time spent within the tracking area at the 520 study site; time from last detection at 520 to first detection at the University Bridge; and time from release to first detection at University Bridge. Data are presented for: all fish from each release group (all fish); only fish that were detected in the LWSC (in SC); and, only fish that were not detected in the LWSC (not in SC). Tenth and 90th percentiles are shown in brackets [], and number of fish comprising each observation are in parenthesis (n).

Release group	Release to 520 (h)	520 area residence (h)	time on 520 study site (h)	ratio of time on site to 520 area residence	520 to Univ. Br. (h)	Release to Univ. Br. (h)
June 12						
all fish	10.2 [8.1 – 71.8] (n = 24)	170 [9.6 – 247] (n = 24)	20.1 [0.6 – 132] (n = 23)	0.42 [0.01 – 0.84] (n = 23)	-	-
in SC	8.1 [4.9 – 25.4] (n = 4)	40.3 [7.6 – 131] (n = 4)	13.7 [3.9 – 70.8] (n = 4)	0.46 [0.33 – 0.94] (n = 4)	64.8 [25.3 – 74.8] (n = 4)	111 [89.0 – 182] (n = 4)
not in SC	10.7 [8.2 – 82.4] (n = 20)	204 [10.6 – 248] (n = 20)	20.1 [0.6 – 135] (n = 19)	0.42 [0.01 – 0.77] (n = 19)	-	-
June 26						
all fish	4.9 [2.3 – 18.8] (n = 40)	141 [2.9 – 264] (n = 40)	44.6 [1.1 – 173] (n = 39)	0.54 [0.05 – 1.0] (n = 39)	-	-
in SC	5.7 [2.9 – 24.3] (n = 24)	93.4 [2.9 – 264] (n = 24)	29.4 [0.9 – 159] (n = 24)	0.54 [0.28 – 1.0] (n = 24)	5.8 [2.2 – 27.7] (n = 24)	178 [26.2 – 272] (n = 24)
not in SC	4.8 [2.2 – 9.8] (n = 16)	157 [10.0 – 265] (n = 16)	89.3 [4.7 – 174] (n = 15)	0.51 [0.11 – 0.99] (n = 15)	-	-
July 3						
all fish	3.7 [1.5 – 18.2] (n = 41)	9.3 [1.9 – 134] (n = 41)	6.9 [0.8 – 49.3] (n = 40)	0.51 [0.08 – 1.0] (n = 40)	-	-
in SC	3.5 [0.9 – 11.0] (n = 29)	8.0 [1.9 – 120] (n = 29)	6.5 [1.1 – 46.5] (n = 29)	0.62 [0.17 – 1.0] (n = 29)	2.7 [1.6 – 29.2] (n = 29)	18.3 [6.4 – 132.9] (n = 29)
not in SC	8.9 [3.1 – 36.3] (n = 12)	47.7 [17.4 – 135] (n = 12)	10.9 [0.6 – 48.6] (n = 11)	0.22 [0.08 – 0.86] (n = 11)	-	-

^a Area residence time is defined as the time difference between the very first and very last detection at the tracking site, regardless of whether the fish was tracked or detected during the entire time.

TABLE 3. (cont.)

Release group	Release to 520 (h)	520 area residence (h)	time on 520 study site (h)	ratio of time on site to 520 area residence	520 to Univ. Br. (h)	Release to Univ. Br. (h)
July 10						
all fish	1.5 [0.8 – 1.5] (n = 41)	11.3 [0.5 – 229] (n = 41)	0.5 [0.1 – 3.2] (n = 41)	0.09 [0.004 – 0.31] (n = 41)	-	-
in SC	1.5 [1.4 – 1.6] (n = 13)	31.6 [0.7 – 196] (n = 13)	0.8 [0.05 – 3.2] (n = 13)	0.02 [0.01 – 0.26] (n = 13)	2.7 [2.0 – 45.9] (n = 13)	58.4 [10.0 – 200] (n = 13)
not in SC	1.4 [0.8 – 1.5] (n = 28)	5.4 [0.5 – 232] (n = 28)	0.4 [0.1 – 3.0] (n = 28)	0.17 [0.01 – 0.31] (n = 28)	-	-

^a Area residence time is defined as the time difference between the very first and very last detection at the tracking site, regardless of whether the fish was tracked or detected during the entire time.

^b Tracking time is an estimate of the minimum amount of time the fish was actually tracked on-site.

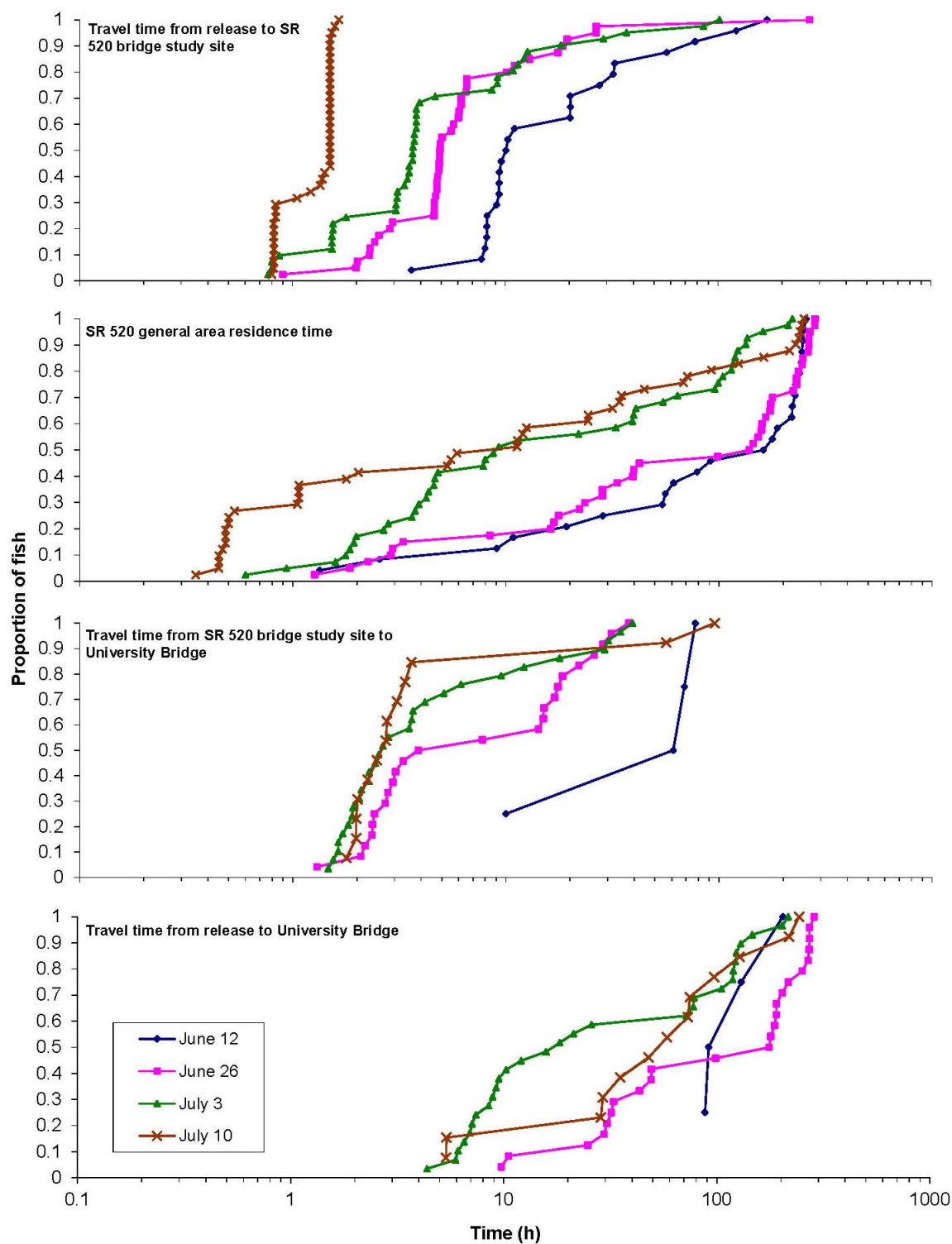


FIGURE 16. Cumulative frequency distributions of tagged Chinook salmon travel and residence times by release date, June-July 2008. Each point represents a tracked fish. For a given fish, the cumulative proportion of fish (y axis) is the proportion of fish (inclusive of that fish) that had travel or residence times equal to or less than that fish.

TABLE 4. Results of statistical tests used for evaluating travel times of tagged Chinook salmon smolts, June 2007. *P*-values are shown for: time from release to first detection at the SR 520 array; area residence time^a at 520; time from last detection at 520 to first detection at the University Bridge in the LWSC; and time from release to first detection at University Bridge. Data are presented for: all fish from each release group (all fish); only fish that were detected in the LWSC. Asterisk indicates a significant difference ($P < 0.05$).

Release group(s) and statistical test	Release to 520	520 area residence	520 to University Br.	Release to University Br.
All fish detected at SR 520 bridge				
All groups (Kruskal-Wallis one-way analysis of variance, $\alpha = 0.05$)	< 0.001*	< 0.001*	-	-
Multiple comparisons (Bonferroni-adjusted Mann-Whitney <i>U</i> test, $\alpha_{FW} = 0.05$)				
June 12, June 26 ($\alpha_{PC} = 0.008$)	< 0.001*	0.551	-	-
June 12, July 3 ($\alpha_{PC} = 0.008$)	< 0.001*	< 0.001*	-	-
June 12, July 10 ($\alpha_{PC} = 0.008$)	< 0.001*	< 0.001*	-	-
June 26, July 3 ($\alpha_{PC} = 0.008$)	0.034	< 0.001*	-	-
June 26, July 10 ($\alpha_{PC} = 0.008$)	< 0.001*	< 0.001*	-	-
July 3, July 10 ($\alpha_{PC} = 0.008$)	< 0.001*	0.216	-	-
Only fish that were detected in LWSC after SR 520 bridge				
All groups (Kruskal-Wallis one-way analysis of variance, $\alpha = 0.05$)	< 0.001*	0.033*	0.135	0.003*
Multiple comparisons (Bonferroni-adjusted Mann-Whitney <i>U</i> test, $\alpha_{FW} = 0.05$)				
June 26, July 3 ($\alpha_{PC} = 0.017$)	< 0.001*	0.008*	0.071	< 0.001*
June 26, July 10 ($\alpha_{PC} = 0.017$)	< 0.001*	0.215	0.119	0.127
July 3, July 10 ($\alpha_{PC} = 0.017$)	< 0.001*	0.577	0.989	0.308
Comparison of fish detected in LWSC with those not detected in LWSC				
Mann-Whitney <i>U</i> test, $\alpha = 0.05$				
June 12 ($\alpha = 0.05$)	0.088	0.088	-	-
June 16 ($\alpha = 0.05$)	0.132	0.307	-	-
July 3 ($\alpha = 0.05$)	0.007*	0.406	-	-
July 10 ($\alpha = 0.05$)	0.015*	0.197	-	-

^a Area residence time is defined as the time difference between the very first and very last detection at the tracking site, regardless of whether the fish was tracked or detected during the entire time.

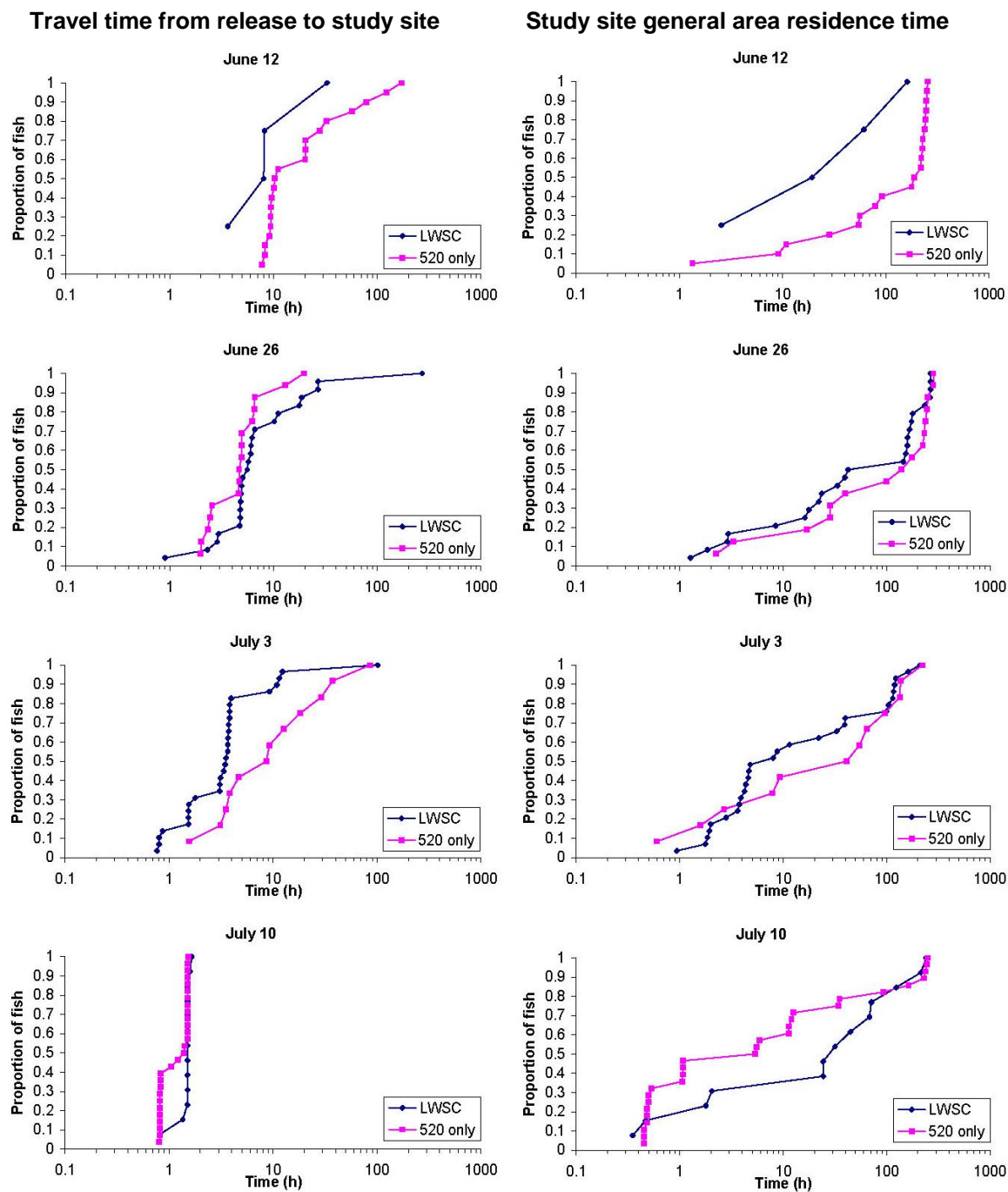


FIGURE 17. Comparison of cumulative frequency distributions of travel time from release to the SR 520 bridge study site and general area residence time at the site between fish that were eventually detected in the LWSC at the University Bridge (blue lines) and those that were not (520 only), June-July 2008. Each point represents a tracked fish. For a given fish, the cumulative proportion of fish (y axis) is the proportion of fish (inclusive of that fish) that had travel or residence times equal to or less than that fish.

times > 20 h. A similar pattern was observed in 2007 suggesting a possible late-season effect on: 1) fish survival between the SR 520 bridge and the University Bridge; and/or, 2) propensity of fish to hold in the general Union Bay area and enter the LWSC.

Most fish from all release groups entered and exited the tracking area repeatedly suggesting that the tracking area was part of a larger area that fish were using during their general area residence. Not all release groups spent the same proportion of time on site. Median proportion of time spent on site (on-site ratio) relative to general area residence was 0.42-0.54 for the first three release groups, and only 0.09 for the last group (Table 3). The first three groups were statistically similar, and all three were significantly different from the fourth (Table 5). There was no difference in on-site ratio between LWSC and non-LWSC fish in the June release groups (Table 3; Table 5). Conversely, non-LWSC fish released on July 3 appeared to have much lower on-site ratios than LWSC fish, although this difference was not statistically significant. The July 10 release also showed a difference between LWSC and non-LWSC on-site ratios, except that the lower ratios were associated with the former rather than the latter. This difference was statistically significant (Table 5).

TABLE 5. Results of statistical tests used for evaluating ratio of time spent on-site to general site area residence time of tagged Chinook salmon smolts, June-July 2008. Release groups were compared to determine if the time spent on site varied between release groups. Within each release group, fish tracked only at the SR 520 bridge site were compared with fish that were tracked at the SR 520 bridge site and later detected in the LWSC at the University Bridge. Asterisk indicates a significant difference ($P < 0.05$).

Release group(s) and statistical test	Results (P)
Comparison between release groups	
All groups (Kruskal-Wallis one-way analysis of variance, $\alpha = 0.05$)	< 0.001*
Multiple comparisons (Bonferroni-adjusted Mann-Whitney U test, $\alpha_{FW} = 0.05$)	
June 12, June 26 ($\alpha_{PC} = 0.008$)	0.048
June 12, July 3 ($\alpha_{PC} = 0.008$)	0.087
June 12, July 10 ($\alpha_{PC} = 0.008$)	0.005*
June 26, July 3 ($\alpha_{PC} = 0.008$)	0.695
June 26, July 10 ($\alpha_{PC} = 0.008$)	< 0.001*
July 3, July 10 ($\alpha_{PC} = 0.008$)	< 0.001*
Comparison of fish detected in LWSC with those not detected in LWSC	
Mann-Whitney U test, $\alpha = 0.05$	
June 12 ($\alpha = 0.05$)	0.330
June 16 ($\alpha = 0.05$)	0.707
July 3 ($\alpha = 0.05$)	0.099
July 10 ($\alpha = 0.05$)	0.036*

Of the four release groups, three - the June 12, June 26, and July 3 releases - were dominated by fish holding on and near the study site. Only 9 of the 101 fish from these three releases exhibited the active migration behavior. The July 10 release was unique in that 38 of the 41 fish tracked on-site initially passed through the site in one of two schools (Figure 18). One school was comprised of 16 fish and moved through the center of the site (mid-site school). The other contained 22 fish that were further off-shore and passed beneath the high-rise part of the bridge on the eastern edge of the site (the high-rise school). Both schools entered the site shortly after release and both appeared to break apart after moving off-site to the north. Many fish from both schools were later observed reentering the tracking area alone, and fish that were detected at the University Bridge in the LWSC were observed at different times. Only 6% (1 fish) of the mid-site school were later detected in the LWSC, whereas 45% (10 fish) of the high-rise school were detected.

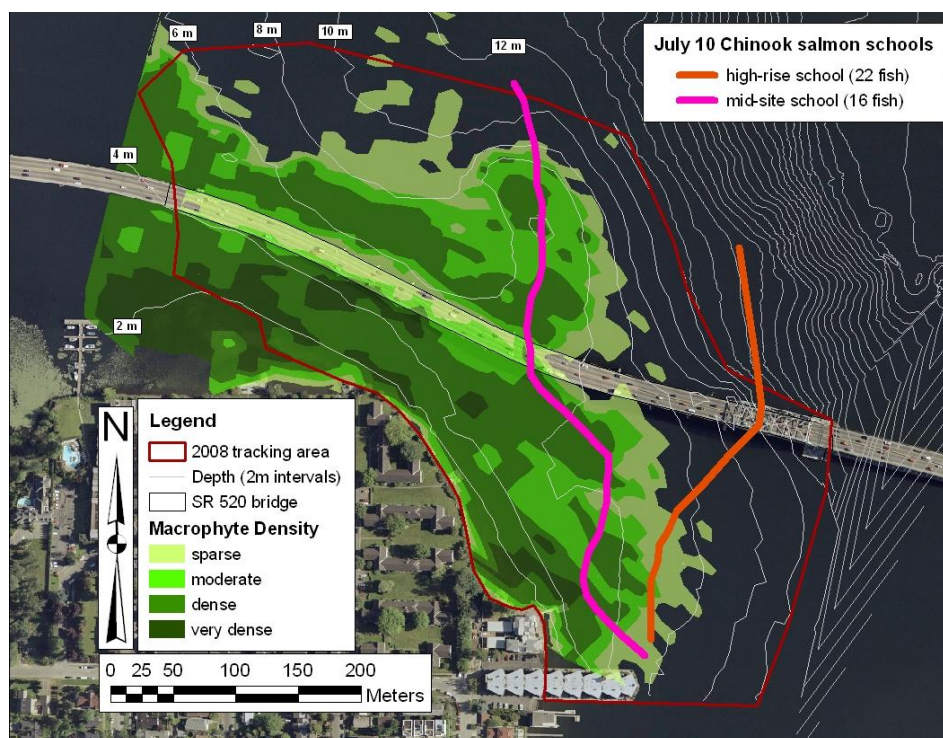


FIGURE 18. Movement pathways of two schools of tagged Chinook salmon through the SR 520 study site, July 10, 2008. Only three fish from this release group moved through the site individually and not in one of these schools. Both schools appeared to break apart after moving north of the site.

Behavior approaching and passing beneath the bridge

In general, we observed the same types and diversity of behaviors in 2008 as we did in 2007 regarding Chinook salmon approaching, encountering, and passing beneath the SR 520 bridge (see Table 4 in Celedonia et al. 2008a). A substantial majority of tagged Chinook salmon passed beneath the bridge: 70%, 95%, 90%, and 100% of fish from the June 12, June 26, July 3, and July 10 release groups (excluding fish that were never detected at the study site), respectively, were known to have passed beneath the bridge (Table 6). Most fish that were known to have passed beneath the bridge - 94-100% of three release groups and 81% of the fourth - were directly observed passing beneath the bridge within the study site. 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. All fish that passed beneath 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. Some off-site passings labeled as “west of site” may have actually occurred within the perimeter of the hydrophone array. This was because coverage on the west side of the site appeared to degrade during the study period, likely as a result of increasing macrophyte density and subsequent acoustic dampening. The result was sparser data and more discontinuous tracks in this area. These affects were primarily observed west of bridge columns 27-28 (Figure 19).

TABLE 6. Proportion (number) of tagged Chinook salmon with different passing characteristics at the SR 520 bridge, 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.”

Observed bridge passing characteristics	Release group			
	June 12	June 26	July 3	July 10
Single, simple pass	0.07 (2)	0.10 (5)	0.08 (4)	0.40 (21)
Multiple and/or complex pass	0.41 (11)	0.60 (30)	0.57 (30)	0.39 (20)
Passed off-site				
passed west of site	0.11 (3)	0.04 (2)	0.04 (2)	0.00 (0)
passed east of site	0.00 (0)	0.00 (0)	0.00 (0)	0.00 (0)
Partial pass only	0.07 (2)	0.00 (0)	0.00 (0)	0.00 (0)
No known pass				
detected and/or tracked on-site	0.22 (6)	0.06 (3)	0.11 (6)	0.04 (2)
not detected on-site	0.11 (3)	0.20 (10)	0.21 (11)	0.16 (8)

June 12 Release



June 26 Release



July 3 Release



FIGURE 19. 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 most fish from the June 12, June 26, and July 3 release groups passed beneath the bridge more than once (Table 6). These additional passes are not shown here.

The remaining fish from each group made only partial passes beneath the bridge, or were not observed and otherwise not known to have passed beneath the bridge. Partial passes occurred when fish moved beneath the bridge without ever crossing beyond the north edge of the bridge. Only two fish - both from the June 12 release - made only partial passes (Table 6). Some fish that were tracked on-site were not observed or otherwise known to cross beneath the bridge. This described 4-22% of fish depending on release group (Table 6). Only three of these fish were observed within 20 m of the bridge while tracked on-site. The others were not tracked near the bridge while on site. Compared to 2007, a greater proportion of fish in 2008 were never detected or tracked at the study site, and were not known to pass beneath the bridge (Table 6). This described 11-21% of tagged fish in 2008, but only 2-13% in 2007.

As in 2007, 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 (a complex pass) (Table 6). Relative to other passing behaviors (i.e., single, simple pass and passed off-site) these behaviors accounted for 69-83% of fish from the first three release groups and 49% of the fourth. This corresponded with observations in 2007: 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. Single, simple passes - that is, fish that were observed passing beneath the bridge only once without lingering beneath the bridge or crossing back to the south - were observed in only 11-14% of fish in the first three release groups and 51% of the fourth. In both 2007 and 2008 single, simple passes were often observed by actively migrating fish as well as by some holding fish.

Tagged Chinook salmon that actively migrated through the approach, encounter and pass areas of the site were used to evaluate effect of the bridge on migration. Only 9 fish from the first three release groups fit this description: 1, 3, and 5 fish from the June 12, June 26, and July 3 groups, respectively. The July 10 group was treated as a special case because of the schooling observed. Instead of taking each fish as an independent sample of behavior, we took each school as an independent sample. The three fish that were not in a school exhibited the holding behavior and thus were not included in the analysis. Upon encountering the bridge, actively migrating fish showed the same three general behaviors as those observed in 2007: 1) minimal to no response ("minimal response"); 2) abruptly changed direction and moved parallel along the edge of the bridge prior to passing underneath ("paralleling"); and, 3) meandered or milled near or away from the edge of the bridge for prolonged periods immediately upon encountering the bridge or after moving parallel along the bridge edge ("meandering/milling"). Of the 11 independent observations of bridge passing behavior, 5 showed minimal response, 3 showed paralleling only, and 3 showed meandering/milling either alone or in combination with paralleling (Table 7). Paralleling fish travelled 41-455 m and 3.9-18.8 min along the edge of the bridge before passing underneath. Meandering/milling fish travelled 202-938 m along the edge of the bridge and took 17.2-45.4 min after initial encounter with the bridge to pass underneath.

TABLE 7. Observations of delay of actively migrating Chinook salmon smolts at south edge of the SR 520 bridge prior to passing beneath the bridge, June-July, 2008. Behavior type describes behavior at initial encounter with bridge and before passing underneath. Direction of movements after initial encounter with bridge and before passing underneath is shown (w = west). Distances were measured parallel with bridge: total length of movement pathways of meandering/milling fish were not determined.

Release group Tag period/fish group	Behavior type(s) ^a	Direction	Westward travel	
			Distance (m)	Time (s)
June 12				
2881	n	-	0	0
June 26				
3106	n	-	0	0
3426	n	-	0	0
3466	p	w	41	232
July 3				
2503	mm, p, os	w	938	2,723
2563	mm, p	w	285	1,033
2723	p	w	405	1,128
3023	mm	w	202	1,841
3083	p	w	455	645
July 10				
S-mid ^b	n	-	0	0
S-HR ^b	n	-	0	0

a Behavior types defined as follows: n = migration negligibly affected by bridge; p = movement parallel with bridge near bridge edge; os = fish moved off-site prior to passing beneath bridge - time and distance shown are to last observed point prior to moving off-site; mm = periods of meandering/milling near or away from bridge edge.

b S-mid = mid-site school; S-HR = high-rise school.

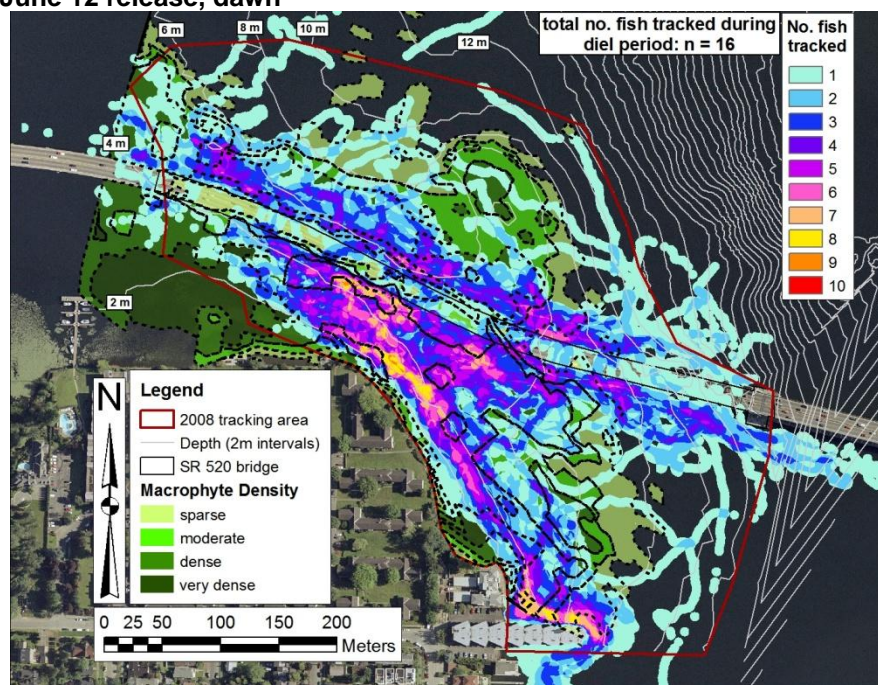
In general, fish passed beneath the bridge throughout the tracking area and no single location appeared more heavily used than others (Figure 19). Passing locations of the June 12 group were evenly distributed between columns 25 and 38, and no fish passed east of Column 38. Passing locations of both the June 26 and the July 3 groups were more concentrated between columns 30 and 37. This area was characterized by macrophytes on both the north and south sides of the bridge, water column depth of 4-8 m, and was where the bridge was elevated above the surface of the water. Fewer fish passed beneath the bridge where the bridge was closer to the surface of the water, or in deeper, open water areas devoid of macrophytes.

Spatial distribution, habitat selection, and bottom depth selection

Spatial distribution, habitat selection, and bottom 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. Highest frequencies of occurrence appeared: around the Lakeshore West Condominium (condo); in shallow water (< 6 m bottom depth) 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 bottom depth) open water areas without macrophytes; and, under the bridge in areas where the bridge was elevated above the surface of the water (Figures 20-22). 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 23). The condo edge usually had the highest selection ratios, but extremely large confidence intervals precluded statistical significance in all but three occasions (Figure 23). 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. When fish were near or under the bridge, they often selected for the northern and southern edges on the western and central portions of the site, and underneath the bridge only in the central portion (Figure 24). The eastern portion was most often selected against or used in proportion to availability.

Fish selected more offshore waters 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 bottom depth (Figures 25-27). When fish were near/under the bridge or near the condo, peak selection was often observed for 6-7 m and 7-8 m bottom depth, respectively. 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 more offshore waters 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.

A. June 12 release, dawn



B. June 12 release, early day

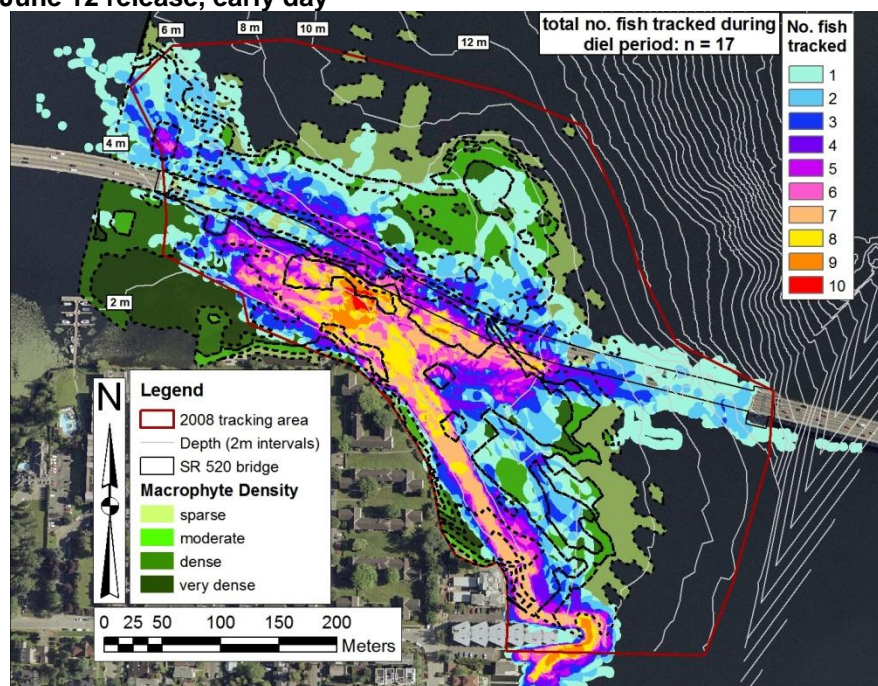
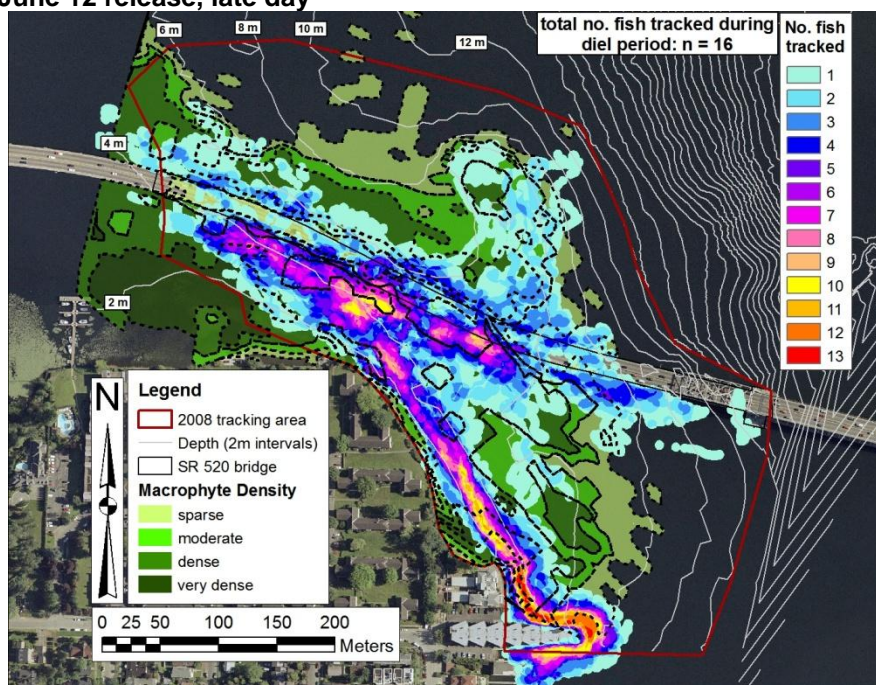


FIGURE 20. Diel spatial frequency distributions of tagged Chinook salmon released on June 12, 2008 and tracked at the SR 520 bridge tracking site. ArcGIS 9.2 Spatial Analyst was used to determine the total number of fish that occurred within a 4 m radius of each tracked fish data point.

C. June 12 release, late day



D. June 12 release, dusk

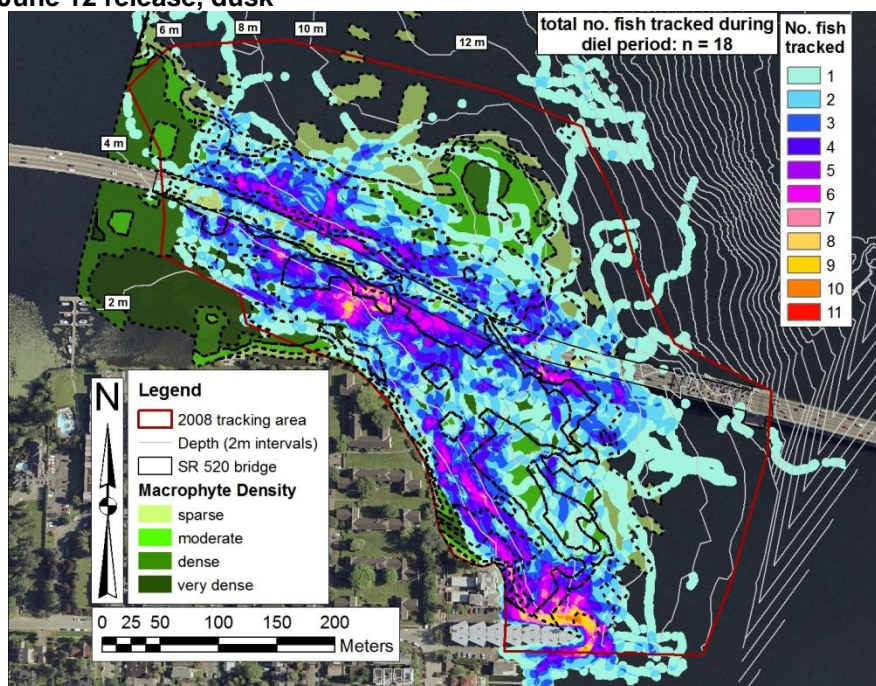


FIGURE 20. (cont.)

E. June 12 release, night

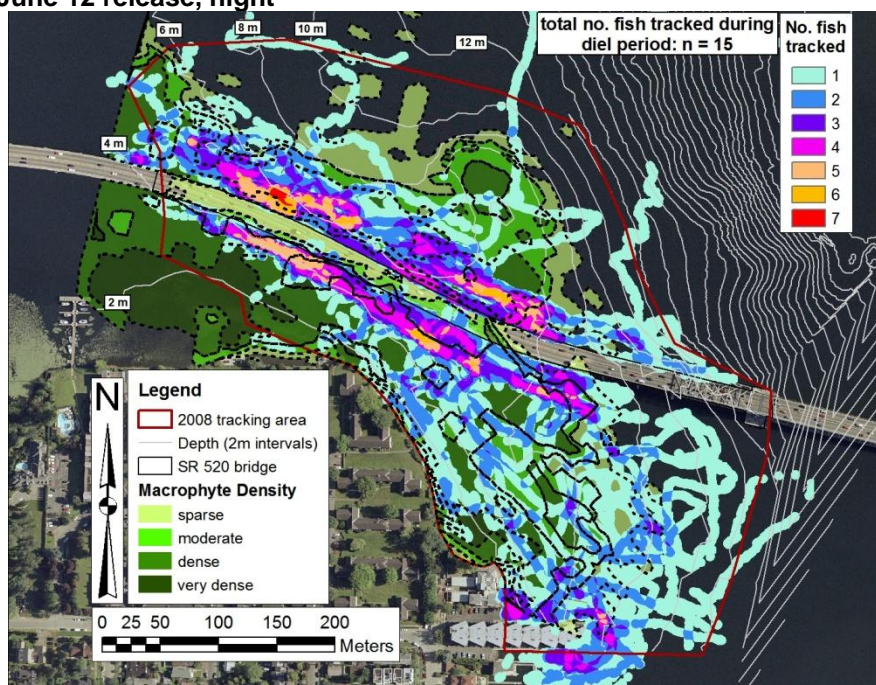
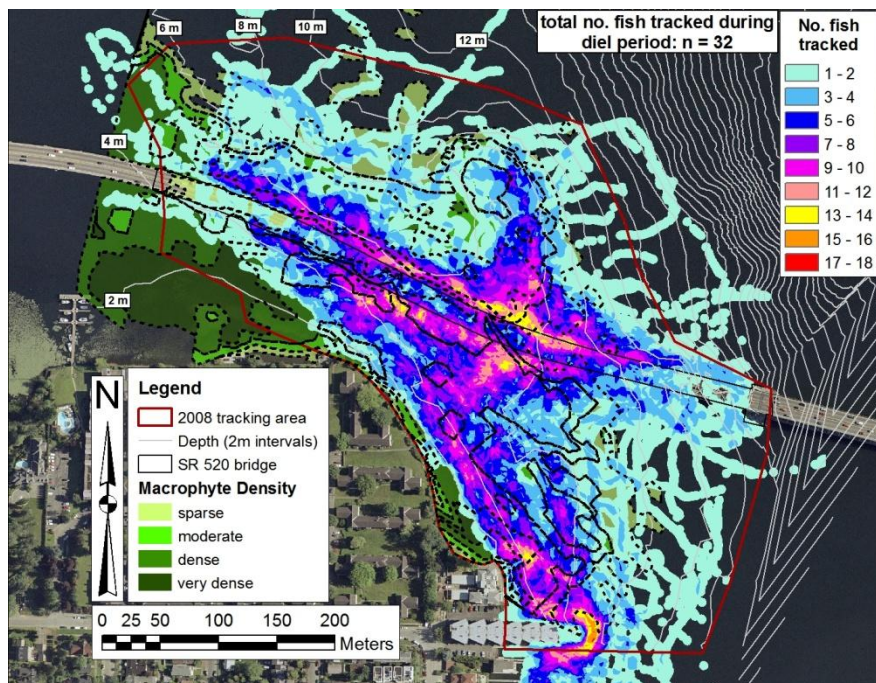


FIGURE 20. (cont.)

A. June 26 release, dawn



B. June 26 release, early day

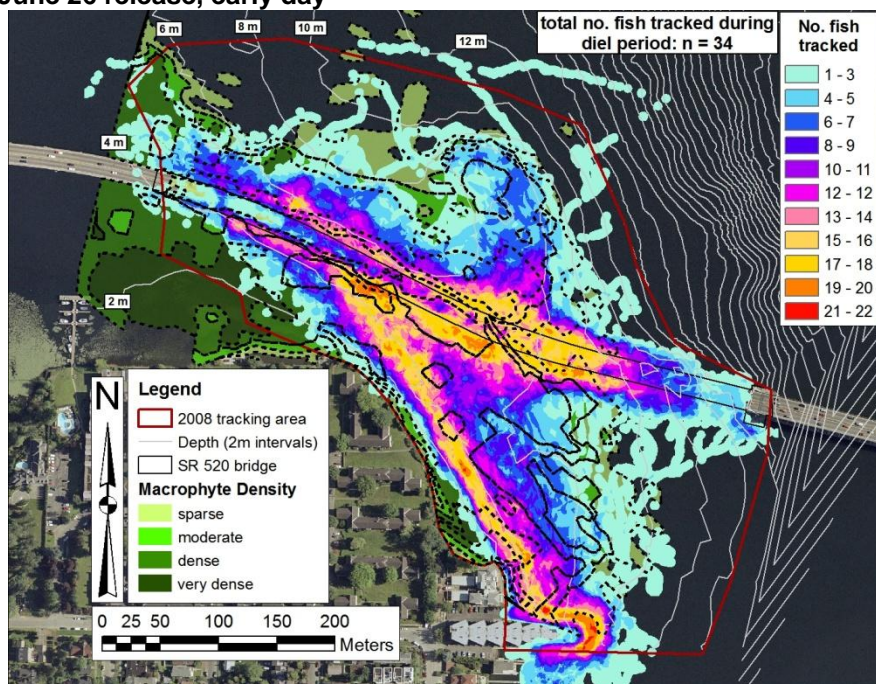
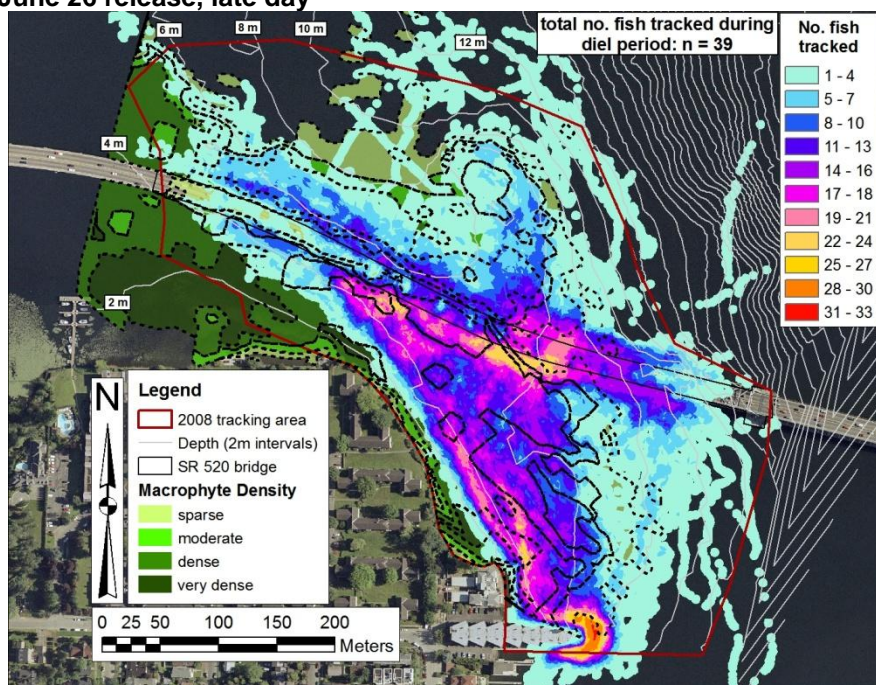


FIGURE 21. Diel spatial frequency distributions of tagged Chinook salmon released on June 26, 2008 and tracked at the SR 520 bridge tracking site. ArcGIS 9.2 Spatial Analyst was used to determine the total number of fish that occurred within a 4 m radius of each tracked fish data point.

C. June 26 release, late day



D. June 26 release, dusk

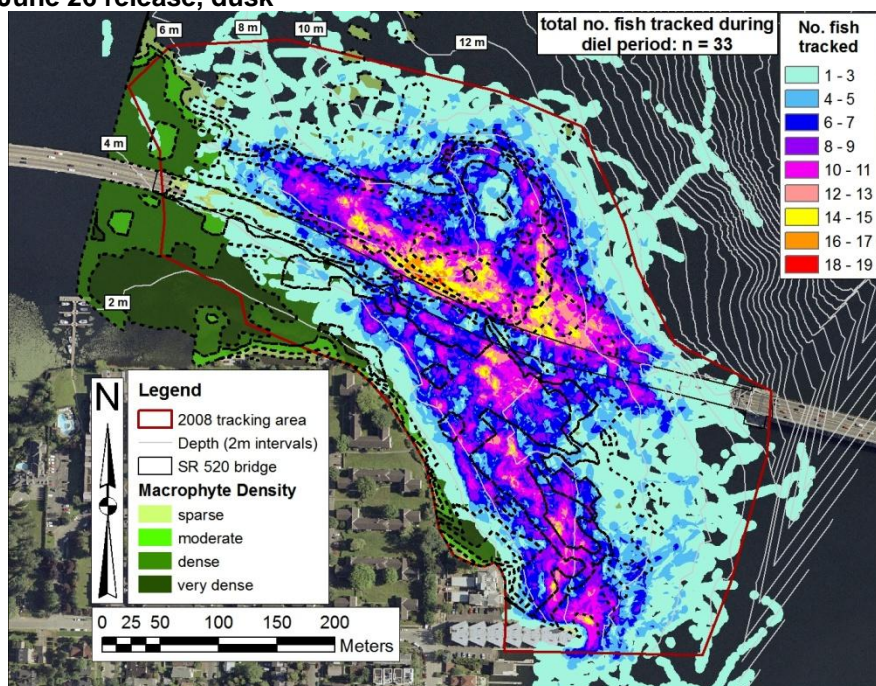


FIGURE 21. (cont.)

E. June 26 release, night

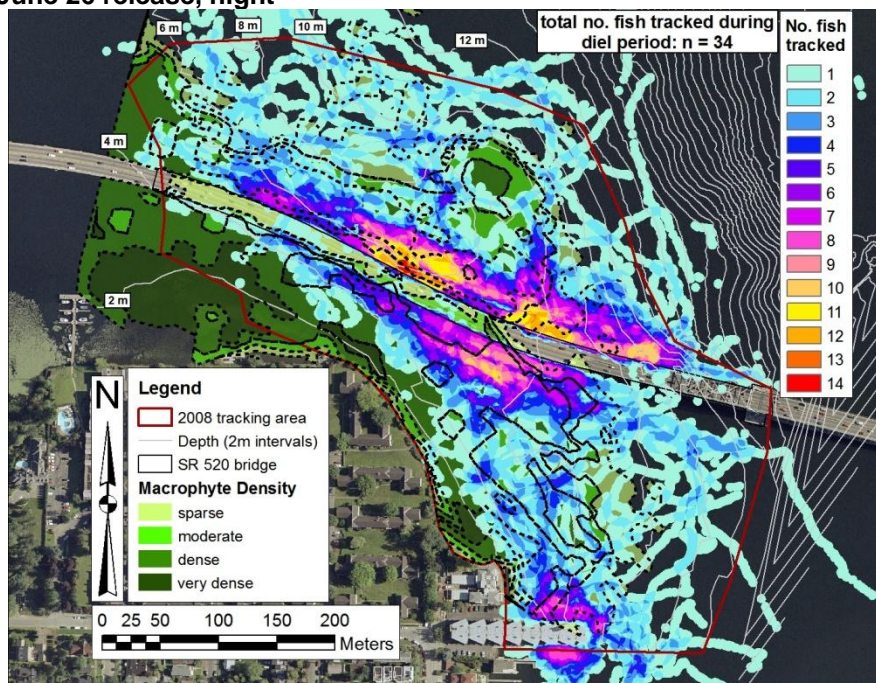
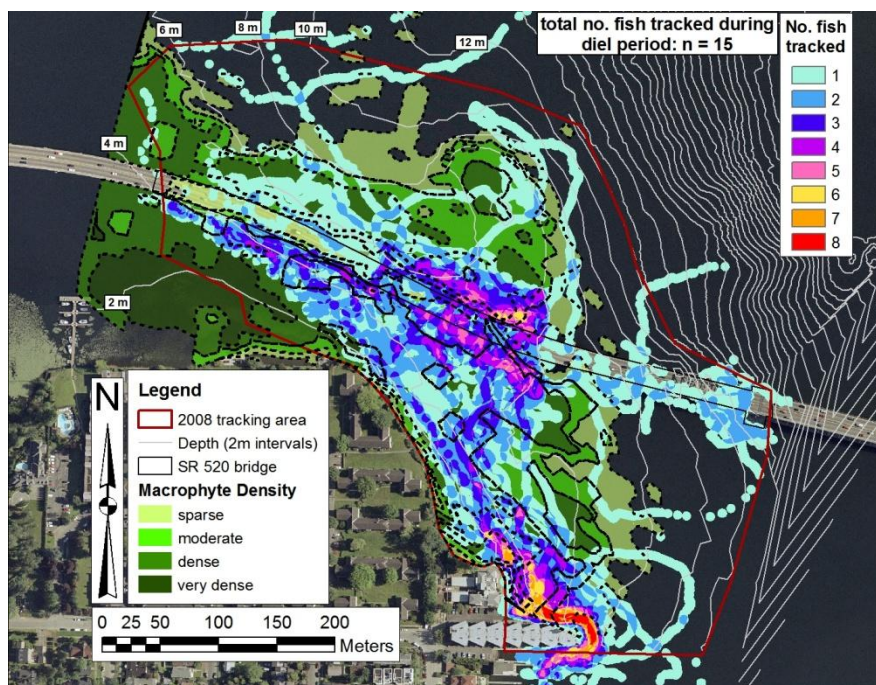


FIGURE 21. (cont.)

A. July 3 release, dawn



B. July 3 release, early day

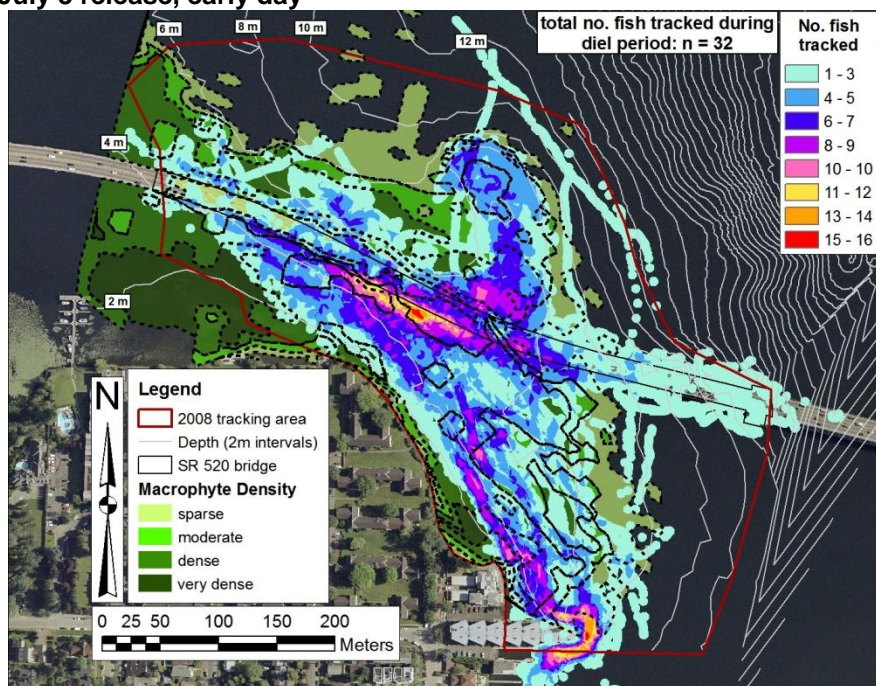
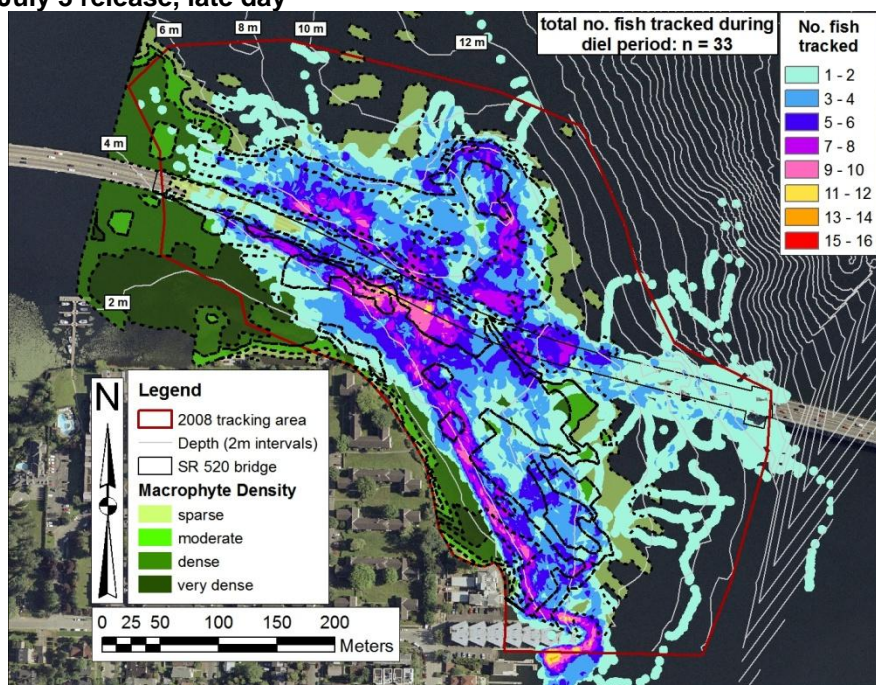


FIGURE 22. Diel spatial frequency distributions of tagged Chinook salmon released on July 3, 2008 and tracked at the SR 520 bridge tracking site. ArcGIS 9.2 Spatial Analyst was used to determine the total number of fish that occurred within a 4 m radius of each tracked fish data point.

C. July 3 release, late day



D. July 3 release, dusk

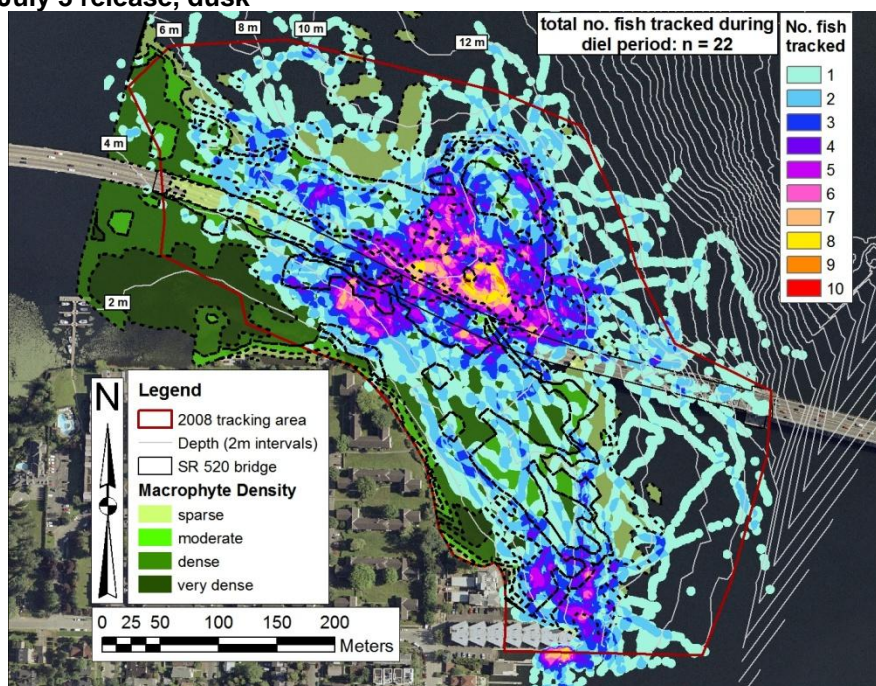


FIGURE 22. (cont.)

E. July 3 release, night

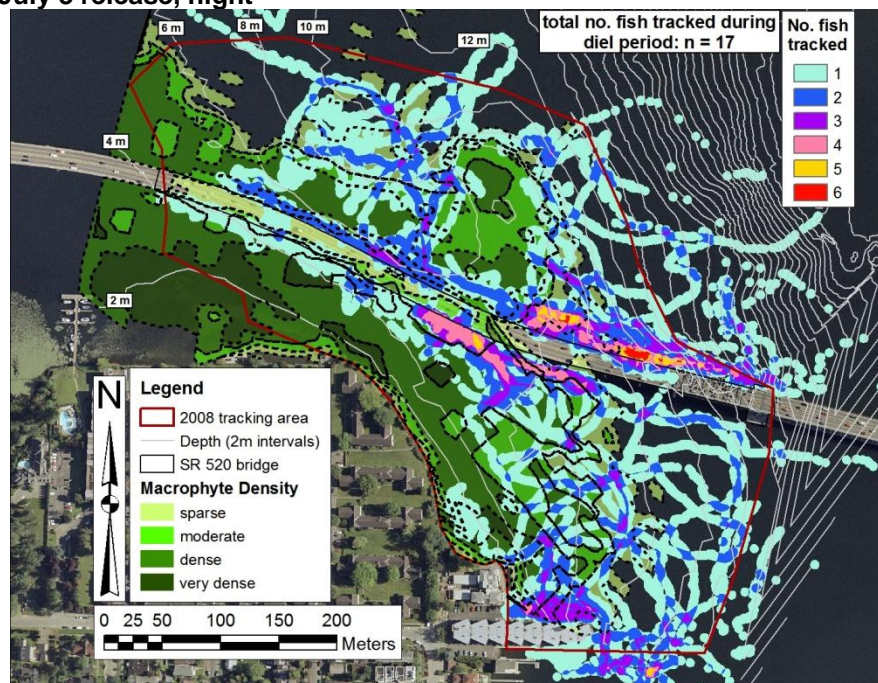


FIGURE 22. (cont.)

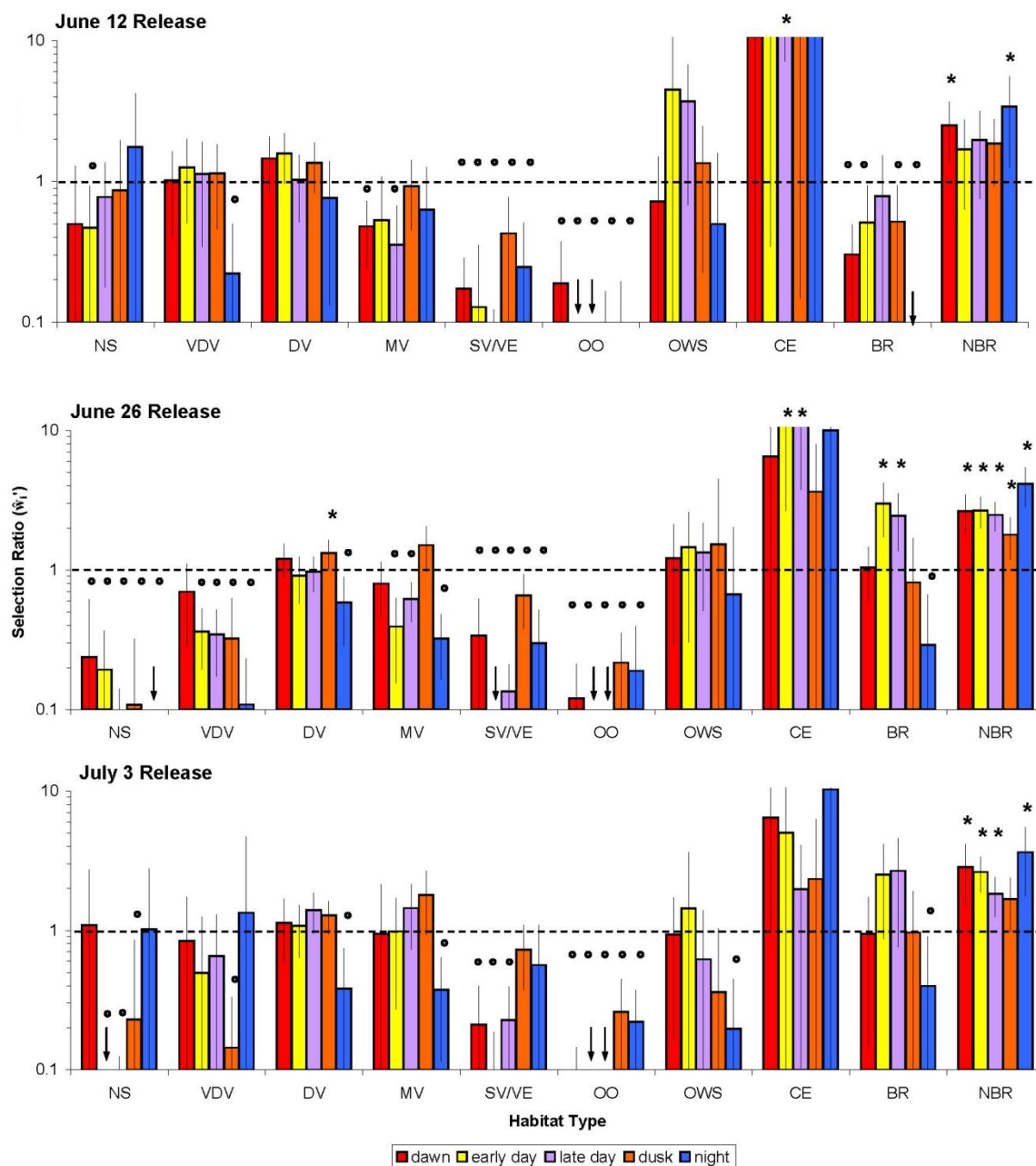


FIGURE 23. Diel habitat selection (\hat{w}_i' , selection ratio; log scale) of Chinook salmon in the SR 520 bridge tracking area, June-July, 2008. Error bars represent Bonferroni-adjusted 90% confidence intervals. Error bars indicate if selection for (>1) or against (<1) a habitat type occurred. An asterisk (*) denotes selection for a habitat and a circle (o) denotes selection against. The July 10 release group was not included because the sample size of fish holding in the study area as opposed to actively migrating through was too small. Habitat types are described in Table 1.

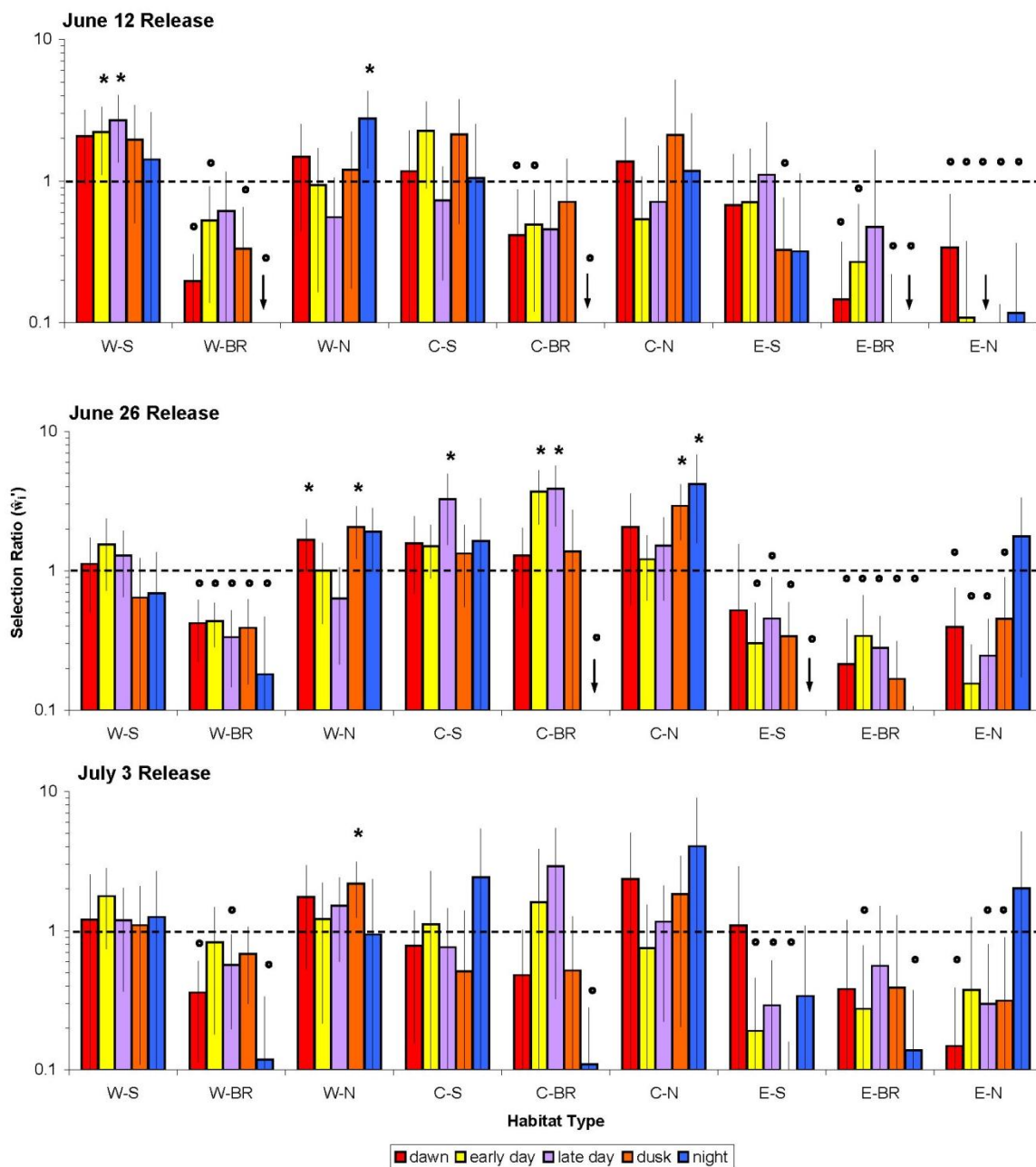


FIGURE 24. Diel habitat selection (\hat{w}_i' , selection ratio; log scale) of Chinook salmon under and near (within 20 m of bridge edge) the SR 520 bridge, June-July 2008. Error bars represent Bonferroni-adjusted 90% confidence intervals. Error bars indicate if selection for (>1) or against (<1) a habitat type occurred. An asterisk (*) denotes selection for a habitat and a circle (o) denotes selection against. The July 10 release group was not included because the sample size of fish holding in the study area as opposed to actively migrating through was too small. See Figure 5 for habitat types.

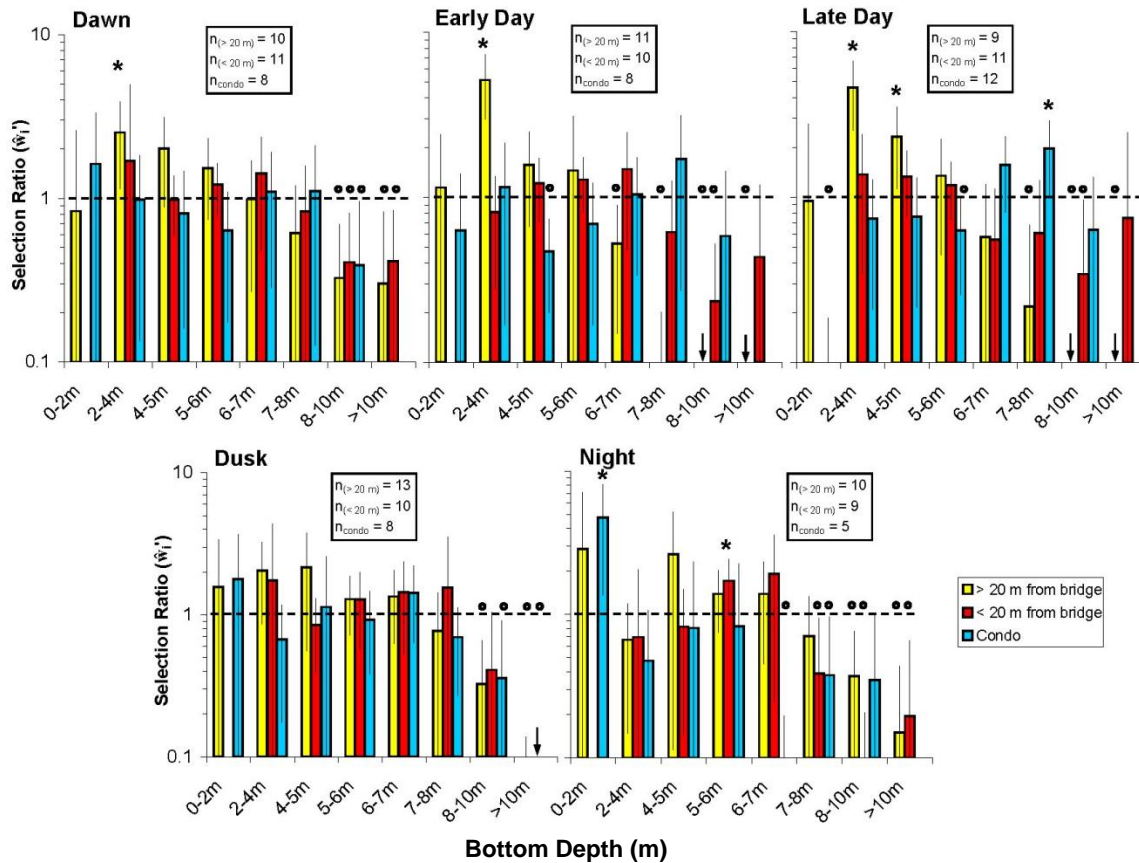


FIGURE 25. Diel bottom depth selection (\hat{w}_i' , selection ratio; log scale) of Chinook salmon released on June 12, 2008. Selection is for the entire water column and not for the position of the fish within the water column. Depth selection was determined for three distinct areas: 1) directly beneath bridge and within 20 m of the bridge edge; 2) > 20 m from bridge edge; and, 3) within 20 m of the edge of the Lakeshore West Condominiums. Error bars represent Bonferroni-adjusted 90% confidence intervals. Error bars indicate if selection for (>1) or against (<1) a water column depth occurred. An asterisk (*) denotes selection for a depth and a circle (o) denotes selection against. Each area contained all depth categories, except minimum depth near bridge was 2-4 m and maximum depth near the condo was 8-10 m.

At night, areas where fish spent a greater proportion of time near the bridge coincided with locations of street lights on the bridge (Figure 28). This suggested that fish were attracted to areas with artificial lighting. Street lights appeared to attract fish in two general areas. The strongest area of attraction was directly adjacent to a street light on the same side of the bridge as the light. Most street lights had high concentrations of fish use near them (Figure 28). A weaker yet still apparent association was observed in 2007 (Figure 29). 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. The distance from the bridge where these lines occurred may correspond with the bridge shadow created by lights on

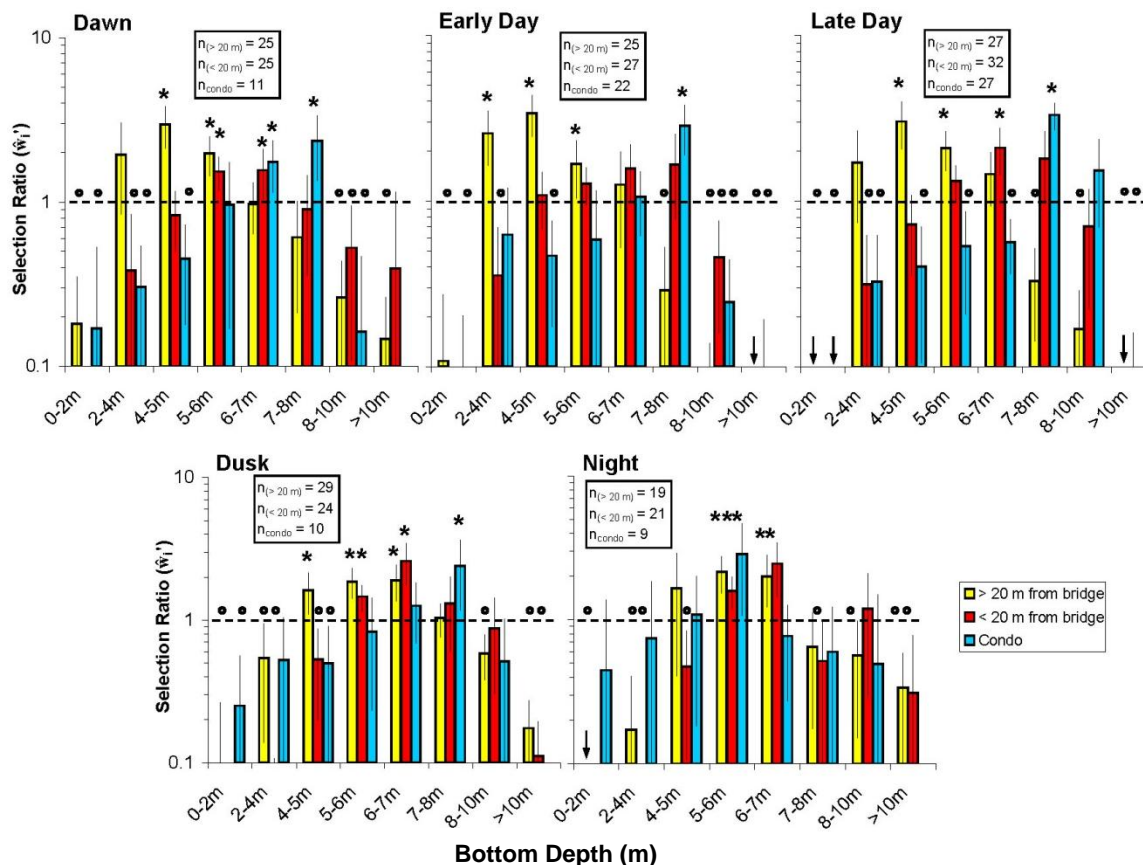


FIGURE 26. Diel bottom depth selection (\hat{w}_i' , selection ratio; log scale) of Chinook salmon released on June 26, 2008. Selection is for the entire water column and not for the position of the fish within the water column. Depth selection was determined for three distinct areas: 1) directly beneath bridge and within 20 m of the bridge edge; 2) > 20 m from bridge edge; and, 3) within 20 m of the edge of the Lakeshore West Condominiums. Error bars represent Bonferroni-adjusted 90% confidence intervals. Error bars indicate if selection for (>1) or against (<1) a water column depth occurred. An asterisk (*) denotes selection for a depth and a circle (o) denotes selection against. Each area contained all depth categories, except minimum depth near bridge was 2-4 m and maximum depth near the condo was 8-10 m.

the opposite site of the bridge. That is, lights on the north side of the bridge were about 14.5 m from the southern edge of the bridge. Therefore, the shadow cast by the bridge would lie not only directly beneath the bridge, but would also be cast some distance from the bridge. We did not measure light levels in any of these areas.

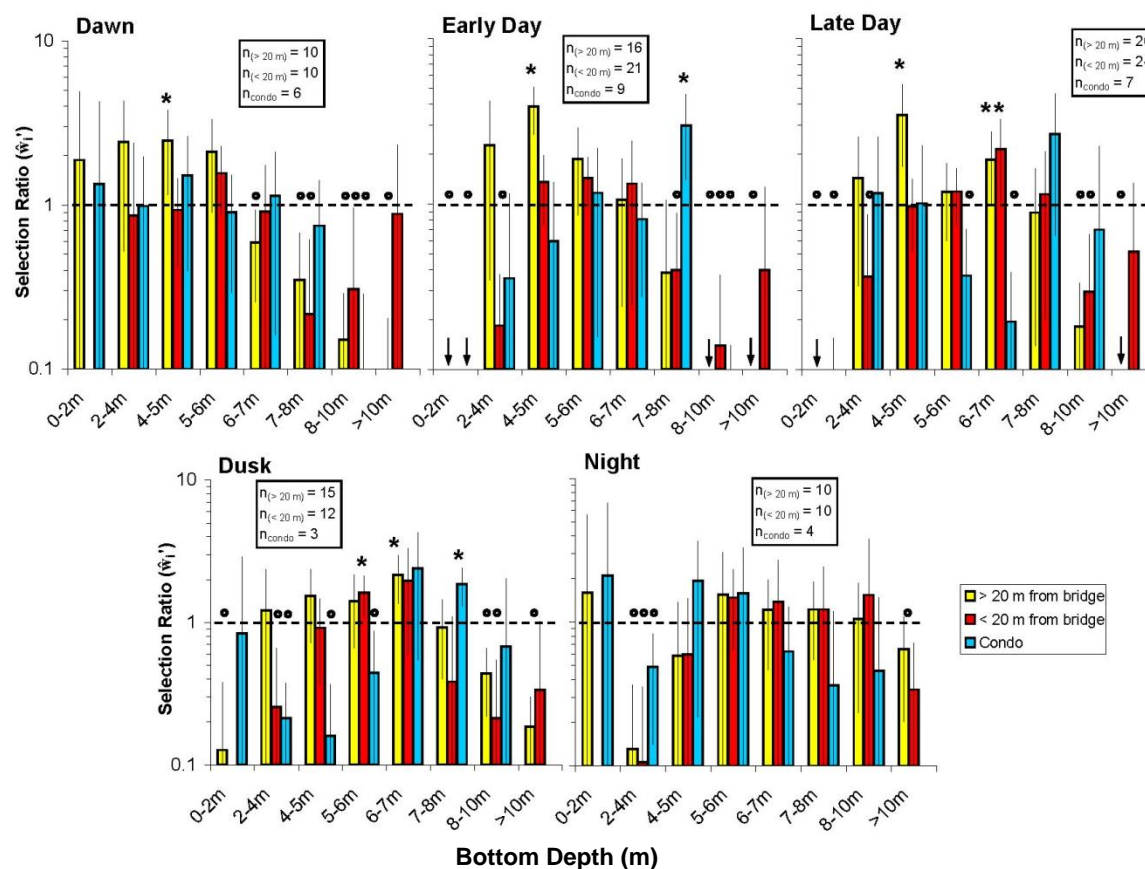


FIGURE 27. Diel bottom depth selection (\hat{w}_i' , selection ratio; log scale) of Chinook salmon released on July 3, 2008. Selection is for the entire water column and not for the position of the fish within the water column. Depth selection was determined for three distinct areas: 1) directly beneath bridge and within 20 m of the bridge edge; 2) > 20 m from bridge edge; and, 3) within 20 m of the edge of the Lakeshore West Condominiums. Error bars represent Bonferroni-adjusted 90% confidence intervals. Errors bars indicate if selection for (>1) or against (<1) a water column depth occurred. An asterisk (*) denotes selection for a depth and a circle (o) denotes selection against. Each area contained all depth categories, except minimum depth near bridge was 2-4 m and maximum depth near the condo was 8-10 m.

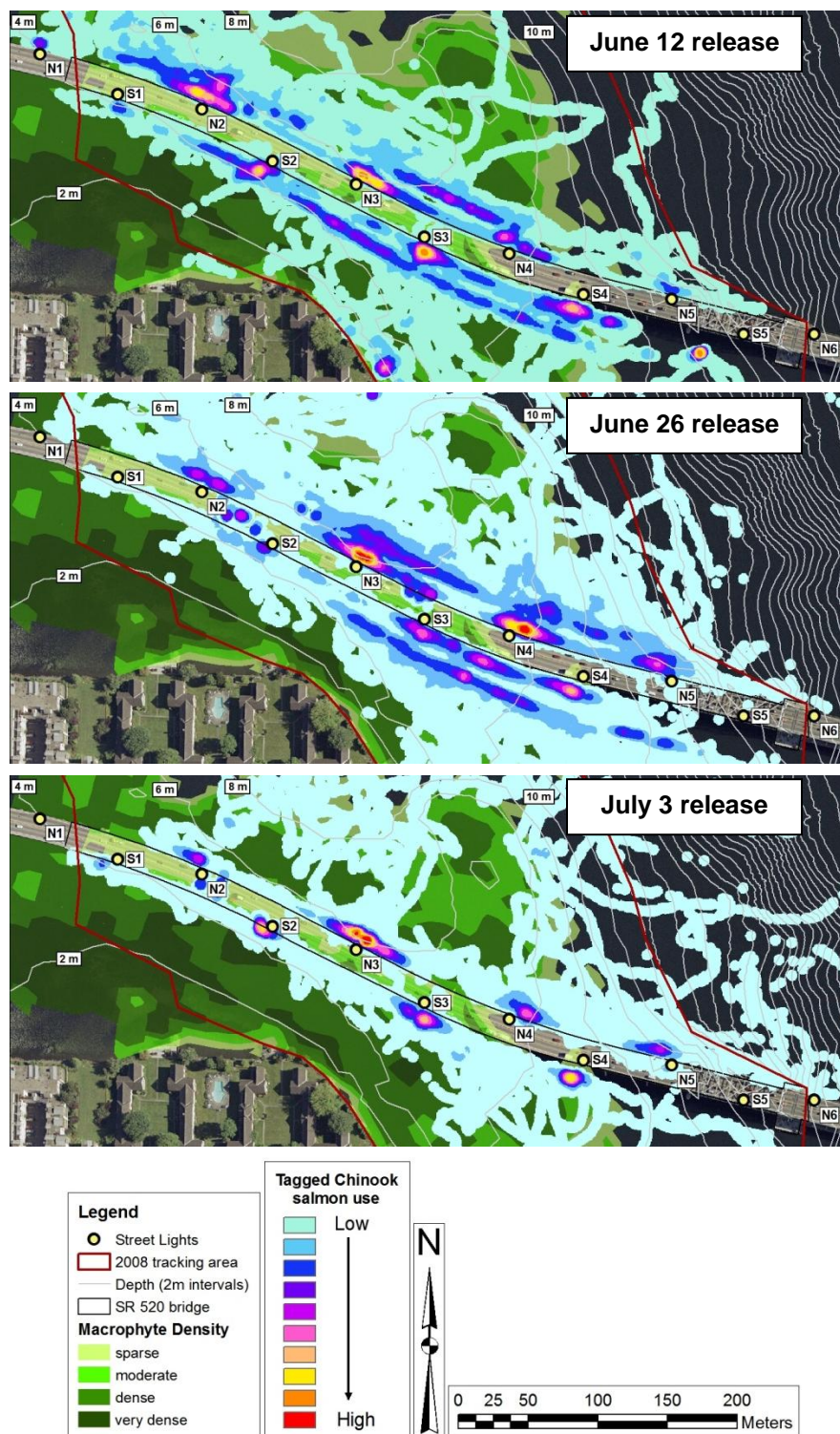


FIGURE 28. Night density plots of tagged Chinook salmon released on June 12, June 26, and July 3, 2008 and tracked near the SR 520 bridge. Relative amount of time spent is indicated by the color bar, with red showing areas where fish spent the most amount of time, and blue the least. Locations of street lights on the bridge are also shown. ArcGIS 9.2 Spatial Analyst was used to generate density plots.

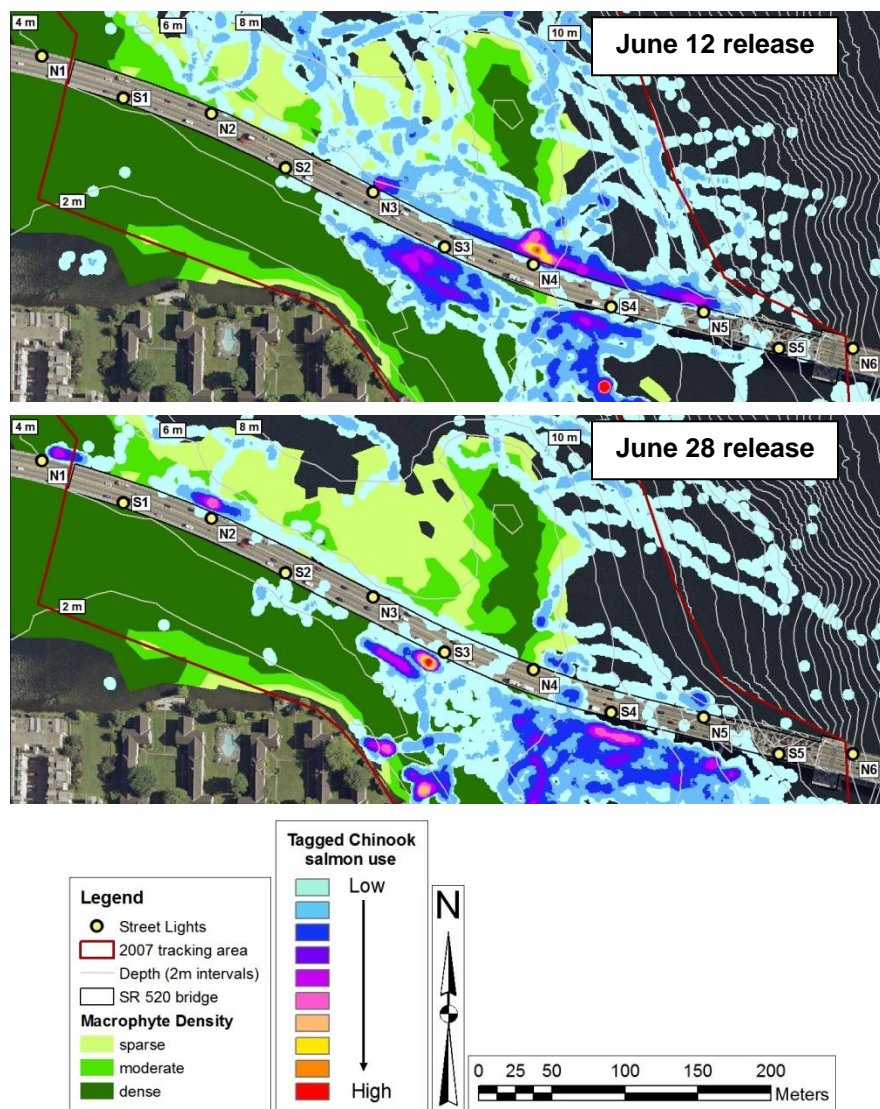


FIGURE 29. Night density plots of tagged Chinook salmon released on June 14 and June 28, 2007 and tracked near the SR 520 bridge. Relative amount of time spent is indicated by the color bar, with red showing areas where fish spent the most amount of time, and blue the least. Locations of street lights on the bridge are also shown. ArcGIS 9.2 Spatial Analyst was used to generate density plots.

Northern Pikeminnow acoustic tracking

A total of 42 northern pikeminnow (21 in 2007 and 21 in 2008) were tagged and released at the SR 520 bridge site. The mean length was 398.2 mm FL and ranged from 281 to 490 mm FL (Figure 30; Table 8). Although the mean length was higher in 2008 (mean length, 408.8 mm FL) than in 2007 (mean length, 387.6 mm FL), the lengths were not significantly different between years (Mann-Whitney U test, $P = 0.22$). All fish were detected after release but many were only present at the study site for less than 48 h after release (Table 8). We obtained useful tracking information (tracked for more than one day and had more than 1,000 total data points) on 15 fish. The mean length of extensively-tracked fish was 421.2 mm FL and was significantly longer than for fish with few data points (385.4 mm FL) (Mann-Whitney U test, $P = 0.044$).

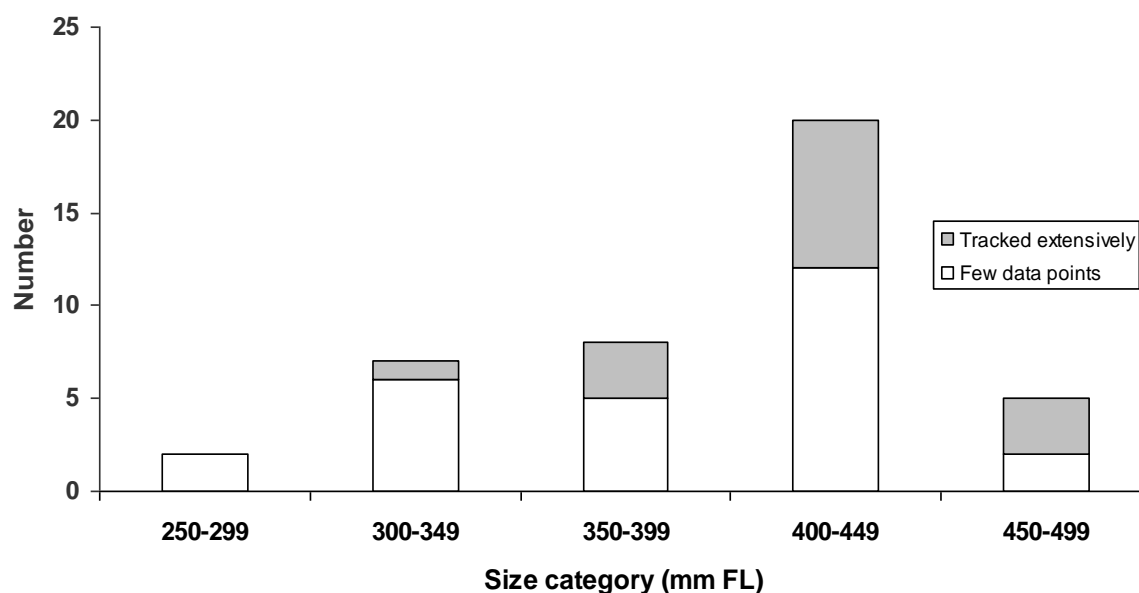


FIGURE 30. Number of northern pikeminnow of different length categories (mm FL) that were tagged with HTI acoustic tags, May-June 2007 and 2008. The number tagged is divided into those that we were able to track extensively (shaded areas) at the SR 520 bridge site and those that had few data points (open areas) and apparently left the study area. Combined, a total of 42 northern pikeminnow were tagged.

TABLE 8. Northern pikeminnow tagged with HTI acoustic tags (60-day G tags), May-June, 2007 and 2008. All fish were captured and released at the SR 520 bridge site. The number of days tracked is the number of days at least one data point was obtained. The first 24 hours after release was not used. Shaded rows are fish we obtained extensive tracking results and were used in the data analyses.

Year	Tag period	Fork length	Weight	Date of first	Date of last	Number of	Number of
Date released	(msec)	(mm)	(g)	data point	data point	days tracked	data points
2007							
24-May	4657	427	1,020	29-May	20-Jul	30	76,894
24-May	4667	430	1,060	29-May	23-Jul	43	183,524
24-May	4677	413	920	7-Jun	17-Jul	2	332
24-May	4687	302	304	4-Jun	8-Jun	3	530
31-May	4727	294	305	--	--	0	0
31-May	4737	400	700	--	--	0	0
31-May	4747	340	530	2-Jun	7-Jun	5	5,311
6-Jun	4777	435	1,110	10-Jun	5-Aug	47	122,577
6-Jun	4787	460	1,280	7-Jul	22-Jul	12	3,722
6-Jun	4797	420	860	7-Jun	4-Jul	17	26,164
6-Jun	4807	367	570	--	--	0	0
6-Jun	4817	425	1,020	8-Jun	9-Jun	2	3,103
6-Jun	4827	345	580	--	--	0	0
6-Jun	4837	415	840	10-Jun	10-Jun	1	32
6-Jun	4847	281	297	7-Jun	7-Jun	1	391
6-Jun	4857	420	930	9-Jun	9-Jun	1	1,083
6-Jun	4867	435	1,040	--	--	0	0
6-Jun	4877	441	1,020	--	--	0	0
15-Jun	4957	318	380	16-Jun	16-Jun	1	1,761
15-Jun	4967	410	890	17-Jun	24-Jun	2	785
15-Jun	4977	362	500	16-Jun	16-Jun	1	529
2008							
29-May	4638	400	767	12-Jun	12-Jun	1	19
30-May	4648	340	514	--	--	0	0
30-May	4658	360	669	16-Jun	20-Jul	14	14,318
5-Jun	4748	365	491	10-Jun	15-Jun	5	184
12-Jun	4758	310	392	13-Jun	13-Jun	1	5
12-Jun	4768	345	518	--	--	0	0
19-Jun	4838	435	958	20-Jun	23-Jun	3	2,694
19-Jun	4848	455	1,018	20-Jun	23-Jun	3	433
19-Jun	4858	475	1,343	20-Jun	29-Jun	4	153
19-Jun	4868	490	1,581	20-Jun	20-Jul	17	6,336
19-Jun	4878	385	630	20-Jun	20-Jul	9	1,423
19-Jun	4888	415	888	20-Jun	25-Jun	5	333
19-Jun	4898	460	1,260	20-Jun	15-Aug	41	168,379
26-Jun	4918	445	1,080	5-Jul	5-Jul	1	26
26-Jun	4928	447	1,269	24-Jul	4-Aug	3	37
26-Jun	4938	385	665	30-Jun	25-Jul	8	1,389
26-Jun	4948	385	689	--	--	0	0
26-Jun	4958	433	1,146	29-Jun	29-Jun	1	118
26-Jun	4968	388	664	--	--	0	0
26-Jun	4978	433	1,220	27-Jun	29-Jun	3	17,074
26-Jun	4988	433	1,093	14-Jul	3-Aug	10	1,220

During each diel period, northern pikeminnow showed the highest use of the 4-6 m bottom depth interval (Figure 31). During dawn, day, and dusk, the 4-6 m bottom depth interval was significantly different than all other depth intervals (Friedman tests; $P < 0.001$). Overall, 69% of all detections (all time periods and years combined) were in the 4-6 m bottom depth interval while this area only comprised about 30% of the coverage area. The 6-8 m bottom depth interval had the second highest rank during most time periods. At night, the 6-8 m bottom depth interval was similar to the 4-6 m bottom depth interval (Friedman test; $P < 0.001$). Northern pikeminnow were still present in 4-6 m bottom depth interval at night but appeared to be spread out over a larger area than during the other diel periods (Figures 32 and 33). Use of offshore waters (> 8 m bottom depth) was only noticeable at night. Use of shallow water (0-2 m bottom depth) was rare except at dawn. Of the eight fish tracked at dawn, two appeared to inhabit shallow water with one having a selection ratio greater than one for this area.

Results of a Friedman test for each diel period indicated there were significant differences ($P < 0.001$) in use between habitat types. The highest ranked habitat type for dawn, dusk, and night was moderate vegetation. Dense and sparse vegetation were also commonly used by northern pikeminnow. These habitat types were not significantly different than the moderate vegetation during dawn, dusk, and night (Figure 34).

Two fish (#4777 and #4898) had a positive selection ratio for the bridge during most diel periods. The other northern pikeminnow occasionally had a positive selection ratio for the bridge but there was no consistent trend between diel period and individual fish. Use of the bridge and the area near the bridge was not significantly different during each diel period. Density plots also indicated that northern pikeminnow showed a slight attraction to street lights in the bridge at night (Figure 35). This slight attraction was not evident during dawn and dusk.

Eight of 13 northern pikeminnow had a high selection ratio (\hat{w}_i range, 9.4 – 47.1) for the other overwater structures during the day. They were occasionally under the Lakeshore West Condominiums structure but most data points were associated with the small pier in front of the Madison Point Condominiums (Figure 36). Some northern pikeminnow used these overwater structures during other diel periods but not to the same degree as during the day (Figure 34).

Use of the open offshore area was highest at night. Although selection ratios were always less than one, their use of this area at night was substantially higher than during the day (Figure 37). Seven of eight northern pikeminnow that were tracked during both day and night had a much higher selection ratio at night for the open offshore area.

During the day, northern pikeminnow preferred areas with silt over areas with large substrates (sign test; $P = 0.013$; Figure 38). In contrast, at night they significantly preferred large substrate areas over silt areas (sign test; $P = 0.039$). There was no significant difference between the use of silt and large substrate areas for dawn (sign test; $P = 0.070$) and dusk periods ($P = 1.0$).

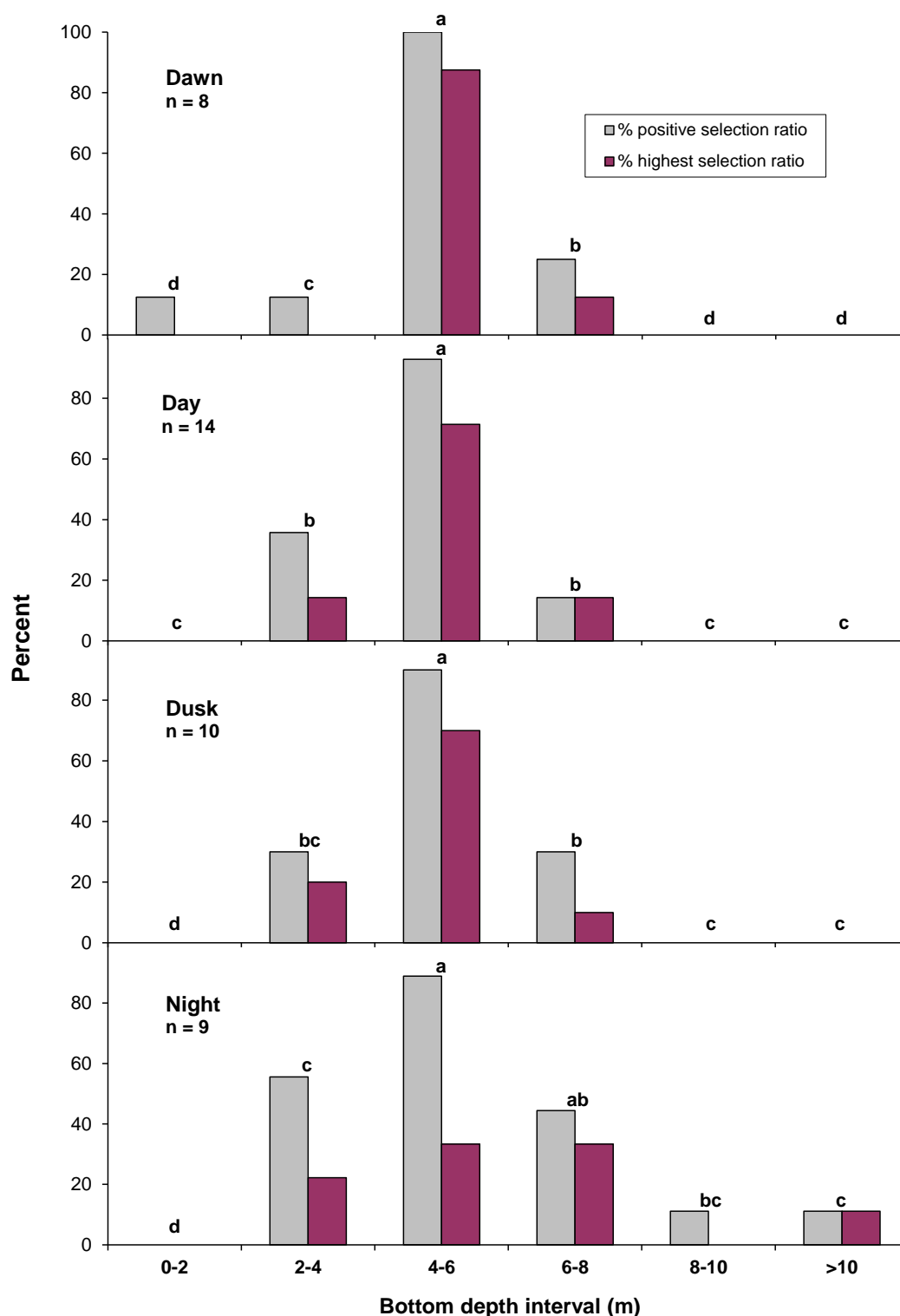


FIGURE 31. Results of Friedman multiple comparisons procedure of all northern pikeminnow (letters above bars), percent of northern pikeminnow with a positive selection ratio ($\hat{w}_i > 1$), and percent of northern pikeminnow that had the highest selection ratio for various bottom depths during different diel periods at the SR 520 bridge site, May-August 2007 and 2008. Bottom depths with different letters indicate significantly different selection by northern pikeminnow; n = the number of tagged northern pikeminnow available (> 200 data points) during each diel period.

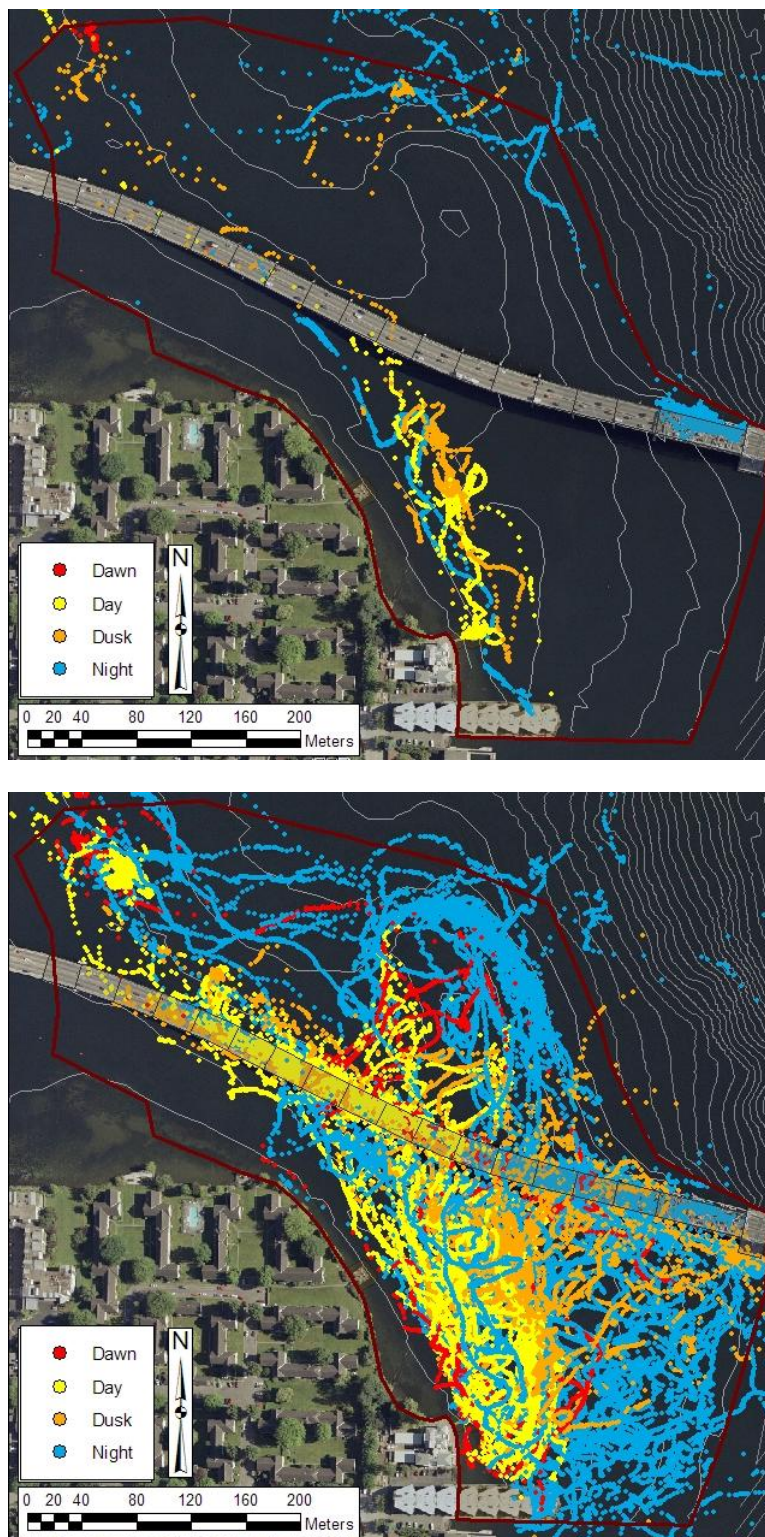


FIGURE 32. Data points of northern pikeminnow #4658 (top panel) and #4898 (bottom panel) during different diel periods at the SR 520 bridge study site, June 16-August 15, 2008. The dark red line is the coverage area of the hydrophone array. White lines are depth contours in 2-m intervals. Lines running perpendicular across the bridge are locations of the bridge columns.

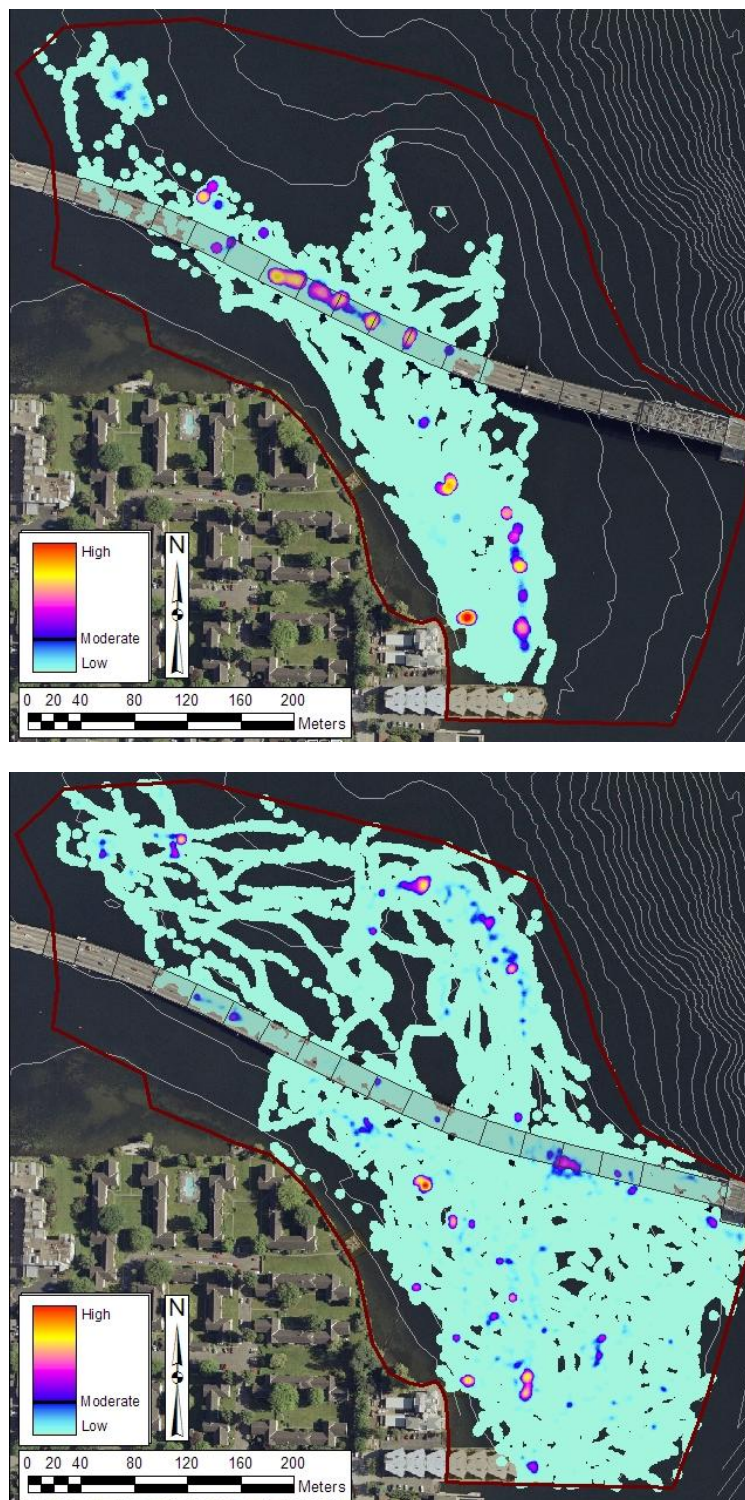


FIGURE 33. Day (top panel) and night (bottom panel) density plots of northern pikeminnow #4898 at the SR 520 bridge study site, June-August 2008. Representation of lowest density was altered to enhance clarity: size of lowest density was made smaller. The dark red line is the coverage area of the hydrophone array. White lines are depth contours in 2-m intervals. Lines running perpendicular across the bridge are locations of the bridge columns.

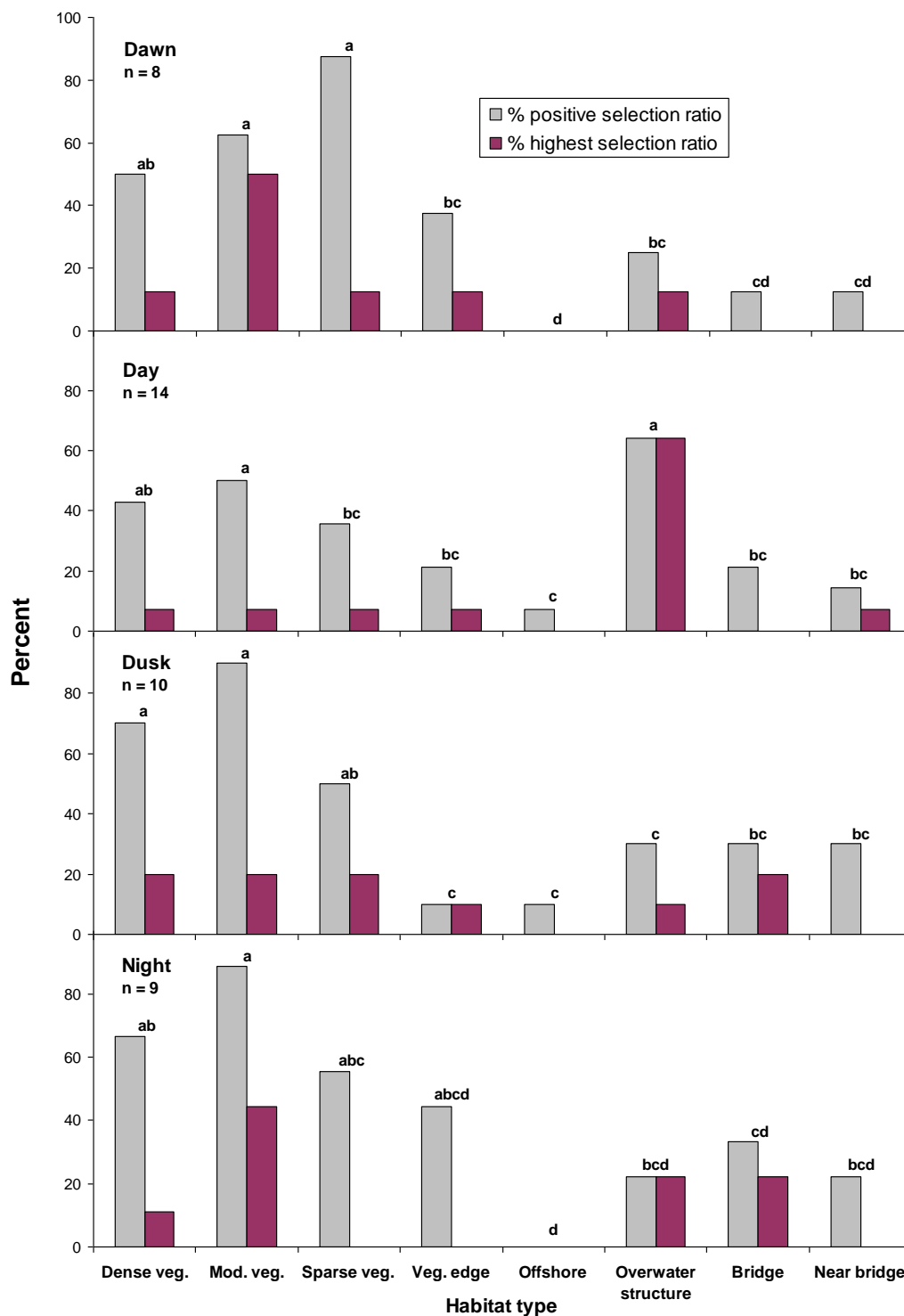


FIGURE 34. Results of Friedman multiple comparisons procedure of all northern pikeminnow (letters above bars), percent of northern pikeminnow with a positive selection ratio ($\hat{w}_i > 1$), and percent of northern pikeminnow that had the highest selection ratio for various habitat types during different diel periods at the SR 520 bridge site, May-August 2007 and 2008. Habitat types with different letters indicate significantly different selection by northern pikeminnow. Veg. = vegetation; n = the number of tagged northern pikeminnow available (> 200 data points) during each diel period.

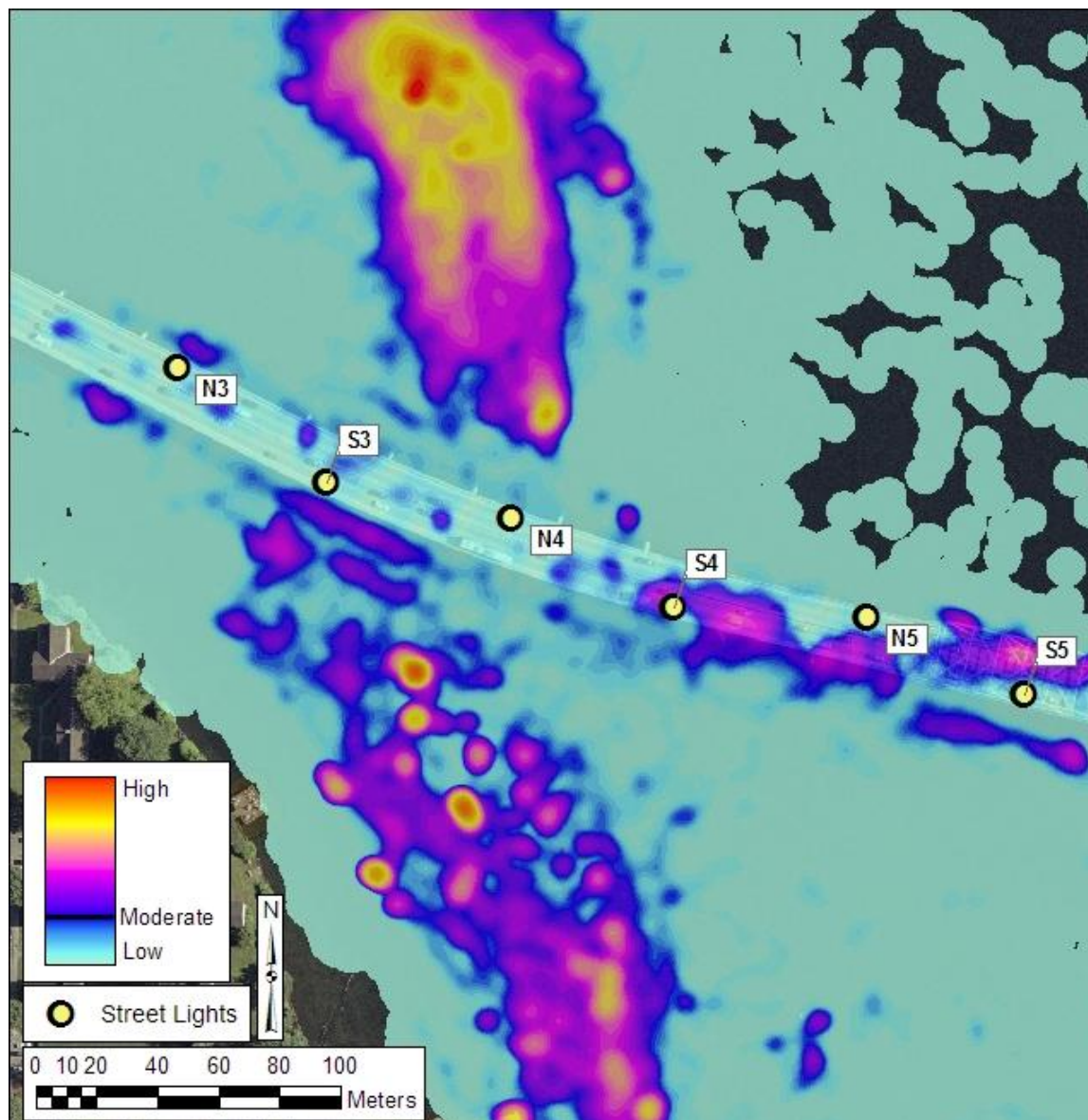


FIGURE 35. Night density plot of northern pikeminnow to display their location in relation to street lights at the SR 520 bridge study site, May-August 2007. All data points were weighted equally for this density plot calculation. Calculations only include northern pikeminnow we extensively tracked (> 1 day and > 1,000 data points).

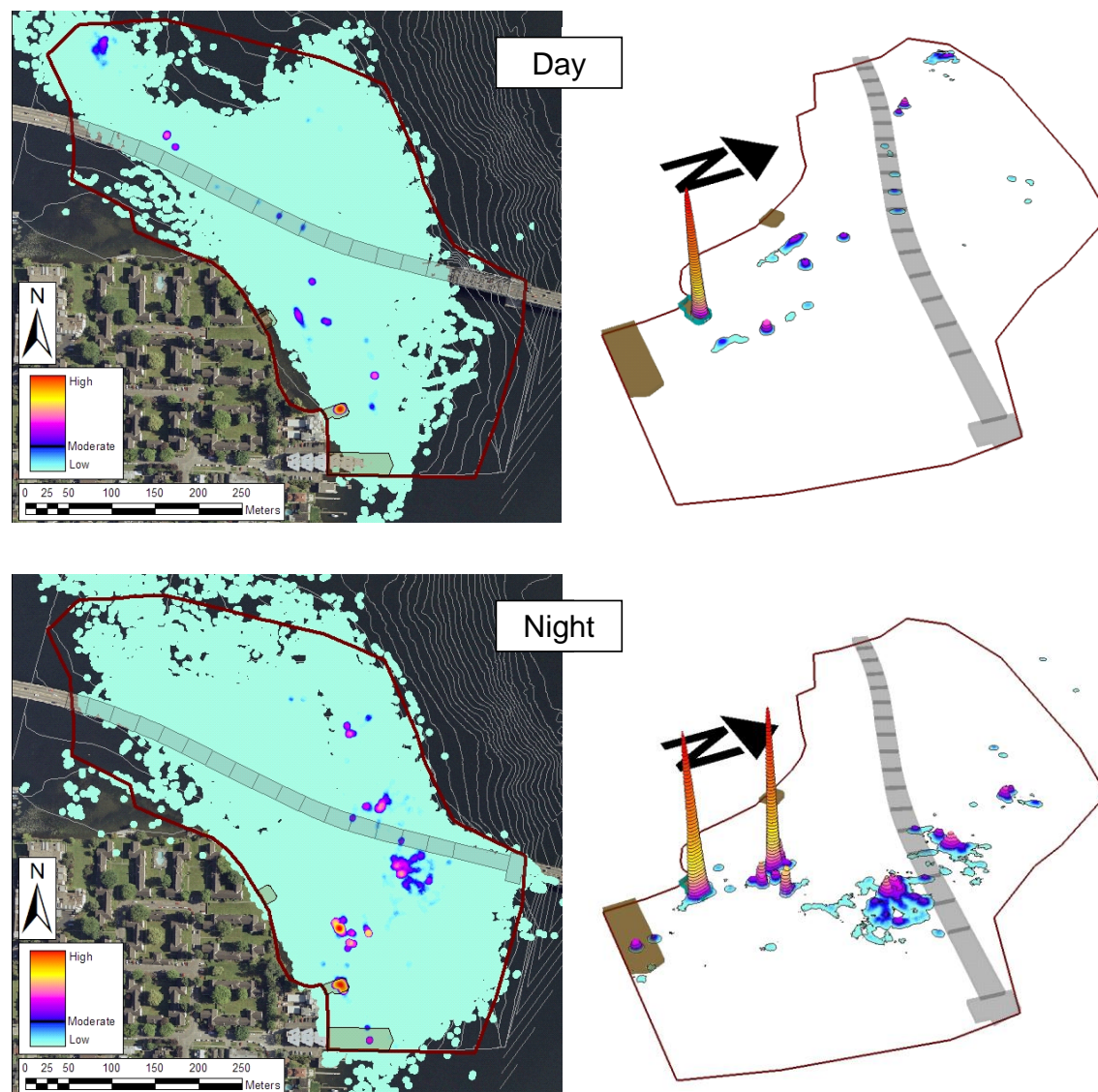


FIGURE 36. Day ($N = 14$) and night ($N = 9$) density plots of northern pikeminnow at the SR 520 bridge study site, May-August 2007 and 2008. The data presented on the left and right images are the same but are displayed in 2D on the left and 3D on the right. Each pikeminnow was weighted equally for the density plot calculation. Calculations only include pikeminnow we extensively tracked (> 1 day and $> 1,000$ data points). Representation of lowest density was altered to enhance clarity: size of lowest density was made smaller in the plots on the left, and lowest density was eliminated from plot on the right. The dark red line is the coverage area of the hydrophone array in both the 2D and 3D pictures. White lines in the 2D pictures are depth contours in 2-m intervals. Lines running perpendicular across the bridge are locations of the bridge columns.

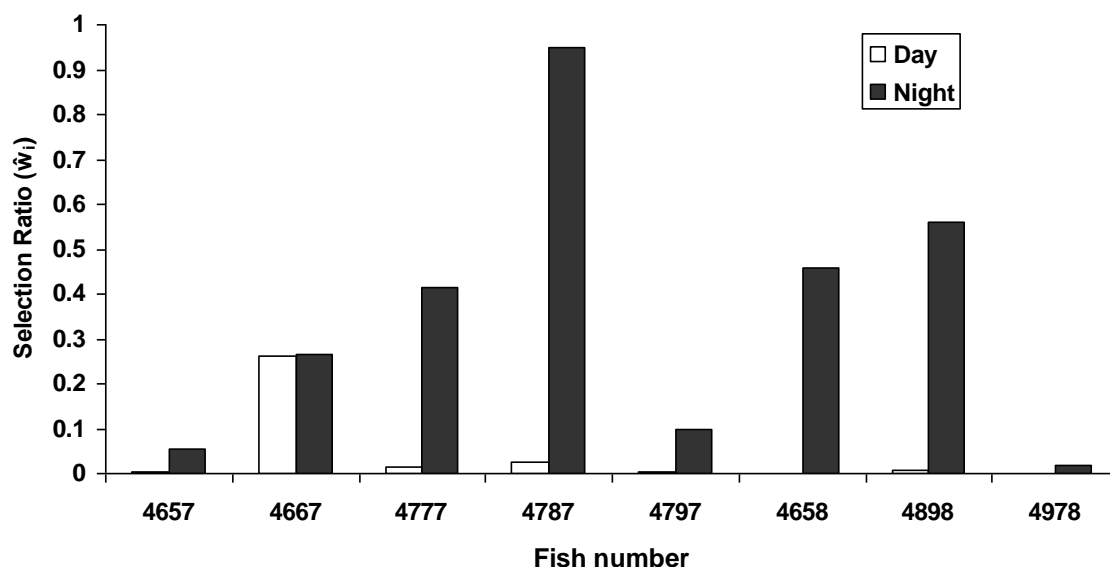


FIGURE 37. Comparison of day and night selection ratios (\hat{w}_i) of eight northern pikeminnow for the open offshore area at the SR 520 bridge site, May-July 2007 and 2008. Only fish that were extensively tracked (> 200 data points) for both diel periods are included. The first five fish are from 2007 and the last three fish are from 2008.

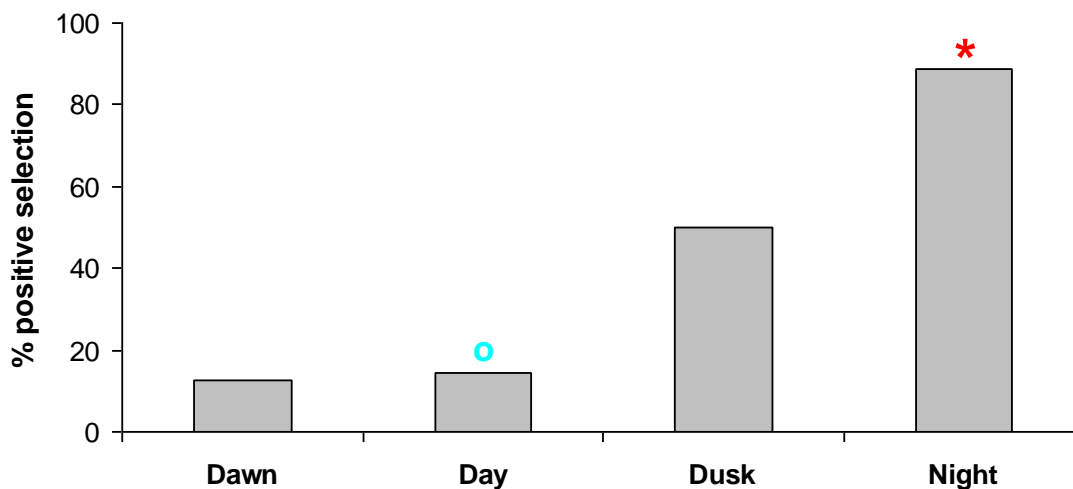


FIGURE 38. Percent of northern pikeminnow with a positive selection ratio ($\hat{w}_i > 1$) for areas with large substrate (> 10% cobble or boulders) during different diel periods at the SR 520 bridge site, May-August 2007 and 2008. An asterisk (significantly higher) or a circle (significantly lower) above the bars indicates if the results were statistically different than areas with predominantly silt substrates (sign test, $P < 0.05$). Calculations only included areas where the depth was 2-10 m deep and did not include areas near overwater structures.

Smallmouth bass acoustic tracking

A total of 16 smallmouth bass (6 in 2007 and 10 in 2008) were released at the SR 520 bridge site (Table 9). In contrast to pikeminnow, most of the smallmouth bass released at the study site were tracked for an extended period of time. In two smallmouth bass that were never detected, we used older M HTI tags. These tags may have been accidentally left on prior to deployment for some amount of time and had little battery power left. Of the remaining 14 smallmouth bass, all but one remained in the study area for an extended period of time. In addition to these 13 fish, we obtained tracking results from an additional eight fish that were captured and released in the LWSC. In 2007, seven of 19 LWSC smallmouth bass (double-tagged with HTI and Vemco tags) were tracked at the SR 520 bridge site and in 2008, only one of 20 LWSC smallmouth bass (double-pulsed HTI tags) was tracked extensively at this site. On average, the LWSC smallmouth bass arrived at the SR 520 bridge site about 30 days after release (Table 10; range, 4 – 57 days).

Of the 21 tracked smallmouth bass, 18 were > 300 mm FL (Figure 39; mean, 359.8 mm FL; range, 173-470 mm FL). All LWSC smallmouth bass tracked at the SR 520 bridge site were large adult fish ranging in size from 318 to 425 mm FL (mean, 379.3 mm FL).

TABLE 9. Smallmouth bass tagged with HTI acoustic tags that were detected at the SR 520 bridge array, May-August, 2007. Location is the area where the fish were captured and released, except the first smallmouth bass listed which was captured in Portage Bay and released at the SR 520 bridge site. G tags are 4.4 g (60-day [if single-pulsed]), E tags are 1.5 g (20-day), and M tags are 0.75 g (12-day).

Year	Date	Capture	Tag period		Fork length	Weight
Location	released	method	(msec)	Tag type	(mm)	(g)
2007						
520 Bridge	24-May	Beach Seine	4697	E	185	92
520 Bridge	31-May	Gill Net	4707	G	363	800
520 Bridge	31-May	Gill Net	4717	G	363	800
520 Bridge	6-Jun	Gill Net	4757	G	375	880
520 Bridge	6-Jun	Gill Net	4767	E	173	83
520 Bridge	15-Jun	Gill Net	4947	G	245	223
Portage Bay	17-May	Beach Seine	4547	G	425	1,520
Gas Works Park	22-May	Angling	4577	G	370	800
Gas Works Park	22-May	Angling	4567	G	365	760
I-5/University Bridge	23-May	Angling	4617	G	318	500
I-5/University Bridge	23-May	Angling	4627	G	348	720
I-5/University Bridge	11-Jun	Angling	4897	G	375	920
I-5/University Bridge	3-Jul	Angling	5177	G	413	1,330
2008						
520 Bridge	5-Jun	Gill net	4738	G	375	1,016
520 Bridge	12-Jun	Gill net	4778	G	380	917
520 Bridge	12-Jun	Gill net	4788	G	425	1,436
520 Bridge	12-Jun	Gill net	4798	G	390	1,113
520 Bridge	12-Jun	Gill net	4808	G	470	1,865
520 Bridge	19-Jun	Gill net	4818	G	335	639
520 Bridge	19-Jun	Gill net	4828	G	450	1,662
520 Bridge	26-Jun	Gill net	4908	G	455	1,624
520 Bridge	1-Jul	Gill net	4998	M	395	1,038
520 Bridge	1-Jul	Gill net	5008	M	223	169
I-5/University Bridge	20-May	Angling	4538	G	420	1,600

TABLE 10. Number and first and last date of data points from tagged smallmouth bass at the SR 520 bridge study site, May-August, 2007 and 2008. The number of days tracked is the number of days at least one data point was obtained. The first 24 hours after release was not used. Shaded rows are fish we obtained extensive tracking results and were used in the data analyses. The 2007-off site fish only had data processed from their first 3-4 days at the study site and thus they may have been at the study site longer than indicated.

Year - release type Tag period (msec)	Date released	Date of first data point	Date of last data point	Number of days tracked	Number of data points
2007 - on site					
4697	24-May	29-May	9-Jun	12	103,908
4707	31-May	2-Jun	30-Jul	54	374,984
4717	31-May	2-Jun	22-Jul	16	9,611
4757	6-Jun	7-Jun	6-Aug	57	240,627
4767	6-Jun	7-Jun	26-Jun	20	116,376
4947	15-Jun	16-Jun	23-Jul	37	187,990
2007 - off site					
4547	17-May	28-Jun	29-Jun	2	4,906
4567	22-May	6-Jul	9-Jul	4	12,412
4577	22-May	18-Jul	21-Jul	3	12,969
4617	23-May	8-Jun	9-Jun	2	10,076
4627	23-May	19-Jun	22-Jun	4	30,847
4897	11-Jun	15-Jun	18-Jun	4	19,902
5177	3-Jul	25-Jul	28-Jul	4	1,681
2008 - on site					
4738	5-Jun	9-Jun	28-Jul	11	87,183
4778	12-Jun	13-Jun	26-Jul	4	15,580
4788	12-Jun	18-Jun	30-Jul	7	84,915
4798	12-Jun	19-Jun	20-Jun	2	7
4808	12-Jun	20-Jun	16-Jul	4	4,075
4818	19-Jun	20-Jun	24-Jun	5	52,947
4828	19-Jun	20-Jun	20-Aug	25	87,675
4908	26-Jun	28-Jun	30-Jun	3	18,882
4998	1-Jul	--	--	0	0
5008	1-Jul	--	--	0	0
2008 - off site					
4538	20-May	6-Jul	18-Jul	13	135,498

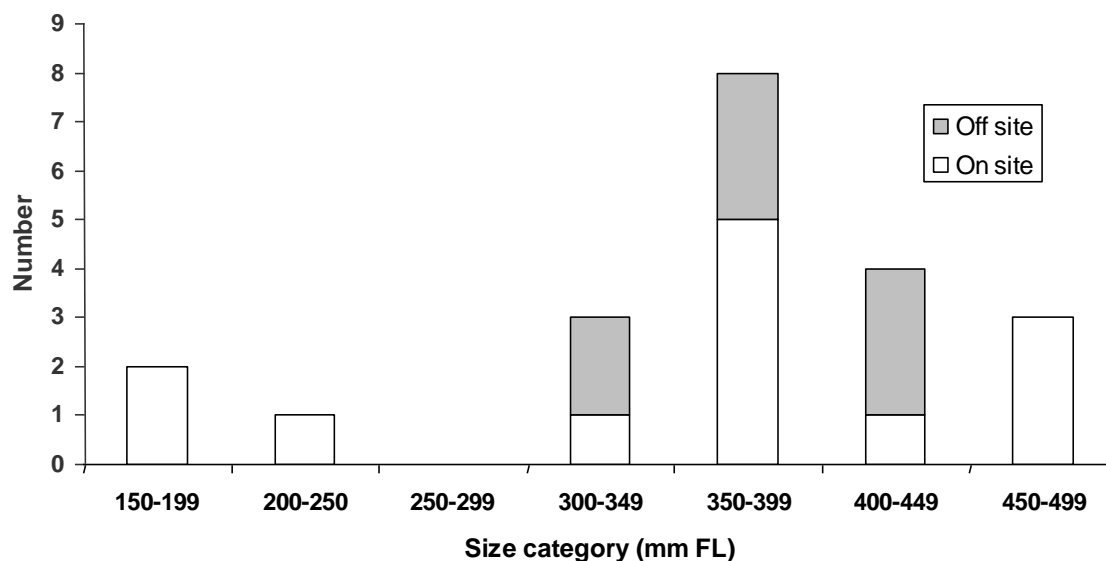
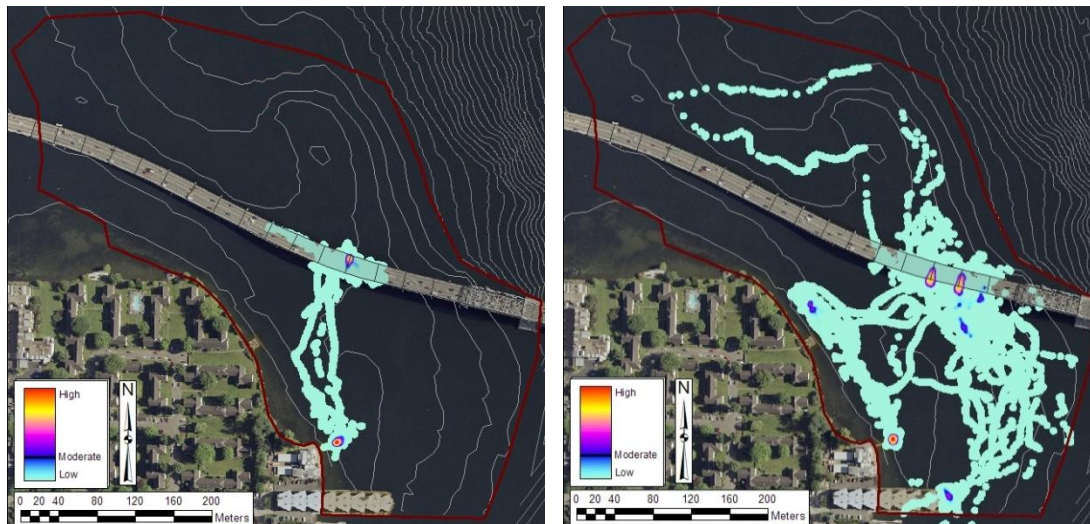


FIGURE 39. Number of smallmouth bass of different length categories (mm FL) that were tracked extensively at the SR 520 bridge site, May-August 2007 and 2008. The number tracked is divided into those that were captured and released at the SR 520 bridge site (open areas) and those that were captured and released in the LWSC (shaded areas). Combined, a total of 21 smallmouth bass were extensively tracked. Fish that were rarely tracked are not included.

The habitat use of the two smallmouth bass less than 200 mm FL that were collected in 2007 appeared to be substantially different than the larger bass and therefore we did not include them in the analysis of the larger fish. During each diel period, the two small smallmouth bass (173, 185 mm FL) were both closely associated with all three nearshore overwater structures and showed a strong preference for water that was 0-2 m deep. The 0-2 m depth interval represented only 3.3% of the coverage area; however, 57% and 72%, respectively, of their data points were in this depth interval. Few data points were under or near the SR 520 bridge for these fish.

Large smallmouth bass (> 240 mm FL) were usually located in water that had a bottom depth of 4 to 8 m. They tended to be in shallower water at night, selecting water that had a bottom depth of 4-6 m (Figure 40). Night was the only time period when the 4-6 m bottom depth interval was significantly different than the 6-8 m bottom depth interval (Figure 41). Of the 15 smallmouth bass that were tracked during both day and night, 11 had their highest selection ratio in a shallower bottom depth interval at night, three had the same bottom depth interval, and only one had a deeper bottom depth interval.

DAY



NIGHT

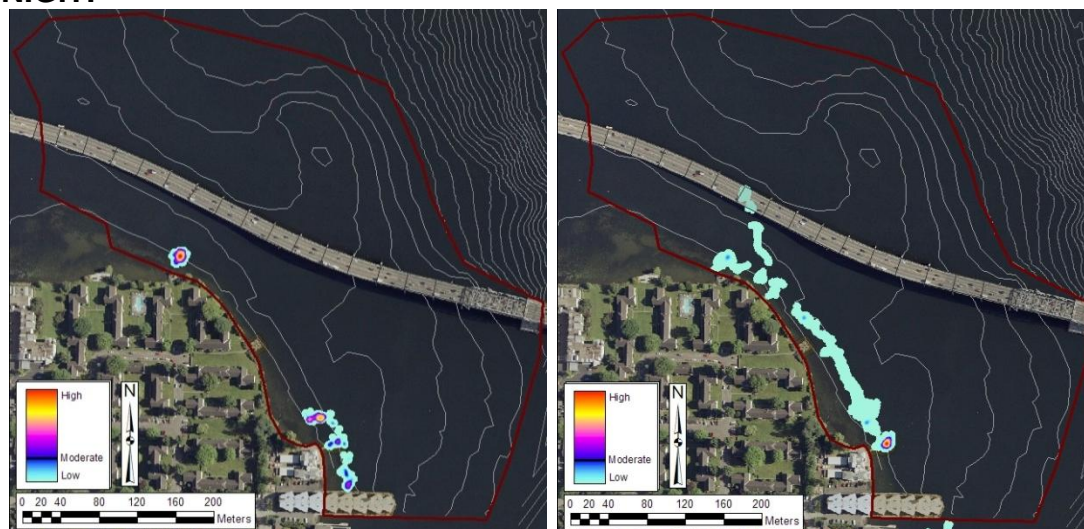


FIGURE 40. Day and night density plots of smallmouth bass # 4818 (left side) and #4788 (right side) at the SR 520 bridge study site, June-August 2008. The dark red line is the coverage area of the hydrophone array. White lines are depth contours in 2-m intervals. Lines running perpendicular across the bridge are locations of the bridge columns.

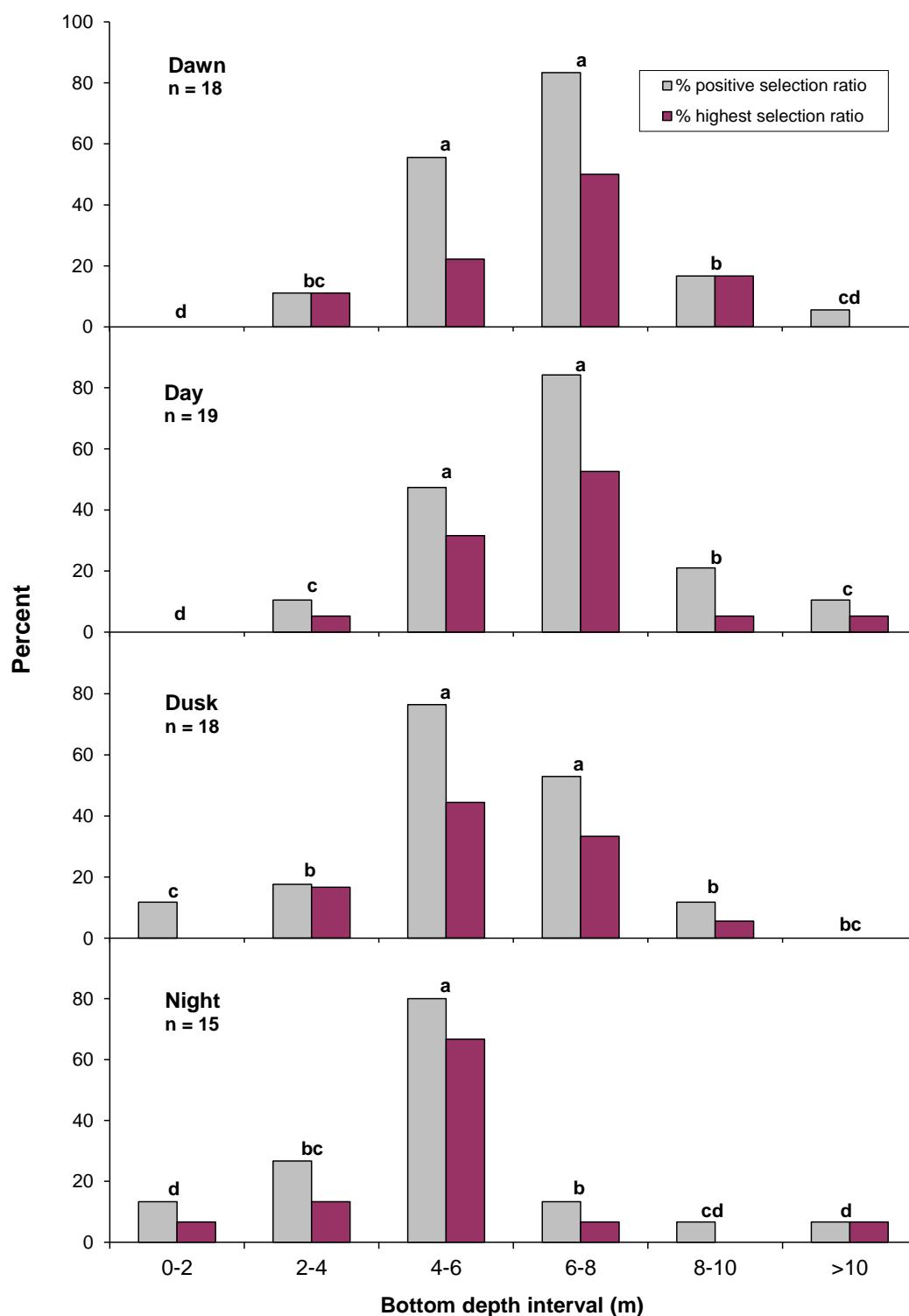


FIGURE 41. Results of Friedman multiple comparisons procedure of all smallmouth bass (letters above bars), percent of smallmouth bass with a positive selection ratio ($\hat{w}_i > 1$), and percent of smallmouth bass that had the highest selection ratio for various bottom depths during different diel periods at the SR 520 bridge site, May-August 2007 and 2008. Bottom depths with different letters indicate significantly different selection by smallmouth bass; n = the number of tagged smallmouth bass available (> 200 data points) during each diel period.

Results of a Friedman test for each diel period indicated there were significant differences ($P < 0.001$) between habitat types used by large smallmouth bass. Overall, smallmouth bass showed a strong preference for overwater structures (Figure 42). The bridge habitat area had the highest rank for each diel period. The area near the bridge was also used to a large degree and its use was not significantly different than the bridge area during each diel period (Figure 43). Density plots indicated smallmouth bass were often closely associated with the bridge columns and the use of deep water (> 10 m) was more prevalent at the bridge than in other areas of our coverage area (Figures 42 and 44). Other overwater structures were also commonly used, with the highest use occurring during the day and at dusk. During these two time periods, habitat use of other overwater structures was not significantly different than the bridge habitats. Use of sparse vegetation and the macrophyte edge was highest at dawn (Figures 43 and 45). At dawn, habitat use of sparse vegetation, macrophyte edge, and the bridge areas was not significantly different. Dense and moderately vegetation areas were also used to some degree with the highest use occurring at dusk. Offshore areas were rarely used; only one fish (#4577) showed a selection ratio greater than one (dawn and day time periods).

Smallmouth bass preferred areas with large substrates over areas with silt during dawn (sign test; $P = 0.022$; Figure 46). There was no significant difference between substrate types for the other diel periods (sign test; day, $P = 0.057$; dusk, $P = 0.774$; night, $P = 1.0$). Based on density plots, smallmouth bass did not show any strong association with street lights on the SR 520 bridge.

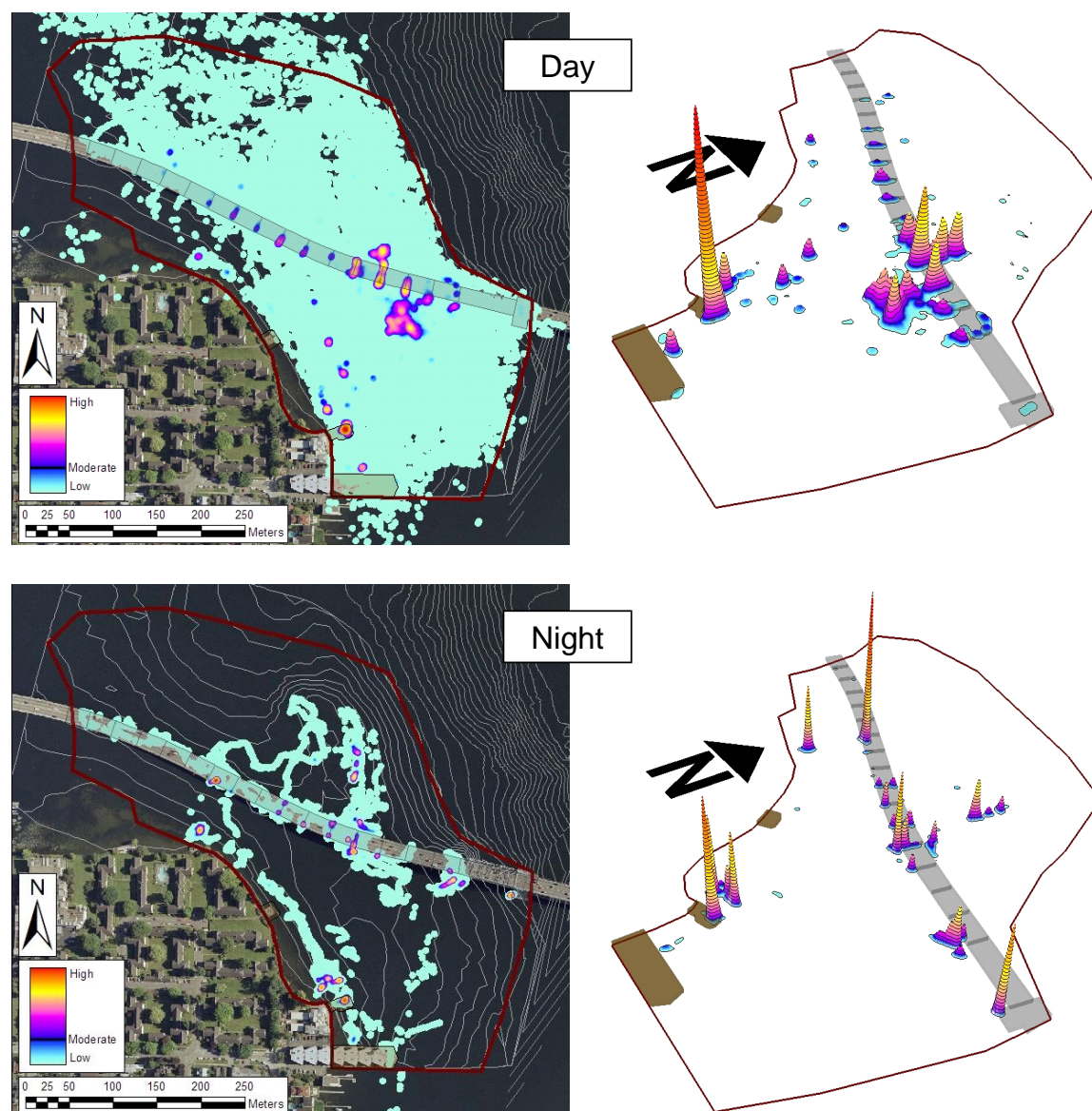


FIGURE 42. Day ($N = 19$) and night ($N = 15$) density plots of adult smallmouth bass at the SR 520 bridge study site, May-August 2007 and 2008. Each bass was weighted equally for the density plot calculation. The data presented on the left and right images are the same but are displayed in 2D on the left and 3D on the right. Representation of lowest density was altered to enhance clarity: size of lowest density was made smaller in the plots on the left, and lowest density was eliminated from plots on the right. The dark red line is the coverage area of the hydrophone array in both the 2D and 3D pictures. White lines in the 2D pictures are depth contours in 2-m intervals. Lines running perpendicular across the bridge are locations of the bridge columns.

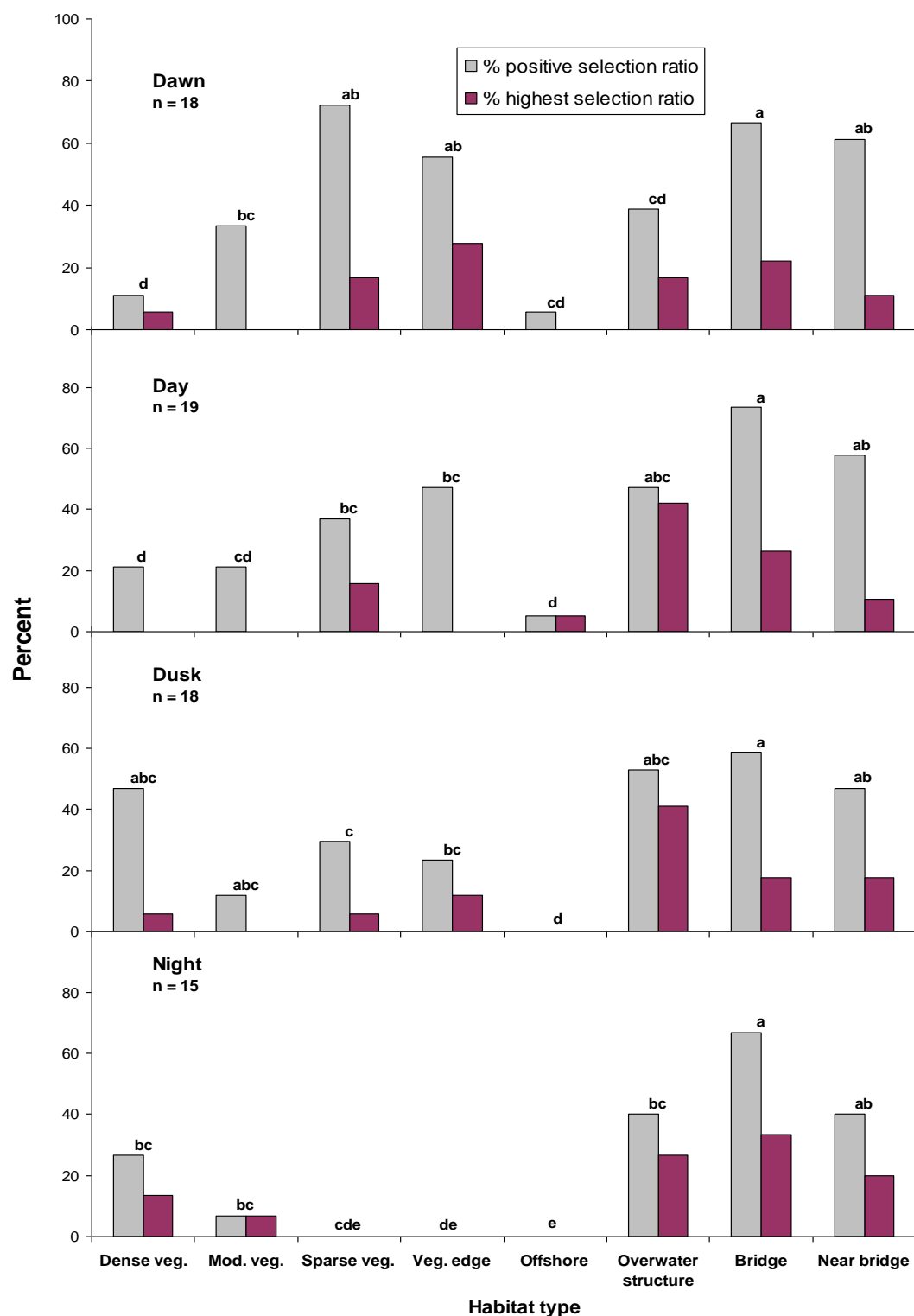


FIGURE 43. Results of Friedman multiple comparisons procedure of all smallmouth bass (letters above bars), percent of smallmouth bass with a positive selection ratio ($\hat{w}_i > 1$), and percent of smallmouth bass that had the highest selection ratio for various habitat types during different diel periods at the SR 520 bridge site, May-August 2007 and 2008. Habitat types with different letters indicate significantly different selection by smallmouth bass. Veg. = vegetation; n = the number of tagged smallmouth bass available (> 200 data points) during each diel period.

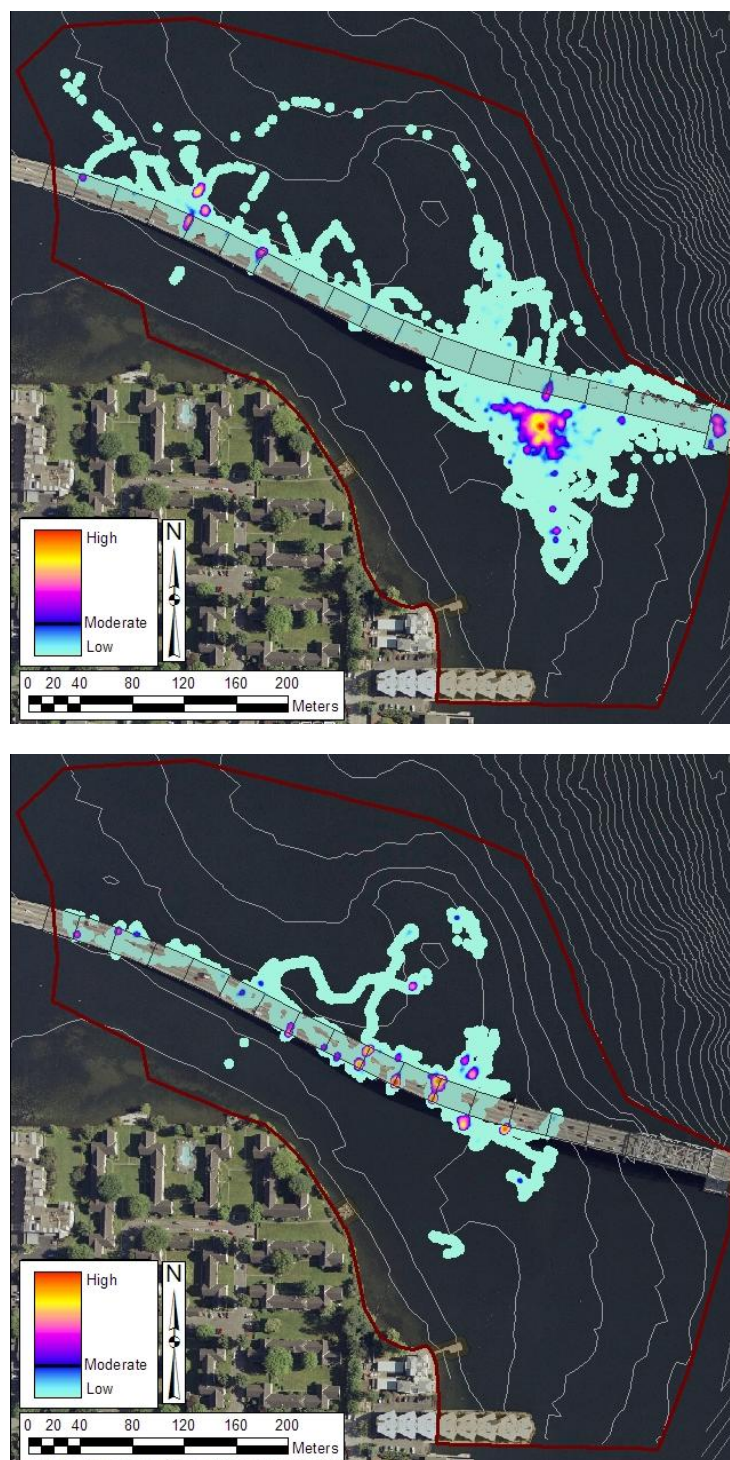


FIGURE 44. Day (top panel) and night (bottom panel) density plots of smallmouth bass (#4538) at the SR 520 bridge study site, May-August 2007. Lines running perpendicular across the bridge are the locations of the columns which support the bridge. Representation of lowest density was altered in both plots to enhance clarity: size of lowest density was made smaller. The dark red line is the coverage area of the hydrophone array. White lines are depth contours in 2-m intervals.

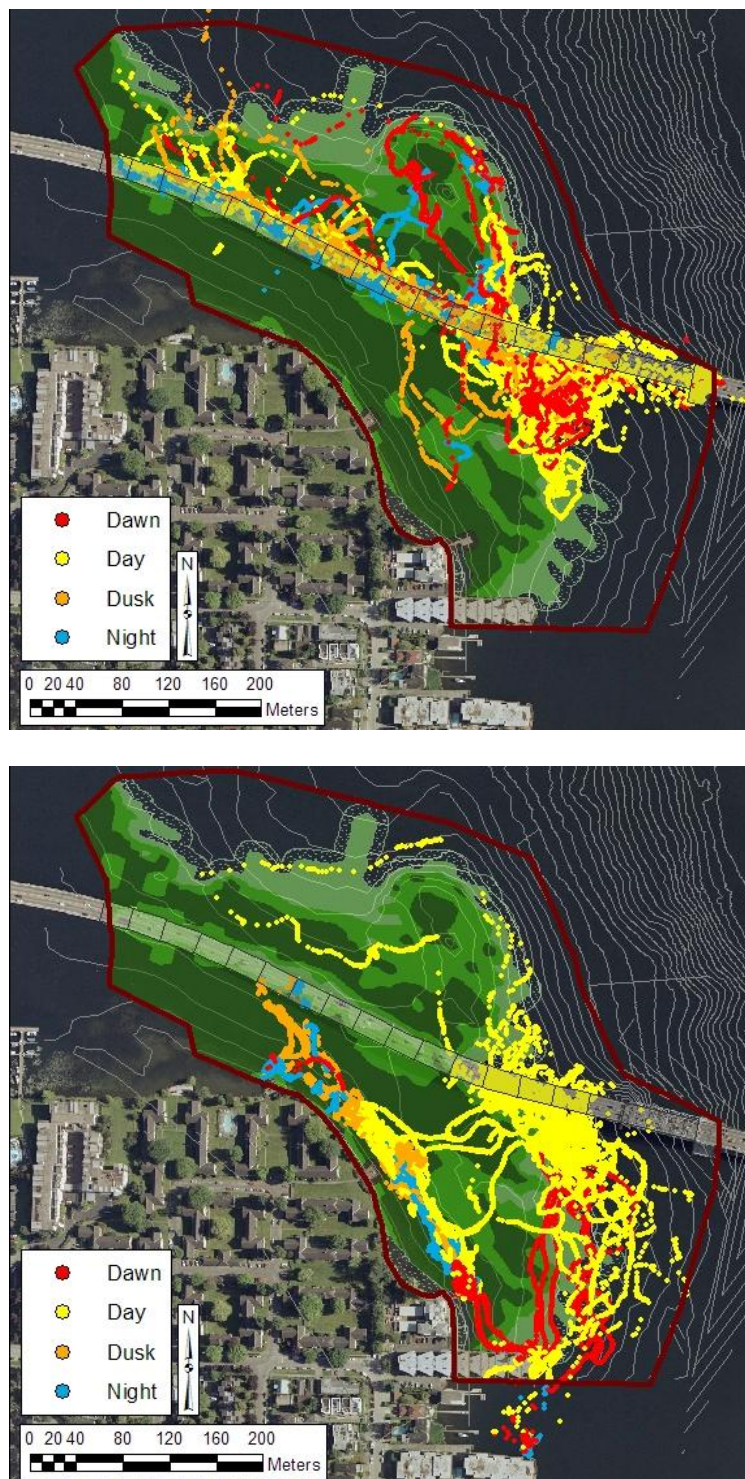


FIGURE 45. Data points of two smallmouth bass (top panel is fish #4538 and bottom panel is fish #4788) at the SR 520 bridge study site, (June-July 2007) showing their relationship to aquatic macrophyte (three density levels and the offshore edge) distribution. The dark red line is the coverage area of the hydrophone array. White lines are depth contours in 2-m intervals. OWS = overwater structures (not including the SR 520 bridge). Lines running perpendicular across the bridge are locations of the bridge columns.

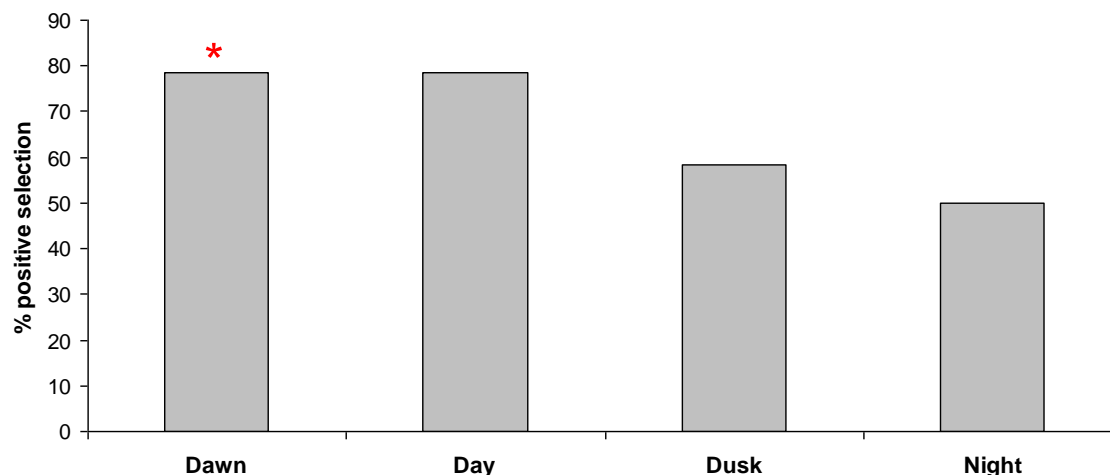


FIGURE 46. Percent of smallmouth bass with a positive selection ratio ($\hat{w}_i > 1$) for areas with large substrate (> 10% cobble or boulders) during different diel periods at the SR 520 bridge site, May-August 2007 and 2008. An asterisk above the bars indicated if the results were significantly different than areas with predominantly silt substrates (sign test, $P < 0.05$). Calculations only included areas where the depth was 2-10 m deep and did not include areas near overwater structures.

Relative abundance and diet of piscivorous fishes at the SR 520 bridge site

Catch

A total of 337 fish were captured with gill nets, of which 135 (40%) were northern pikeminnow and 111 (33%) were peamouth *Mylocheilus caurinus* (Table 11). Overall, 59% of the fish were caught in the 5-m deep net. Of the piscivorous fishes, smallmouth bass were only caught in the 5-m net, 64% of northern pikeminnow were caught in the 5-m net, and salmonids (excluding adult sockeye salmon *O. nerka*) were in roughly equal numbers between the two depth contours (Table 11). The only species that was primarily caught in the 10-m net was peamouth, where 66% were captured in the 10-m net.

The highest catch rates of northern pikeminnow were observed in 3.8-cm square-mesh; however, several northern pikeminnow were also caught in the 3.2- and 5.1-cm square mesh (Table 12). Few fish were caught in the 6.4-cm square-mesh. Except for catching a couple of smallmouth bass, this mesh size provided little data.

TABLE 11. Number of fish caught with gill nets along two depth contours in central-west Lake Washington, May-July, 2008. Catch for all five sites was combined. Whether a particular fish species was sampled for diet analysis is also indicated.

Family		Diet	Depth contour (number caught)		
Species	Scientific name	analysis?	5 m	10 m	Total
Salmonidae					
Cutthroat trout	<i>Oncorhynchus clarkii</i>	Yes	5	5	10
Rainbow trout	<i>Oncorhynchus mykiss</i>	Yes	2	2	4
Chinook salmon	<i>Oncorhynchus tshawytscha</i>	Yes	2	2	4
Coho salmon	<i>Oncorhynchus kisutch</i>	Yes	1	0	1
Sockeye salmon	<i>Oncorhynchus nerka</i>	No	3	2	5
Cyprinidae					
Northern pikeminnow	<i>Ptychocheilus oregonensis</i>	Yes	86	49	135
Peamouth	<i>Mylocheilus caurinus</i>	No	38	73	111
Common carp	<i>Cyprinus carpio</i>	No	1	0	1
Tench	<i>Tinca tinca</i>	No	1	0	1
Catostomidae					
Largescale sucker	<i>Catostomus macrocheilus</i>	No	28	2	30
Ictaluridae					
Brown bullhead	<i>Ameiurus nebulosus</i>	No	1	0	1
Centrarchidae					
Smallmouth bass	<i>Micropterus dolomieu</i>	Yes	23	0	23
Rock bass	<i>Ambloplites rupestris</i>	No	3	0	3
Percidae					
Yellow perch	<i>Perca flavescens</i>	No	5	3	8

TABLE 12. Number of fish caught in different mesh sizes (square mesh) of gill nets, central-west Lake Washington, May-July, 2008. Each gill net consisted of five panels; the 5.1-cm mesh represents the catch for two panels and the other mesh sizes represent one panel each. Catch for all five sites and two depth contours (5 m and 10 m) was combined.

Family Species	Mesh size (number caught)			
	3.2 cm	3.8 cm	5.1 cm	6.4 cm
Salmonidae				
Cutthroat trout	5	2	3	0
Rainbow trout	2	2	0	0
Chinook salmon	1	0	2	1
Coho salmon	1	0	0	0
Sockeye salmon	1	0	1	3
Cyprinidae				
Northern pikeminnow	28	49	58	0
Peamouth	96	14	1	0
Common carp	0	0	1	0
Tench	0	0	1	0
Catostomidae				
Largescale sucker	5	1	21	3
Ictaluridae				
Brown bullhead	0	0	1	0
Centrarchidae				
Smallmouth bass	0	3	18	2
Rock bass	3	0	0	0
Percidae				
Yellow perch	6	2	0	0

A total of 135 northern pikeminnow were caught in the gill nets. The highest mean CPUE (fish/h) of northern pikeminnow was observed at the Seattle Tennis Club site (mean, 0.98 fish/h); however, CPUE was not statistically different between sites (Friedman test; $T = 1.47$; $P = 0.83$; Figure 47). Lengths of northern pikeminnow were marginally significant between sites (ANOVA; $F = 2.42$; $df = 4,130$; $P = 0.052$). Results of Tukey's HSD test indicated the only two sites that were significantly different from each other were the Seattle Tennis Club and Webster Point (Figure 48). Combined, 82% of the northern pikeminnow were females (mean length, 422 mm FL), 16% were males (mean length, 331 mm FL), and 2% were immature (mean length, 335 mm FL).

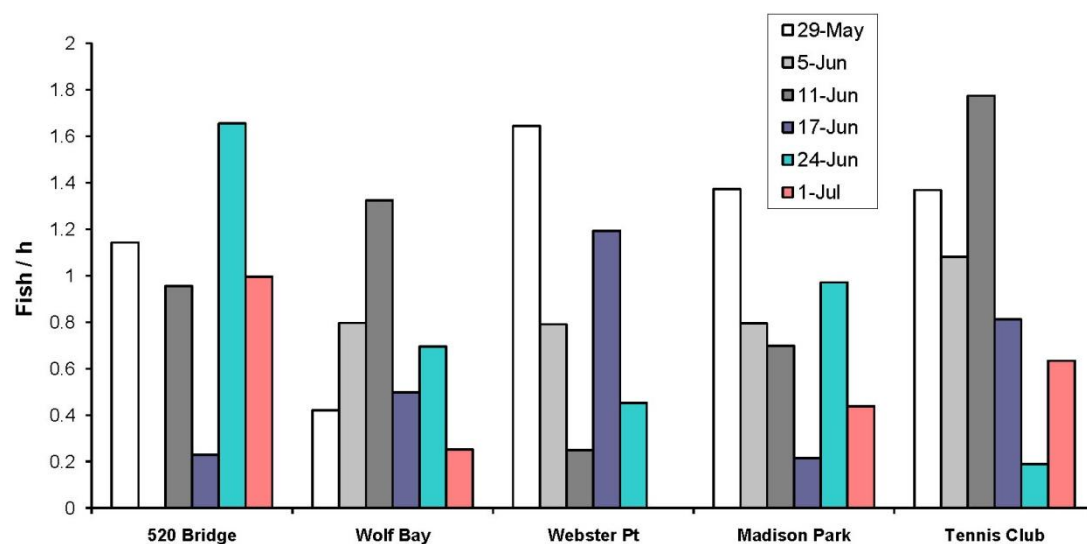


FIGURE 47. Catch (fish/h) of northern pikeminnow at five sites in central-west Lake Washington, May-July, 2008. Catch represents the total for two gill nets, a 5-m and 10-m depth contour. May 29 nets were fished from dusk to dawn (mean, 10.2 h), while on the other dates the nets were fished from about 200 hours to shortly after dawn (mean, 4.3 h).

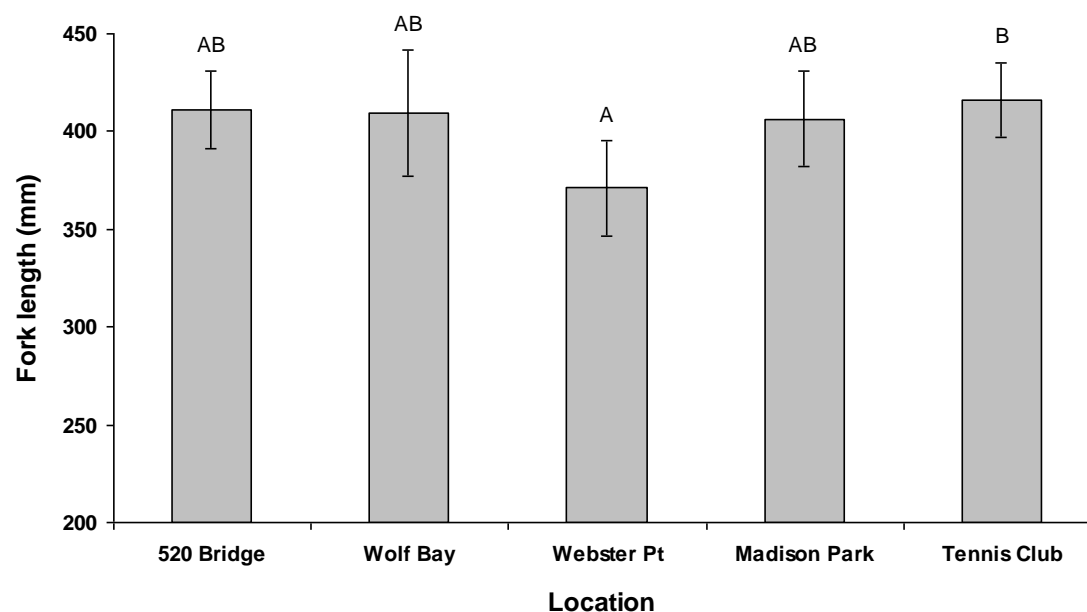


FIGURE 48. Mean fork length (mm, \pm 2SE) of northern pikeminnow at five sites in central-west Lake Washington, May-July, 2008. Groups of bars with different letters are significantly different (ANOVA and Tukey's HSD; $P < 0.05$).

Overall, the CPUE of smallmouth bass was much higher at the Webster Point site (mean, 0.32 fish/h) than any other site (mean, 0.11 fish/h); however it was not significantly different (Friedman test; $T = 6.83$; $P = 0.145$; Figure 49). Also, lengths of smallmouth bass were not significantly different between sites (ANOVA; $F = 0.68$; $df = 3,25$; $P = 0.57$; Figure 50).

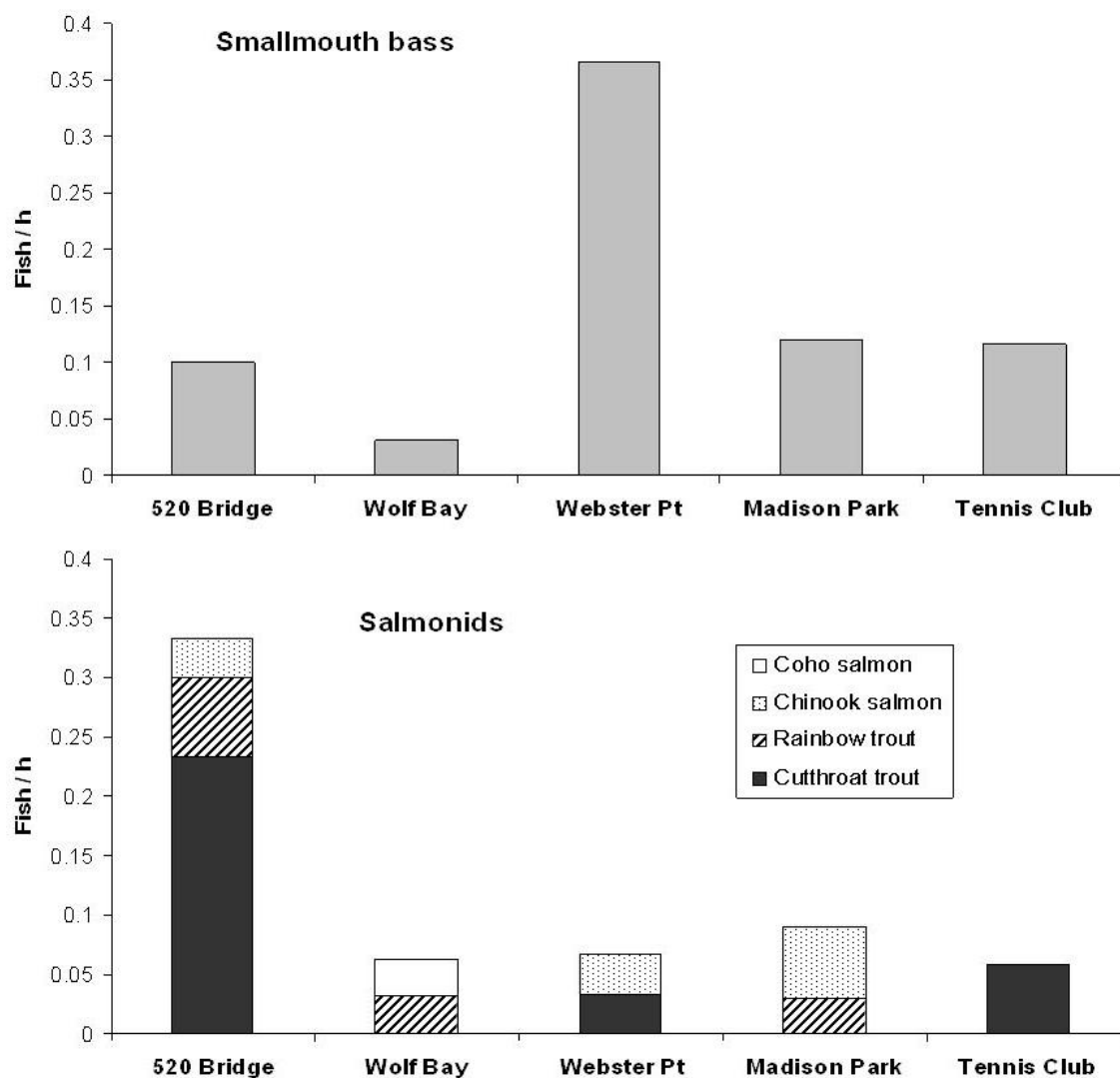


FIGURE 49. Catch (fish/h) of smallmouth bass and resident salmonids at five sites in central-west Lake Washington, May-July, 2008. Catch represents the total for two gill nets, one each at 5-m and 10-m depth contours. Because of small sample sizes, all sample dates were combined.

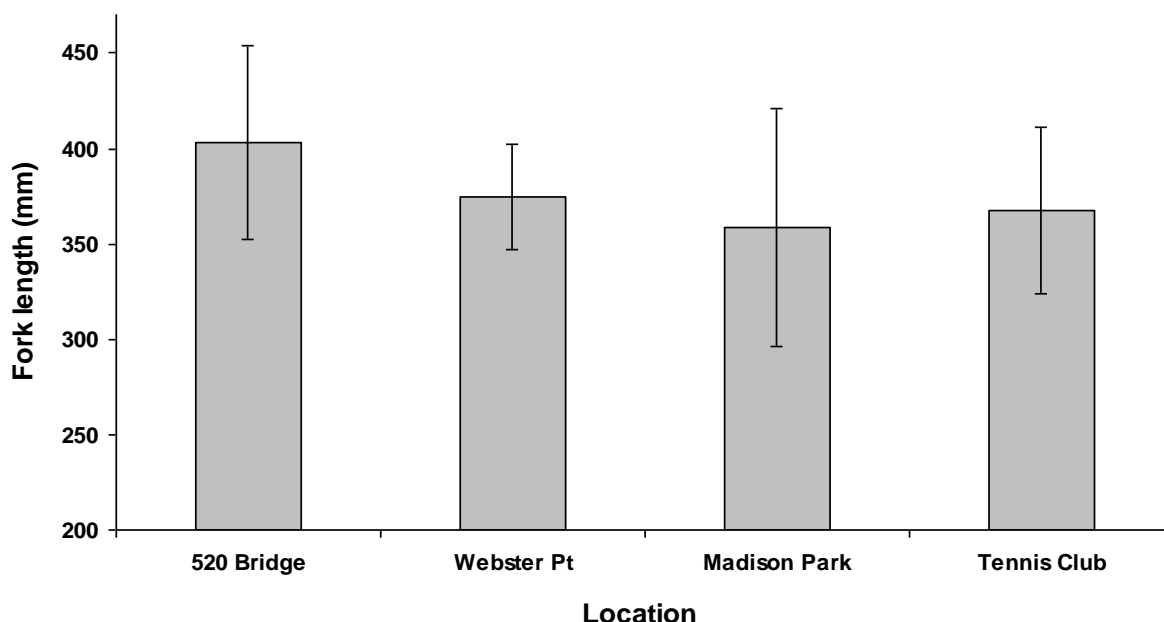


FIGURE 50. Mean fork length (mm, \pm 2SE) of smallmouth bass at four sites in central-west Lake Washington, May-July, 2008.

Small numbers of resident salmonids were also collected in the gill nets. A total of 19 resident salmonids were collected, which included 10 cutthroat trout *O. clarkii*, 4 rainbow trout *O. mykiss*, 4 Chinook salmon and 1 coho salmon *O. kisutch*. Ten of the 19 resident salmonids were collected at the SR 520 bridge site (Figure 49). Resident salmonids ranged in size from 305 to 600 mm FL (mean length, 452 mm FL). The Chinook salmon and coho salmon appeared to be residual salmonids based on their size, heavy internal parasite load, and timing in the lake. Of the four Chinook salmon; two had their adipose fin clipped. A few adult sockeye salmon were also collected but no information was collected on them.

Diet analysis

The percentage of northern pikeminnow that had empty digestive tracts was similar between the SR 520 bridge (51.7% empty) and the other sites (51.9% empty; Figure 51). Overall, 64 northern pikeminnow had food in their digestive tracts. We combined diet data for different dates because of small sample sizes.

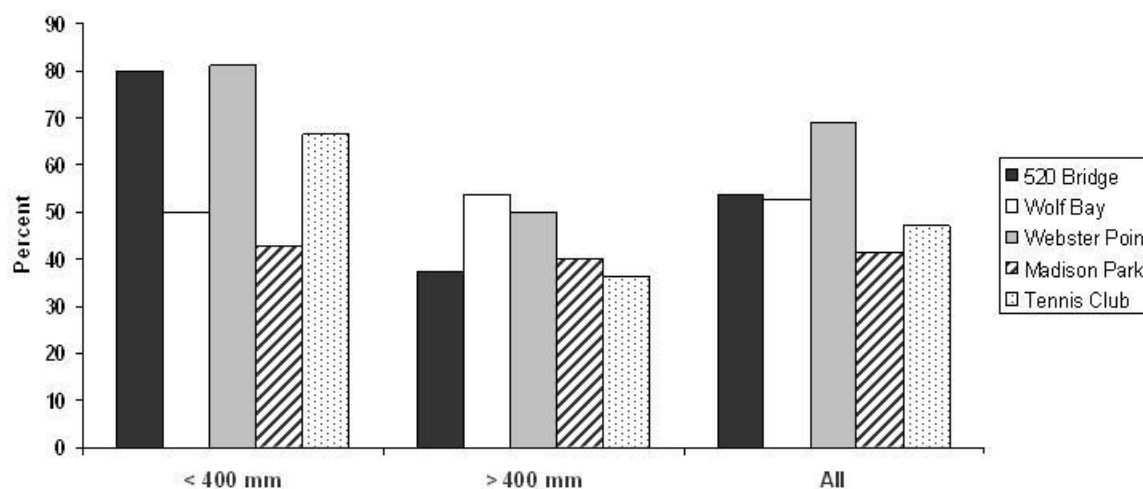


FIGURE 51. Percentage of northern pikeminnow with empty digestive tracts, central-west Lake Washington, May-July, 2008. All sample dates were combined.

The overall diet (%MW) of northern pikeminnow consisted primarily of fish, comprising 71% of the overall diet. The remainder was composed of crayfish (14.4%) and other invertebrates (14.4%, primarily aquatic insects and mollusks). Ingested fish consisted of juvenile salmonids (35.5% of the overall diet), river lamprey *Lampetra ayresi* (16.5%) sculpin *Cottus* spp. (8.7%), threespine stickleback *Gasterosteus aculeatus* (3.1%), and longfin smelt *Spirinchus thaleichthys* (2.3%). Of the juvenile salmonids ingested, 26% (10 of 38) were identified as Chinook salmon. We were unable to identify the remainder to species. Based on their size and time of the year, most were likely Chinook salmon.

Diet composition was similar between most sites (Figure 52). There was no difference between the diet at the SR 520 bridge site and each of the other sites. The only major difference was between Webster Point and two sites, Wolf Bay and Seattle Tennis Club. A large portion of the diet at Webster Point was composed of crayfish while it only made up a small portion of the diet at the other two sites (Figure 52). The amount of food in the digestive tracts of northern pikeminnow varied widely among individuals at each site. Northern pikeminnow at Webster Point had a lower MBW_i than other sites (Figure 53); however, there was no significant difference in percent food per body weight between sites (Kruskal-Wallis test = 4.9; $P = 0.30$).

Based on the percent index of relative importance (%IRI), the most important prey item at the SR520 Bridge was river lamprey (42.3%) followed by juvenile salmonids (30.5%, Figure 54). At the Wolf Bay, Madison Park, and Seattle Tennis Club sites, juvenile salmonids were the most important prey (range, 51.1-56.9%). Crayfish was the most important prey item (55%) at Webster Point; %IRI of salmonids was only 13.6% at this site.

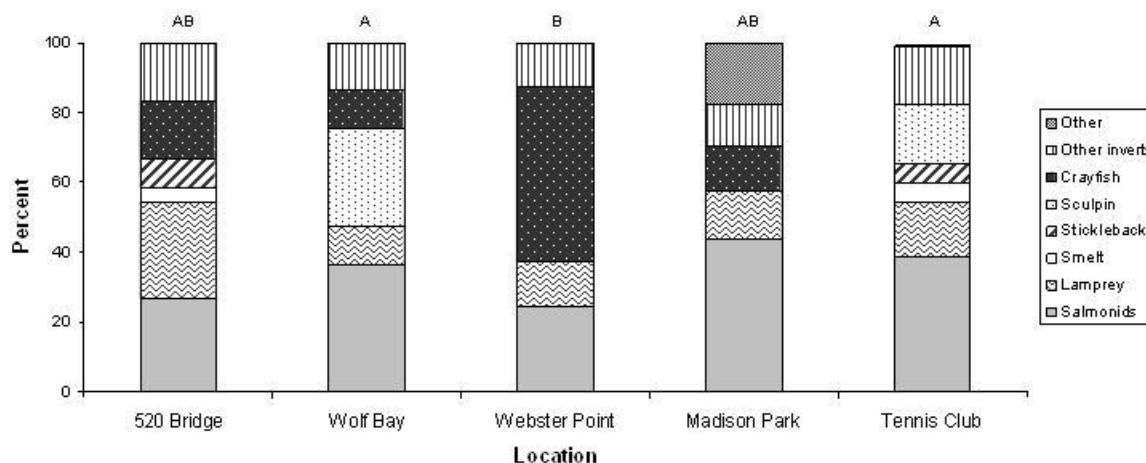


FIGURE 52. Mean proportion by weight (%MW_i) of northern pikeminnow at five sites in central-west Lake Washington, May-July, 2008. All sample dates were combined. Groups of bars with different letters are significantly different (Schoener's diet overlap index, $C < 0.6$).

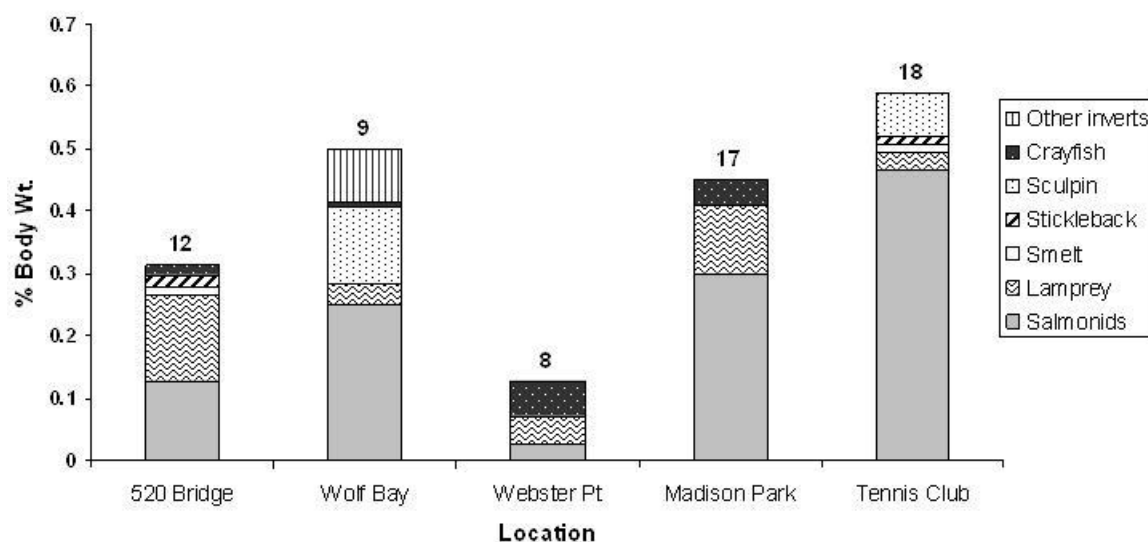


FIGURE 53. Mean proportion of body weight (MBW_i) of northern pikeminnow at five sites in central-west Lake Washington, May-July, 2008. All sample dates were combined. Numbers above each bar represents the number of northern pikeminnow with food in their digestive tract.

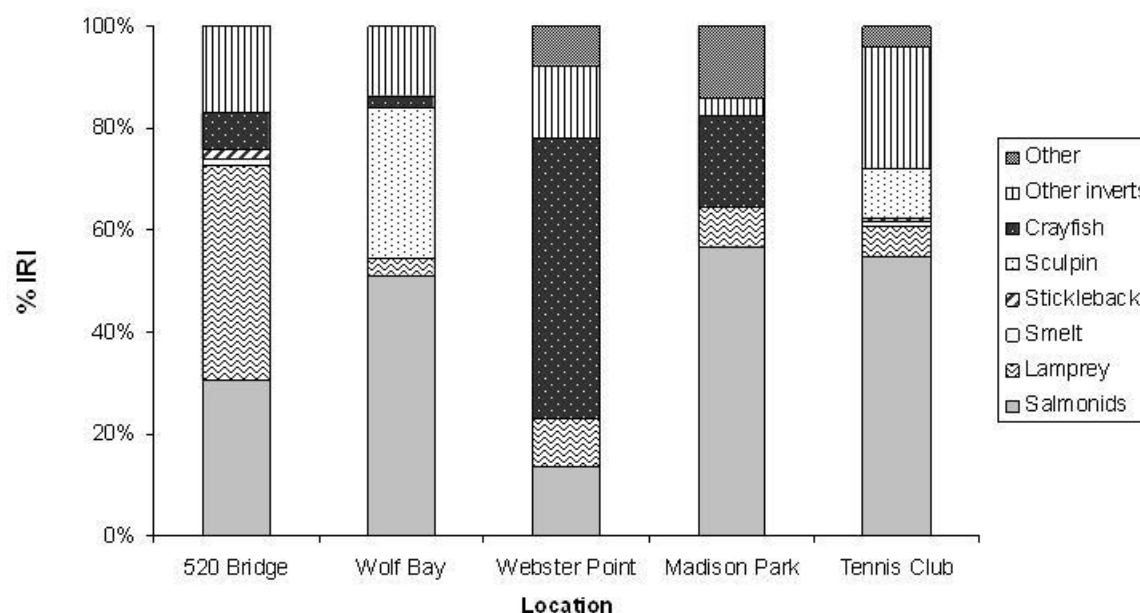


FIGURE 54. Percent index of relative importance (%IRI) of northern pikeminnow at five sites in central-west Lake Washington, May-July, 2008. All sample dates were combined.

We were able to estimate the length of 36 of 38 salmonids and 17 of 29 other fish ingested by northern pikeminnow. Ingested salmonids ranged in size from 70 to 188 mm (mean, 104.5 mm FL; Figure 55). Eighty-six percent of the ingested salmonids were between 85 and 125 mm FL. Size of ingested Chinook salmon (mean, 107.8 mm FL) and unidentified salmonids (mean, 106.7 mm FL) was similar. Size of ingested salmonids was not different between sites (ANOVA; $F = 1.04$; $df = 3,31$; $P = 0.39$). Lengths of ingested lamprey were also measured; however, because they do not have a bony vertebral column, their lengths may not be accurate.

Overall, 50% of the smallmouth bass had an empty stomach. Sixty percent (6 of 10) of the smallmouth bass from the SR 520 bridge were empty, while 45% (9 of 20) were empty from the other sites. The mean proportion of body weight (MBW_i) was substantially higher at Webster Point than the other sites (Figure 56); however, the differences were not significant (Mann-Whitney U test = 14.0; $P = 0.11$). Smallmouth bass diet was comprised primarily of either salmonids (50%), yellow perch *Perca flavescens* (13.2%), crayfish (12.9%) or sculpin (9.2%). Of the juvenile salmonids ingested, two were Chinook salmon, one was a cutthroat trout, and eight were unidentified. Three relatively large yellow perch (range, 130-146 mm FL) were found in smallmouth bass stomachs at Webster Point. There was no strong difference between the diet composition at Webster Point and the other sites combined (diet overlap index, $C = 0.62$).

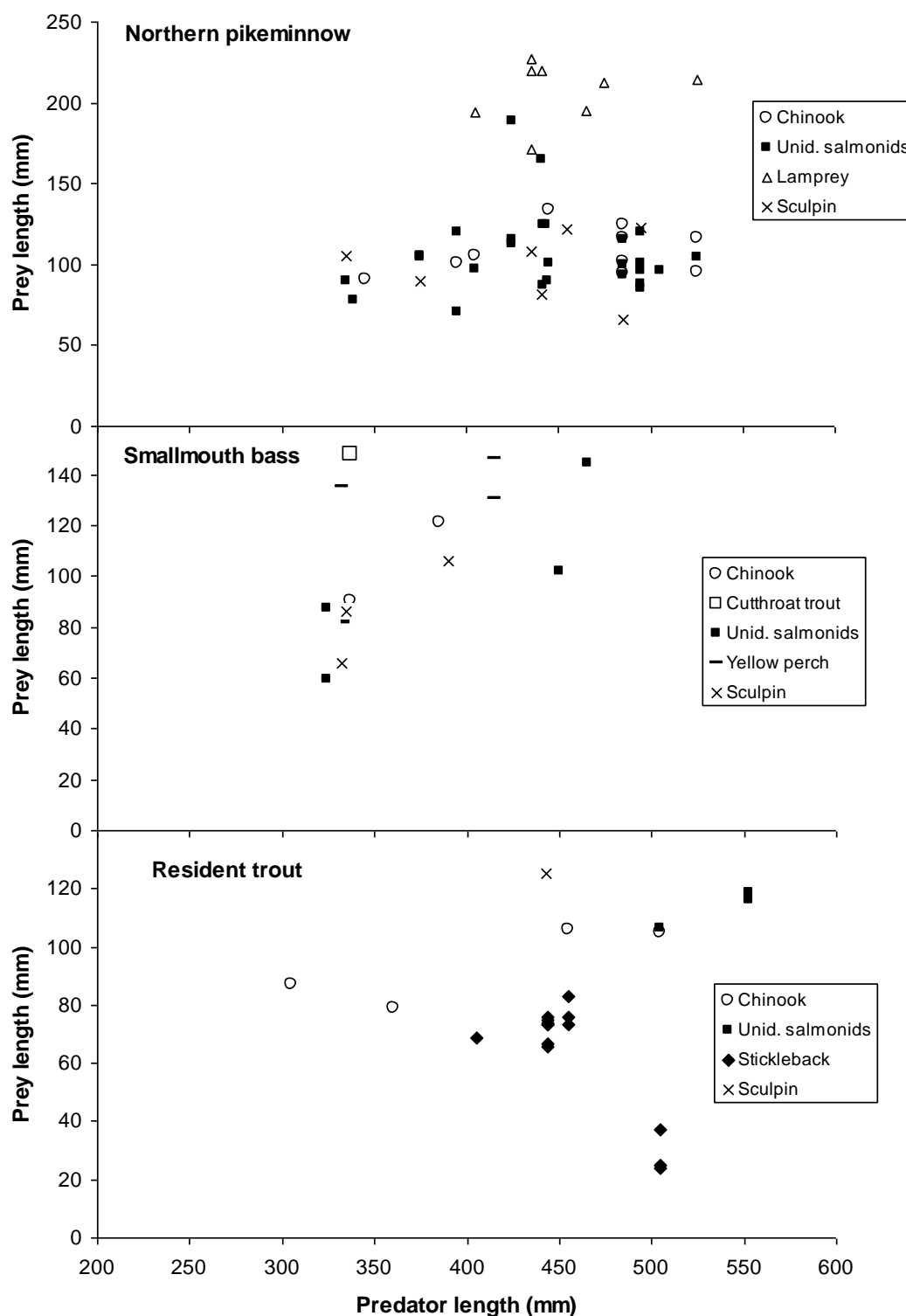


FIGURE 55. Relation between predator length and ingested fish length, central-west Lake Washington, May-July, 2008. Resident trout includes cutthroat trout and rainbow trout.

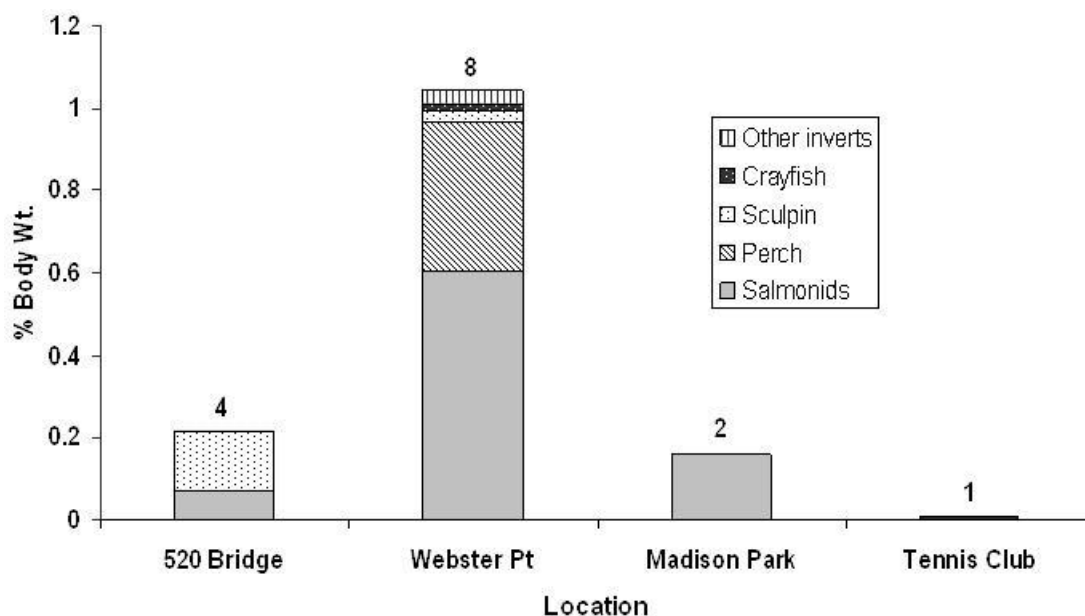


FIGURE 56. Mean proportion of body weight (*MBW*) of smallmouth bass at four sites in central-west Lake Washington, May-July, 2008. All sample dates were combined. Numbers above each bar represents the number of smallmouth bass with food in their stomach.

Of the 19 resident salmonids collected, 9 had an empty stomach. Forty percent (4 of 10) of the resident salmonids from the SR 520 bridge were empty, while 55% (5 of 9) were empty from the other sites. All of the Chinook salmon and coho salmon had an empty stomach. Thirty percent (3 of 10) of the cutthroat trout had an empty stomach and 25 % (1 of 4) of the rainbow trout had an empty stomach. There was no significant difference in percent food per body weight between the SR 520 bridge site and the other sites combined (Mann-Whitney U test = 14.0; $P = 0.67$). Diet composition was somewhat different between SR 520 bridge and the other sites combined (diet overlap index, $C = 0.50$); however, the small sample sizes make it difficult to make any meaningful comparisons.

Four of the seven ingested salmonids were identified as Chinook salmon and the rest were unidentified. Unlike the other piscivores, a large portion of the diet of cutthroat trout was comprised of threespine stickleback (both young-of-the-year and adults; Figures 55 and 57). For example, one cutthroat trout (505 mm FL) from SR 520 bridge had consumed 28 young-of-the-year and one adult threespine stickleback.

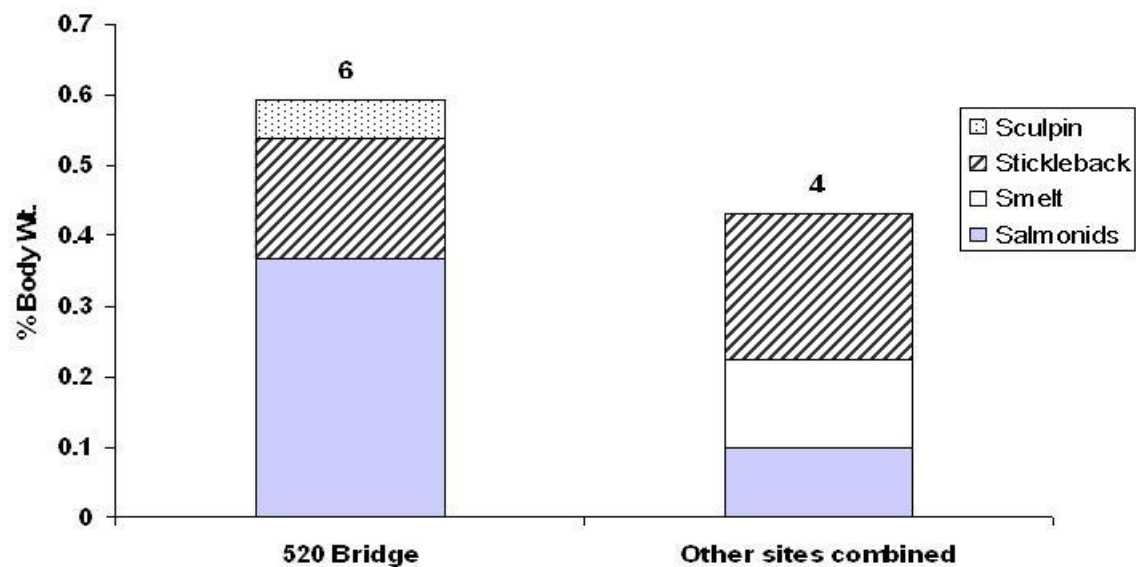


FIGURE 57. Mean proportion of body weight (MBW_i) of resident trout (cutthroat trout and rainbow trout) at five sites in central-west Lake Washington, May-July, 2008. All sample dates were combined. Numbers above each bar represents the number of trout with food in their stomach.

DISCUSSION

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 be used infrequently. Furthermore, less preferred habitats may be used frequently 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; Tabor et al. 2006; Celedonia et al. 2008b; Celedonia et al. 2011). 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.

Chinook salmon smolts

Our results must be interpreted with caution in extrapolating to naturally produced outmigrating Chinook salmon smolts. We likely tracked during only a portion of the smolt outmigration period, and we only tracked hatchery smolts large enough to tag. Naturally produced smolts may be of different size and may encounter the bridge at different times and thus under different environmental conditions (e.g., macrophyte abundance, temperature) than our study fish. In both 2007 and 2008, each release group of tagged fish exhibited its own unique set of behavioral traits with regard to migrational status, travel and residence times, proportion of time spent on-site, and habitat use. Unique behavioral traits were likely the product of the unique combination of specific exogenous factors and physiological (e.g., smoltification) states experienced by individuals within each release group. For example, moon apogee can be a strong migrational cue for Lake Washington

Chinook salmon (DeVries et al. 2004), although this is not always the case (DeVries et al. 2007). Our results likely do not represent all possible combinations of important factors at all possible states, and may not even represent the most common or likely combinations. In addition, different rearing conditions between natural and hatchery settings may cause the degree of smoltification to differ between hatchery and naturally produced smolts at a given point in time. Furthermore, the full effects of releasing study fish relatively near to the study site as compared to a more lengthy migration along the entire shoreline of the lake cannot be known with certainty.

Our results may thus not represent the full range of possible behaviors and habitat use patterns exhibited during the natural outmigration of naturally produced smolts. For example, smolts that are smaller or that are tracked at a different time (i.e., earlier or later than our study period) may exhibit different behaviors and habitat use patterns. In addition, the proportions of various behaviors and habitat use patterns in relation to one another that we observed are likely not representative of the natural outmigration. For example, the ratio of actively migrating to holding fish may differ dramatically in the natural smolt outmigration compared to our observations of tagged fish. What our results do represent is a variety of possible smolt behaviors and habitat use patterns at this study site, at least some of which are likely exhibited during the natural smolt outmigration.

We observed the same two dominant overarching migrational behaviors - active migration and holding - as those observed in 2007 (Celedonia et al. 2008a) and in other studies of Lake Washington Chinook salmon (Celedonia et al. 2008b; Celedonia et al. 2011). The active migration phase was characterized by rapid, direct movement through the study site with little or no meandering or milling. The holding phase was characterized by long general area residence times and often substantial meandering and milling through the site. Response to the bridge depended on which behavioral type the fish was exhibiting during its on-site presence. General bridge responses corresponded with 2007 observations. Specifically, actively migrating fish either showed minimal or no response to the bridge, or delayed at the bridge for short to moderate times and distances. In general, delaying fish abruptly changed their direction of travel upon encountering the bridge, and moved parallel with the bridge presumably seeking a more acceptable passage route. Some delaying fish also exhibited a milling behavior after encountering the bridge. In stark contrast to actively migrating fish, holding fish often selected for areas near the bridge (within 20 m of the bridge edge) to reside in for prolonged periods. The June 26, 2008 release group also selected for areas directly beneath the bridge during the day. Thus, effect of the bridge on Chinook salmon smolt behavior and habitat use depends upon migrational behavior.

Lake Washington Chinook salmon smolts are planktivorous during June (Koehler et al. 2006) and general behavioral and habitat use patterns observed in this and other studies (e.g., Koehler et al. 2004; Celedonia et al. 2008a; Celedonia et al. 2008b; Celedonia et al. 2011) are typical of small planktivorous prey fishes. During the day, smolts are often observed inhabiting shallow littoral areas with moderately dense to dense aquatic macrophytes, although areas lacking macrophytes have not been well studied. Smolts are rarely observed in offshore areas during the day. At night, fish are observed in deeper

water, and dawn and dusk appear to be transitional periods. Such diel horizontal movement from shallow, vegetated daytime habitat to deeper water at night is typical of planktivorous fishes in lacustrine habitats and is largely attributed to food availability and predation risk (Hall and Werner 1977; Hall et al. 1979; Werner et al. 1983; Naud and Magnan 1988; Werner and Hall 1988; Tabor and Wurtsbaugh 1991; Diehl and Eklöv 1995; Jacobsen and Berg 1998; Shoup et al. 2003). During the day, small planktivores typically inhabit nearshore littoral areas with aquatic macrophytes or other structural complexity to avoid predation by piscivorous fishes (Hall and Werner 1977; Hall et al. 1979; Werner et al. 1983; Naud and Magnan 1988; Werner and Hall 1988; Tabor and Wurtsbaugh 1991; Diehl and Eklöv 1995; Jacobsen and Berg 1998; Shoup et al. 2003). Structural complexity provides a well-documented benefit to small fish by considerably reducing predation rate (Werner and Hall 1988; Tabor and Wurtsbaugh 1991; Diehl and Eklöv 1995; Persson and Eklöv 1995). However, this comes at a cost. The preferred foraging base of small planktivores - typically *Daphnia* spp. - are often larger and more abundant farther offshore (Hall et al. 1979; Naud and Magnan 1988; Werner and Hall 1988; Tabor and Wurtsbaugh 1991; Diehl and Eklöv 1995). Thus, open water limnetic areas often provide the best foraging opportunities, but also present the greatest predation risk from piscivorous fishes. Therefore, planktivores use these areas during crepuscular periods and at night when low light levels diminish predation risk from visual predators. Visual predatory fishes that may prey on juvenile Chinook salmon in limnetic and deeper littoral areas of Lake Washington include cutthroat trout, northern pikeminnow, smallmouth bass, and largemouth bass *M. salmoides*.

Planktivores will often take advantage of opportunities to forage in limnetic waters during the day in order to capitalize on the more productive foraging base. When predation risk is reduced or absent, small fish will use open water areas more (Persson and Eklöv 1995; Jacobsen and Berg 1998), particularly when these areas provide more profitable foraging opportunities (Werner et al. 1983; Diehl and Eklöv 1995; Shoup et al. 2003). This can lead to greater growth rates compared to fish restricted to shallow littoral areas during the day (Werner et al. 1983; Werner and Hall 1988; Diehl and Eklöv 1995). This apparent preference for offshore habitat may explain: 1) daytime offshore use of Chinook salmon in the LWSC observed by Celedonia et al. (2008b and 2011); and, 2) daytime use of deeper water along the edges of the SR 520 bridge and the condo in 2007 and 2008. The hypothesized mechanisms permitting offshore use are different in each case but both are related to cover and predation risk. Specifically, cover sufficient to allow offshore habitat use may have been provided by: 1) diminished water clarity in the LWSC (Celedonia et al. 2008b; Celedonia et al. 2011); and, 2) physical structure and/or shading at the SR 520 bridge and condo.

Celedonia et al. (2008b and 2011) observed that Chinook salmon smolts in the LWSC were offshore in deeper water during the day and night, and were rarely observed in water < 8-10 m deep during any time period. Conversely, at a site on the western shore of Lake Washington located 2 km south of the SR 520 bridge, fish were in shallow water generally < 6 m deep during the day which is consistent with other observations in the lake. The authors hypothesized that water clarity and concomitant perceived predation risk may have played a key role in the dramatic difference in daytime habitat use between Lake

Washington and the LWSC. Water clarity was generally lower in the LWSC than along the western shore of Lake Washington during the study period. Turbidity and light intensity can substantially alter juvenile fish habitat use patterns (Gregory 1993; Miner and Stein 1996; Abrahams and Kattenfeld 1997; Reeb 2002). In general, predation risk declines in turbid conditions allowing prey species to abandon anti-predator behaviors. For example, in clear water small bluegill remain in shallow areas when predators are present, but spend substantial proportions of time (> 80%) in deepwater habitat under turbid conditions (Miner and Stein 1996). Similarly, Gregory (1993) observed that juvenile Chinook salmon concentrated in one part of a test arena under clear conditions, but that fish distributed more evenly throughout the arena under turbid conditions. Higher water clarity in Lake Washington may force Chinook salmon closer to shore, and diminished clarity in the LWSC may allow fish to utilize open water areas during the day and take advantage of presumably better foraging opportunities as well as lower, more favorable water temperatures.

In both years of the SR 520 bridge studies, holding Chinook salmon smolts showed significant selection for and/or considerable use of the SR 520 bridge edge and the condo edge, and selected for deeper water when near these structures than when they were away from the structures. Chinook salmon and other salmonids have also been observed at high densities along outside edges of overwater structures in Puget Sound (Toft et al. 2007). In 2007, we hypothesized that during the day holding Chinook salmon have a positive selection for deep waters near the bridge, which may be related to access to preferred foraging locations and/or cooler, more favorable water temperatures. This hypothesis can also be extended to the condo. Specifically, the bridge, the condo, and other overwater structures extending into deeper littoral and pelagic zones may provide a source of cover or refuge from open water predators, thus allowing juvenile Chinook salmon to access areas that they would otherwise avoid.

The depths selected by smolts near the 520 bridge and the condo corresponded with elevated *Daphnia* abundance. Zooplankton typically avoid nearshore areas and are instead found in greatest abundance farther from shore (Wetzel 1975; Hall et al. 1979; Naud and Magnan 1988; Werner and Hall 1988; Tabor and Wurtsbaugh 1991; Diehl and Eklöv 1995). The width of the nearshore zone of low abundance depends on elevation of the horizon, position of the sun, and differential light levels nearshore compared with offshore (Wetzel 1975). In 2008, our zooplankton sampling at the SR 520 study site showed zooplankton mass substantially higher at areas where the bottom depth was ≥ 7 m than at areas with bottom depths ≤ 5 , suggesting that the zone of low abundance extended from the shoreline to 5-7 m bottom depth. Chinook salmon smolts selected for depths within the zone of low zooplankton abundance when not near the bridge or condo during the day: daytime depth selection of Chinook salmon smolts was highest for 2-5 m and typically quite low for depths > 7 m when not near the bridge or condo. When at the bridge edge, however, daytime depth selections were typically highest for 5-7 m - the transitional area between low and high *Daphnia* abundance - and deeper depths consistently showed higher selection ratios when fish were near the bridge than when they were not (condo excluded). When at the condo edge, daytime depth selections were highest for 7-8 m depth.

Water temperature can also influence habitat use. Specifically, juvenile salmonids will move from areas of higher temperature to areas with more preferred temperatures (Bjornn and Reiser 1991; McCullough 1999). Lab studies suggest that most juvenile Pacific salmon, including Chinook salmon, prefer temperatures between 12-14°C (Brett 1952). However, maximum growth of juvenile salmonids is usually attained at higher temperatures (14-19°C) depending on species and food abundance (Brett et al. 1969; Brett et al. 1982; Bjornn and Reiser 1991). Prolonged exposure to temperatures of 23-25°C are generally considered life threatening to juvenile salmonids (Bjornn and Reiser 1991; McCullough 1999). Juvenile salmonids can tolerate elevated temperatures as long as temperatures don't become too high (< 24°C) and they can access substantially cooler water (< 12-15°C) for part of the day (Bjornn and Reiser 1991). Juvenile salmonids generally appear to avoid areas where mean maximum temperatures exceed about 20°C (McCullough 1999). Water temperatures in nearshore areas (≤ 8 m bottom depth) at the SR 520 bridge study site were < 20°C during tracking of most groups of tagged Chinook salmon smolts in both 2007 and 2008 (Figure 8). There was little difference in temperature between 2 and 8 m depth during tracking of the June 14, 2007 and June 12, 2008 groups, yet these groups showed similar deeper-water use near the bridge and condo as release groups subjected to higher temperatures at 2 m depth and greater thermal gradients from 2 to 8 m depth. Also, temperature at 8 m depth during tracking of these groups was closer to preferred temperatures of 12-14°C (Brett 1952), and temperature at 2 m depth was slightly less than or well within the range of maximum growth (14-19°C) (Brett et al. 1969; Brett et al. 1982; Bjornn and Reiser 1991). Thus, the selection for deeper water near the bridge and condo does not appear in these cases to be related to a physiological need for refuge from elevated water temperatures.

There are numerous examples in the literature of fish using artificial structures as habitat to inhabit areas they formerly avoided, yet few examples of fish using artificial structures as corridors to access areas otherwise avoided because of predation risk. Randall (1965) describes a manipulation experiment by Robert E. Schroeder at a coral reef in the Virgin Islands. Reefs in this area are typically ringed by an approximate 10-m wide halo of bare sand devoid of vegetation, with beds of sea grass lying beyond the halo (Randall 1965). The halo is often due to heavy grazing by reef fishes that stay close to the reef in order to avoid predators. Mr. Schroeder installed an artificial corridor of concrete blocks extending from the natural coral reef, across the bare sand halo, and into the sea grass bed terminating in a 1.5-m-diameter pile of blocks. Herbivorous fishes used this corridor to move from the natural reef into the sea grass bed and a halo of bare sand developed around the pile of blocks. Roberts and Angermeier (2007) studied movement of three riffle-dwelling benthic fishes through pools in a Virginia river. These species generally avoid moving through pools to get from one riffle to another because of high predation threat in pools. The researchers installed artificial corridors of hollow concrete blocks through pools to connect the riffles on either side. Two of the three species studied showed significantly greater movement through pools when the artificial corridors were present than through control pools containing no artificial corridors.

The bridge appears to function as such a corridor for Chinook salmon smolts to access better foraging areas; however, the specific features of the bridge that facilitate its use are

uncertain. Two obvious possibilities are the bridge shadow and the in-water structural complexity provided by the bridge support columns. One would expect that if shadow were responsible that the location of Chinook usage would change depending on time of day. That is, the position of the bridge's shadow relative to the bridge itself changes considerably during the day due to the orientation of the bridge, the changing position of the sun throughout the day, and the height of the bridge above the water surface. For example, early in the day we observed that the bridge shadow was cast on the south side of the bridge and was at times 10 m or more away from the bridge, and by afternoon the shadow was on the north side of the bridge and was also at times 10 m or more away from the bridge. Despite this variation in shadow position, fish selection did not appear to vary although we did not perform a detailed analysis. That is, which side of the bridge fish selected for and distance of fish from the bridge did not appear to vary throughout the day. Instead, use along the edge of the bridge appeared quite consistent throughout the day based on early day and late day selection ratios on the north and south sides of the bridge and on visual inspection of spatial frequency distributions and individual fish tracks. However, this cursory review may not be sufficient to elucidate important patterns. A detailed analysis would perhaps be more informative and would require: 1) modeling the position of the bridge shadow throughout each day of the study period; 2) incorporating meteorological conditions (e.g., sunny or overcast); and, 3) evaluating near-bridge locations of fish relative to this model. This would be a complicated endeavor and was beyond the scope of this study.

The influence of the bridge columns themselves must also be considered. The influence of in-water structures that extend through the entire length of the water column on juvenile salmonids is not clear or well-studied. Studies that appear to suggest a possible affinity for in-water structure by juvenile Chinook salmon (e.g., Friesen et al. 2007) do not distinguish between those with overwater structures attached and those without. Artificial structures that extend through all or part of the water column are known to attract a wide variety of juvenile fish in freshwater and marine environments (Myatt 1985; Bohnsack et al. 1991). This is generally attributed to the refuging function provided by the heterogeneity and complexity of the structure and shadow. Additional study would help provide more conclusive determinations of factors contributing to Chinook salmon use of overwater structure edge. Such studies could evaluate differential diets, foraging rates, growth rates, and predation rates of Chinook salmon in littoral vegetated areas compared with limnetic areas and areas near overwater structures. Manipulative experiments could also be conducted to evaluate the relative contribution of physical structure (e.g., bridge/condo support columns), shading and light/dark contrast, and presence of nearby aquatic macrophytes on Chinook salmon use of overwater structure edges. The influence of water clarity, temperature, and predation risk should also be considered.

In both 2007 and 2008, we observed that at night many Chinook salmon were often located near areas with artificial lighting. Similarly, in an experiment in south Lake Washington on February 23, 2005, juvenile Chinook salmon (mean, 50 mm FL) were four times more abundant in lighted areas than in non-lighted areas (R. Tabor, unpublished data). Juvenile Chinook salmon appear to be attracted to artificial lighting but the exact reasons for this attraction is unclear. The attraction may be a 'forced movement or trapping effect' similar to that observed in insects,

birds, and other fishes (Woodhead 1966). Artificial lighting may allow juvenile Chinook salmon to feed actively at night. Commonly, small zooplanktivorous fishes feed heavily at dawn and dusk and do not feed much at night (Hall et al. 1979; Wurtsbaugh and Li 1985). However, they may feed throughout the night during full moon conditions (Gliwicz 1986). Artificial lighting generally reduces the abundance of *Daphnia* in surface waters (Moore et al. 2000); however, other components of the zooplankton community such as larval fishes (Gregory and Powles 1985) may be more abundant and vulnerable to predation by juvenile Chinook salmon.

Lighted areas may allow zooplanktivorous fishes an opportunity to forage throughout the night but their increased abundance may attract their predators (Nightingale et al. 2006). Even if piscivorous fishes are not attracted to lighted areas, the predation rate by piscivorous fishes that inhabit the lighted area may be dramatically higher than that in other areas (Tabor et al. 2004a). Research at petroleum platforms has shown that artificial lighting allows fish to feed on zooplankton that have concentrated in the light field; however, they may be more vulnerable to large piscivorous fishes (Stanley and Wilson 1997; Keenan et al. 2003). In Lake Tanganyika in Africa, fishermen use lights to attract zooplanktivorous fishes, which in turn attract large piscivorous fishes (Coulter 1990). In Lake Washington, we have observed great blue herons and western grebes feeding around lights but no information is available on their nighttime diet. Piscivorous fishes may also be attracted to lighted areas due to an aggregation of small fishes like juvenile Chinook salmon. Cutthroat trout appear to feed heavily at night in Lake Washington because of reflected artificial lighting from surrounding urbanized areas (Mazur and Beauchamp 2006). Obviously artificial lighting on the bridge is important for safety concerns; however, lighting should be designed to minimize the amount of light that reaches the water surface.

Gill ATPase sampling suggested that the physiological smoltification process was dampened or muted in our study fish. This may explain the predominance of holding behaviors observed: lacking sufficient physiological cues, fish may be more prone to holding than actively migrating seaward. However, ATPase activity may not be a good predictor of predisposal to migrate seaward. Seaward movement can occur without elevated ATPase activity (Ewing et al. 1980a; Tiffan et al. 2000), and, conversely, slow moving fish can have high levels of ATPase activity (Tiffan et al. 2000). Nonetheless, the general suppression of ATPase activity in our study fish was curious because ATPase should peak at some point during the outmigration season. ATPase suppression can be associated with adverse or stressful conditions, such as elevated water temperatures (Marine and Cech 2004), low levels of food abundance (Ewing et al. 1980b), high levels of suspended sediment (Shrimpton et al. 2007), and high rearing densities (Strange et al. 1978). Shrimpton et al. (1994) found ATPase activity suppressed in hatchery-reared coho salmon and speculated that stressful hatchery rearing conditions may have been to blame. Release from the hatchery environment can stimulate smoltification (McCormick et al. 2003) assuming release occurs within the environmental smolt window.

Northern pikeminnow

Results of 2008 northern pikeminnow tracking appeared to be similar to 2007 results. Both depth selection and habitat use of northern pikeminnow appeared to be similar between years. In both years they were primarily concentrated in 4-6 m depth interval during all diel periods. At

dawn, dusk, and night, they were concentrated in this depth interval but often moved out into deeper water. Also, in both years, a few fish showed an affinity for the bridge. During the day, several fish were often under the small pier at the Madison Point Condominiums. Moderately dense vegetation, which occurs at the 4-6 m depth interval, was the most commonly used habitat.

In both 2007 and 2008, we were only able to effectively track less than 40% of the northern pikeminnow captured and released at the SR 520 bridge site. We did detect each pikeminnow, thus indicating the tags were active and functioning properly. Most fish appeared to move outside the coverage area shortly after release and were not detected again. In an earlier study, Brocksmith (1999) tagged 19 northern pikeminnow with acoustic tags in a variety of locations in Lake Washington and found many pikeminnow moved to a new location immediately after release and then stayed within their new area over the duration of the tracking period (1-5 months). By combining results of 2007 and 2008, we were able to obtain a reasonable sample size and make a good evaluation of northern pikeminnow habitat use.

Of the 15 northern pikeminnow that we obtained useful tracking results, there was a large variation in the amount time they spent in the tracking area. Four fish (three in 2007 and one in 2008) were in the study area for several weeks and we obtained more than 50,000 data points for each fish. Other fish were in the study area periodically over the course of a few weeks. Because of our limited tracking area, we were unable to determine the home range size of northern pikeminnow, but our results indicated there may be a large variation in their home range. Monitoring of large-scale movements (Vemco tags) of northern pikeminnow by Brocksmith (1999) and Tabor et al. (2010) in Lake Washington and the LWSC also indicated there can be large variation in movement patterns. Other tracking studies of a wide variety of resident freshwater fishes have often found movement patterns can vary widely between individual fish (Fausch and Young 1995).

Of the four fish with over 50,000 data points, three showed a positive relationship with the bridge. Of the other fish that were periodically tracked, few showed a positive selection for the bridge. There may be some segment of the population that will extensively use the bridge and it is likely an important foraging site for these fish. Overall, our tracking and gillnetting results indicate northern pikeminnow are common near the SR 520 bridge but they do not appear to use the bridge substantially more than other nearby areas.

Overall, our depth selection results were remarkably consistent between individual fish. Every fish had a positive selection ratio for the 4-6 m bottom depth interval during at least one diel period. Also, no fish had a positive selection ratio for offshore areas that were > 8 m deep except at night. Based on our results, northern pikeminnow appear to mostly inhabit the littoral zone in June and July. Martinelli and Shively (1997) also found that northern pikeminnow were commonly associated with inshore areas less than 5 m deep in two lower Columbia River reservoirs. McPhail (2007) stated that northern pikeminnow in the summer cruised the littoral zone about 1 m above the bottom on the offshore side of aquatic macrophytes.

Because we collected fish in the littoral zone, we may have excluded segments of the population that primarily inhabit the limnetic zone. Overnight gill net sampling in Lake Washington by Bartoo (1972) and Olney (1975) indicated most northern pikeminnow were in the

littoral zone during the summer. They collected some northern pikeminnow in the limnetic areas but this may be just indicative of diurnal inshore-offshore movements of northern pikeminnow. We documented that some northern pikeminnow will move offshore to deep limnetic areas (> 30 m deep) at dusk and at night. In Lake Ozette, Beauchamp et al. (1995) collected northern pikeminnow in both limnetic and nearshore areas in the summer and because the diet of nearshore-caught fish in Lake Ozette was different from limnetic-caught fish, the authors felt their habitat use may also be different. Additional summer tracking of northern pikeminnow throughout Lake Washington is needed to determine if segments of the population remain in limnetic zone throughout the day.

In general, all tagged northern pikeminnow remained close to shore during the day and often moved offshore at night. Diel behavior of northern pikeminnow in lentic systems has not been well studied. In contrast to our results, Brocksmith (1999) found that five of six northern pikeminnow tracked in April in Lake Washington were in deep water during the day and moved inshore at night. Brocksmith (1999) only tracked two fish in May and further tracking was not done until October. Our tracking was done in June and July and thus our results may be quite different due to a seasonal change in pikeminnow behavior. Northern pikeminnow show a strong seasonal change in distribution from offshore in the winter to onshore in the summer (Olney 1975; Brocksmith 1999).

In general, the diel distribution of northern pikeminnow was similar to that of juvenile Chinook salmon. Both species were often close to shore during the day and they moved further offshore at dusk and during the night. Juvenile Chinook salmon are an important prey item of northern pikeminnow and it would seem reasonable that their distribution would overlap to some degree. In this area, northern pikeminnow also prey heavily on river lamprey, which may also have a strong overlap with juvenile Chinook salmon. Based on lamprey scars of juvenile Chinook salmon at the Ballard Locks, river lamprey is potentially an important predator of juvenile Chinook salmon during this time period (E. Warner, Muckleshoot Indian Tribe, unpublished data). Northern pikeminnow movements may also be due in part to other prey items. Northern pikeminnow diel behavior is probably influenced largely by their feeding patterns but other factors such as predator avoidance (i.e., from large piscivorous birds) and thermoregulation may be more important during some times of the day.

The habitat types most strongly selected by northern pikeminnow at our study site were moderately dense and dense vegetation. These levels of vegetation occurred where the bottom depth was 2 to 6 m, which corresponded with depth selection results. Therefore, it is difficult to determine whether pikeminnow were selecting the vegetation or the depth interval. It may also be a combination of the two variables. The complexity of the macrophytes may provide northern pikeminnow a location to effectively ambush prey (e.g., juvenile Chinook salmon) as well as provide cover from piscivorous birds. Additionally, the macrophytes may provide a complex location where they can inhabit warm surface waters. Some fish have been shown to undergo diel migrations to thermoregulate (Wurtsbaugh and Neverman 1988) to improve growth efficiency. Additional tracking needs to be conducted in littoral areas where vegetation is sparse or absent; however, there are few places in Lake Washington where macrophytes are not present at these depths.

Although northern pikeminnow did not strongly use the bridge structure, several used the Madison Point Condominium pier. Within our study area, there were four overwater structures from a small pier (Edgewater Apartments) in shallow water to the large bridge structure. The Edgewater Apartment pier was probably in too shallow of water to attract northern pikeminnow. The Madison Point Condominium pier is a narrow pier but extends out into the water depths (4-5 m) preferred by northern pikeminnow. It is unclear why they would prefer this small pier over the two larger structures (Lakeshore West Condominiums and SR 520 bridge). The Madison Point pier may enable pikeminnow to observe approaching prey (i.e., juvenile Chinook salmon) from a variety of directions and still provide overwater cover from their predators such as piscivorous birds. Also, vegetation under the pier may be denser and more preferred by northern pikeminnow. Perhaps this site attracts northern pikeminnow because of some other type of forage. Northern pikeminnow often consume plant material and dead animal remains (Tabor et al. 1993; Petersen et al. 1994; Shively et al. 1996; Tabor et al. 2004b). If condominium residents regularly discard fish or shellfish remains at this pier or another source of plant or animal material is present, northern pikeminnow may congregate here.

Substrate selection by northern pikeminnow was markedly different between day and night. Differences may reflect their foraging strategies and prey availability. Northern pikeminnow are opportunistic predators with a wide range of prey types. During the day they may attempt to prey on diurnally-active prey (e.g., juvenile salmonids, threespine stickleback, and other littoral fishes) near macrophyte beds where silt substrates predominate. At night, they may attempt to prey on nocturnally-active prey such as sculpin and crayfish which are often more abundant in areas with larger substrates (Mueller 2002; Tabor et al. 1998).

Northern pikeminnow showed a slight attraction to street lights on the SR 520 bridge. Because juvenile Chinook salmon congregate near the lights, pikeminnow may in turn be attracted to the increased density of potential prey. Northern pikeminnow actually appear to prey more effectively on juvenile salmonids at extremely low light levels than at high light levels (Petersen and Gadomski 1994). However, the increased density of juvenile salmonids could result in higher predation rates by northern pikeminnow. Similarly, sockeye salmon fry are more vulnerable to sculpin predation at street lights because of the increase in density of fry even though sculpin are more effective at preying on fry at extremely low light levels (Tabor et al. 2004a).

Smallmouth bass

In 2008, we were able to track an additional eight large smallmouth bass. In general, results of these fish appeared to be similar to 2007 smallmouth bass tracking results. Combined, they showed a strong affinity for overwater structures. In both years, they were primarily concentrated in 4-8 m depth interval during all diel periods. At dawn, they often moved into sparse vegetation and the offshore edge of vegetation. Additionally, they occasionally used dense and moderately-dense vegetation, primarily at dusk and at night.

Unlike northern pikeminnow, we were able to effectively track most tagged smallmouth bass. Smallmouth bass usually have a defined home range (Kraai et al. 1991; Ridgway and Shuter 1996; Hodgson et al. 1998; Cole and Moring 1997) and may not be as mobile as northern

pikeminnow. Additionally, studies have shown that displaced smallmouth bass will often return to the original capture site (Pflug and Pauley 1983; Ridgway and Shuter 1996; Hodgson et al. 1998). Also, bass and northern pikeminnow may respond differently to the stress of being captured and tagged. For example, smallmouth bass may immediately seek cover in the same area; whereas northern pikeminnow may move to a new location (Brocksmitth 1999). In our tagging of smallmouth bass in the LWSC, we did have some bass that moved away shortly after tagging but it was a much lower percent than we observed for northern pikeminnow at the SR 520 bridge site.

Our tracking results clearly showed that the bridge structure provides some suitable habitat for smallmouth bass. The bridge provides both overwater and in-water structure and covers a large area where the water depth is 4-8 m deep, the preferred depth of the water column that smallmouth bass inhabit. However, based on gillnet sampling in 2008, the bridge does not appear to support a large number of smallmouth bass. The bridge structure probably does not support a large number of smallmouth bass because the structure is not very complex, the substrate consists mostly of fine sediments, and the bottom has a gentle slope within the preferred depth of 4-8 m (Hubert and Lackey 1980; Fresh et al. 2001). It would seem reasonable that increasing the size or number of bridge columns would benefit the smallmouth bass population. However, it is unclear if a few large columns would be more beneficial than several smaller columns.

In examinations of lakes in Massachusetts (Belding 1927) and Michigan (Hubbs and Bailey 1938), investigators found lakes with sparse vegetation had higher abundance of smallmouth bass than lakes with no vegetation or lakes with dense vegetation. Lakes with no vegetation may be indicative of low productive systems and may have a low abundance of suitable prey. Alternatively, lakes with dense aquatic vegetation may have abundant prey but dense vegetation generally decreases the foraging success of piscivores (Werner et al. 1983; Gotceitas and Colgan 1989). Lakes with sparse vegetation may have a good balance between having enough suitable prey and having a moderate level of complexity where smallmouth bass can forage effectively. Our results appear to provide some support for this concept. We found smallmouth bass were frequently present in areas of sparse vegetation and along the offshore edge of the macrophyte beds, especially at dawn when they were probably actively searching for prey. Sparse vegetation and the offshore edge of vegetation may be a valuable location for smallmouth bass to locate their preferred prey: crayfish, cottids, and other benthic prey. Additionally, the use of sparse vegetation and the edge of the vegetation may provide smallmouth bass an ideal location to observe and ambush prey that is in open water. Winemiller and Taylor (1987) found that smallmouth bass usually came up from the bottom at an angle and attacked fish near the surface.

The two small smallmouth bass (< 190 mm FL) we tracked in 2007 were both primarily in water close to shore (< 2 m bottom depth). The other smallmouth bass we tracked were greater than 240 mm FL and all but one was over 300 mm FL. These larger smallmouth bass were primarily in waters where the bottom depth was 4 to 8 m. Fresh et al. (2001) also found that smallmouth bass less than 250 mm FL in Lake Washington generally inhabit shallower water than larger smallmouth bass. For many fish species, there is a progression for fish to move offshore into deeper waters as they increase in size (Power 1987)

At dawn and dusk, some smallmouth bass made forays along the shore or into deeper waters. These movements may have been movements to actively search for prey. Piscivores, such as smallmouth bass, are well adapted to feed in dim light and are often more active during crepuscular periods because they have the greatest advantage over prey species. Results of two smallmouth bass implanted with depth tags at the SR 520 bridge site showed crepuscular activity patterns (Celedonia et al. 2008a). In the Columbia River, smallmouth bass show a crepuscular feeding pattern, but it is not pronounced (Vigg et al. 1991). An extended period of morning feeding has also been observed. Emery (1973) also found peak feeding was at dawn and dusk and they fed opportunistically during the daytime. In the Snake River, smallmouth bass were most active in the early morning (Munther 1970). In laboratory experiments, Reynolds and Casterlin (1976) also found smallmouth bass displayed a crepuscular activity pattern.

Most smallmouth bass did not appear to be active at night. Other studies have also found they are inactive at night and rest on the bottom near some type of cover such as large woody debris (Munther 1970; Emery 1973). During our snorkeling in Lake Washington and the LWSC, we often encountered smallmouth bass that were motionless and appeared to be resting on the bottom (R. Tabor, unpublished data). Our tagged smallmouth bass were mostly inactive at night, however there were some exceptions. Nighttime activity may be related to artificial lighting or moonlight. Some of the night-active smallmouth bass in Portage Bay and at a site near the Seattle Tennis Club in Lake Washington were near artificial lighting (Celedonia et al. 2008b). In laboratory experiments, Reynolds and Casterlin (1976) found smallmouth bass were often active at night. Largemouth bass, which have similar crepuscular activity patterns (Reynolds and Casterlin 1976), can feed at night especially under full moon light conditions (McMahon and Holanov 1995).

Restricted movement at night by smallmouth bass is most likely indicative of resting behavior; whereas restricted movement throughout the day may be related to either resting behavior, typical behavior of an ambush predator, or related to spawning activity. During the spring, male smallmouth bass often are guarding a nest and have a small home range during this period (Savitz et al. 1993) and foraging activity is presumably reduced. Of the adult smallmouth bass we tagged at the study site, all appeared to move over a relatively large area during the day and did not appear to be nest guarding. Spawning activity occurs in the spring and our tracking may have been conducted after spawning season was over. Also, adult smallmouth bass collected at the study site were collected with gill nets, which selects for more active fish and probably not for nest guarding males.

Relative abundance and diet of piscivorous fishes at the SR 520 bridge site

We found no evidence that northern pikeminnow were congregated at the SR 520 bridge in comparison to four other nearby sites. Northern pikeminnow have been shown to congregate around dams (Beamesderfer and Reiman 1991) and at the outlets of hatchery facilities (Collis et al. 1995); however, this is likely due to prey availability and not the structure itself. The use of overwater structures by northern pikeminnow in lakes has not been well documented. Acoustic tracking of northern pikeminnow at SR 520 bridge indicated they occasionally use overwater structures; however, they most frequently used a small pier near shore instead of the SR 520 bridge. Exactly why they preferred this small structure is unclear.

The diet composition of northern pikeminnow at the SR 520 bridge site consisted of juvenile salmonids, river lamprey, threespine stickleback, longfin smelt, and crayfish. They did not appear to be feeding on juvenile salmonids to a larger degree than at other sites. Northern pikeminnow are considered opportunity predators that will eat a wide variety of food including plant material (Tabor et al. 1993; Shively et al. 1996) and dead fish (Petersen et al. 1994) and will quickly switch to other prey items as it becomes abundant (Collis et al. 1995; Shively et al. 1996). The diet composition of northern pikeminnow at the SR 520 bridge is probably a reflection of prey abundance and availability. There was no evidence to support the hypothesis that juvenile salmonids are more vulnerable to northern pikeminnow predation due the bridge structure. Similarly, Ward et al. (1994) found no difference in the frequency of occurrence of juvenile salmonids in northern pikeminnow diets between developed and undeveloped areas of the lower Willamette River.

Juvenile salmonids made up a substantial portion of the diet of northern pikeminnow at all of our five sites in the central-west part of the lake. All of the identifiable salmonids were Chinook salmon. Previous studies of northern pikeminnow in Lake Washington have found Chinook salmon is a rare prey item in their diet (Olney 1975; Brocksmith 1999; Beauchamp et al. 2007a). The others studies usually had small sample sizes in June and their sampling was spread out over the entire lake and thus they could have missed this predation event. If predation of Chinook salmon is strongly concentrated in the central-west part of the lake and little sampling occurred in this area, the overall predation levels on juvenile salmonids may be underestimated by these other studies.

One important finding of our diet analysis was the prevalence of river lamprey in the diet of northern pikeminnow. In previous sampling of northern pikeminnow in Lake Washington by Olney (1975), Brocksmith (1999), Beauchamp et al. (2004) and Beauchamp et al. (2007a), river lamprey was not mentioned as an important prey item. Olney (1975) only states that a few Pacific lamprey *Entosphenus tridentatus* were consumed and does not mention river lamprey. Brocksmith (1999) found lamprey in 3 of 124 gut samples but does not mention which species was present. Beauchamp et al. (2004) and Beauchamp et al. (2007a) did not mention lamprey; instead they found northern pikeminnow preyed on longfin smelt, threespine stickleback, salmonids, yellow perch, and sculpin. These other studies conducted sampling throughout the year and across the entire lake. In our study, we intensively sampled one area of the lake over a short time period. River lamprey may congregate in this area to prey on juvenile salmonids and are in turn preyed on by northern pikeminnow. Because river lamprey was only observed in northern pikeminnow, river lamprey may be particularly vulnerable to piscivorous fishes at night. Northern pikeminnow appear to be able to forage under lower light conditions than the other species (Petersen and Gadomski 1994).

The ecology and abundance of river lamprey in Lake Washington is poorly understood. Typically, river lamprey are anadromous, spending about 5 years in freshwater as ammocoetes and then migrating to estuarine and marine environments to feed on fish and then return to freshwater as adults to spawn and die (McPhail 2007). In Lake Washington, they appear to be able to complete their life history in freshwater. Other landlocked populations have been documented in British Columbia lakes (McPhail 2007). Currently river lamprey is listed as a

species of concern by Washington Department of Fish and Wildlife. Their population levels in the Lake Washington basin are not known. However, since they are an important prey item for northern pikeminnow and northern pikeminnow are abundant, river lamprey population levels may also be relatively robust. Research at the Ballard Locks found up to 12% of sockeye salmon smolts have lamprey marks (E. Warner, Muckleshoot Indian Tribe, unpublished data), which also suggests river lamprey may be abundant in some areas of Lake Washington or the Ship Canal. Additionally, their genetic relation to western brook lamprey *Lampetra richardsoni* is unclear. Some recent genetic work has suggested they may be the same species (McPhail 2007). Western brook lamprey appears to be common and widespread in the Lake Washington basin.

River lamprey was especially important in the diet of northern pikeminnow at the SR 520 bridge site. Why they were more important at this site than has been previously documented in other parts of the lake is unknown. It may be just an artifact of our small sample sizes. Alternatively, river lamprey may be more abundant at this site. Chinook salmon may be more concentrated at the SR 520 bridge than other sites and river lamprey may respond to this high prey abundance. Also, the relationship between river lamprey and the bridge structure and other overwater structures is unknown. Additional studies are needed to assess river lamprey abundance, habitat use patterns, and impact on anadromous salmonid populations.

Almost half of the smallmouth bass from standardized gill-net sets were caught at Webster Point. Smallmouth bass generally inhabit water that is 2-8 m deep and are rare in deeper waters (Celedonia et al. 2008a; Celedonia et al. 2008b; Tabor et al. 2010). For example, we did not catch any smallmouth bass in our 10-m net. 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. Differences in substrate between the sites is not known. At the SR 520 bridge site, the bottom slopes steeply to over 60 m; however, the steep slope area is in relatively deep water (10-30 m), beyond the preferred depth of smallmouth bass.

Over half of the large resident salmonids were caught at the SR 520 bridge and those caught at the bridge had a higher occurrence of juvenile salmonids in their stomachs compared to other sites. However, our sampling was designed to catch northern pikeminnow and our sample size of resident salmonids was too small to make any meaningful comparisons between sites. Additionally, large resident trout are highly mobile predators (Warner and Quinn 1995; Nowak and Quinn 2002) and it's difficult to determine where they forage. They may use the bridge only as overwater cover during resting periods and move to other locations to forage. A large tracking and diet study is needed to get a clear picture of their relation to the bridge.

Implications of observations to bridge design

This study did not nor was it intended to identify design thresholds where impacts to fish would exist or could be avoided. Nonetheless, considering our results in context of the proposed design features of the new bridge is useful. Several design options are being considered for the new bridge. In the immediate vicinity of the acoustic tracking study site, all 6-lane options would: 1) considerably widen the bridge; 2) move parts of the bridge north of its current location (Figure 58); 3) increase the size of support columns; 4) increase the distance between rows of

support columns; and, 5) decrease the overall number of support columns. Two options (Options A and L) would raise portions of the bridge higher than current elevations. It is unclear how the third design option (Option K) would affect bridge height in the study site area.

Based on our acoustic tracking studies and other studies of migrating Chinook salmon (Kemp 2005; Tabor et al. 2006; Celedonia et al. 2008b; R. Tabor, USFWS, unpublished data), actively migrating Chinook salmon smolts attempt to avoid passing beneath overwater structures. Upon encountering structures such as docks and piers, fish generally move into deeper water and either pass beneath the structure or swim around the perimeter of the structure. Once beyond the structure, fish generally move back into shallower water. Some factors that appear to influence behaviors are structure width, height of structure above the water surface, light conditions beneath the structure, degree of contrast at the light/shadow edge, type and size of adjacent structures, and macrophyte distribution. These are anecdotal observations, however, and more rigorous study is needed to better understand how size, shape, and other parameters of overwater structures influence salmonid behavior. Elevating the bridge above the surface of the water may allow more ambient light beneath the bridge and may thus diminish any influence the bridge shadow has on migrating Chinook salmon. However, a wider bridge may counteract this. It is uncertain how these two factors (bridge width and height of bridge above the surface) would interact to influence behaviors of actively migrating Chinook salmon behaviors.

Given the complexity and uncertainty of factors influencing holding Chinook salmon's use of the bridge, we cannot infer with much certainty the influence of the new bridge design on holding Chinook salmon. Specific features that may influence attraction of Chinook salmon smolts to the current bridge during the day may include one or more of the following: 1) shading under and near the bridge; 2) structural complexity provided by the bridge (i.e., the bridge columns); and, 3) the presence of macrophytes near and/or under the bridge. Elevating the new bridge may diminish the bridge shadow's darkness and the degree of contrast at the light-dark edge, and may thus diminish the attractiveness of shadow as cover as well as allow more dense growth of macrophytes beneath the bridge. The greater width of the new bridge may, however, offset these effects as a wider bridge would allow less ambient light underneath thereby darkening the shadow. Tagged Chinook salmon smolts usually selected for the bridge edge. Thus, a wider bridge would have no influence on these fish. However, we did observe occasional selection for a small area directly beneath the bridge where the bridge was elevated above the surface of the water. A wider bridge that is elevated throughout the study area may thus increase under-bridge area used by Chinook salmon. Fewer and more widely spaced bridge columns may diminish any role the columns serve in providing cover to holding Chinook salmon smolts. The new bridge alignment moves the new bridge slightly north of the current location which will change the proportion of water column depths spanned. For example, the current bridge spans a large proportion of 4-6 m deep water relative to other depths. The proposed bridge alignment will diminish this proportion and will increase the proportion spanning 6-8 m depth. When Chinook salmon were near the bridge, depths of 6-8 m had the highest selection ratios in 2007 and in the later 2008 releases. The proposed bridge would increase the availability of near bridge habitat at these depths. Although it is difficult at best to predict how these changes in bridge design and alignment will interact to influence holding Chinook salmon during the day, we believe that patterns in holding Chinook salmon habitat use near and under the bridge will most likely either be similar to those observed at the current bridge or that selection

for near bridge areas will decrease. It is altogether possible, however, that undiscovered factors or unanticipated interactions may contribute to an increase in selection for near bridge habitat.

Exactly how the new bridge alignment will affect the distribution and abundance of northern pikeminnow and smallmouth bass is difficult to predict. Although the new bridge will be substantially wider, the increased elevation would likely reduce the amount of overhead cover for predators and perhaps reduce their overall abundance. Also, a higher bridge may cause macrophytes to be denser under the bridge, which may reduce the foraging ability of smallmouth bass. Alternatively, the increase in macrophytes may increase the habitat suitability for northern pikeminnow. The new bridge alignment is in slightly deeper water which may have a small negative effect on northern pikeminnow which prefer shallow water (4-6 m). The bottom slope of the new bridge alignment is slightly steeper at the depth range used by smallmouth bass, which may slightly improve their habitat conditions. Lastly, a reduction in the number of bridge columns may have a strong negative effect on the abundance of smallmouth bass, which appear to be strongly associated with the existing bridge columns. Overall, the new bridge alignment appears to reduce the quality of the habitat conditions for northern pikeminnow and smallmouth bass.

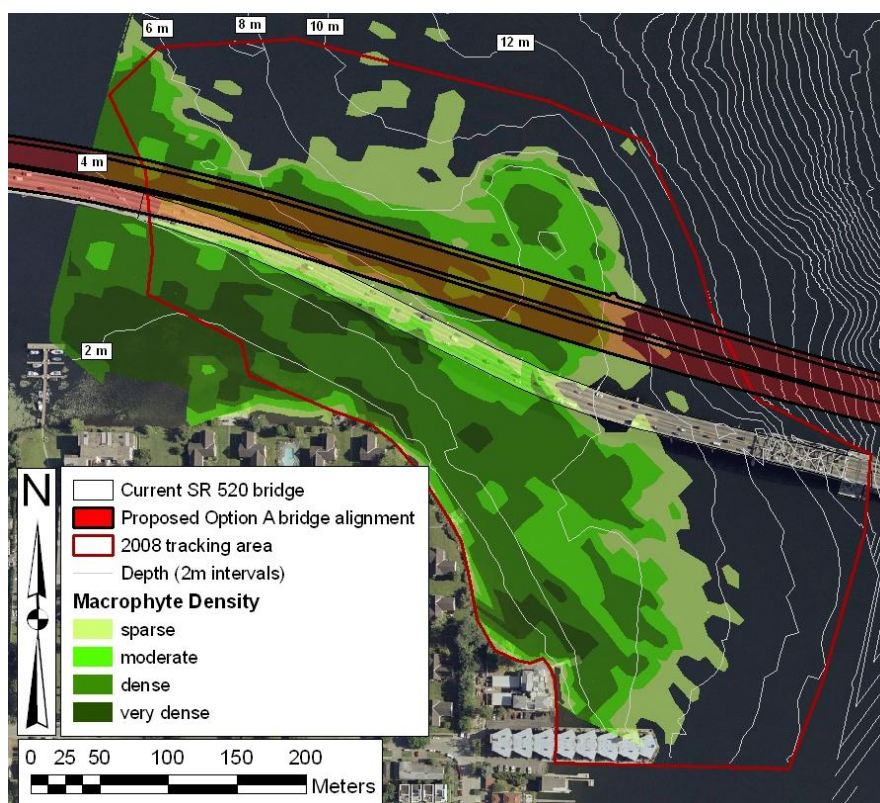


FIGURE 58. Map showing Proposed Option A SR 520 bridge alignment relative to the current bridge alignment at the acoustic tracking study area. Other bridge options would result in similar alignment but with different bridge width. Macrophyte density shown is based on a survey conducted in July 28-August 12, 2008 (see Methods section for survey details).

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