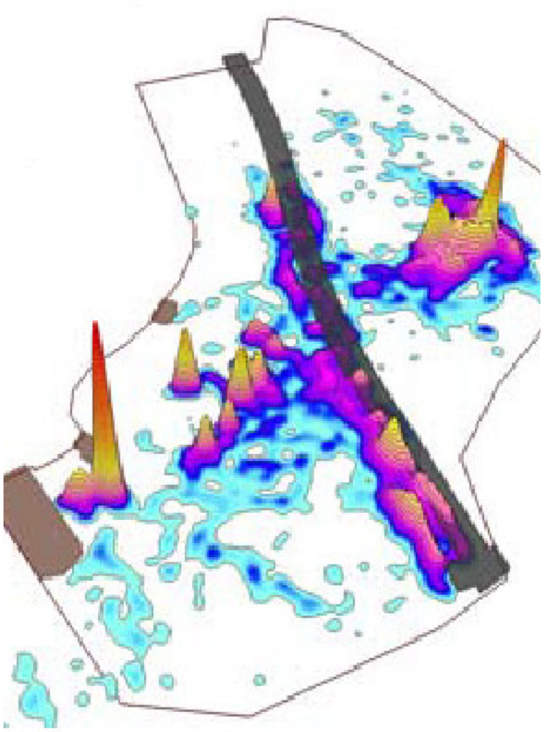
Movement and Habitat Use of Chinook Salmon Smolts, Northern Pikeminnow, and Smallmouth Bass Near the SR 520 Bridge

WA-RD 694.1

Mark T. Celedonia, Roger A. Tabor, Scott Sanders, Steve Damm, Daniel W. Lantz, Terence M. Lee, Zhuozhuo Li, Jon-Michael Pratt, Benjamin E. Price, and Lauren Seyda

October 2008



Washington State
Department of Transportation
Office of Research & Library Services

WSDOT Research Report

U.S. Fish and Wildlife Service

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

2007 Acoustic Tracking Study

October 2008

By Mark T. Celedonia, Roger A. Tabor, Scott Sanders, Steve Damm, Daniel W. Lantz, Terence M. Lee, Zhuozhuo Li, Jon-Michael Pratt, Benjamin E. Price, and Lauren Seyda

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

Washington State Department of Transportation

Funded by the Washington State Department of Transportation

MOVEMENT AND HABITAT USE OF CHINOOK SALMON SMOLTS, NORTHERN PIKEMINNOW, AND SMALLMOUTH BASS NEAR THE SR 520 BRIDGE

2007 ACOUSTIC TRACKING STUDY

FINAL REPORT TO THE WASHINGTON STATE DEPARTMENT OF TRANSPORTATION

by

Mark T. Celedonia, Roger A. Tabor, Scott Sanders, Steve Damm, Daniel W. Lantz, Terence M. Lee, Zhuozhuo Li, Jon-Michael Pratt, Benjamin E. Price, and Lauren Seyda

U.S. Fish and Wildlife Service
Western Washington Fish and Wildlife Office
Fisheries Division
510 Desmond Drive SE, Suite 102
Lacey, Washington 98503

October 2008

TECHNICAL REPORT STANDARD TITLE PAGE

1. REPORT NO. **WA-RD 694.1**	2. GOVERNMENT ACCESSION NO.	3. RECIPIENTS CATALOG NO

4. TITLE AND SUBTILLE Movement and habitat use of Chinook salmon smolts, northern pikeminnow, and smallmouth bass near the SR 520 bridge, 2007 acoustic tracking study, annual report	5. REPORT DATE October 2008 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Mark T. Celedonia, Roger A. Tabor, Scott Sanders, Steve Damm, Daniel W. Lantz, Terence M. Lee, Zhuozhuo Li, Jon-Michael Pratt, Benjamin E. Price, and Lauren Seyda	8. PERFORMING ORGANIZATION REPORT NO. None
9. PERFORMING ORGANIZATION NAME AND ADDRESS U.S. Fish and Wildlife Service, Western Washington Fish and Wildlife Office, Fisheries Division 510 Desmond Drive SE, Suite 102 Lacey, Washington 98503	10. WORK UNIT NO. 11. CONTRACT OR GRANT NO. WSDOT agreement GCA5175
12. SPONSORING AGENCY NAME AND ADDRESS Washington State Department of Transportation 310 Maple Park Avenue SE Olympia, Washington 98504-7372	13. TYPE OF REPORT AND PERIOD COVERED Annual report, May-Aug 2007 14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

This study was conducted in cooperation with the U.S. Department of Transportation, Federal Highway Administration.

16. ABSTRACT

We used a fine-scale acoustic tracking system to track tagged fish in a 17.2 ha area along a 560 m stretch of the SR 520 bridge from late May through early August 2007. The study site was the west end of the bridge in Lake Washington, Washington near Union Bay and lies within a major migratory corridor for Chinook salmon smolts. Thirty-seven, 68 and 66 tagged Chinook salmon smolts were released on June 1, 14, and 28, respectively. Migratory behaviors of tracked fish were similar within release groups but varied considerably between release groups. Most actively migrating Chinook salmon appeared delayed by the bridge. Conversely, fish that were holding in the area rather than actively migrating through appeared to selectively choose to reside in areas near the bridge for prolonged periods. The holding behavior did not appear triggered by the bridge. Results from tagged northern pikeminnow suggest that the bridge may not be a major foraging site. Smallmouth bass strongly selected the bridge as well as nearshore overwater structures.

17. KEY WORDS Juvenile Chinook salmon, habitat use, depth use, smallmouth bass, northern pikeminnow, migration, movement patterns, overwater structures, bridge, acoustic tracking	18. DISTRIBUTION STATEMENT

19. SECURITY CLASSIF. (of this report) None	20. SECURITY CLASSIF. (of this page) None	21. NO. OF PAGES 125	22. PRICE

EXECUTIVE SUMMARY

Large anthropogenic infrastructure such as major bridges in and near waterways can influence the ecological dynamics of the proximate aquatic environment. Such influences can, in turn, affect behavior, habitat use, fitness, and survival of fishes. Many naturally-reared Chinook salmon *Oncoryhnchus tshawytscha* smolts in Lake Washington, Washington must pass beneath the four-lane SR 520 bridge en route to Puget Sound. The goal of our study was to evaluate movement and habitat use of Chinook salmon smolts and two predators - northern pikeminnow *Ptychocheilus oregonensis* and smallmouth bass *Micropterus dolomieu* - near the SR 520 bridge.

We used a fine-scale acoustic tracking system developed by Hydroacoustic Technology, Inc. (HTI), Seattle, Washington to track tagged fish in a 17.2 ha area along a 560 m stretch of the SR 520 bridge from late May through early August. The study site was on the west end of the bridge near Union Bay, and was believed to lie within a major migratory corridor for Chinook salmon smolts. Naturally-reared smolts moving from south Lake Washington travel north along the western shore of the lake and encounter the bridge before moving into Union Bay and the entrance to the Lake Washington Ship Canal (LWSC) en route to Puget Sound. Additionally, hatchery-reared smolts occur throughout Lake Washington and many move along the southwestern shore of the lake and encounter the bridge before moving into Union Bay. We used hatchery-reared Chinook salmon smolts as a surrogate for naturally-reared fish due to various tagging constraints and lack of available naturally-reared smolts of suitable size. Tagged smolts were released 800 m south (upstream) of the study site to observe behaviors as they volitionally entered the study site and encountered the bridge. Most predators were captured on-site, tagged, and released near the place of capture.

Thirty-seven, 68, and 66 tagged Chinook salmon smolts were released on June 1, 14, and 28, respectively. Migratory behaviors of tracked fish were similar within release groups and varied considerably between release groups. June 1 smolts exhibited an active migration pattern, rapidly migrating through the study site and into the LWSC. Most of these fish spent < 2 h at the study site and reached the University Bridge in the LWSC < 5 h after release. Conversely, June 14 and 28 smolts exhibited holding behaviors at and near the study site, which did not appear to be a direct consequence of the bridge. Most of these fish spent > 30 h at and near the study site, and took > 65 h to reach the University Bridge after release. Differences in timing of migrational cues (e.g., moon apogee), physiological smolt status, water temperature, water clarity, and prey availability may have contributed to the differences in migrational behaviors observed between release groups.

Fish response to the bridge appeared to be at least partially dependent upon migratory behavior – i.e., whether fish were actively migrating or holding. About two-thirds (67%) of actively migrating smolts appeared delayed by the bridge. The remaining one-third (33%) appeared negligibly affected by the bridge. Of the fish that delayed, time of delay and distance traveled during delay varied widely. Nearly half (45%) of the delayed smolts took < 3 min to pass beneath the bridge after initial encounter, travelling < 33 m

along the edge of the bridge during this time. Conversely, many smolts that were holding as opposed to actively migrating appeared to selectively choose to reside in areas near the bridge for prolonged periods. This behavior was distinctly different from the apparent bridge-induced delay observed in some actively migrating smolts. Instead, holding fish often crossed beneath the bridge to the north and were later observed returning to and holding in areas immediately adjacent to the bridge's southern edge (< 20 m from the edge of the bridge). Reasons for this behavior were uncertain, but may have been associated with fish using the bridge as potential cover (i.e., shadow and/or structure). The bridge did not appear to be a factor in delaying migration of holding fish.

Tagged Chinook salmon passed beneath the bridge throughout the study area and no single location appeared more heavily used than others. The eastern portion appeared more favored particularly with the June 14 and June 28 releases. This may have been partially due to increasing macrophyte density and height during the study period on the western portion of the site, and perhaps also the different migrational status of the latter two releases. Passage behavior may have also been influenced by water depth and bridge shadow, as well as such related parameters as specific location of the bridge shadow at time of encounter, the degree of contrast at the light-shadow edge, height of the bridge above the surface of the water, light intensity at time of crossing (i.e., sunny or cloudy day), and presence of and variation in macrophytes and macrophyte density. Many of these factors varied together through much of the study site, and thus could not be isolated for their individual influence on passage behavior.

We observed holding behaviors in a large number of Chinook salmon at and near the study site, which appeared to increase the total amount of time spent at and near the bridge. Such holding behaviors may be triggered by an inhibition to enter the Montlake Cut arising from one or more ecological barriers, such as high water clarity and lack of a suitable shallow water migrational corridor through the Montlake Cut, and/or elevated water temperatures in this area. Inhibitions may also arise from a decrease in migrational urge associated with desmoltification caused by prolonged exposure to elevated water temperatures and/or high prey availability. Minimizing these non-bridge related effects may diminish time spent by Chinook salmon smolts at and near the bridge.

The bridge appeared to influence habitat use of holding (i.e., not actively migrating) Chinook salmon smolts. Holding smolts statistically selected for areas near the bridge (5-20 m from bridge edge), as well as areas of dense macrophytes away from the bridge. When near the bridge, smolts shifted to deeper water: smolts selected most for 4-6 m water column depth when not near the bridge, and 6-8 m depth when near the bridge. These differences were less apparent at night. The reasons for this are uncertain, but may have been due to the bridge serving as a source of cover that allowed smolts to access deeper, cooler water and/or presumably better foraging opportunities.

Twenty-one northern pikeminnow were captured, tagged and released at the study site. Only six of these fish used the tracking area to any appreciable extent. The other 15 fish appeared to leave the site shortly after release and returned for only short periods if at all. Other studies have indicated that captured pikeminnow often vacate the area where they were captured after release. In general, the six fish that used the site did not show statistical selection for or against the bridge or areas near the bridge. That is, the bridge and areas near the bridge were generally used in proportion to their availability. Use of the bridge varied widely between individuals. Exactly when pikeminnow feed and what they consume at the study site is not known. Given this uncertainly, the variability between individuals, and the small sample size used in this study, it is difficult at best to ascertain the relationship between the bridge and pikeminnow foraging behavior, predator-prey interactions, and predation rate on Chinook salmon. Although our findings suggest that the bridge may not be a major foraging site for northern pikeminnow, further study is needed to reach more conclusive results.

Most often, northern pikeminnow selected moderately dense to dense vegetation during all times of day and night, and strongly selected overwater structures other than the bridge during the day only. Offshore open water areas and the offshore edge of vegetation were most often selected against. Northern pikeminnow selected for 4-6 m water column depth during all diel periods. Northern pikeminnow remained nearshore during the day, and used both nearshore and offshore areas during dusk and night.

Six smallmouth bass were captured, tagged, and released on-site. Also, seven smallmouth bass that were captured, tagged and released in the LWSC as part of a separate study were observed at the SR 520 study site. Of the six on-site fish, two were small (≤ 185 mm FL) and four were large (245-375 mm FL). The small fish overwhelmingly selected for nearshore overwater structures (i.e., boat docks), and made no notable use of the bridge. The four larger fish selected for both nearshore overwater structures and the bridge. Some bass appeared to associate closely with bridge columns. The seven smallmouth bass released in the LWSC generally showed similar patterns as the four large bass released on-site.

The ultimate questions of how the current bridge affects fitness and survival of Chinook salmon, and how the new bridge might be designed and sited so as to minimize any negative impacts to Chinook salmon are complicated and require further study. Future studies should consider: 1) evaluating consequences of migrational delay to predation rate; 2) evaluating causes of migrational delay and methods for minimizing delay, perhaps through some manipulation-type experiments; 3) evaluating why some holding smolts select areas near the bridge; 4) evaluating why holding smolts near the bridge select for deeper water; 5) consequences of #3 and #4 on predation rates and migration delay; 6) evaluating non-bridge sources of migrational delay (e.g., inhibitions to enter Montlake Cut), and subsequent consequences as they relate to the bridge; 7) increasing sample sizes of predators; 8) evaluating foraging behavior and diet of predators near the bridge; 9) evaluating predation rates of Chinook salmon at the bridge and in areas not near the bridge.

TABLE OF CONTENTS

LIST OF FIGURES

Page

LIST OF TABLES

INTRODUCTION

Puget Sound Chinook salmon *Oncoryhnchus tshawytscha* (listed as threatened under the Endangered Species Act) are an important component of the Lake Washington ecosystem. Within Lake Washington, juvenile Chinook salmon primarily rear in the south end of the lake from January to May (Tabor et al. 2006). In May through July, they are located throughout the lake and outmigrate to the marine environment through the Lake Washington Ship Canal (LWSC). The shoreline of Lake Washington has been extensively modified and recent research efforts by the U.S. Fish and Wildlife Service (USFWS) and the City of Seattle have attempted to understand how these changes affect juvenile Chinook salmon. Extensive armoring reduces the amount of gentle sloping shorelines that small juvenile Chinook salmon use from January to May (Tabor and Piaskowski 2002). Overwater structures can provide overhead cover for small juvenile Chinook salmon in February and March but afterwards they tend to avoid these structures as they grow larger and predators, such as smallmouth bass *Micropterus dolomieu*, move inshore. During the outmigration period, juvenile Chinook salmon in Lake Washington often move along the shore in the morning in about 1-5 m deep water and as they encounter overwater structures they often move to deeper water, presumably to reduce their predation risk (Celedonia et al. 2006). Their behavior at each structure varies depending on a variety of factors, such as structure size, proximity to other structures, light conditions under the structure, and the occurrence of aquatic macrophytes. When Chinook salmon outmigrate in Lake Washington, they are close to shore in shallow water during the day and far offshore in limnetic areas at night. However, in the LWSC, they are broadly distributed across deep-water areas (water column depth, >8-10 m) during all time periods, not just the day (Celedonia et al. 2006).

The State Route (SR) 520 bridge is a unique structure in Lake Washington in that it completely spans the lake and the west end is located in a transition area between Lake Washington and the LWSC. In this transition area, Chinook salmon smolts are presumed to concentrate in large numbers during the outmigration period. The Issaquah Creek Hatchery releases over 2 million Chinook salmon and wild production from the Cedar

River, Bear Creek, and other tributaries are also be present. Most naturally-produced fish in the basin originate from the Cedar River, and must therefore pass beneath the bridge during outmigration. Chinook salmon coming from the north part of the lake (including the hatchery fish) can exit the system without having to pass under the bridge. However, hatchery-produced fish appear well distributed around the entire lake, including south of the bridge. Thus, large numbers of hatchery fish also pass under the bridge during outmigration. How juvenile Chinook salmon migrate past the SR 520 bridge is not known. The Washington State Department of Transportation (WSDOT) has proposed to build a new bridge to improve mobility for people and goods across Lake Washington and replace the existing structure. Information on fish movements at the existing structure will allow WSDOT to better understand how the new structure may impact Chinook salmon and perhaps make modifications to improve fish passage.

An important factor influencing juvenile Chinook salmon behavior is predation risk. Their behavior near a large structure such as the SR 520 bridge may be influenced by predator avoidance. Most large in-water structures can be avoided by juvenile Chinook salmon by moving into deeper water and away from the structure. However, juvenile Chinook salmon inhabiting the south part of the lake must pass under SR 520 to reach the marine environment. As they pass under the bridge they may encounter various predatory fish; however, the extent that predators inhabit and feed beneath the bridge, and whether there is increased predation risk near the bridge is not known. The primary focus of our study was to document the movement patterns of juvenile Chinook salmon but we also wanted to determine the interrelationship between the bridge, Chinook salmon behavior, and predatory fish distribution.

Important fish predators of outmigrating juvenile Chinook salmon and other salmonids in Lake Washington include cutthroat trout *O. clarkii* (Nowak et al. 2004), northern pikeminnow *Ptychocheilus oregonensis* (Olney 1975; Brocksmith 1999), and smallmouth bass (Tabor et al. 2007). Predaceous cutthroat trout inhabit the pelagic zone and are highly mobile (Nowak and Quinn 2002) and would most likely be difficult to study at the SR 520 bridge. Northern pikeminnow inhabit the littoral zone as water temperatures increase and may be abundant at our study site in response to an increase in juvenile salmonid abundance. They have been shown to congregate in other areas in Lake Washington (Olney 1975) and in other systems (Collis et al. 1995) where prey is abundant. Little is known if they use overwater structures, such as the SR 520 bridge, to ambush their prey. They have been shown to congregate around various structures at dams to prey on migrating juvenile salmonids; however, their exact location is more related to water velocity and prey abundance and not necessarily the in-water structure.

In contrast to northern pikeminnow, smallmouth bass have been well documented to use overwater structures. For example, Fresh et al. (2001) found 49% of all smallmouth bass observed in Lake Washington were within 2 m or less of an overwater structure. However, Fresh et al. (2001) also found their distribution was strongly influenced by substrate type. Cobble and boulder substrates are preferred over finer substrates. Smallmouth bass also appear to prefer areas where the bottom slope is steep (Hubert and Lackey 1980). The area around the SR 520 bridge has overwater structure and steep slopes but the substrate consists primarily of fine substrates. Therefore, it’s unclear if smallmouth bass use the bridge to any extent.

We used a fine-scale acoustic tracking system to monitor fish movements and habitat used at the west end of the SR 520 bridge. This area was selected based on prior observations suggesting that large numbers of migrating Chinook salmon move northward along the western shore of Lake Washington south of the SR 520 bridge. The objectives of the study were to: 1) document juvenile Chinook salmon migration patterns near the existing bridge; and 2) determine the relationship in space and time between outmigrating juvenile Chinook salmon and piscivorous fishes. In developing this research project we created an initial conceptual model for fish activity near the SR 520 bridge. This conceptual model generated several expectations which guided the study design and formed testable hypotheses. With regard to Chinook salmon smolts, we predicted that the bridge would not influence movement or habitat use of tracked fish. We assumed that the intent of tagged fish to migrate through the study area and beyond the bridge would be clear, and that abrupt changes in direction of travel at the bridge would indicate a bridge effect. For both Chinook salmon smolts and predators we predicted that habitat selection would be similar in areas near and away from the bridge, and that areas near the bridge would not be selected any more or less than areas away from the bridge. Differences in habitat selection ratios between areas near the bridge compared with areas away from the bridge would suggest a bridge effect.

METHODS

Fine-Scale Acoustic Tracking System

Tracking was performed using a fine-scale acoustic system developed by Hydroacoustic Technology, Inc. (HTI), Seattle, Washington. This system uses acoustic tag transmitters implanted within the study fish, and a fixed array of underwater listening devices - termed hydrophones - to track fish movements in a specific study area. Tag transmitters are programmed to periodically emit a signal, or ping. The length of time between each ping is called the ping rate. Each fish is given a unique ping rate so that movements of individual fish can be tracked. When a tagged fish moves through or near a hydrophone array, each ping is detected by the hydrophones at slightly different times depending on how far the fish is from each hydrophone. The system then uses these time differentials to triangulate a 3-dimensional position for the origin of each ping. Calculated positions are relatively accurate, estimated to be ± 0.5 m in the horizontal plane when the fish is within the perimeter of the hydrophone array. Accuracy declines outside the array perimeter, but has been estimated to be approximately ± 3 m in the horizontal plane at a distance of 1 array width from the array perimeter. In general, we accepted calculated fish positions from both within and outside the array perimeters. We excluded positions that were apparently beyond the area that the equipment could effectively track. Accurate results in the vertical dimension require that hydrophone positioning meet specific geometric parameters, which were not obtainable due to various constraints at the study site.

All of the hydrophones in a given array are cabled into a shared receiver which processes tag pings and other acoustic signals detected by the hydrophones. HTI Model 290 Acoustic Tag System receivers were used for this study. Each receiver is connected to a personal computer that logs the acoustic data. An individual raw data file is created for each hour that the equipment is operating. Each raw data file contains all acoustic signals detected during that hour, including signals from tagged fish as well as noise from such sources as passing motor boats and raindrops striking the water surface. Each raw data file must be processed through HTI MarkTags software to identify fish signals and isolate them from any noise that might be present. This can be accomplished in two ways: manually, or through an “autotrack” feature built in to MarkTags. The manual method is more precise and certain, and was the method used for this study. This method requires the researcher to open each raw data file, look for each fish that could possibly be present, and highlight any observed tag signals. Isolated tag signals are then processed through HTI AcousticTag software. AcousticTag performs the triangulation calculations and provides a database of point locations for each fish. For the remainder of this report, we refer to these calculated point locations simply as “data points.” The “track” for an individual fish is the temporally sequenced collection of all its data points.

Study Overview

The study site was located on the western shore of Lake Washington and included an approximately 0.5 km stretch of the bridge (Figure 1). This general area comprises a transition between the 60 m-deep Lake Washington proper, and the much shallower 10-12 m-deep Union Bay and entrance to the LWSC. The shoreline within the study area changed abruptly from a north-south orientation to a west-east orientation at the opening to Union Bay. The study site had a gently sloping gradient extending north and east from the shoreline. On the east side of the site the gradient steepened considerably starting at ~ 10-12 m depth. Prominent features of the study area in addition to the bridge included: a large condominium building that extended over the water on the very southern edge of the site; two small boat docks along the southern shoreline; dense and abundant macrophytes (primarily the non-natives Brazilian elodea *Egeria densa* and Eurasian milfoil *Myriophyllum spicatum*) generally in most areas < 6 m deep and particularly on the south side of the bridge; and, an anomalous peninsula-like ledge with shallower water (4-6 m depth) extending northward from the bridge on the east side of the site (Figures 2 and 3). Substrate throughout the area appeared to consist largely of sand and silt, although we did not perform a formal substrate survey to verify this.

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

Previous studies suggest that migrating Chinook salmon smolts move northward along the western shoreline of Lake Washington prior to encountering the SR 520 bridge and Union Bay (Tabor et al. 2006; Celedonia et al. 2006). Migration has generally been observed during the early day (approximately 0800-1400 hours) and close to shore in shallow water 1-5 m deep. Migrating Chinook salmon smolts appeared to avoid overwater structures such as boat docks. Fish usually moved farther from shore into deeper water to pass beneath the structure, or, rather than passing beneath the structure, fish traveled around the structure along its perimeter. Migrating smolts did not appear to avoid non-native aquatic macrophytes. Instead, macrophytes appeared to serve as a false-bottom that smolts simply moved above.

We deployed a 16-hydrophone array on the south side of the bridge, and a 10-hydrophone array on the north side (Figure 2). Each array was cabled into separate receivers, and therefore functioned independently. We initially spread hydrophones further apart on the west end of the south array in order to cover more bridge length. However, aquatic macrophytes in this area were quite dense and diminished tag signal strength enough that fish would not have been tracked here. Thus, we spaced hydrophones closer together to ensure a strong enough signal for tracking fish. The combined area covered by both arrays totaled 17.2 ha, encompassing 560 m of bridge length. Once hydrophones were deployed, we performed extensive system testing to ensure sufficient operability and quality of data. Testing included ping arounds, tag drags, and release of tagged test fish (coho salmon *O. kisutch*). The size of the array coverage area was determined by results of tag drags and plotting all Chinook salmon and predator data points and visually determining the outside boundary.

Hydrophones were either bottom-mounted or surface-mounted. Bottom-mount anchors consisted of nominal 30-kg blocks of concrete. Posts of 2.54-cm-diameter conduit protruded approximately 0.5-1.5 m above the top surface of the concrete. Hydrophones were mounted at or near the top of these posts using metal hose clamps. Metal rods of 0.64- or 0.95-cm-diameter rebar extended approximately 0.5 m in four directions from the base of each anchor to stabilize them on the substrate. Eyebolts were embedded at the top of each anchor so that they could be deployed and retrieved with ropes from a boat. Deployed anchors were inspected to ensure that they were in an appropriate upright position on the substrate. Shallow water locations were inspected visually from a boat, and deep water locations were inspected using an underwater camera. Surface mounts were constructed of 2.54-cm-diameter conduit and attached to bridge columns using stainless steel banding material. Surface mounted hydrophones were generally about 1.25 m below the water surface. The water depth at each hydrophone location was measured, and a Global Positioning System (GPS) unit was used to record the location of each hydrophone. StowAway TidbiT temperature loggers were attached near the hydrophone on each mount. Temperature loggers were programmed to record water temperature at 30-minute intervals.

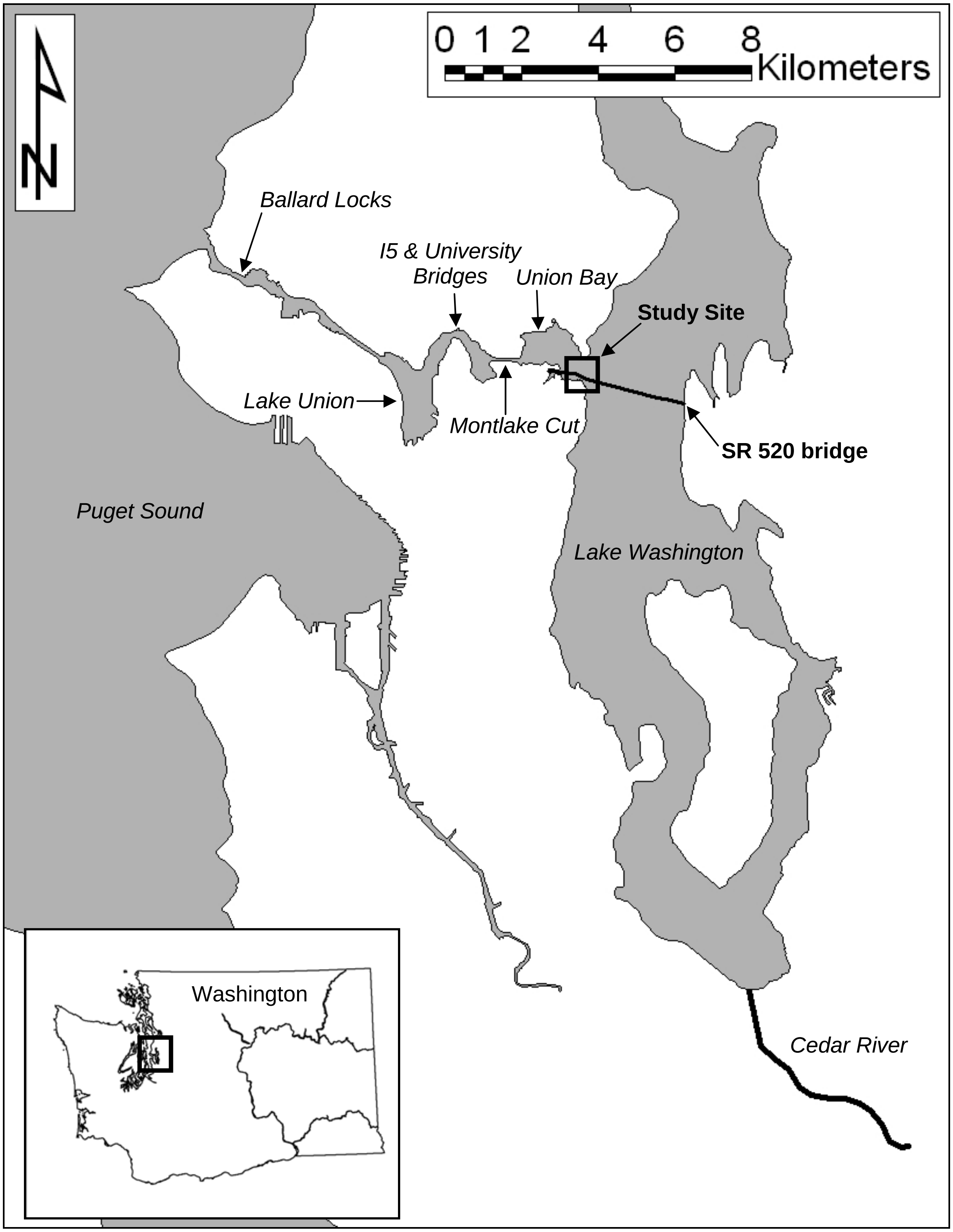


FIGURE 1. Map of Lake Washington showing 2007 study site location at the west end of the SR 520 bridge.

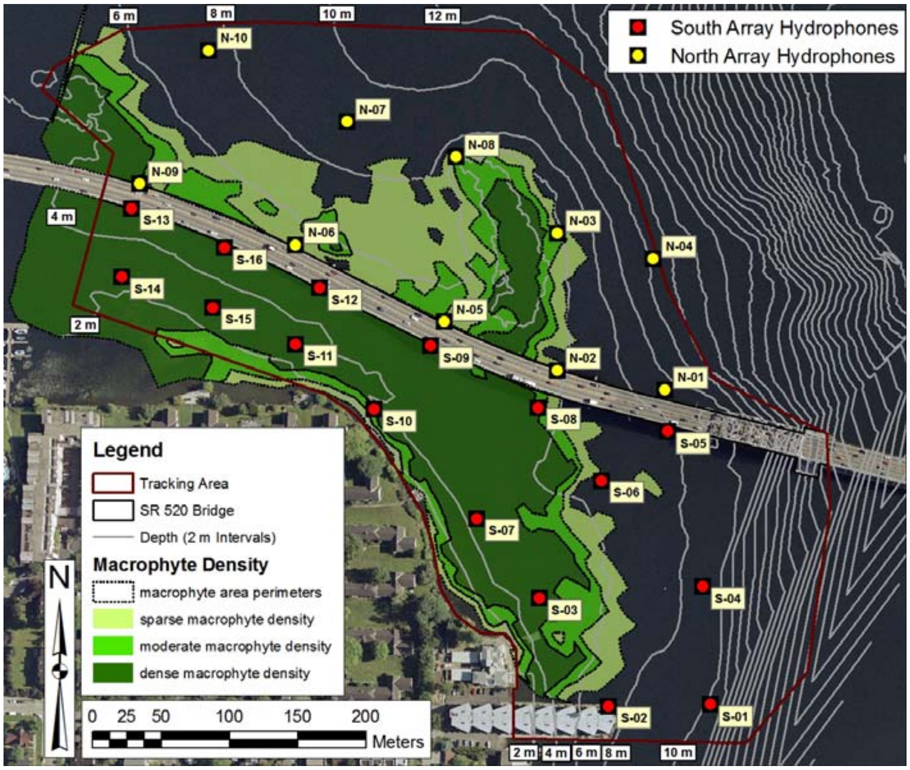


FIGURE 2. Locations of acoustic hydrophones operated at the SR 520 bridge study site, May-August 2007. Hydrophones on the south (red) and north (yellow) sides of the bridge were connected to separate receivers. Thus, each array functioned independently of the other.

Chinook salmon smolts

The study design for Chinook salmon smolts was to release three groups of 60 tagged fish, one each in early- mid- and late-June. Two sizes of acoustic tags were used for Chinook salmon smolts. In general, larger smolts (≥ 12.5 g) were implanted with HTI Model 795m MicroAcoustic Tags. These tags weighed 0.75 g in air, and measured 6.8 mm in diameter and 16.5 mm in length. Smaller smolts were implanted with HTI Model 795s MicroAcoustic Tags, which weighed 0.65 g in air and measured 6.7 mm in diameter and 16.4 mm in length. Each tag was programmed to emit a signal unique from other tags, which allowed us to track movements of specific fish. Salmonid tags were programmed with ping rates of 2.6-3.6 s. Tag life varies with water temperature, pulse width and ping rate. For this study, the 795m and 795s tags were expected to last 12 d.

Usually tags are switched on immediately prior to implant, meaning that some tag life is essentially wasted during the post-implant/pre-release recovery period which is usually at least 24 h. However, new technology developed by HTI and procured by USFWS allowed tags to be switched on after implant thereby saving pre-release tag life. For this study, tags were not switched on until the morning of release.

Hatchery-reared smolts obtained from Washington State's Issaquah Hatchery were exclusively used for this study. Hatchery-reared Chinook salmon smolts were assumed to provide a reasonable surrogate for naturally-reared fish in Lake Washington. Multi-year PIT tagging studies indicate that movement timing of Issaquah Hatchery juveniles is similar to their naturally-reared counterparts (DeVries et al. 2005; DeVries et al. 2007). Also, acoustic tracking studies conducted in 2004 and 2005 by USFWS at 3 sites in Lake Washington and the LWSC indicated that movement timing, spatial distribution, habitat use and movement patterns were largely equivalent between hatchery- and naturally-reared Chinook salmon smolts (Celedonia et al. 2006).

Study fish were held and reared at the Issaquah Hatchery until tagging. Juveniles intended for this study were held in a separate tank at the hatchery and were placed on an accelerated growth regimen to ensure that sufficient numbers of adequately sized fish would be available for tagging when needed. The accelerated growth regimen consisted of rearing the fish in warmer water than what is normally used at the hatchery. Study fish were transported from the Issaquah Hatchery to the King County Environmental Laboratory (MetroLab) the Monday or Tuesday prior to release. Fish were mildly anesthetized in a solution of tricaine methane sulphonate (MS-222) and measured prior to transport to ensure that they were of sufficient size to tag. Fish were acclimated from Issaquah Hatchery water temperature (approximately $13^{o}C$) to MetroLab temperature over a period of approximately 0.5 h. Temperatures between the two facilities were generally within $3^{o}C$ of each other. Fish were allowed to recover from transport for approximately 24 h prior to tagging.

All tags were implanted using a surgical procedure. All surgical instruments and tags were sterilized in a solution of distilled water and 2-5% Nolvasan ® disinfectant. Instruments and tags were allowed to soak for ≥ 5 min, then rinsed in a 5-10% saline bath. Fish were anesthetized in a solution of MS-222 buffered with sodium bicarbonate. Most fish were adequately anesthetized within 3 min. Anesthetized fish were removed from the MS-222 solution, washed with cool fresh water, and measured for length and weight. Smolts were placed on a customized surgical platform consisting of a piece of foam with a depression scored in the center. This was soaked in cold water prior to tagging. The foam surgical platform held the fish in a suitable and stable position, and helped keep it cool during the surgery. Fish were placed in the platform's depression with the ventral side exposed. During the surgery, a pipette was used to irrigate the gills with MS-222 solution at 30 s intervals. An incision approximately 8-12 mm long was made between the pectoral and pelvic fins. The tag was then inserted into the peritoneal cavity through the incision. Two or three sutures of 6-0 coated Vicryl® braided suture material were used to close the incision. Fish were then placed in a recovery tank of cool fresh water. The entire operation was usually completed in 5-8 min. After implant, smolts were allowed to recover for approximately 36 h prior to transport from the King County Lab to the tag programming facility. Tank water temperature was slowly elevated from approximately 13°C to 18-20°C which corresponded with nominal lake surface water temperature. Temperature elevation began within 1-2 h after surgery and was completed over a period of 24 h. Fish behaving abnormally after the recovery period were removed from the sample.

Implanted tags were programmed the morning of release at the University of Washington Hatchery. Fish were transported from the King County Lab to the University of Washington Hatchery during late-afternoon the day prior to programming and release. An in-situ tag programmer developed by HTI was used to program and switch tags on the morning of release. This device is essentially a large plastic tube with a programming coil in the center. Fish were placed in one end of the tub, and flowing water was used to help guide individual fish into the programming coil. Once the fish was in the coil area, gates were closed at either end to hold the fish in place. The programming coil was connected to a standard laptop computer which was used to program the tag and switch the tag on. Once this was accomplished, the gate at the downstream end of the coil was opened and the fish was transported via flowing water into a temporary holding tank. Independent acoustic verifiers on the programming coil and in the holding tank verified that tags had been switched on. The entire programming process and transport to the release site was performed without anesthetic. Tagged Chinook salmon were released at the Madison Park swim beach approximately 800 m south of the study site in water 1.5 - 2.0 m deep.

Raw acoustic data files were evaluated for the presence of all fish released within 12 d prior to the time period included in the file. Raw acoustic data was used to determine movement timing of each Chinook salmon released. Movement timing of released Chinook salmon was determined between 3 sites: 1) release site, 2) SR 520 bridge study site, and, 3) the University Bridge in the LWSC (Figure 1). The study site at the University Bridge was part of a separate study for Seattle Public Utilities (SPU). We operated a 12-hydrophone array here during the same time and with equipment identical to that used at the SR 520 bridge site. The University Bridge array covered the full width of the LWSC. Thus, we were able to determine when and how many SR 520 study fish migrated through this area. Specifically, Chinook salmon movement timing was determined for: 1) release to first detection at the SR 520 study site; 2) last detection at the SR 520 study site to first detection in the LWSC at the University Bridge; and, 3) release to first detection in the LWSC at the University Bridge.

We also determined a general site area residence time and tracking time for each fish at the SR 520 site. The general area residence time was defined as the time from the first detection at the SR 520 site to the last detection at the site, regardless of any gaps in between. For example, a fish may be detected on-site, then leave the area and go undetected for some amount of time, then appear detected on-site again. Fish showing such discontinuities were assumed to remain relatively near the tracking site. The tracking time was defined as the total amount of time the fish was actually tracked on site, and therefore excluded gaps when the fish was not present.

Raw fish location point data output from the AcousticTag software was imported into ArcMap 9.2 Geographic Information System (GIS) software. Fish tracks were graphically represented and analyzed by overlaying them on an orthophoto with bathymetry and vegetation contours. Each fish track was evaluated for signs of mortality which included: 1) no sign of fish movement in the fish track; 2) no sign of fish movement in the raw hydrophone data; and, 3) extraordinarily unusual characteristics in the fish track. An existing orthophoto and bathymetry data were obtained from SPU. Bathymetry was checked against depth measurements that we collected while surveying for aquatic macrophytes. SPU bathymetry data was generally accurate, however some adjustments were necessary at depths ≤ 4 m.

We evaluated population-level habitat and depth selection for each release group of fish. We calculated a population-level selection ratio proposed by Manly et al. (2002) and advocated by Rogers and White (2007). For a given release group of Chinook salmon, the selection ratio for habitat type or depth category *i* was calculated as

$$\hat{w}_i = (u_{i+} / u_{++})/(\pi_i)$$

where u_{i+} is the amount of time spent by all fish in habitat or depth *i*, u_{++} is the amount of time spent by all fish in all habitats or depths within the study area, and π_i is the proportion of available habitat or depth in category *i* relative to all available habitats or depths at the study site. The study site tracking area was divided into eight habitat types based on density of aquatic macrophytes and proximity to overwater structures (Table 1, Figure 3). For depth selection, the tracking area was segregated into water column depths at 2 m intervals (i.e., 0-2 m, 2-4 m, etc.). The total horizontal area of each habitat and depth category contained within the tracking area was considered that category's availability. For each fish, the proportion of points lying within each habitat or depth category was used as a surrogate for the amount of time spent in that habitat or water column depth. This assumes that the probability of obtaining a data point is equal throughout the array coverage area, and that array coverage is not biased for or against any habitat types or depth categories. The point data for each fish were separated into appropriate habitat and depth categories using standard tools in ArcMap 9.2.

To determine if there was significant selection among a release group of fish for a particular habitat type or depth category, simultaneous Bonferroni 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 depth categories, and

$$SE(\hat{w}_i) = \sqrt{\frac{n}{(n-1)(u_{++})^2} \sum_{j=1}^{n} \left(\frac{u_{ij}}{\pi_i} - \hat{w}_i (u_{+j}) \right)^2}$$

where n is the number of fish tracked across all habitat types or depth categories, u_{ij} is the amount of time spent in habitat type or depth category i by fish j, and u_{+j} is the amount of time fish j was tracked across all habitat types or depth categories. Selection for a habitat or depth occurs if the lower confidence interval is > 1, and selection against a habitat or depth occurs if the upper confidence interval is < 1. Confidence intervals that include 1 indicate proportional distribution across that habitat type or depth category. That is, the habitat type or depth category is nether selected for nor selected against, but rather is used in proportion to its availability. These methods avoid the problem of pseudoreplication by taking each animal as the experimental unit (Aebischer et al. 1993; Garton et al. 2001; Manly et al. 2002; Rogers and White 2007). Also, by evaluating each animal's proportional use of habitats and depths, serial correlation between an individuals data points does not present a problem (Aebischer et al. 1993; Rogers and White 2007). In fact, the high frequency of location sampling achieved with the HTI system provides a concomitantly high level of detail with regards to habitat use. Such detail, according to Aebischer et al. (1993), provides more precise estimates of habitat use, and the associated high degree of serial correlation is rendered a non-issue as long as proportional habitat use of individuals is the basis for analysis.

We determined spatial frequency distribution of each release group of fish using ArcGIS 9.2 Spatial Analyst. The total number of fish that occurred within a 4 m radius of each tracked fish data point was determined. Graphical representation of results provided an indication of Chinook salmon dispersal throughout the site and highlighted areas of the site that were commonly used by the fish. For analyses involving diel periods, early day was defined as the period from 1 h after sunrise to 1359 hours. Late day was defined as 1400 hours to 1 h before sunset. Night was defined as the period from 1 h after sunset to 1 h before sunrise. The two crepuscular periods of dawn and dusk were also recognized.

Northern Pikeminnow and Smallmouth Bass

All predators collected at the study area except one were collected with sinking horizontal gill nets. 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. One end of the net was set directly under SR 520 and the net was then deployed perpendicular to the highway. By setting the net directly under the highway and running it perpendicular to the highway, we were able to ensure that the net did not get tangled in any of the hydrophone anchors. Under the highway, the hydrophones were attached to the columns and thus we were easily able to avoid the anchors. The gill nets were set in approximately 5 to 10 m deep water. In general, predatory fish were collected in all three gillnet sites. To minimize stress to fish, we slowly brought the net 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

TABLE 1. Eight habitat types used to determine habitat selection at the SR 520 bridge study site, May-August 2007. The total coverage of the tracking area was 17.2 ha.

Habitat type	Abbreviation	Description	Area (ha)	Percent
Dense vegetation	DV	Area of dense macrophytes not including area near SR520 Bridge	3.29	19.13
Moderately dense vegetation	MV	Area of moderate density macrophytes not including area near SR520 Bridge	1.16	6.74
Sparsely dense vegetation	SV	Area of low density macrophytes not including area near SR520 Bridge	1.77	10.32
Offshore edge of vegetation	VE	Offshore area that is within 20 m of macrophytes not including area near SR520 Bridge	2.10	12.24
Open offshore area	OO	Open offshore area that is not within 20 m of macrophytes and does not include area near SR520 Bridge	5.24	30.47
Other overwater structures	OWS	Area that is directly under or within 5 m of three nearshore structures (the piers at Edgewater Apartments and Madison Point Condominiums and the building of the Lakeshore West Condominiums)	0.31	1.79
SR520 Bridge	BR	Area that is directly under bridge or within 5 m	1.66	9.63
Area near SR520 Bridge	NBR	Area that is between 5 and 20 m of the bridge	1.66	9.66

was tagged. In addition to gill nets, we also tried to collect predatory fish through angling; however, catch rates were low. Only two northern pikeminnow were collected and only one was tagged because the other was killed by an otter while in a holding pen. We also tagged and released one smallmouth bass (185 mm) at the study site that was captured by beach seining at West Montlake Park on the west end of Montlake Cut (Figure 1). Based on previous work in the LWSC, small smallmouth bass appear to stay in a localized area; whereas, larger fish are more mobile and often return quickly to the location where they were collected. Therefore, we thought this small fish would probably stay within the SR 520 study site for an extended period of time and provide valuable information of its habitat use patterns. To increase our sample size of smallmouth bass, we also included seven fish that were tagged and released in the

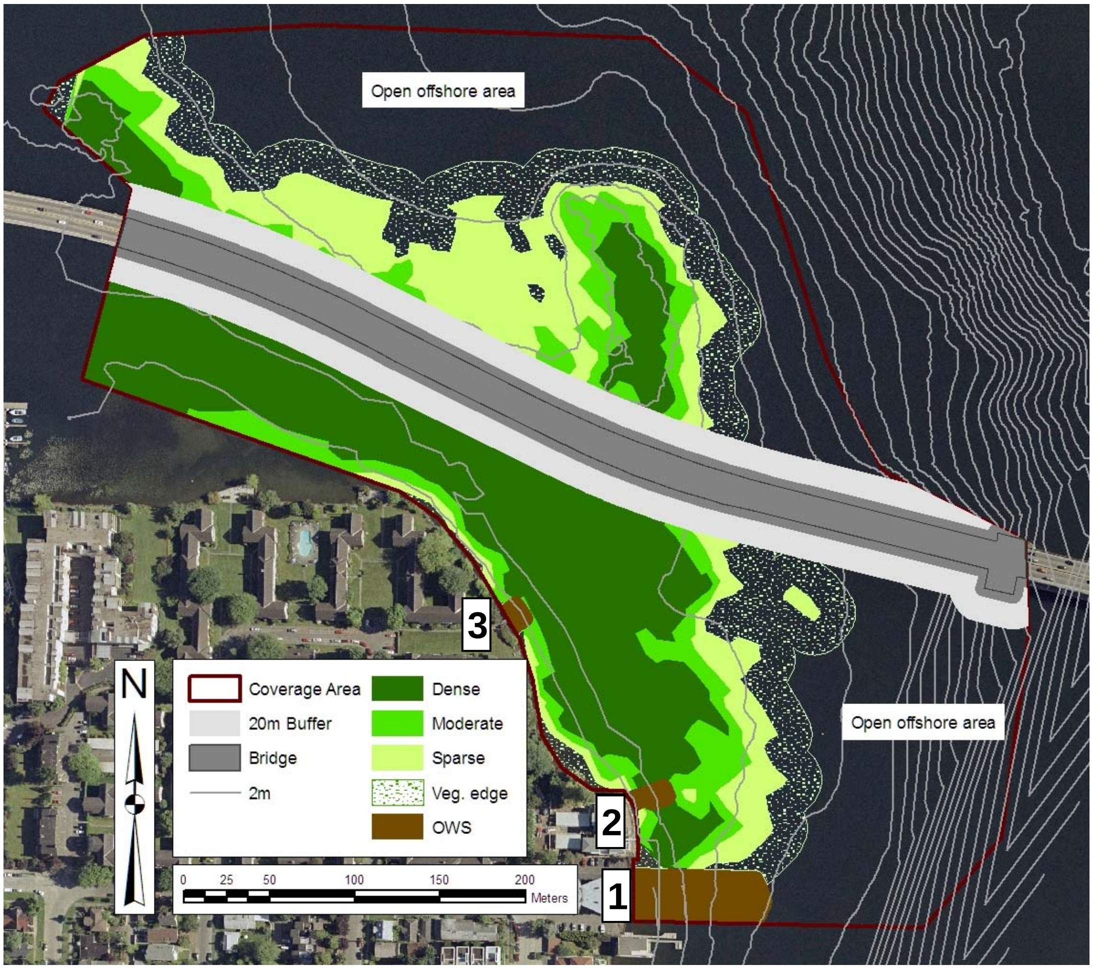


FIGURE 3. Eight habitat types used to determine habitat selection of Chinook salmon smolts and predators at the SR 520 bridge tracking site, May-August 2007. See Table 1 for abbreviations and descriptions of habitat types. Structure names are as follows: #1 is the Lakeshore West Condominiums, #2 is the pier at the Madison Point Condominiums, and #3 is the pier at the Edgewater Apartments.

LWSC (as part of our research with SPU) and later migrated to the SR 520 study site. We only included their first three days at the SR 520 study area to minimize data processing time. These fish were tagged with a HTI tag as well as a Vemco tag. The Vemco tags were part of another study to understand the seasonal movement patterns of predatory fishes in the LWSC. Instead of searching through numerous HTI data files to determine when a fish was and was not 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. The Vemco tags were coded V9 or V13 tags that last 280-400 days. The tags send out a signal every 40-60 seconds which is decoded by the receiver (VR2). The VR2 is a self-contained, submersible unit with a built-in hydrophone. The VR2 has a lithium battery that lasts approximately 15 months. The VR2 was typically downloaded once a month. In general, the VR2 can detect fish that are within 500 m. The VR2 was located at the northeast corner (offshore edge) of the Lakeshore West Condominiums in the same vicinity as HTI hydrophone S-02 (Figure 2). Of the seven smallmouth bass used, six were collected by angling and the other was collected with a beach seine. The fish were collected 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).

Twelve of the northern pikeminnow collected at the SR 520 array were also tagged with a Vemco tag to collect information on their seasonal movement patterns as part of our research with SPU. Of the 12 tags used, eight were depth tags meaning that they also provide information on depth of the fish when near a Vemco hydrophone. Because we had a VR2 (Vemco receiver) in the same general area as the HTI array, we also used data from this receiver to document the depth used by northern pikeminnow at the SR 520 study site. The HTI data accompanied with bathymetry data provides information on the water column depth where the fish is located and the Vemco data provides information on where in the water column the fish is located. Additionally, three of the seven smallmouth bass from the LWSC had depth tags. We also included these data in our analyses. For both species, we only included data from June 1 to August 14 as the approximate time period when the HTI tags would still be active and the array was operational. We also combined the Vemco and HTI data to determine the depth of the fish in relation to the overall water column depth. Data were merged on a minute by minute basis. For both data sets, we only used the first detection of each minute. Vemco data is recorded by the minute and therefore the data could not be merged on a second by second basis.

All fish were brought to the UW pier for tagging. After each fish was anesthetized with MS222, the weight (g) and fork length (mm) was measured for each fish. HTI Model 795E tags (20 day; 1.5 g) were used with small-sized bass (< 200 mm FL). For larger bass and northern pikeminnow, we used HTI Model 795G tags (60 day; 4.4 g). We only used a tag (single HTI tag) or tags (double tagged with a Vemco and HTI tag) that would have a combined weight less than 2% of body weight (Winter 1996). The same tagging procedures used with juvenile Chinook salmon were used for predatory fishes except we used larger suture material. Fish were allowed to recover before being released at their approximate capture location.

Data points for the first 24 h after release were not used to allow time for the fish to recover and start to behave naturally. Predator tracking data were separated into dawn, day, dusk, and night time periods to examine diel behavior. Selection for the SR 520 bridge structure and other habitat types was estimated by determining the number of data points observed in each habitat category. Habitat and depth selection were determined in a similar manner as that for Chinook salmon smolts. The same habitat types and water column depths used for Chinook salmon were also used for pikeminnow and smallmouth bass. Population-level selection ratios were determined for groups of pikeminnow and smallmouth bass, and selection for or against habitat types and depth categories were determined using the same equations as those for Chinook salmon. In addition, habitat selection of individual fish was evaluated. We calculated Manly's standardized selection ratio as

$$B_i = \hat{w}_i / (\sum_{i=1}^{I} \hat{w}_i),$$

which can be interpreted as the estimated probability that habitat type or depth category *i* would be selected next if all types or categories were equally available (Manly et al. 2002).

Additional site ecological data

Aquatic macrophytes were surveyed from July 23 to August 1, 2007 and mapped. We used a point-intercept to survey macrophytes. Transects were established at approximate 20-m intervals perpendicular to shore, and survey points were established at approximate 15-m intervals along each transect. A GPS unit was used to navigate a boat to each preestablished point. At each point, an underwater camera was lowered from the boat and the following data were collected: presence/absence of macrophytes; density of macrophytes; species of macrophyte(s) present; water column depth to top of macrophytes; and total water column depth. Macrophyte density was categorized according to ocular coverage within the viewing area of the camera: > 75% cover was categorized as "dense"; 25-75% was "moderate"; and 1-25% was sparse. Areas with < 1% cover were considered unvegetated. We surveyed a total of 664 points in the study area (Figure 4). We used ArcGIS 9.2 to generate a Triangulated Irregular Network (TIN) based on macrophyte density recorded at each point. This TIN was then used to generate macrophyte density contours.

Water quality was periodically sampled throughout the tracking area during the study period. Six sample points were established on the south side of the bridge, and four points on the north side (Figure 5). 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. Water quality was sampled on the day of release for two Chinook salmon release groups, the day before for the third Chinook salmon release, and also several days after each release.

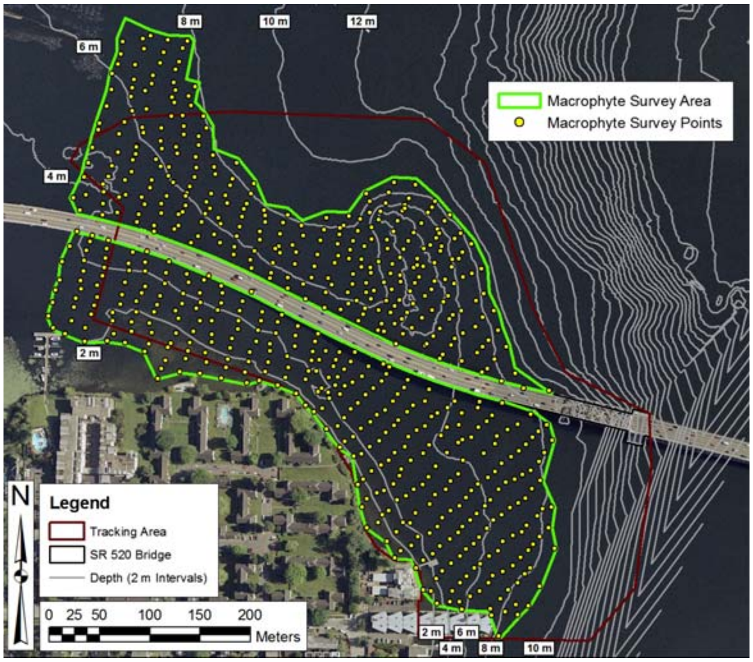


FIGURE 4. Aquatic macrophyte survey area and survey points at the SR 520 tracking site, July 23 - August 1, 2007. An underwater camera was lowered from a boat to determine macrophyte presence/absence, species present, macrophyte density, depth to top of marcophytes, and total water column depth at each survey point. Survey point locations were recorded using a GPS unit.

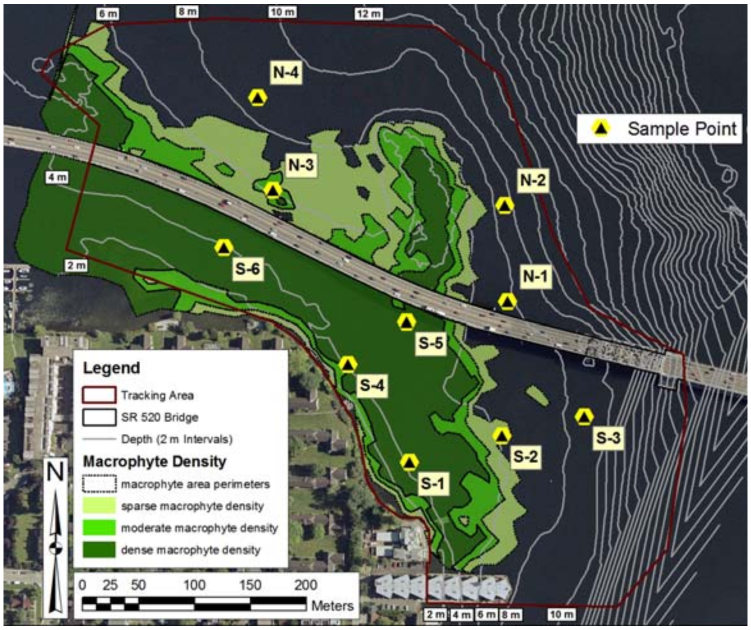


FIGURE 5. Sampling point locations where water quality was monitored, May 31 - July 11, 2007.

RESULTS

Site Ecology

Surface water temperature at 2 m depth fluctuated mostly between 16.0 °C and 19.5°C during the study period (Figure 6). A larger temperature range of 12.5 °C - 17.5°C was evident at 8 m depth. Rather than the steady warming that was expected during June, temperature generally seemed to be stable. Water clarity steadily increased during the study period, from about 3.2 m Secchi depth on May 31, to 4.2 m on June 14, and 4.7 m on June 28 (Figure 7). Water clarity was generally similar on the north and south sides of the bridge, although the south side consistently measured less clear than the north side. It is unclear if this difference was real or an artifact of the sampling regime. Water quality measurements were taken in the morning (0800-1230 hours). The south side was always sampled first, and the north side was sampled second when later-morning lighting may have been brighter contributing to better visibility.

Chinook salmon smolts

Tagging and release

Three groups of tagged Chinook salmon smolts were released, one each on June 1, June 14 and June 28 (Table 2). The June 1 release group consisted of only 37 fish instead of the planned 60 because not enough fish were sufficiently large enough to tag. We tagged more than the planned 60 fish for the June 14 and June 28 release groups in attempt to use all of the 180 tags that were intended for the study. However, post-tagging/pre-release mortalities from these latter two release groups diminished the total number we were able to release. Thus, despite tagging additional fish and releasing more than the planned 60 on June 14 and 28, the total number released for all groups was 171.

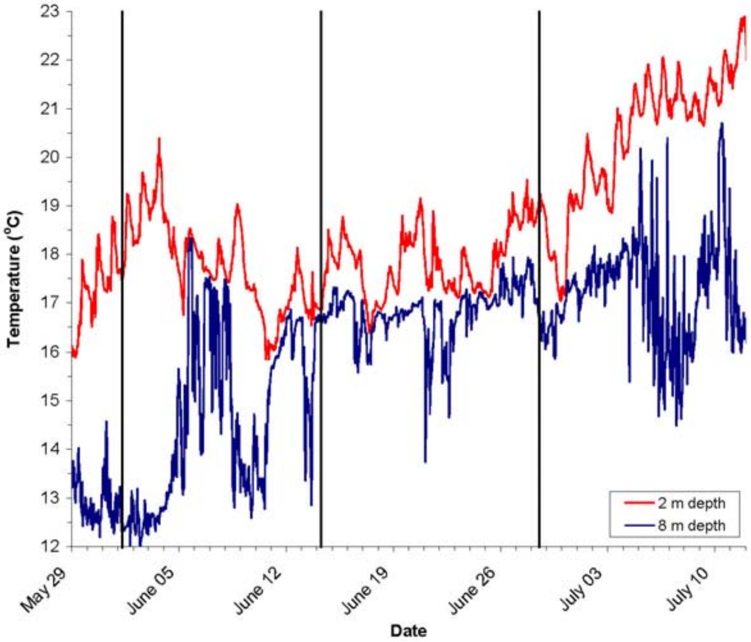


FIGURE 6. Water temperature at 2 m depth (red) and 8 m depth (blue) at the SR 520 tracking site, May 29 - July 13, 2007. Water temperature was recorded at 30 min intervals using TidbiT temperature loggers attached to hydrophone mounts. Temperature at 2 m depth is represented by hydrophone S-05, and temperature at 8 m depth is represented by hydrophone S-01. Vertical black lines indicate when tagged Chinook salmon were released. See Figure 2 for hydrophone locations.

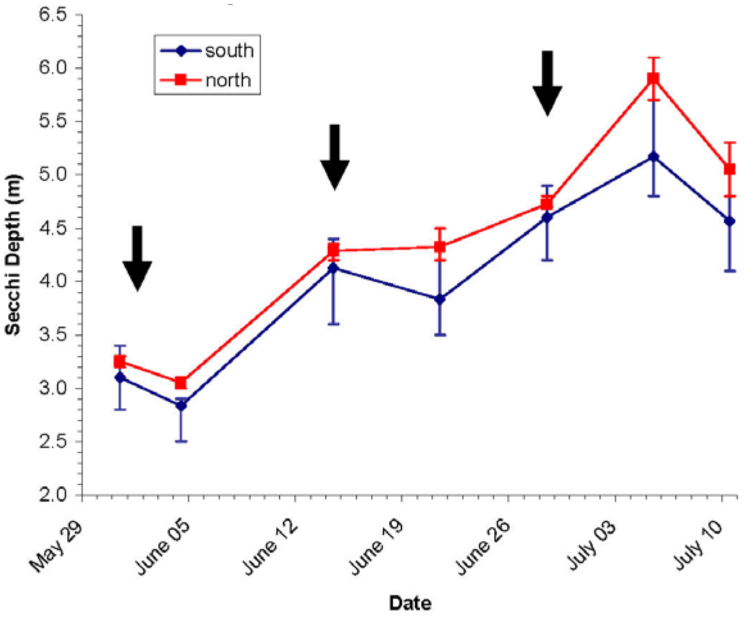


FIGURE 7. Water clarity at the SR 520 tracking area as measured with a Secchi disk, May 31 - July 11, 2007. Mean Secchi depth for all sampling points on the south (blue) and north (red) sides of the bridge are shown. Error bars represent the minimum and maximum measurements. Arrows indicate dates when tagged Chinook salmon were released. See Figure 5 for sample point locations.

Time of release was similar for the June 1 and June 14 groups: 1008 hours and 0942 hours, respectively (Table 2), achieving our target of releasing fish no later than mid-morning. Conversely, the June 28 group was not released until early afternoon at 1303 hours due to equipment malfunctions. We chose to continue programming later that morning rather than waiting until the next day. Waiting would have placed further stress on the fish as a result of the additional handling. Thus we felt that a later release was the better option.

Fish size was generally comparable between release groups (Table 1), however single-factor analysis of variance (Zar 1999) suggested that lengths and weights were not statistically the same ($\alpha = 0.05$). Subsequent Tukey multiple comparison tests (Zar 1999) showed that lengths and weights were similar between the June 1 and June 14 releases, and were different between these and the June 28 fish ($\alpha = 0.05$). Fish released on June 28 were slightly larger, but the magnitude of difference was small and likely had little biological significance.

TABLE 2. Three groups of tagged Chinook salmon smolts released during June 2007 and tracked at the SR 520 study site, including proportion of tagged fish detected at the SR 520 bridge hydrophone arrays, the number of detected fish that yielded tracks, and the proportion 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)	Proportion detected at 520[a]	No. tracked at 520[a]	Proportion detected in LWSC
June 1	10:08	37	105.7 (3.1)	13.3 (1.0)	0.97	36	0.83
June 14	9:42	68	106.0 (2.7)	12.9 (0.9)	0.90	59	0.46
June 28	13:03	66	108.5 (4.9)	14.3 (2.2)	0.98	64	0.38

[a] These include observed on-site tag losses: one each from the June 1 and June 28 releases.

Chinook salmon tracking

The substantial majority of tagged fish from all release groups were both detected and tracked at the SR 520 bridge arrays. The June 14 groups had the lowest percentage of detected and tracked fish: 90% detected and 87% tracked. The June 1 and June 28 groups both had exceptionally high percentages of tracked fish: 97% of fish from each of these release groups were tracked at the study site. All releases, including the June 14 release, far exceeded our expectations: prior work in Lake Washington suggested that we would likely track only 50-66% of released fish.

One on-site tag loss was observed in each of the June 1 and June 28 releases. These fish were initially observed moving into and around the study site. However, at some point movement ceased and the signal was stationary for the duration of the time it was tracked (Figure 8). There are at least three different circumstances under which this can occur: the tag can fall out of the incision; mortality can occur as a result of a flawed surgery and/or the cumulative stress of surgery, handling and release into potentially inhospitable environmental conditions (e.g., elevated water temperatures); or the fish may become preyed upon. The fish we observed appeared to have been preyed upon. For example, Chinook salmon #2768 from the June 28 release was observed moving into the study site on the day of release (Figure 8). However, after a certain point, tracked data points became very localized for the duration of the time period that the tag was tracked. The first three days (June 28, 29 and 30) exhibited a territoriality that has not been observed in Chinook salmon, but which bears close resemblance to many bass that we have tracked in Lake Washington and the LWSC (Celedonia et al. 2006). The very close clustering of points on July 4 – 8 may be the result of the tag lying on the substrate after being evacuated from the digestive track of the presumed predator. The observed on-site tag losses were excluded from all analyses except for determining travel time to site after release.

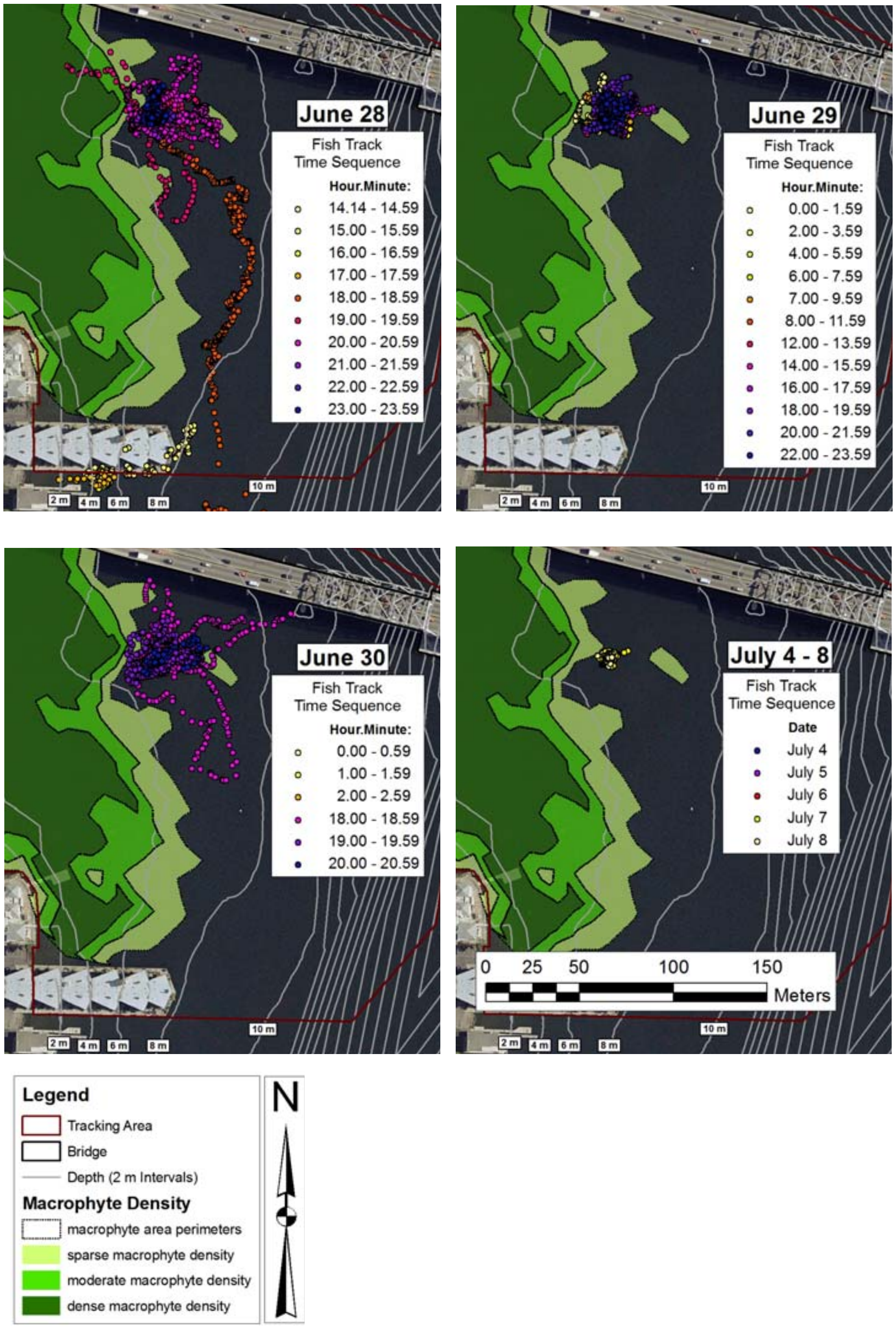


FIGURE 8. Observed on-site tag loss of Chinook salmon #2768, June 28 – July 6, 2007. The territoriality observed on June 28, 29 and 30 is not normal Chinook salmon behavior, but rather is indicative of territorial predators such as smallmouth bass. The close clustering of points on July 4 – 6 is suggestive of a stationary tag lying on the substrate, possibly after being evacuated from a predators digestive tract.

Movement timing and migratory status

Each release group exhibited unique patterns in timing of movement. The June 1 group traveled to the tracking array quickly after release (median, 1.0 h), were detected in the study area for a short period of time (median, 1.3 h), and traveled quickly to the University Bridge array (median, 3.0 h) (Table 3; Figure 9). Overall median travel time from release to the University Bridge was 4.9 h. This release group showed relatively little variability in movement timing (Figure 9). The rapid movement of these fish suggested that they were in an active migration phase and thus used the study area primarily as a migration corridor. This may be partially attributable to the fish being released only 5 days after moon apogee, which can be a strong migrational cue in Lake Washington Chinook salmon (DeVries et al. 2004).

The June 14 group moved more slowly and was more variable than the June 1 group, perhaps partially due to these fish being released between apogees: release date was 18 days after the previous apogee, and 12 days before the next one. Only 28% of detected fish traveled to the tracking site within 1.7 h of release, compared with 97% of the June 1 group. Instead, median time to site was 4.1 h, and many fish were not detected until 10 h or more after release. Area residence time of the June 14 group also appeared substantially longer than the June 1 release. Median area residence time for the June 14 group was 47.4 h, and 44% of detected fish had area residence times > 100 h. The prolonged residence times and slower movement into the LWSC suggested that these fish were temporarily holding, resting and/or rearing in the general area before continuing their migration or otherwise moving elsewhere.

TABLE 3. Movement timing of tagged Chinook salmon after release, June-July, 2007. Median time (in hours) are shown for: time from release to first detection at the SR 520 array; area residence time[a] at 520; tracking time[b] at 520; 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). First and third quartiles are shown in brackets [ ], and number of fish comprising each observation are in parenthesis (n).

Grouping	Release to 520	520 area residence	520 tracking time	520 to University Br.	Release to University Br.
June 1					
all fish	1.00 [0.94 – 1.13] (n = 36)	1.30 [0.83 – 4.53] (n = 35)	0.15 [0.09 – 0.38] (n = 35)	-	-
in SC	1.00 [0.97 – 1.12] (n = 30)	1.22 [0.82 – 2.46] (n = 30)	0.13 [0.08 – 0.32] (n = 30)	2.98 [2.60 – 3.62] (n = 26)	4.91 [4.45 – 6.64] (n = 26)
not in SC	0.98 [0.89 – 1.12] (n = 6)	6.43 [1.30 – 11.02] (n = 5)	0.36 [0.18 – 0.44] (n = 5)	-	-
June 14					
all fish	4.12 [1.33 – 6.20] (n = 61)	47.42 [7.47 – 138.77] (n = 61)	1.20 [0.25 – 4.29] (n = 59)	-	-
in SC	2.79 [1.10 – 4.90] (n = 28)	43.97 [5.52 – 143.48] (n = 28)	0.89 [0.16 – 3.53] (n = 28)	3.54 [2.38 – 9.67] (n = 28)	122.78 [23.16 – 172.42] (n = 28)
not in SC	4.68 [2.42 – 6.37] (n = 33)	71.57 [15.28 – 128.82] (n = 33)	1.42 [0.40 – 10.00] (n = 31)	-	-
June 28					
all fish	1.02 [1.00 – 1.02] (n = 65)	31.70 [7.62 – 109.71] (n = 64)	2.70 [1.20 – 3.75] (n = 63)	-	-
in SC	1.02 [1.00 – 1.07] (n = 25)	39.22 [30.45 – 112.20] (n = 25)	3.08 [1.44 – 4.09] (n = 25)	7.92 [4.02 – 18.48] (n = 25)	67.55 [46.77 – 144.30] (n = 25)
not in SC	1.02 [1.00 – 1.02] (n = 40)	9.87 [6.81 – 96.85] (n = 39)	2.13 [0.83 – 3.59] (n = 38)	-	-

[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.

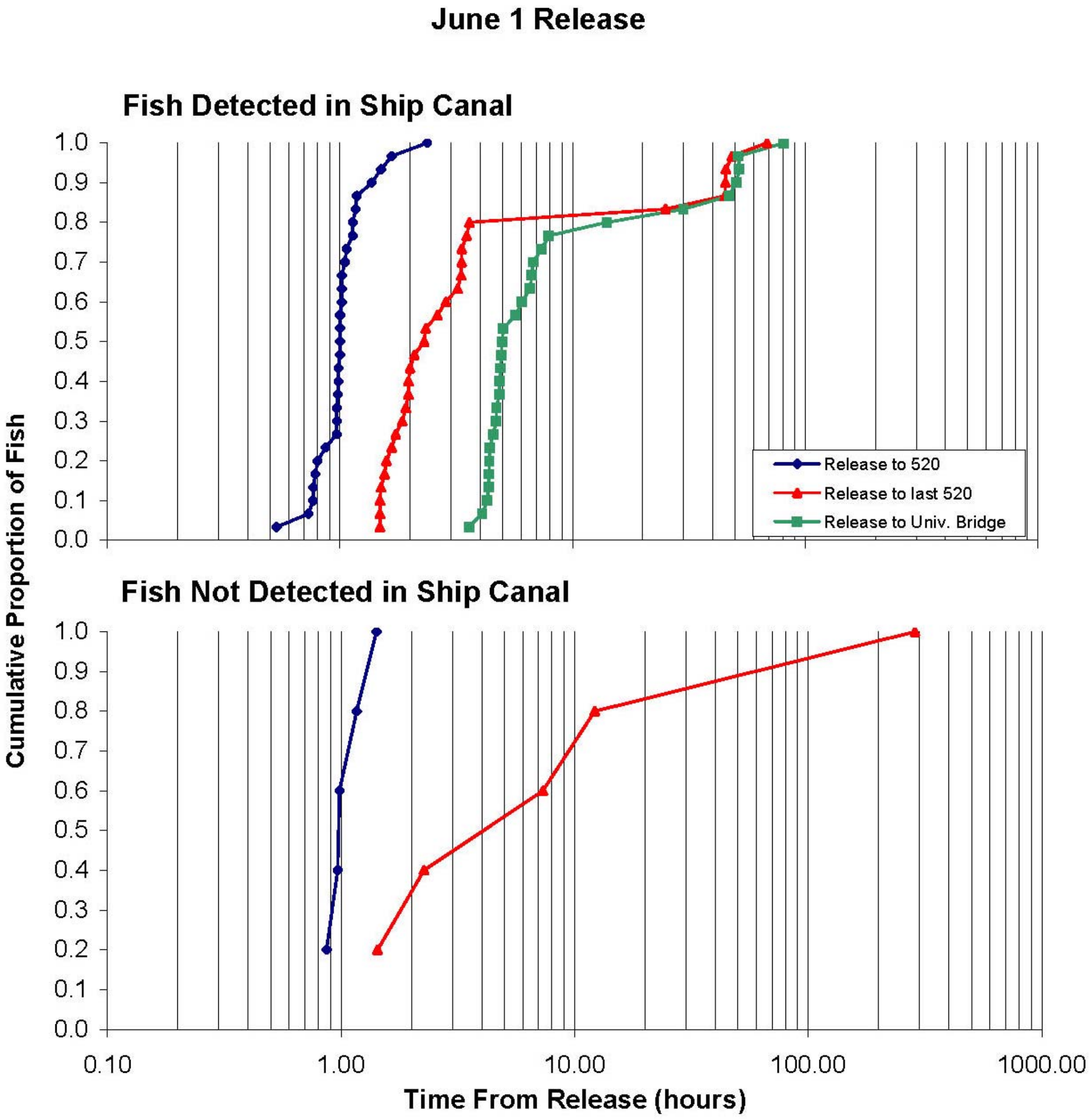


FIGURE 9. Cumulative frequency distributions of tagged Chinook salmon movement timing, June-July, 2007. Movement timing is from release to: first detection at the SR 520 bridge tracking site (blue line); last detection at the SR 520 bridge tracking site (red line); and first detection at the University Bridge tracking site in the LWSC (green line), June-July, 2007. Data are presented separately for fish that were detected in the LWSC (top) and those that were not (bottom). Data are grouped by release date.

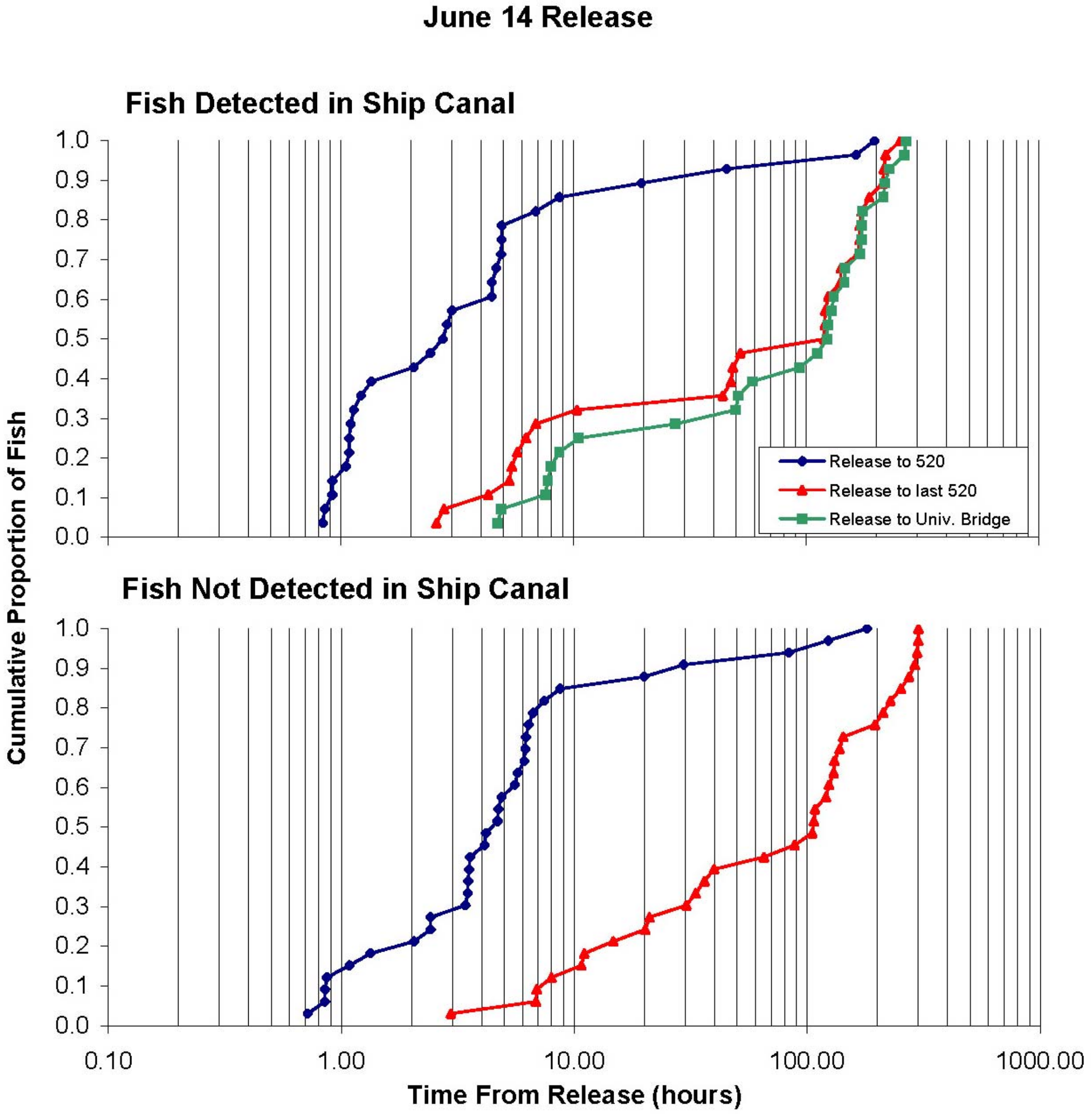


FIGURE 9. (cont.)

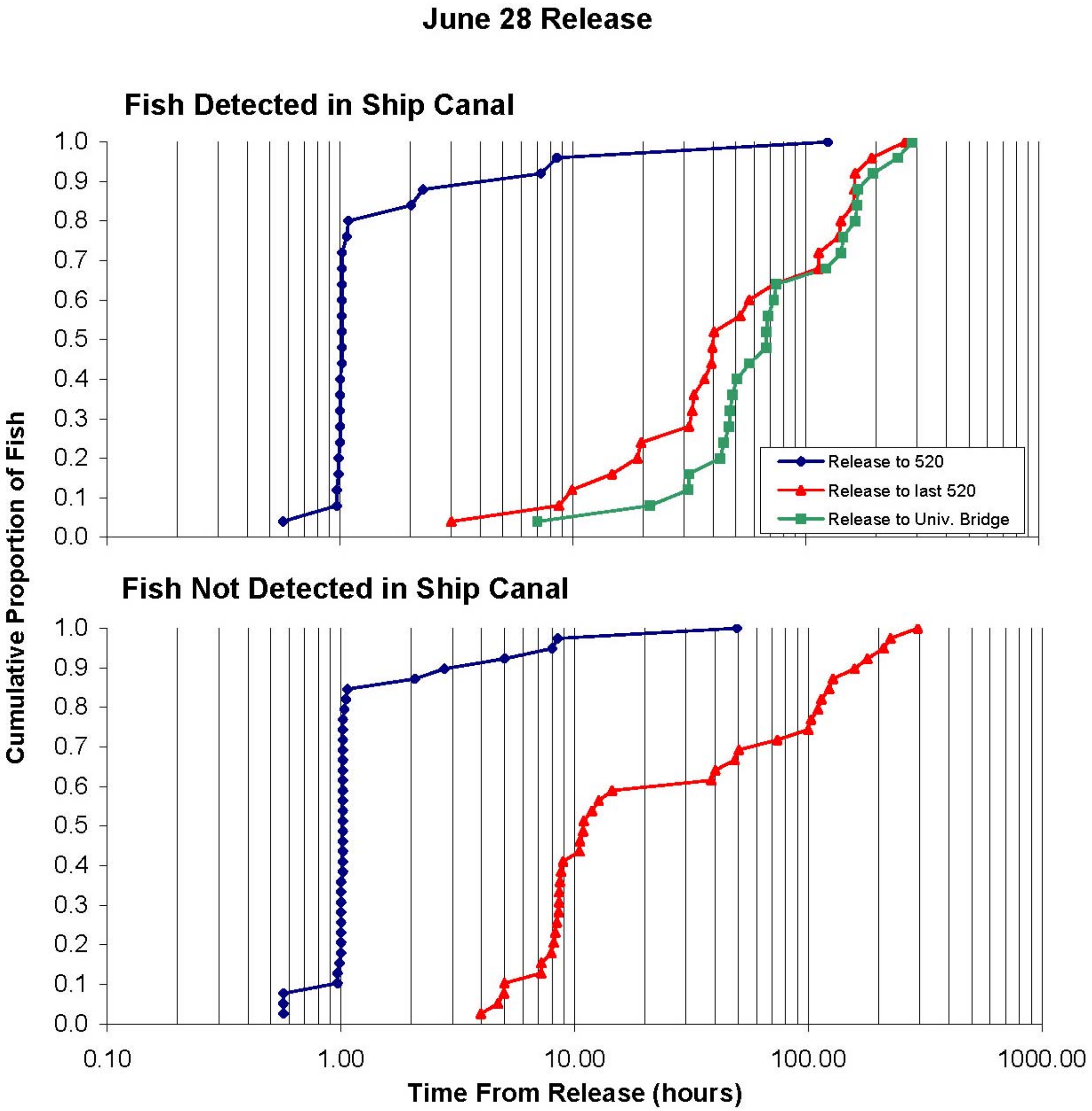


FIGURE 9. (cont.)

The June 14 group resembled the June 1 group in moving relatively quickly to the University Bridge (median. 3.5 h), although there was slightly more variability particularly toward somewhat longer times (3rd quartile of June 14 release was 9.7 h compared to 3.6 h for June 1 release). Overall, movement of the June 14 fish from the release site to the University Bridge was highly variable and spread out over several days (interquartile range 23.1 – 172.4 h).

The June 28 release group showed characteristics of both of the previous release groups. Similar to the June 1 release, the June 28 group moved quickly to the study site after release (Table 3; Figure 9). Median travel time to the site was 1.0 h, and 83% of detected fish arrived < 1.1 h after release. However, unlike the June 1 release, the June 28 fish were detected in the study area for a much longer period of time resembling the June 14 group. Median area residence time was 31.7 h, and 38% of detected fish had residence times > 48 h. Similar to the June 1 release, the June 28 fish were also released near moon apogee (4 days after apogee), suggesting that active migration through the study area and into the LWSC would be the expected predominate behavior. This did not appear to be the case. Instead, June 28 fish appeared to temporarily hold, rest and/or rear in the general area prior to continuing their migration similar to the June 14 group. The disparity in timing from release to the study site between the June 14 and June 28 groups may have been partially due to the later release time of the latter group, as well as higher water temperature at release.

The June 28 group also took longer to reach the University Bridge array in the LWSC after last detection at the SR 520 site. Median travel time to the University Bridge was 7.9 h – more than double that of the previous two releases. Variability again appeared to increase, particularly toward longer times (3rd quartile was 18.5 h). Interestingly, travel time from the SR 520 bridge site to the University Bridge appeared to get progressively longer and more drawn out from one release group to the next (Figure 10). Despite this trend, overall time of movement from release to the University Bridge appeared somewhat less variable in the June 28 group than the June 14 group: the interquartile range of the former was 98 h, while that of the latter was 149 h (Table 3).

Chinook salmon were usually tracked on most or all days during prolonged general area residence despite often entering and exiting the tracking area repeatedly. Most or all fish from all release groups were tracked on ≤ 3 days, although some were tracked on as many as 6-7 days (Figure 11). Some fish were not observed on consecutive days. For example, a fish may have shown a general area residence time of 6 days but may have only been tracked for parts of 3 of those days. These fish were apparently residing in areas outside of the tracking site for considerable periods of time. Thus, the tracking area appeared to be part of a larger area that fish were using and periodically returning to during general area residence.

Similarities and differences between fish that were detected in the LWSC (“LWSC fish”) and those that were not (“non-LWSC fish”) varied between release group. The June 1 release had very few non-LWSC fish (n = 6), making any comparisons tenuous. Nonetheless, upon release non-LWSC fish generally appeared to travel to the SR 520 site in about the same time as the LWSC group (Table 3; Figure 9). However, non-LWSC fish appeared to remain in the SR 520 area for a longer period of time: median residence was 1.2 h for the LWSC group and 6.4 h for the non-LWSC group.

Timing of movement and general area residence times of LWSC and non-LWSC fish were considerably different between the June 14 and June 28 release groups. June 14 non-LWSC fish generally appeared to travel more slowly and remain in the SR 520 area longer than LWSC fish. The non-LWSC group took longer to move to the SR 520 site after release: median travel time was 4.7 h for the non-LWSC group and 2.8 h for the LWSC group, with similar variability observed in each group. Also, more non-LWSC fish were detected in the SR 520 area longer: median residence was 71.6 h for the non-LWSC group and 44.0 for the LWSC group. Slightly more variability was evident in the LWSC group: the interquartile range was 138 h for the LWSC group and 114 h for the non-LWSC group (Table 3).

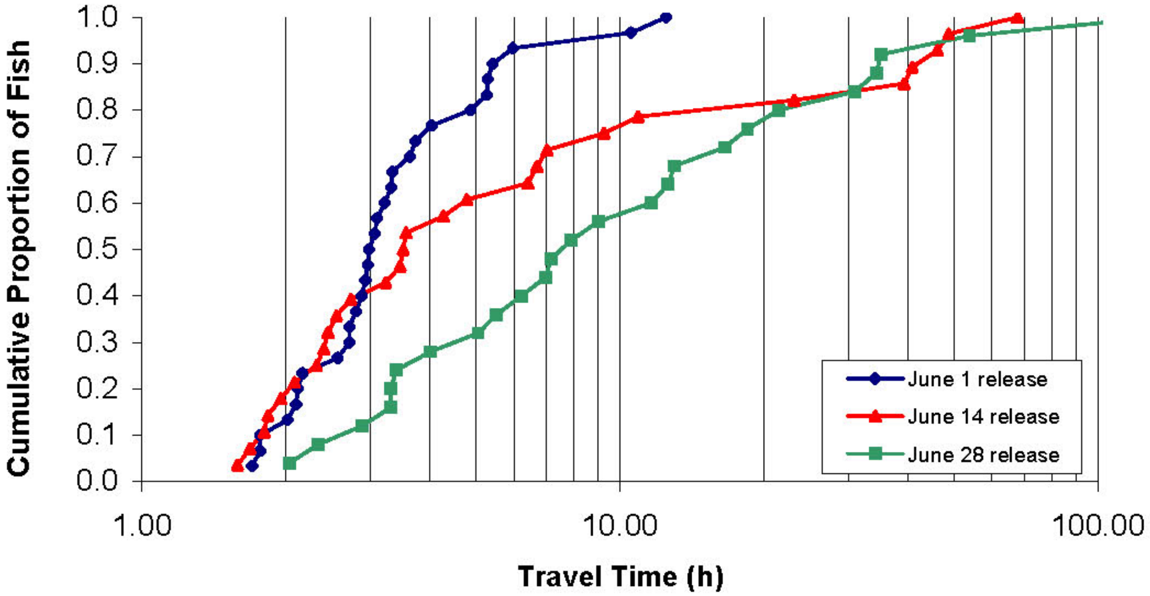


FIGURE 10. Cumulative frequency distribution of timing of tagged Chinook salmon from last detection at the SR 520 bridge study area to first detection at the University Bridge tracking site in the LWSC, June-July, 2007. Data are grouped by release date.

In contrast to the June 14 release, fish released on June 28 showed nearly identical patterns in timing of movement from release to the tracking site regardless of whether they were later detected in the LWSC or not (Table 3; Figure 9). General area residence time between LWSC and non-LWSC fish was also starkly different between the two release dates. Non-LWSC fish appeared to vacate the area much sooner that LWSC fish, the opposite of what was observed with the June 14 fish. With the June 28 group, 62% of non-LWSC fish were detected in the area < 14 h, while only 16% of LWSC fish were detected in this time. Median area residence time of non-LWSC fish was 9.9 h compared to 39.2 h for LWSC fish. Both groups showed similar degrees of variability: interquartile range was 90 h for LWSC fish and 82 h for non-LWSC fish (Table 3).

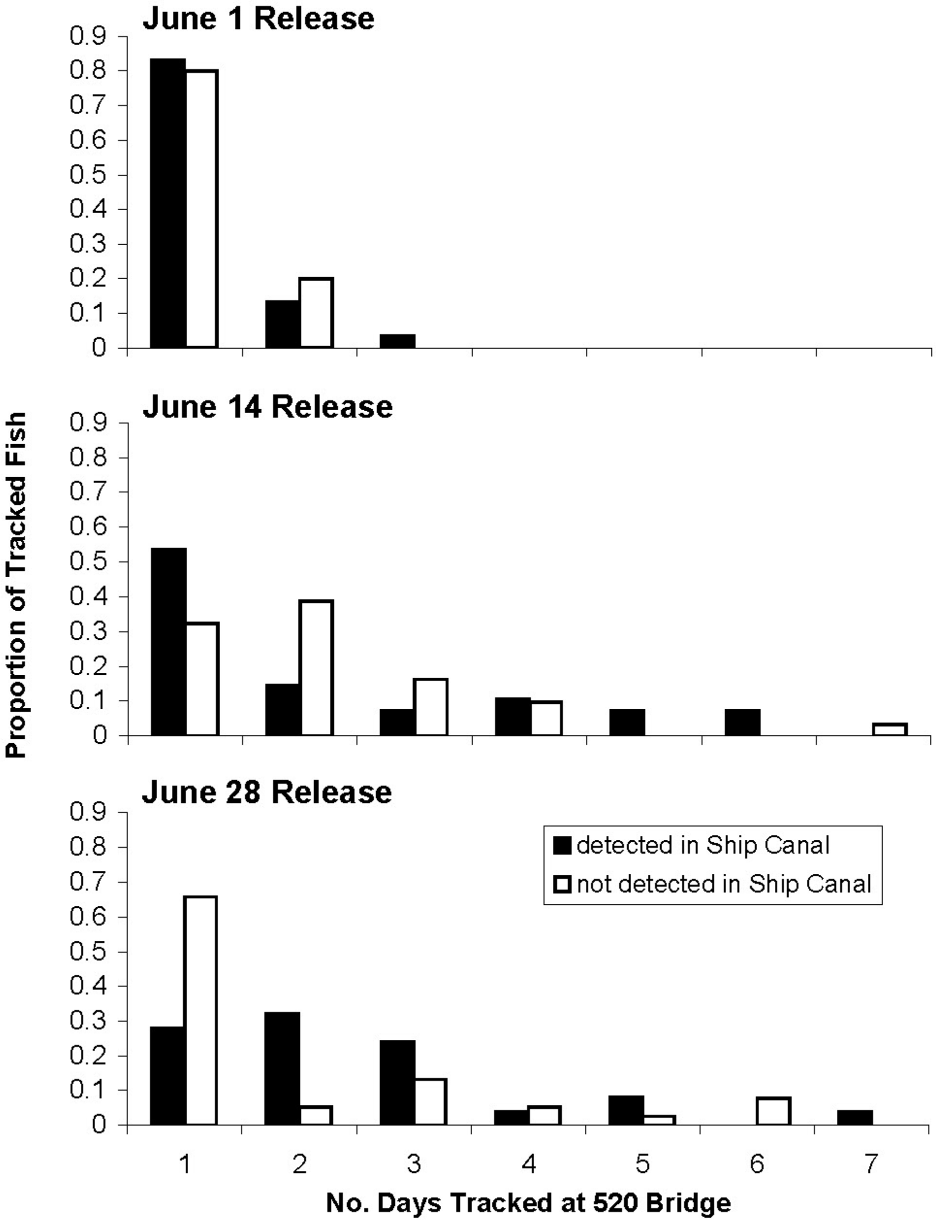


FIGURE 11. Frequency distribution of the number of different days that fish were tracked at the SR 520 bridge tracking site, June-July, 2007. Data are presented separately for fish that were detected in the LWSC and those that were not. Note that most fish that were tracked > 1 day entered and exited the tracking site repeatedly during this time, and were often outside the tracking area for substantial periods of time. Also note that many fish were not tracked on consecutive days (e.g., tracked for part of one day, not tracked the next, and reappeared on the third day). Only the days when fish were tracked were included.

Behavior approaching and passing beneath the bridge

Chinook salmon showed a wide variety of behaviors as they approached, encountered, and passed beneath the SR 520 bridge. Chinook salmon behaviors in each area (i.e., approach, encounter, pass, post-pass) appeared as a spectrum between two opposing ends, which we labeled Behavioral Types A and B (Table 4). In general, Behavioral Type A was represented by direct pathways of travel toward Puget Sound with no meandering, milling or abrupt changes in direction. Conversely, Behavioral Type B was represented by abrupt changes in direction, extensive meandering and milling for prolonged periods, and substantial movements in directions away from Puget Sound. Chinook salmon behaviors at both ends of the spectrum and throughout were common. For individual fish, location on the spectrum in one category was generally not a predictor of location on spectrum in another category. For example, fish exhibiting Behavioral Type A during approach were observed on all parts of the behavioral spectrum - including Type B - during encounter, pass and post-pass. Nonetheless, broad, overarching patterns were apparent within each release group. Based on qualitative review of the data, fish from the June 1 release generally tended toward the A end of the spectrum, while fish from the June 14 and 28 groups generally spanned the range from mid-spectrum to B. These general behavioral patterns coincided with patterns in movement timing and apparent migrational status. In general, June 1 fish were actively migrating through the general area, and thus exhibiting Type A behaviors, whereas June 14 and 28 fish were temporarily holding, resting and/or rearing in the general area, and thus exhibiting more Type B behaviors.

Regardless of general behavioral patterns, a substantial majority tagged Chinook salmon passed beneath the bridge: 97%, 79%, and 89% of tagged fish from the June 1, 14 and 28 release groups (excluding on-site tag losses), respectively, were known to have passed beneath the bridge (Table 5). Most fish that were known to have passed beneath the bridge (> 88% of each release group) were directly observed passing beneath the bridge within the study site. A small proportion from each release group (< 12%) 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

TABLE 4. Spectrum of observed Chinook salmon behaviors in approaching, encountering and passing beneath the SR 520 bridge, June-July, 2007. For individual fish, location on the spectrum in one category was generally not a predictor of location on spectrum in another category. For example, fish exhibiting Behavioral Type A during approach were observed on all parts of the behavioral spectrum during encounter.

Behavior relative to bridge	Area	Behavioral Type A	Spectrum between Behavioral Types	Behavioral Type B
approach	between condos on southern edge of site and 5 m of bridge	generally direct line of travel toward bridge	minimal to moderate meandering and/or milling in one or more areas, or throughout entire area	extensive meandering and/or milling throughout entire area
encounter	from 5 m south of bridge to bridge's southern edge	move through encounter area and enter area beneath bridge with minimal change in direction of travel	upon encounter with bridge: 1) abruptly change direction and parallel bridge for short to moderate distance in one or few passes; or, 2) minimal to moderate milling commencing near bridge and continuing near and/or away from bridge; or, 3) some combination of 1 and 2	upon encounter with bridge: 1) abruptly change direction and parallel bridge for long distances making numerous east-west passes; or, 2) extensive milling commencing near bridge and continuing near and/or away from bridge; or, 3) some combination of 1 and 2
pass	directly beneath bridge	generally direct line of travel perpendicular with bridge	travel beneath bridge for short to moderate distances at angles between perpendicular and parallel, exclusive; and/or mill around for short to moderate periods beneath bridge, sometimes including areas along bridge margins; continue pass to north side of bridge, or exit back to the south	travel beneath bridge for long distances generally parallel with bridge; and/or mill around for prolonged periods beneath bridge, sometimes including areas along bridge margins; continue pass to north side of bridge, or exit back to the south
post-pass	from north edge of bridge	generally direct line of travel away from bridge and out of tracking area; never detected again	pass back under bridge, either immediately in same location or short to moderate time later in the same or different location; and/or meander and/or mill near or away from bridge for short to moderate periods, sometimes exiting and entering the tracking area one or few times before either finally exiting the tracking area or passing back under the bridge to the south	meander and/or mill near or away from bridge for prolonged periods, sometimes exiting and entering the tracking area numerous times before either finally exiting the tracking area or passing back under the bridge to the south

of the tracking area. We were able to discern whether these fish passed beneath the bridge to the west or east of the site. West-passing 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. If these fish were subsequently observed on-site, it was on the north side of the bridge. East-passing fish were either never observed on the south side of the bridge prior to being observed to the north, or they were tracked on-site on the south side of the bridge and were observed moving off-site to the east without first passing beneath the bridge. Subsequent observations of these fish were on the north side of the bridge. Although only a small proportion of each release group passed beneath the bridge outside of the tracking area, there appeared to be an easterly shift in off-site bridge passings during the study period (Table 5). 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 in this area that may have obscured passing on the very far western side of the site. These affects were primarily observed west of bridge columns 27-28 (Figure 14).

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 28 release - made only partial passes (Table 5). Other fish were observed making partial passes, but these all completely passed beneath the bridge at a later time (e.g., Figure 12, Chinook #3578). Some fish that were tracked on-site were not observed or otherwise known to cross beneath the bridge. This described 7% and 6% of the June 14 and 28 releases, respectively (Table 5). Only one 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. Small proportions of the June 1 and 28 groups - 3% and 2%, respectively - were never detected or tracked at the study site, and were not known to pass beneath the bridge (table 5). This described a slightly larger proportion (13%) of the June 14 release.

Each release group showed different behavioral patterns in passing beneath the bridge. A large proportion (72%) of fish from the June 1 release made a single, simple pass beneath the bridge (Table 5). In contrast, only 12% of the June 14 group and 26% of the June 28 group passed in a similar manner. Instead, large proportions of these latter two releases - 59% and 57% of the June 14 and 28 releases, respectively - made multiple passes beneath the bridge and/or showed complex crossing patterns (Figure 12). Again, these differences between the early-June release and the later two releases coincided with dominant migratory status and related overarching behavioral patterns. The variety of behaviors observed complicated the intended analysis of the interaction between migrating Chinook salmon and the bridge. We assumed *a priori* that the intent of tagged Chinook salmon to migrate through the study area and beyond the bridge would be clear, and that abrupt changes in direction of travel at the bridge could be used to evaluate bridge-induced delay. Behavior of at least some study fish - actively migrating, Type A - was generally consistent with this expectation (e.g., Figure 13). However, this analytical approach was not generally feasible for holding, resting and/or rearing fish exhibiting

TABLE 5. Characteristics of tagged Chinook salmon that passed under the SR 520 bridge, excluding on-site tag losses, June-July, 2007. 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.”

	Release group		
Observed bridge passing characteristics	June 1	June 14	June 28
Single, simple pass	0.72 (26)	0.12 (8)	0.26 (17)
Multiple and/or complex pass	0.14 (5)	0.59 (40)	0.57 (37)
Passed off-site			
passed west of site	0.11 (4)	0.06 (4)	0.02 (1)
passed east of site	0.00 (0)	0.03 (2)	0.05 (3)
Partial pass only	0.00 (0)	0.00 (0)	0.03 (2)
No known pass			
detected and/or tracked on-site	0.00 (0)	0.07 (5)	0.06 (4)
not detected on-site	0.03 (1)	0.13 (9)	0.02 (1)

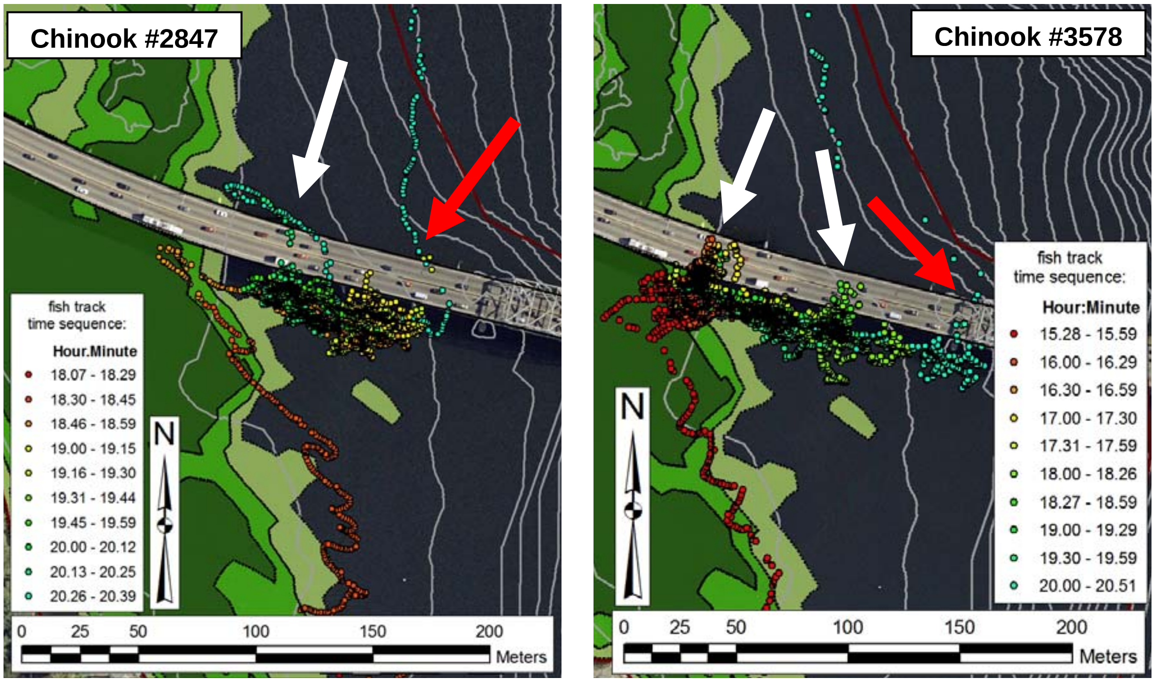


FIGURE 12. Two examples of Chinook salmon making complex-type passes of the SR 520 bridge, June 2007. Chinook salmon #2847 (left) was released on June 14, 2007 and tracked here on June 22, 2007. Chinook salmon #3578 (right) was released and tracked here on June 28, 2007. Chinook salmon #2847 approached the bridge from the south and milled around near the bridge for about 2 h. During this time the fish passed beneath the bridge to the north then immediately back to the south (white arrow) before making the final pass north (red arrow). Chinook salmon #3578 also approached the bridge from the south and appeared to mill around near and beneath the bridge in several areas (white arrows) for about 4 h before making the final pass north (red arrow).

primarily Type B behaviors. For example, many fish meandered or milled about in the “approach” area prior to encountering the bridge, making it impossible to discern whether similar behaviors in the “encounter” area were triggered by the bridge or were part of the overarching Type B behavioral pattern the fish were exhibiting at the time. Also, many fish milled around directly beneath the bridge and along the bridge’s southern edge, during which time they encountered the north edge of the bridge and beyond, only to pass back to the south (e.g., Figure 12). Given the prolonged presence directly beneath the bridge and/or forays to the north, it appeared that these fish were not inhibited by the presence of the bridge itself, although the role of any shadow cast from the bridge is unclear.

Tagged Chinook salmon that actively migrated through the approach, encounter and pass areas of the site (Table 4; Figure 13) were used to evaluate affect of the bridge on migration. We identified 28, 13, and 5 fish from the June 1, 14, and 28 release groups, respectively for this analysis (Table 6). These fish showed three general behaviors upon encountering the bridge: 1) minimal to no response ("minimal response"); 2) abruptly changed direction and move 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").

Minimal response was observed in most fish from the June 14 and 28 groups - 69% and 60%, respectively (Table 6). Only 11% of the June 1 group showed this behavior. These fish appeared largely unaffected by the bridge, showing minimal changes in direction of movement or time delay upon encountering and passing beneath the bridge. Most of these did show a subtle shift in direction of movement to align perpendicular to the bridge as they passed underneath (e.g., Fig. 12).

The second behavior - paralleling (e.g., Figure 13) - was observed in 57%, 23%, and 40% of the June 1, 14, and 28 groups, respectively (Table 6). Most of these fish (62%) moved along the edge of the bridge for < 25 m and ≤ 66 s before passing underneath. Other fish moved much longer distances over greater times while moving along the edge of the bridge: up to 255 m and 1,063 s. Three fish exhibiting the paralleling behavior traveled in one direction along the bridge, then turned 180° and traveled in the opposite direction (e.g., Fig. 12). One of these made an additional 180° turn. All others traveled in only one direction. Four fish from the June 1 group moved off-site prior to passing beneath the bridge. All of these fish were observed moving back on-site on the south side of the bridge, and then passing beneath the bridge. Three of these fish were off-site (not tracked) for 7-15 min, and the fourth was off-site for 99 min. We could not determine passing behaviors while these fish were off-site. Because of this, only westward direction of travel is shown prior to passing beneath the bridge (Table 6). Time and distance measurements for these fish are to last point observed prior to moving off-site, and are therefore underestimates of the total distance and time traveled along the bridge.

The third behavior - meandering/milling - was observed in a minority of fish. Only 32%, 8%, and 0% from the June 1, 14, and 28 groups, respectively showed this behavior (Table 6). Upon encountering the bridge - either immediately or usually after paralleling the bridge for some distance - these fish began meandering or milling around moving > 5 m from the edge of the bridge and often times > 20 m from the bridge. All but two of these fish moved off-site prior to passing beneath the bridge. As with the paralleling fish that moved off-site, time and distance measurements for meandering/milling fish are to last point observed prior to moving off-site, and are therefore underestimates of the total distance and time traveled along the bridge. Meandering/milling fish generally moved the longest distances along the bridge and spent the most time prior to passing underneath or moving off-site: all but one moved ≥ 92 m and spent > 470 s. Maximum distance and time were 601 m and 2,774 s.

In general, fish passed beneath the bridge throughout the tracking area and no single location appeared more heavily used than others (Figure 14). Locations of fish passing appeared to shift somewhat eastward with later releases toward deeper water and away from the very dense macrophytes in the southwest corner of the tracking area. The June 1 group passed mostly between Columns 26 and 37, and no fish passed east of Column 39. Fish appeared to pass in areas with dense to moderate macrophytes on both the north and south sides of the bridge. Areas with sparse or no macrophytes and/or water > 6 m deep were used by few or no fish. The June 14 group passed mostly between Column 33 and the east tower of the ship channel span, although 5 fish passed west of here at sporadic intervals to Column 25. Fish appeared to pass in deep water (> 6 m) and in areas with dense to moderate macrophytes on both the north and south sides of the bridge, except in the southwest part of the site where macrophytes appeared extremely dense. The June 28 group was similar to the June 14 group except that many from the former passed between Columns 30 and 33 while only 2 fish from the latter passed here.

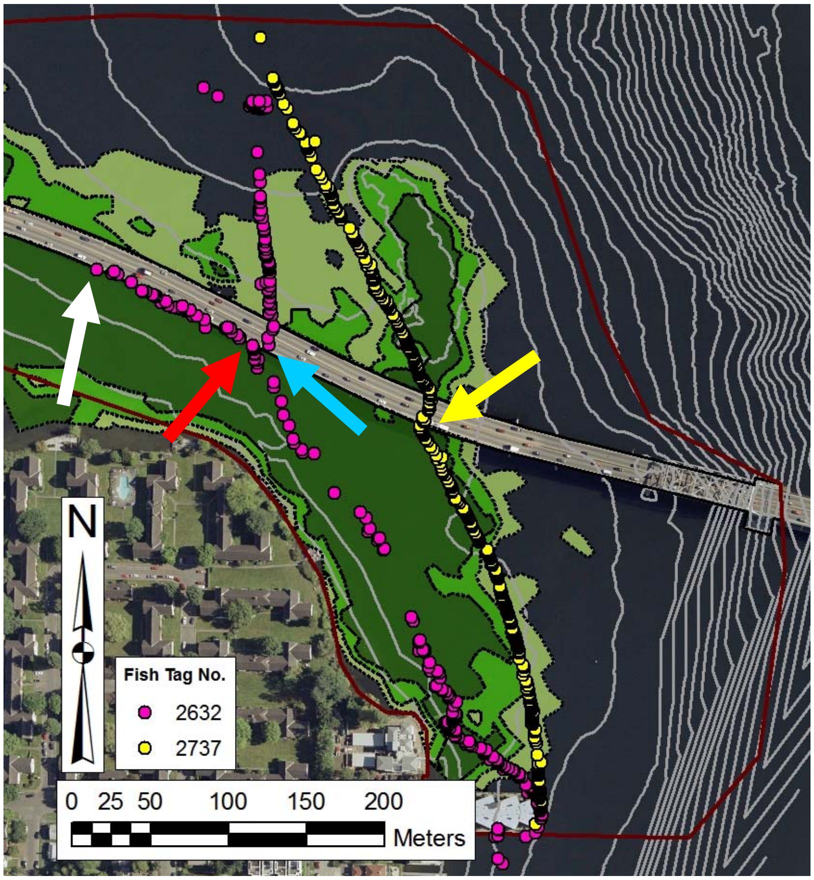


FIGURE 13. Two examples of Chinook salmon tracks used to evaluate affect of bridge on migration, June-July, 2007. Both fish traveled north directly through the south side of the site (the "approach" area) without meandering or milling. Upon encountering the bridge, Chinook salmon #2737 made a slight adjustment in direction of travel (yellow arrow) aligning perpendicular to the bridge and parallel with nearby rows of bridge columns. Bridge-induced delay to this fish was seemingly minimal if non-existent. Chinook salmon #2632 made a substantial change in direction of travel upon encountering the bridge (red arrow), turning abruptly westward and moving parallel to the bridge until turning 180° (white arrow) and traveling back to the east and passing underneath near where it first encountered the bridge (blue arrow). Distance and time of travel from first encounter to western most point was 112.7 m in 298 s, and from western most point to point of passing beneath the bridge was 120.9 m in 376 s. After passing beneath the bridge, both fish traveled directly out of the tracking area and were soon detected in the LWSC.

TABLE 6. Movements and delay of actively migrating Chinook salmon smolts at south edge of the SR 520 bridge prior to passing beneath the bridge, June-July, 2007. Movement type describes movement after initial encounter with bridge and before passing underneath. Direction of movements are shown in the order in which they occurred (w = west; e = east). Distances were measured parallel with bridge: total length of movement pathways of meandering/milling fish were not determined.

			Westward travel		Eastward travel		Total	
Fish Tag Period	Movement type(s)[a]	Direction	Distance (m)	Time (s)	Distance (m)	Time (s)	Distance (m)	Time (s)
June 1 Release								
2662	n	-	0	0	0	0	0	0
2737	n	-	0	0	0	0	0	0
2767	n	-	0	0	0	0	0	0
2797	p	w	6.3	14	0	0	6.3	14
2902	p	w	6.1	16	0	0	6.1	16
2677	p	w	8.3	25	0	0	8.3	25
2992	p	w	13.1	27	0	0	13.1	27
2602	p	w	11.6	37	0	0	11.6	37
3097	p	w	12.1	41	0	0	12.1	41
3007	p	w	17.3	51	0	0	17.3	51
2947	p	w	18.7	59	0	0	18.7	59
2872	p	w	24.8	66	0	0	24.8	66
2917	mm	w	92.0	163	0	0	92.0	163
3127	p, os	w	168.1	319	0	0	168.1	319
2752	p	w, e	46.1	264	65.0	198	111.1	462
2722	mm	e	0	0	45.9	472	45.9	472
2962	p, os	w	162.3	640	0	0	162.3	640
2632	p	w, e	112.7	298	120.9	376	233.6	674
2647	p	w, e	208.2	540	46.4	177	254.6	717
2857	p, os	w	128.0	808	0	0	128.0	808
2932	mm, os	w	148.3	1008	0	0	148.3	1008
2977	p, os	w	194.5	1063	0	0	194.5	1063
3112	mm	e	0	0	183.0	1152	183.0	1152
2827	mm, os	w, e, w	213.3[b]	552[b]	92.9	712	306.2	1264
3022	mm, os	w	211.2	1568	0	0	211.2	1568
3082	mm, os	e, w	453.6	592	147.8	987	601.4	1579
2842	mm	w	101.3	1835	0	0	101.3	1835
2782	mm, os	w	196.9	2774	0	0	196.9	2774

[a] Movement 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.

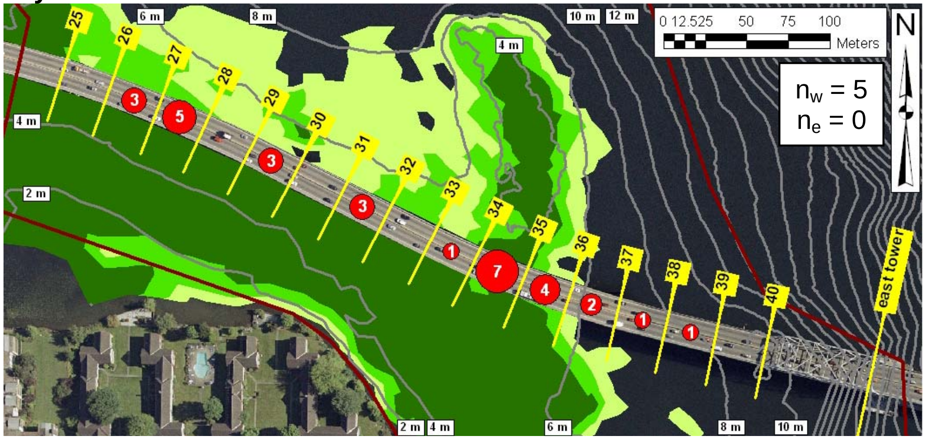
[b] Two separate westward segments were combined.

TABLE 6. Continued.

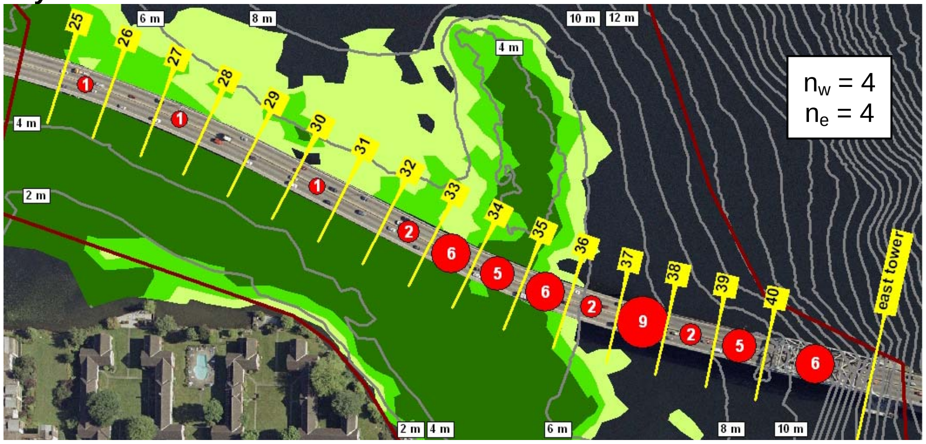
Fish Tag Period	Movement type(s)[a]	Direction	Westward travel Distance (m)	Westward travel Time (s)	Eastward travel Distance (m)	Eastward travel Time (s)	Total Distance (m)	Total Time (s)
June 14 Release								
2892	n	-	0	0	0	0	0	0
2937	n	-	0	0	0	0	0	0
3042	n	-	0	0	0	0	0	0
3177	n	-	0	0	0	0	0	0
3232	n	-	0	0	0	0	0	0
3282	n	-	0	0	0	0	0	0
3297	n	-	0	0	0	0	0	0
3342	n	-	0	0	0	0	0	0
3357	n	-	0	0	0	0	0	0
2922	p	e	0	0	9.9	38	9.9	38
3267	p	w	12.0	49	0	0	12.0	49
3447	p	w	32.7	283	0	0	32.7	283
2637	mm, os	w	176.3	1314	0	0	176.3	1314
June 28 Release								
2648	n	-	0	0	0	0	0	0
2663	n	-	0	0	0	0	0	0
2933	n	-	0	0	0	0	0	0
3038	p	e	0	0	2.3	6	2.3	6
3488	p	w	9.4	21	0	0	9.4	21

[a] Movement 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.

July 1 Release



July 14 Release



July 28 Release

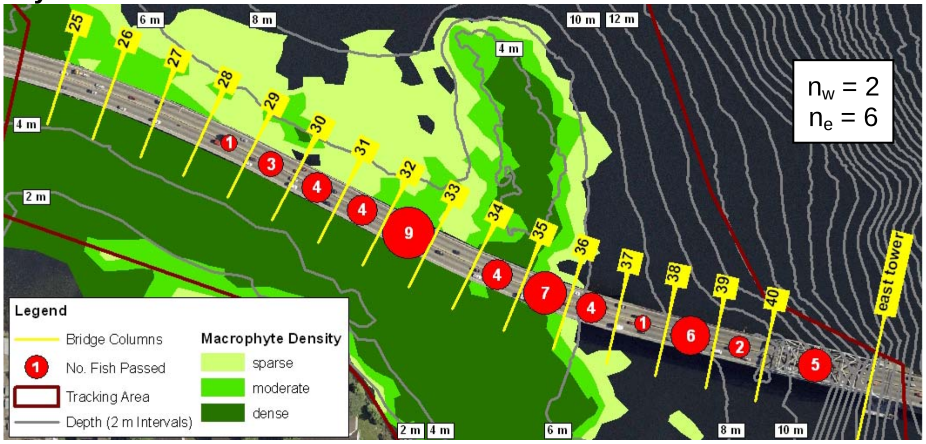


FIGURE 14. Locations where tagged Chinook salmon first crossed beneath the SR 520 bridge, June-July, 2007. Bridge column locations are shown in yellow. Size of the red circle is relative to the number of fish that passed (white). The number of fish known to have initially passed beneath the bridge outside 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 many fish from the June 14 and 28 release groups passed beneath the bridge more than once (Table 5). These additional passes are not reflected here.

Spatial distribution, habitat selection, and depth selection

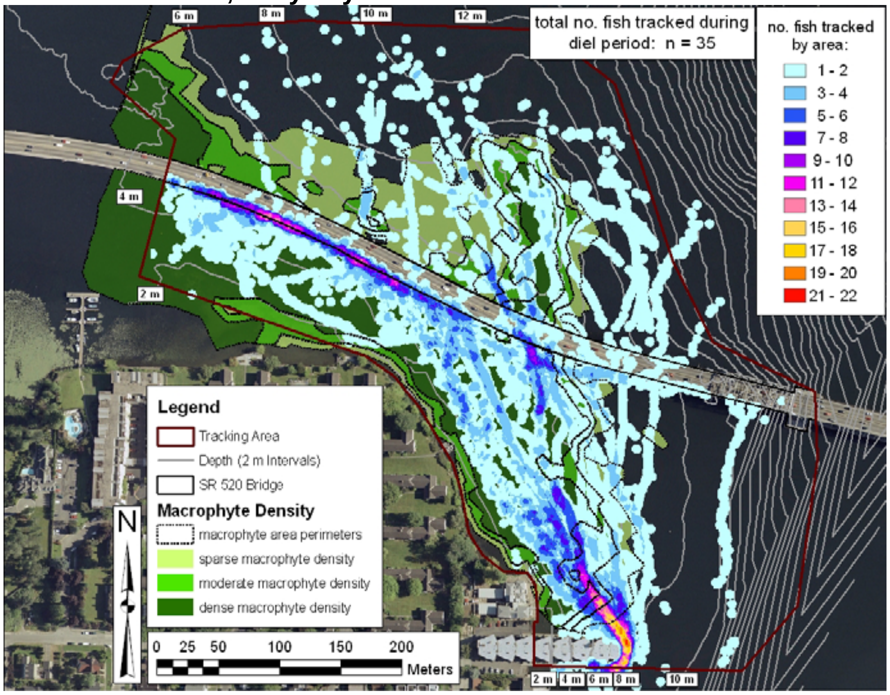
Spatial distribution, habitat selection, and depth selection was similar between the June 14 and 28 release groups, and varied between these groups and the June 1 group. Differences between release groups coincided with differences in movement timing, general area residence and migrational status.

Most fish released on June 1 were observed during early day (Table 7) entering the tracking area around the overwater condo on the south side of the site (Figure 15). Most activity north of the condo was associated with macrophyte presence and little activity was observed in offshore open water areas. Highest frequencies of occurrence appeared around the condo and along the south side of the bridge where dense macrophytes were also present (Figure 15). These observations were reflected in habitat selection calculations: fish selected for dense vegetation, overwater structures and areas under or < 5 m from the bridge, and selected against open water areas (Figure 16). Moderately and sparsely dense vegetation and offshore edge of vegetation were proportionally selected. Chinook salmon selected for 4-6 m water column depth and against water column depths > 8 m during early day. Water column depth selection was similar regardless of where fish were in relation to the bridge (Figure 17).

TABLE 7. Number of tagged Chinook salmon tracked at the SR 520 bridge by diel period, June-July, 2007.

Release date	Dawn	Day, early	Day, late	Dusk	Night
June 1	2	35	8	3	2
June 14	22	40	50	31	26
June 28	25	25	62	50	25

A. June 1 release, early day



B. June 1 release, late day

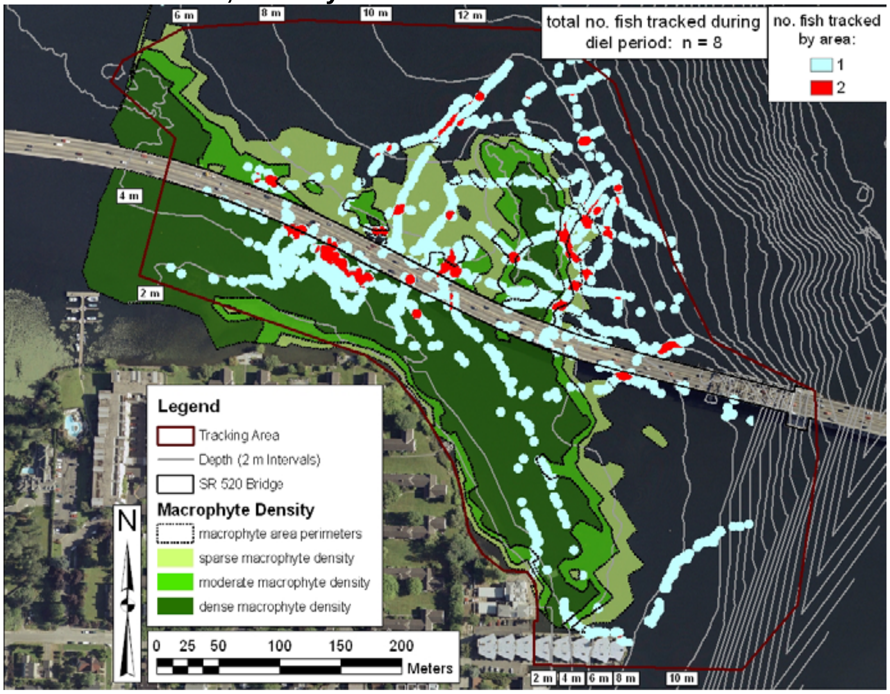


FIGURE 15. Diel spatial frequency distributions of tagged Chinook salmon released on June 1, 2007 and tracked at the SR 520 bridge tracking site. ArcGIS 9.2 Spatial Analyst was used to determine the total number of fish that occurred within a 4 m radius of each tracked fish data point.

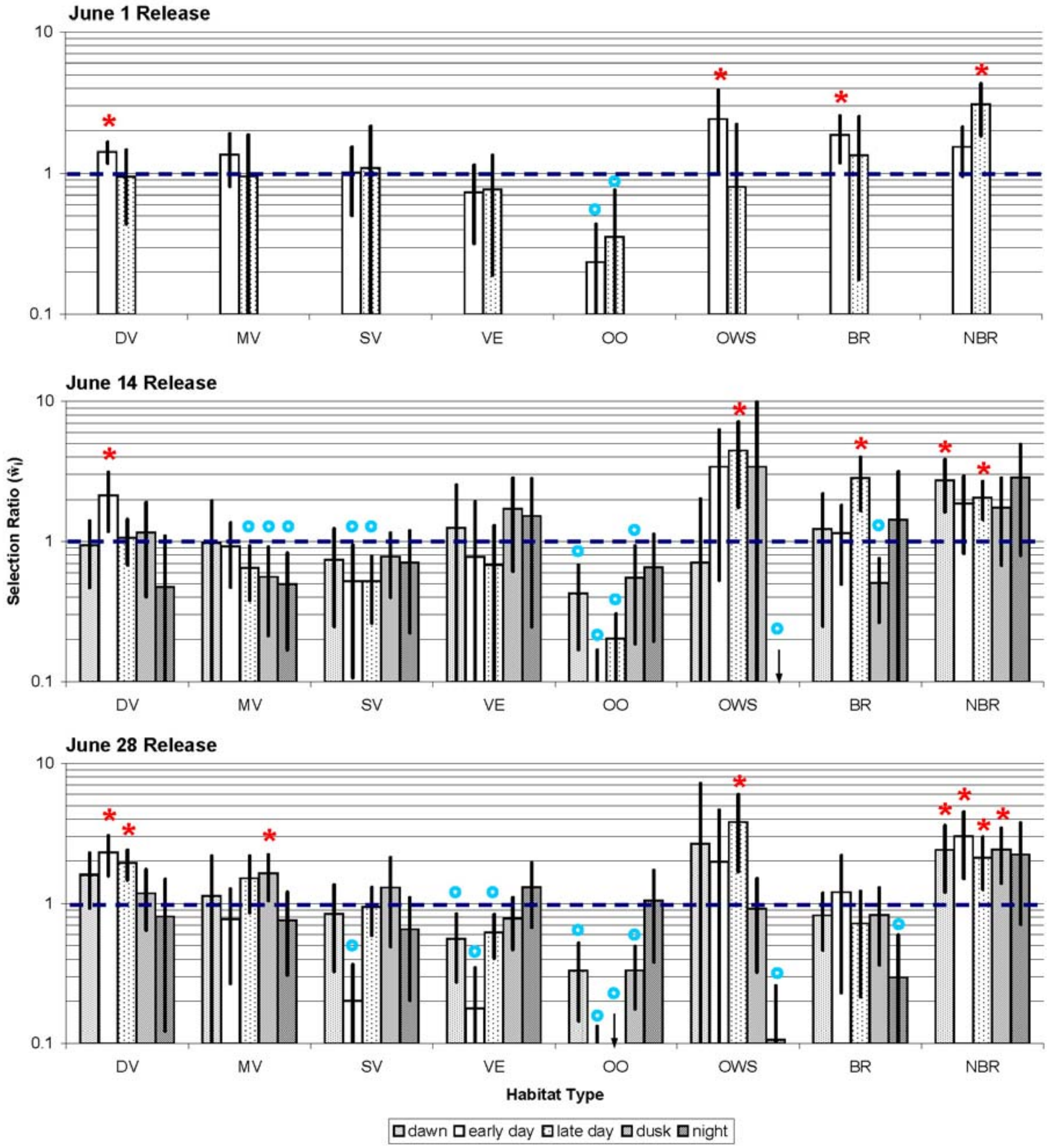


FIGURE 16. Diel habitat selection ($\hat{w}_i$, selection ratio; log scale) of Chinook salmon in the SR 520 bridge tracking area, June-July, 2007. Error bars represent Bonferroni-adjusted 90% confidence intervals. Errors bars indicate if selection for (>1) or against (<1) a habitat type occurred. A red asterisk (*) indicates selection for a given habitat and a blue circle (o) indicates selection against. Only early day and late day are shown for June 1 because too few fish were tracked during other diel periods. Habitat types are described in Table 1.

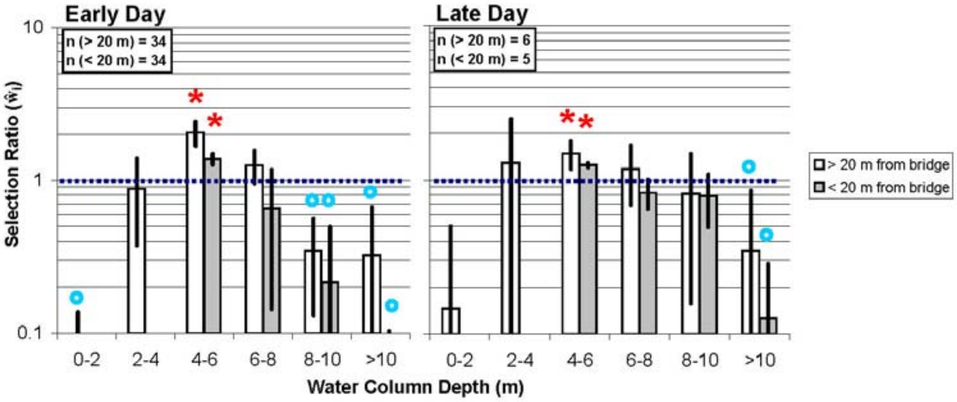


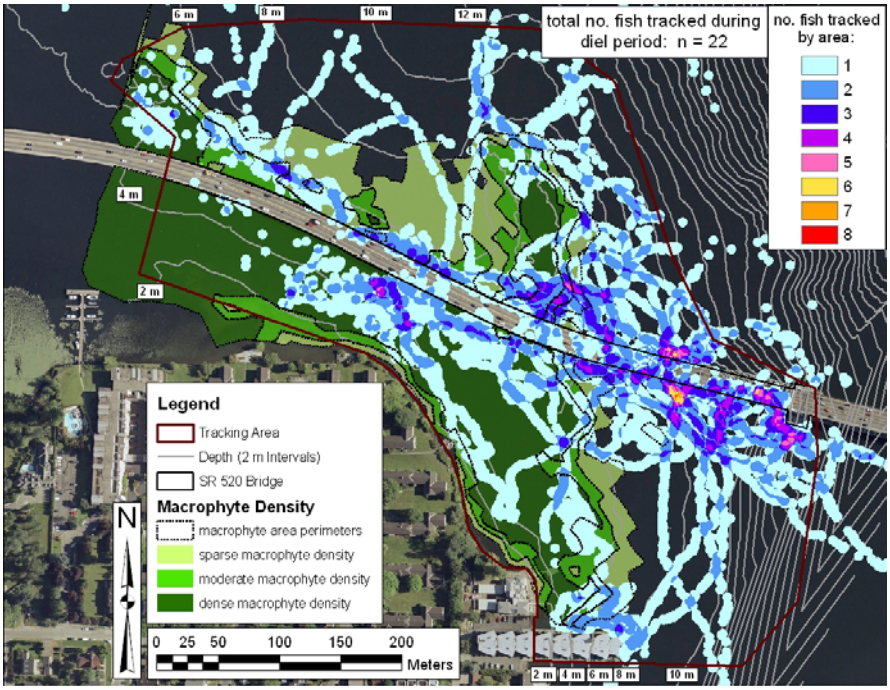
FIGURE 17. Diel water column depth selection ($\hat{w}_i$, selection ratio; log scale) of Chinook salmon released on June 1, 2007. Selection is for the entire water column (inshore versus offshore) and not for the position of the fish within the water column. Selection when fish were near the bridge (< 20 m from bridge edge and directly beneath bridge) was determined separately from when fish were not near the bridge (> 20 m from bridge edge). Error bars represent Bonferroni-adjusted 90% confidence intervals. Errors bars indicate if selection for (>1) or against (<1) a water column depth occurred. A red asterisk (*) indicates selection for a given depth and a blue circle (o) indicates selection against. Only early day and late day are shown because too few fish were tracked during other diel periods.

Relatively few June 1 fish were observed during other diel periods (Table 7). Most of these fish initially entered the site during early day, and were observed during late day meandering and milling north of the bridge and near the bridge's south edge on the west side of the site (Figure 15). The near bridge habitat was the only habitat type selected for during late day (Figure 16). Despite this dissimilarity with early day observations, selection ratios were generally similar between early and late day although late day confidence intervals were almost always considerably wider.

Chinook salmon from the June 14 release group first entered the tracking site largely during early and late day, and ≥ 22 fish were tracked during each of the five diel periods (Table 7). Both early day and late day spatial frequency plots showed high frequency of occurrence around the overwater condo on the south side of the site - which was where most fish initially entered the site - and with dense macrophytes north of the condo (Figure 18). There were also higher frequencies of occurrence along much of the south side of the bridge in the central portion of the site where there were dense macrophytes, and also in the eastern portion of the site in deeper water where there were no macrophytes. This band of higher frequency extended approximately 20 m from the edge of the bridge and was wider in some places and narrower in others. It also extended beneath the bridge in some places. These observations were reflected in habitat use and depth selection calculations. During early day, Chinook salmon showed high selection ratios for dense vegetation, overwater structures, and areas near the bridge, although only dense vegetation was significant (Figure 16). During late day, Chinook salmon significantly selected for the bridge, areas near the bridge, and overwater structures other than the bridge. All other habitat types except dense vegetation were selected against or had selection ratios < 1 during both early day and late day. Depth selection calculations showed that Chinook salmon generally shifted to deeper water when at or near the bridge. When fish were away from the bridge, they selected for 4-6 m depth during both early and late day, and selected against depths > 8 m (Figure 19). In contrast, fish at or near the bridge selected against the 4-6 m depth (late day) or had selection ratios < 1 (early day). Instead, when fish were at or near the bridge the 6-8 m depth had the highest selection ratio during both early and late day. Selection for 6-8 m depth was observed during late day. Selection ratios were also uniformly higher for depths > 8 m when fish were at or near the bridge.

At night, Chinook salmon shifted to a broader spatial distribution across deeper depths and with weaker habitat selections than during the day. This pattern was somewhat obscured and slightly altered when fish were at or near the bridge. Nighttime spatial frequency distribution showed fewer localized areas of higher occurrences than during the day. Those that did appear were of a lesser magnitude: a smaller proportion of fish were observed in localized high occurrence areas at night (Figure 18). The most prominent area occurred in a 15-20 m wide band along the north edge of the bridge in the central and eastern portion of the site. The near-bridge habitat type was not statistically selected

A. June 14 release, dawn



B. June 14 release, early day

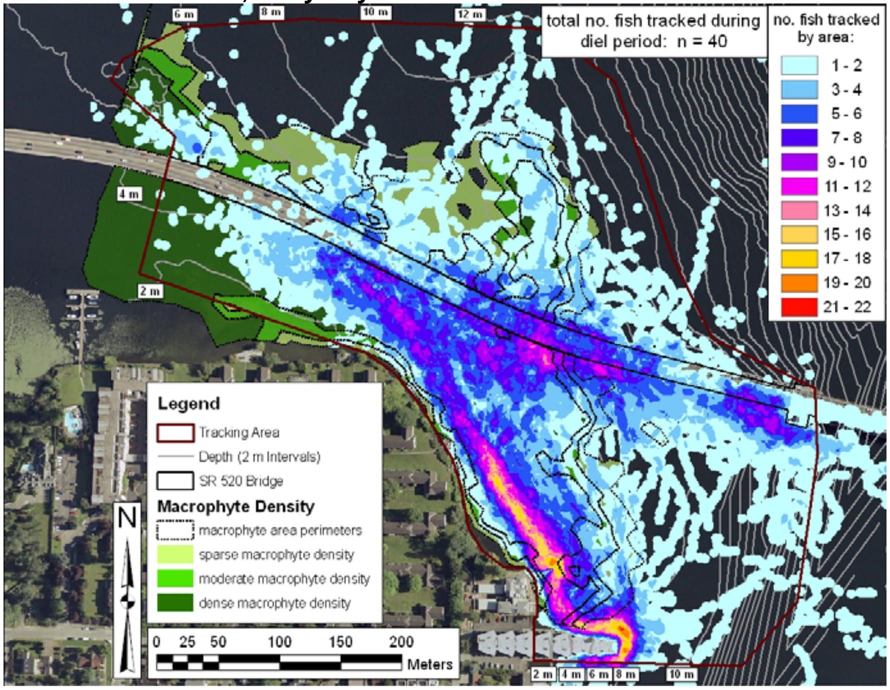
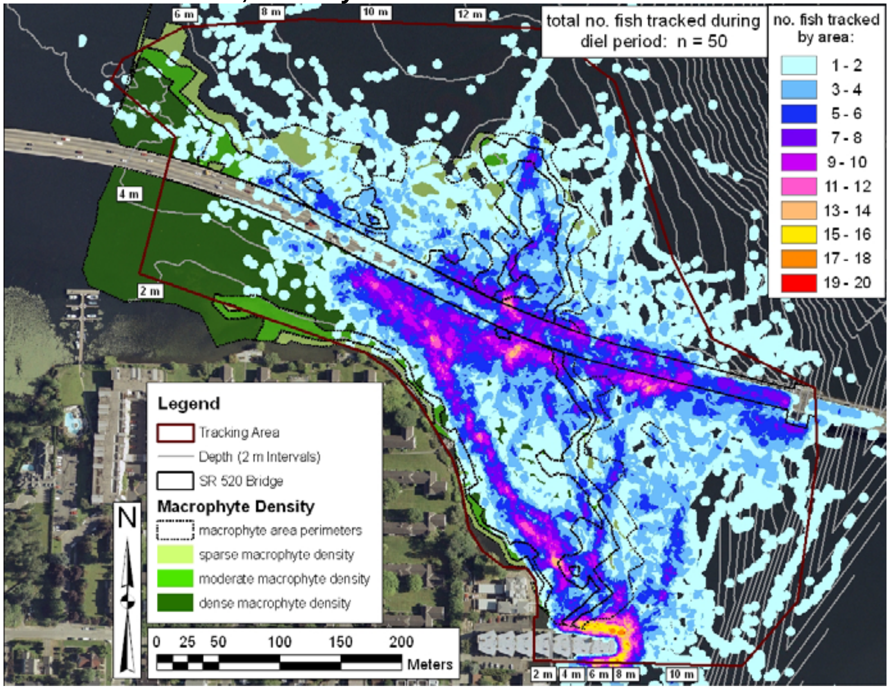


FIGURE 18. Diel spatial frequency distributions of tagged Chinook salmon released on June 14, 2007 and tracked at the SR 520 bridge tracking site. ArcGIS 9.2 Spatial Analyst was used to determine the total number of fish that occurred within a 4 m radius of each tracked fish data point.

C. June 14 release, late day



D. June 14 release, dusk

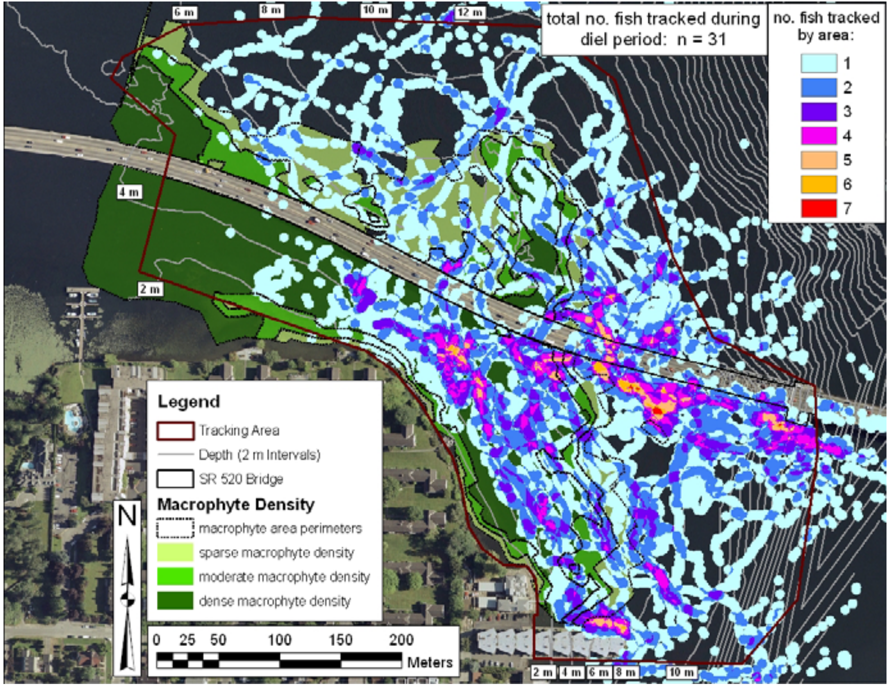


FIGURE 18. (cont.)

E. June 14 release, night

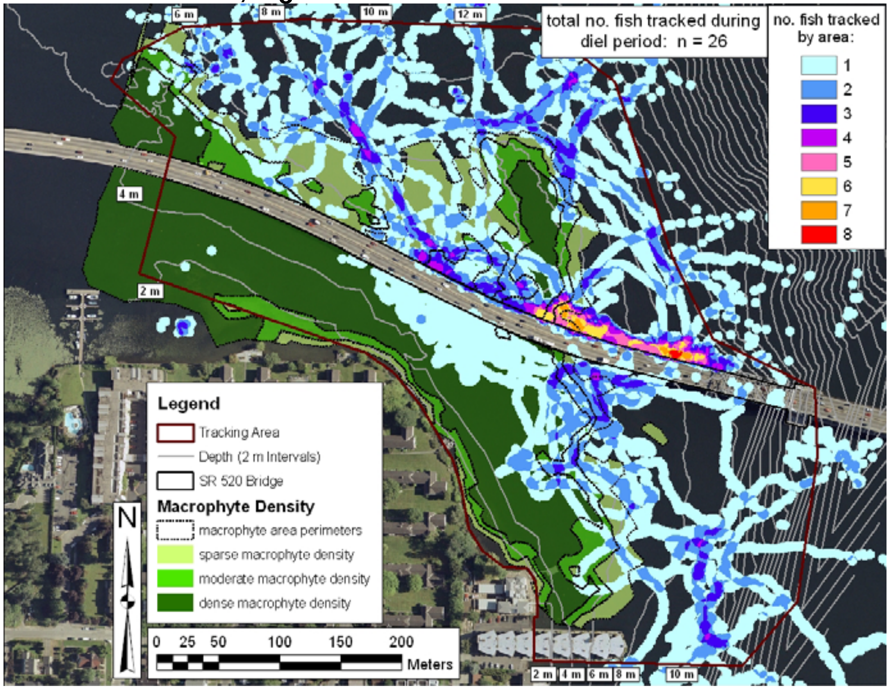


FIGURE 18. (cont.)

for; however, it had the highest selection ratio of all the habitat types, and also had a much larger proportion of its confidence interval > 1 (Figure 16). Habitat types selected against included moderate vegetation and overwater structures other than the bridge. Dense vegetation, sparse vegetation and offshore open water areas also had low selection ratios with much of their confidence intervals falling < 1. Proportional selection was observed in along the offshore edge of vegetation and at the bridge. Nighttime depth selection was generally deeper and more proportional than during the day, and differences associated with proximity to the bridge were apparent but less pronounced. When fish were away from the bridge, they were in deeper water than during the day, selecting for the 6-8 m depth and selecting against depths < 4 m (Figure 19). Proportional selection was observed at 4-6 m, and at depths > 8 m. Selection ratios were similar across 4-10 m depths regardless of proximity to bridge, although confidence intervals varied and no depths were statistically selected for at or near the bridge. The most prominent difference in relation to bridge proximity was observed at the > 10 m depth category: fish at or near the bridge showed strong selection against this depth,

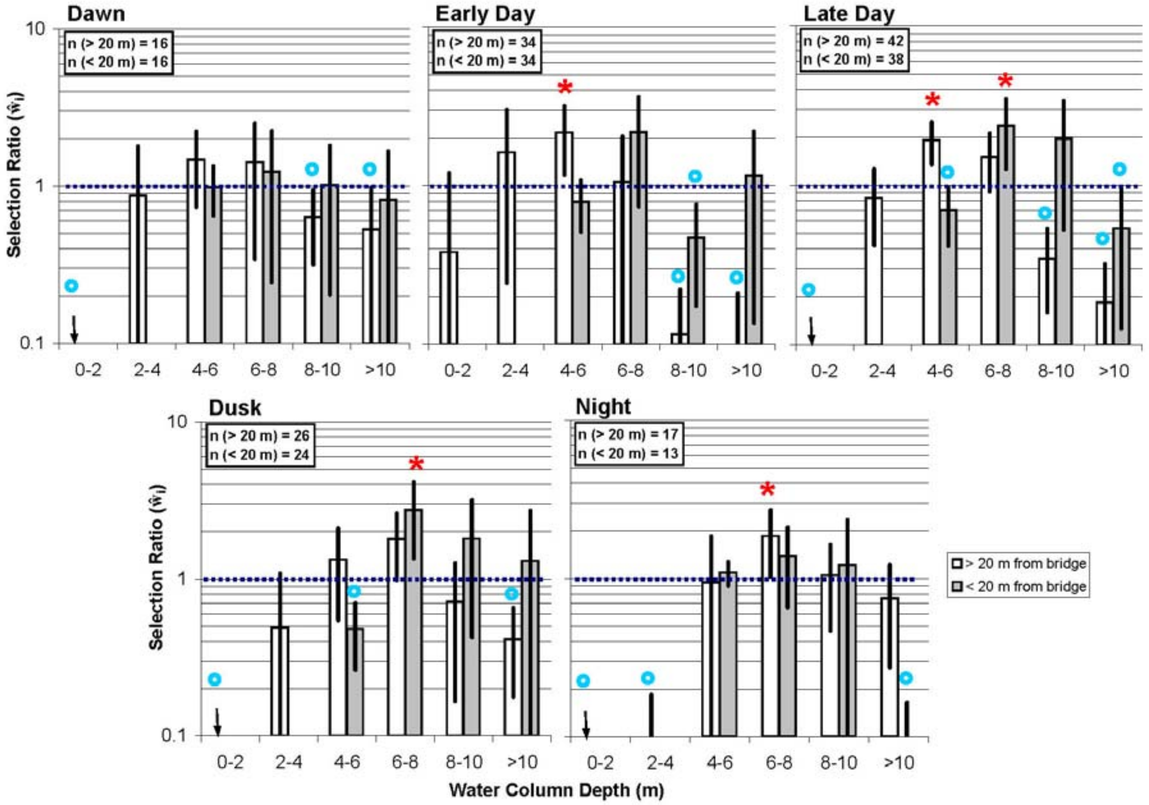


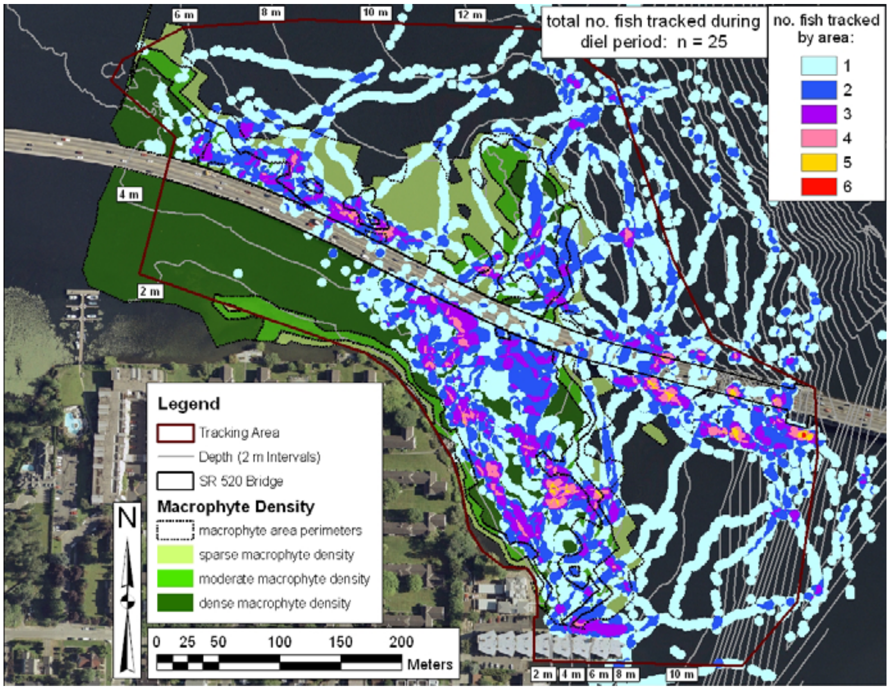
FIGURE 19. Diel water column depth selection ($\hat{w}_i$, selection ratio; log scale) of Chinook salmon released on June 14, 2007. Selection is for the entire water column (inshore versus offshore) and not for the position of the fish within the water column. Selection when fish were near the bridge (< 20 m from bridge edge and directly beneath bridge) was determined separately from when fish were not near the bridge (> 20 m from bridge edge). Error bars represent Bonferroni-adjusted 90% confidence intervals. Errors bars indicate if selection for (>1) or against (<1) a water column depth occurred. A red asterisk (*) indicates selection for a given depth and a blue circle (o) indicates selection against.

whereas away from the bridge fish proportionally selected it. This was a general reversal of the pattern observed during the day.

Crepuscular periods showed patterns of transition between day and night. Spatial frequency distributions, and habitat and depth selections of crepuscular periods generally resembled those from either day or night, or appeared in between. Spatial frequency distribution at dusk covered a similar area as late day, but areas of higher occurrence appeared more disperse, less localized, and of a lower magnitude at dusk (Figure 18). Similarly, dawn spatial frequency distribution covered a similar area as night, but more activity is apparent closer to shore, in dense vegetation and near the bridge which were prominent areas of daytime use. The near-bridge habitat type was selected for at dawn, and was the only habitat statistically selected for during either crepuscular period (Figure 16). At dusk the near-bridge habitat had a selection ratio >> 1 ($\hat{w}_i = 1.76$) but had too wide a confidence interval to show statistical selection for. The bridge and moderate vegetation were selected against at dusk, and proportionally selected at dawn. Dense vegetation, offshore edge of vegetation, and overwater structures other than the bridge were proportionally selected. Offshore open water was selected against and sparse vegetation had selection ratios << 1 during both crepuscular periods. Depth selection ratios at dawn and dusk were largely intermediate between day and night. Fish at or near the bridge appeared to shift toward deeper water, although this was much more subtle than during the day (Figure 19). Selection ratios at depths > 8 m were greater when fish were at or near the bridge.

Patterns in spatial frequency distribution, and habitat and depth selection were largely similar between the June 14 and June 28 release groups albeit with some notable differences. Fish from the June 28 group first entered the tracking site largely during late day shortly after release, and ≥ 25 fish were tracked during each of the five diel periods (Table 7). Both early day and late day spatial frequency plots showed high frequency of occurrence around the overwater condo on the south side of the site - which was where most fish initially entered the site - and with dense macrophytes north of the condo (Figure 20). There were also higher frequencies of occurrence along much of the south side of the bridge in the central portion of the site where there were dense macrophytes, and also in the eastern portion of the site in deeper water where there were no macrophytes. As with the June 14 group, this band of higher frequency extended approximately 20 m from the edge of the bridge and was wider in some places and narrower in others. It also extended beneath the bridge in some places. The farthest western extent of occurrence on the side south of the bridge appeared about 150-200 m east of that from the June 14 group. This was true for all diel periods. Another disparity

A. June 28 release, dawn



B. June 28 release, early day

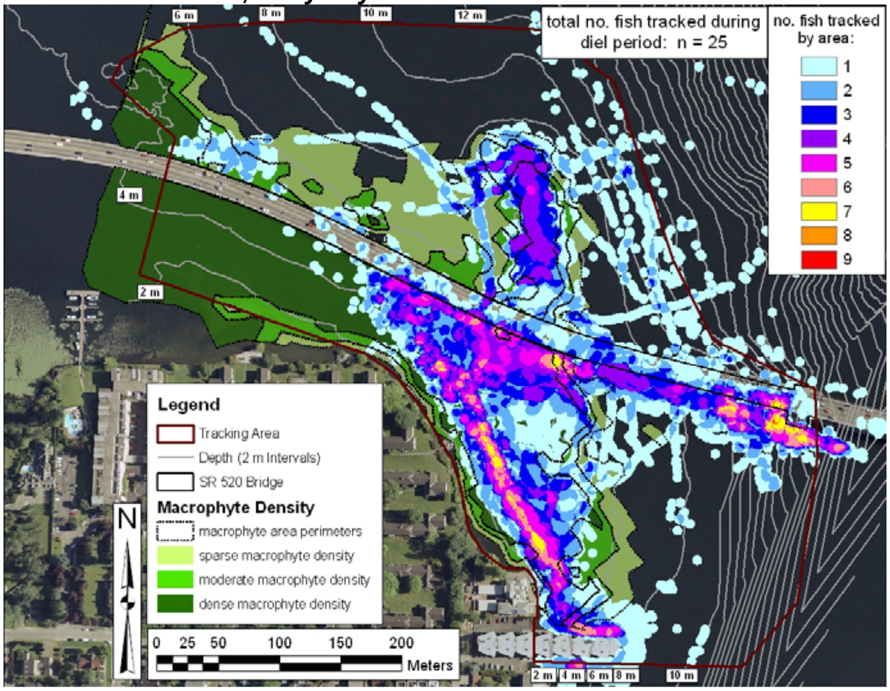
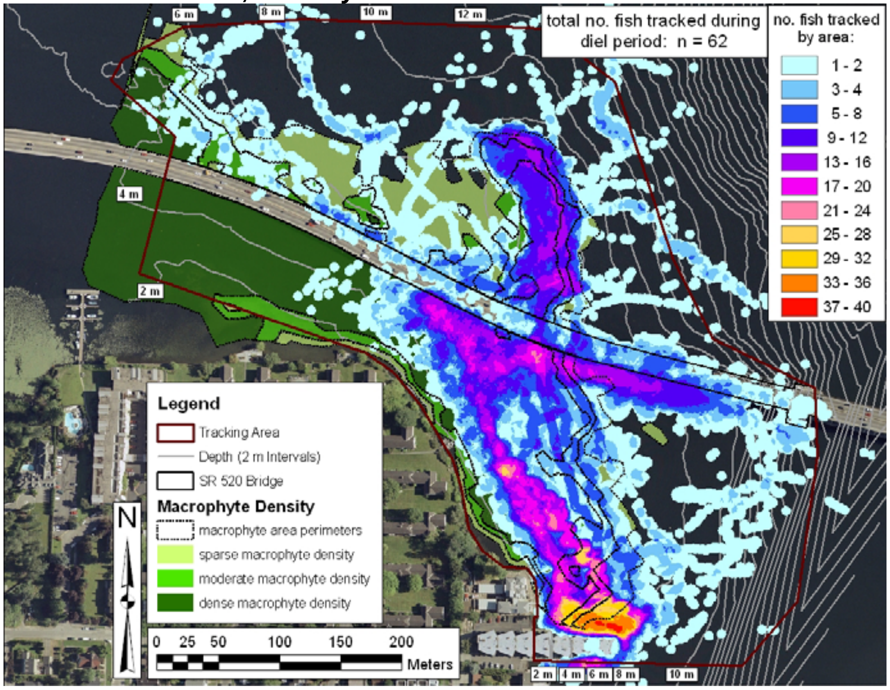


FIGURE 20. Diel spatial frequency distribution of tagged Chinook salmon released on June 28, 2007 and tracked at the SR 520 bridge tracking site. ArcGIS 9.2 Spatial Analyst was used to determine the total number of fish that occurred within a 4 m radius of each tracked fish data point.

C. June 28 release, late day



D. June 28 release, dusk

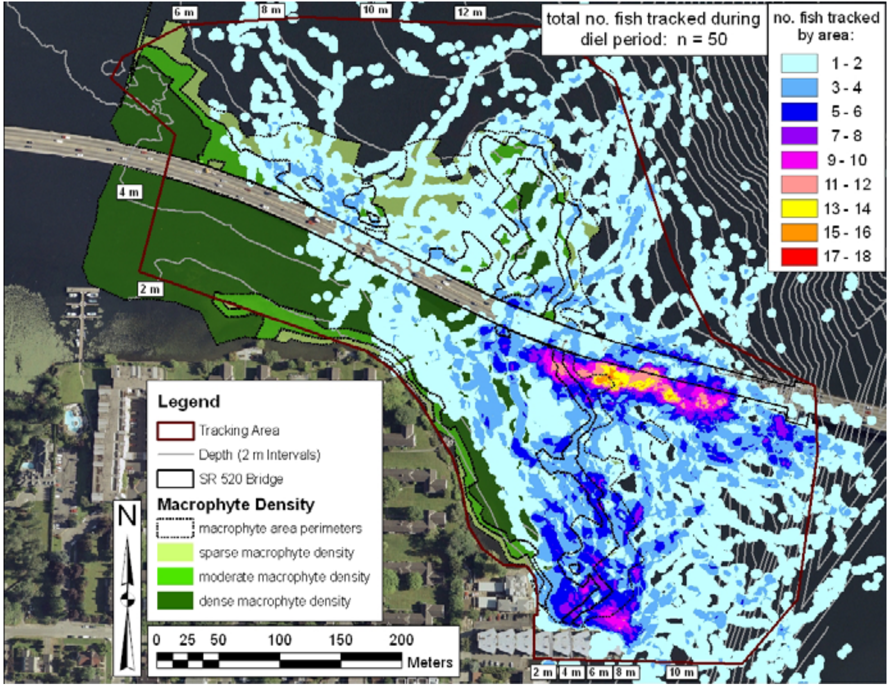
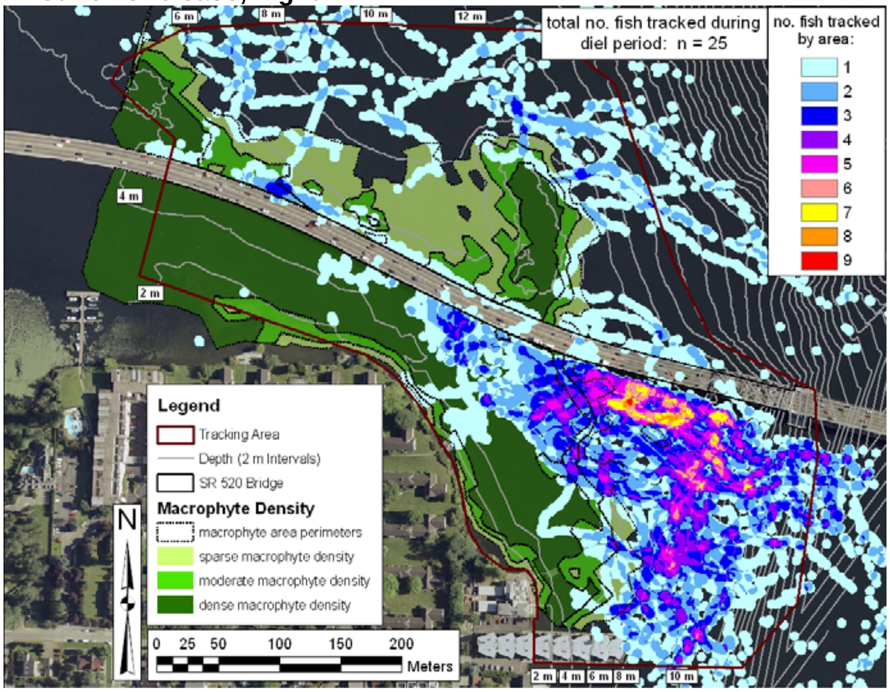


FIGURE 20. (cont.)



E. June 28 release, night

FIGURE 20. (cont.)

between release groups was the extensive usage of the shallow vegetated peninsula on the north side of the bridge by the June 28 fish during both early and late day. June 14 fish did not show any particular affinity for this area.

Spatial frequency observations were reflected in habitat use and depth selection calculations. During both early and late day, Chinook salmon statistically selected for dense vegetation and areas near the bridge (Figure 16). During late day, Chinook salmon also significantly selected for overwater structures other than the bridge. Proportional selection was observed for moderate vegetation and the bridge. Offshore edge of vegetation and offshore open water areas were selected against. Sparse vegetation was strongly selected against during early day but was proportionally selected during late day. Depth selection was nearly identical to the June 14 group with fish generally shifted to deeper water when at or near the bridge (Figure 21). When fish were away from the

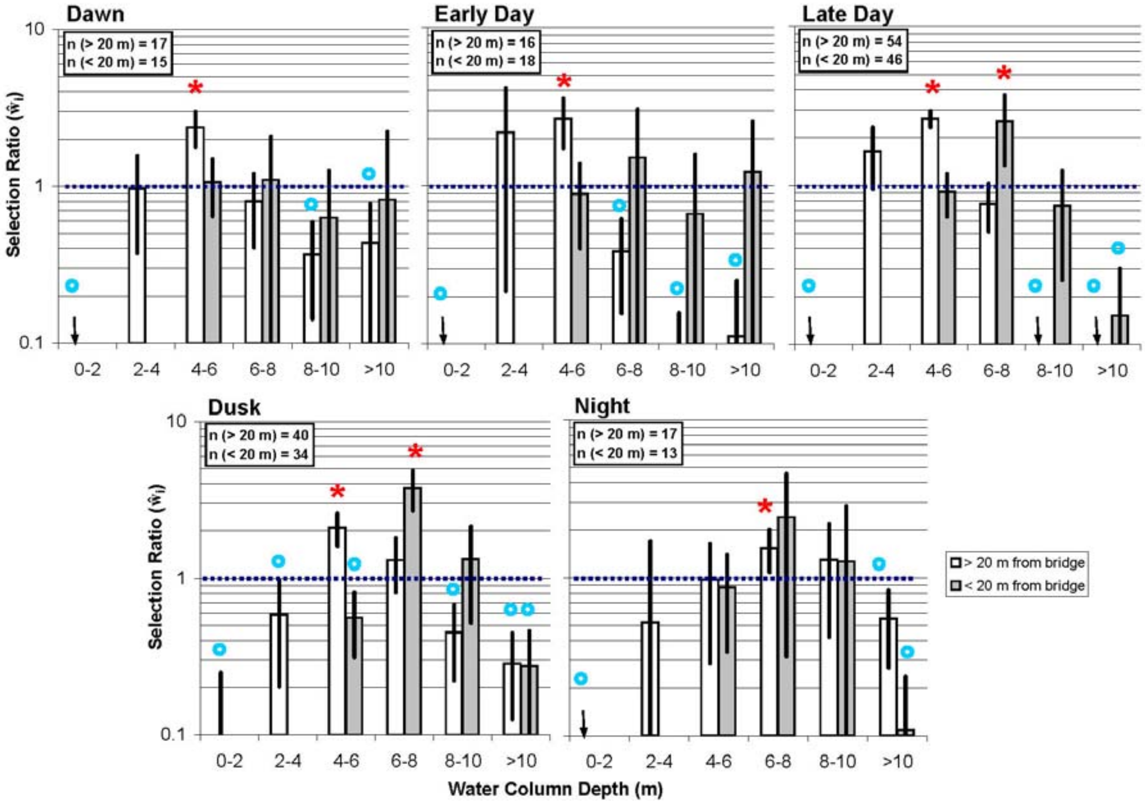


FIGURE 21. Diel water column depth selection ($\hat{w}_i$, selection ratio; log scale) of Chinook salmon released on June 28, 2007. Selection is for the entire water column (inshore versus offshore) and not for the position of the fish within the water column. Selection when fish were near the bridge (< 20 m from bridge edge and directly beneath bridge) was determined separately from when fish were not near the bridge (> 20 m from bridge edge). Error bars represent Bonferroni-adjusted 90% confidence intervals. Errors bars indicate if selection for (>1) or against (<1) a water column depth occurred. A red asterisk (*) indicates selection for a given depth and a blue circle (o) indicates selection against.

bridge, they selected for 4-6 m depth during both early and late day, and selected against depths > 8 m (Figure 21). In contrast, fish at or near the bridge had selection ratios < 1. Instead, when fish were at or near the bridge the 6-8 m depth had the highest selection ratio during both early and late day. Selection for this depth was observed during the latter. Selection ratios were also uniformly higher for depths > 6 m when fish were at or near the bridge.

At night, Chinook salmon shifted to a broader spatial distribution across deeper depths and with weaker habitat selections than during the day much as the June 14 group did. This pattern was similarly obscured and slightly altered when fish were at or near the bridge. Nighttime spatial frequency distribution showed fewer localized areas of higher occurrences than during the day. Those that did appear were of a lesser magnitude: a smaller proportion of fish were observed in localized high occurrence areas at night (Figure 20). The most prominent area occurred in a band along the south edge of the bridge on eastern portion of the site - different from that observed with the June 14 group. Also unlike the June 14 observations, the June 28 band started not at the edge of the bridge but rather 5 m from the edge of the bridge, and extended 35 m from here. Despite this, the near-bridge habitat type was not statistically selected for; however, it had the highest selection ratio of all the habitat types, and also had a much larger proportion of its confidence interval > 1 (Figure 16). Habitat types selected against included the bridge and overwater structures other than the bridge. Moderately and sparsely dense vegetation had selection ratios << 1 with much of their confidence interval falling < 1. Proportional selection was observed along the offshore edge of vegetation, and in offshore open water areas.

Nighttime depth selection was nearly identical to the June 14 release: fish were generally deeper and more proportional than during the day, and differences associated with proximity to the bridge were apparent but less pronounced. When fish were away from the bridge, they were in deeper water than during the day, selecting for the 6-8 m depth and selecting against depths < 2 m and > 10 m (Figure 21). Unlike June 14 fish, the 2-4 m depth was not statistically selected against, however it did have a low selection ratio (0.52) and a much wider confidence interval that was mostly < 1. Proportional selection was observed at 4-6 m, and 8-10 m. Selection ratios were similar across 4-10 m depths regardless of proximity to bridge, although confidence intervals varied and no depths were statistically selected for at or near the bridge. As with the June 14 release, the most prominent difference in relation to bridge proximity was observed at the > 10 m depth category: fish at or near the bridge had a substantially lower selection ratio than fish away from the bridge, although both groups selected against this depth. Again, this was a general reversal of the pattern observed during the day.

Crepuscular periods showed similar patterns of transition between day and night. Spatial frequency distributions, and habitat and depth selections of crepuscular periods generally resembled those from either day or night, or appeared in between. Spatial frequency distribution at dusk covered a similar area as late day, but areas of higher occurrence appeared smaller and of a lower magnitude at dusk (Figure 20). Similarly, dawn spatial frequency distribution covered a similar area as night, but more activity was apparent closer to shore, in dense vegetation and near the bridge which were prominent areas of daytime occurrence. Habitats statistically selected for included near-bridge areas during both crepuscular periods, and moderate vegetation at dusk (Figure 16). Dense vegetation at dawn had a selection ratio >> 1 ($\hat{w}_i = 1.60$) with much of its confidence interval > 1. Proportional selection was generally observed in sparse vegetation, at the bridge, and overwater structures other than the bridge during both crepuscular periods, in moderate vegetation at dawn, and dense vegetation at dusk. The offshore edge of vegetation and offshore open water areas were selected against or had selection ratios << 1. Patterns in depth selection at dawn and dusk were nearly identical to those observed in the June 14 release, and were largely intermediate between day and night. Fish at or near the bridge appeared to shift toward deeper water, although this was much more subtle than during the day (Figure 21). Selection ratios at depths > 6 m were greater when fish were at or near the bridge, except during dusk at depths > 10 m where bridge selection was equivalent regardless of bridge proximity.

Many Chinook salmon from the June 14 and 28 releases that used the near-bridge area along the bridge's southern edge moved here after passing beneath the bridge to the north, then moving back south at some point. This described 23 and 12 fish respectively from the June 14 and 28 releases. These fish often moved into and away from this area several times, and spent prolonged periods of time here. In total, June 14 fish spent mean 6.2 h and June 28 fish spent mean 6.2 h in this area, all after moving north of the bridge then back south. This pattern suggested that Chinook salmon occurrence in this area was volitional and not the result of some holding behavior caused by some inhibition to move beyond the bridge. Many other fish from both the June 14 and 28 releases also occurred in this area, but did so prior to moving north of the bridge.

Northern pikeminnow

The only two predatory fish species we captured at the SR 520 study site were northern pikeminnow and smallmouth bass. Several adult peamouth *Mylocheilus caurinus* and small yellow perch *Perca flavescens* were also captured and released. We tagged 25 northern pikeminnow with HTI G tags (60 day); of which, 21 were captured and released at the study site and four were captured and released in Portage Bay at the west end of Montlake Cut (Figure 1). The mean length of northern pikeminnow tagged was 385.4 mm FL and ranged from 281 to 460 mm FL (Table 8). Of the fish released at the study site, all were detected but many were only present at the study site for less than 48 h after release (Table 9). We obtained extensive tracking results (> 27 days) for four fish and two additional fish we tracked periodically over a 4 to 15 day period. Ninety-eight percent of all pikeminnow data points were from these six fish. Each of the four northern pikeminnow released in Portage Bay were briefly detected at the SR 520 study site but no data points were obtained from two and the other two were only present for a brief period of time (less than 3 h).

Habitat selection analysis of the six northern pikeminnow indicated areas of dense and moderately dense macrophytes were selected, while the open offshore areas and the offshore edge of the macrophytes were selected against (Figures 22 and 23). The nearshore overwater structures were selected but only during the daytime. Five of the six pikeminnow used the small pier at the Madison Point Condominiums or the large Lakeshore West Condominium structure during the day. As a group, tagged pikeminnow did not statistically select for the SR 520 bridge. However, five of the six fish made substantial use of the bridge during at least one time period (Figures 24, 25, and 26). One fish, #4777, was often under the bridge or near it, especially at night (Figure 26).

TABLE 8. Northern pikeminnow tagged with HTI acoustic tags (60-day G tags), May-June, 2007. Location is the area where the fish were captured and released. Shaded fish are the six fish we obtained extensive tracking results and were used for most of the data analyses.

Location	Date released	Capture method	Tag period (msec)	Fork length (mm)	Weight (g)
Portage Bay	10-May	Angling	4507	445	1,100
Portage Bay	10-May	Gill Net	4517	390	750
Portage Bay	17-May	Gill Net	4527	330	400
520 Bridge	24-May	Gill Net	4657	427	1,020
520 Bridge	24-May	Angling	4667	430	1,060
520 Bridge	24-May	Gill Net	4677	413	920
520 Bridge	24-May	Gill Net	4687	302	304
520 Bridge	31-May	Gill Net	4727	294	305
520 Bridge	31-May	Gill Net	4737	400	700
520 Bridge	31-May	Gill Net	4747	340	530
520 Bridge	6-Jun	Gill Net	4777	435	1,110
520 Bridge	6-Jun	Gill Net	4787	460	1,280
520 Bridge	6-Jun	Gill Net	4797	420	860
520 Bridge	6-Jun	Gill Net	4807	367	570
520 Bridge	6-Jun	Gill Net	4817	425	1,020
520 Bridge	6-Jun	Gill Net	4827	345	580
520 Bridge	6-Jun	Gill Net	4837	415	840
520 Bridge	6-Jun	Gill Net	4847	281	297
520 Bridge	6-Jun	Gill Net	4857	420	930
520 Bridge	6-Jun	Gill Net	4867	435	1,040
520 Bridge	6-Jun	Gill Net	4877	441	1,020
Portage Bay	7-Jun	Gill Net	4887	330	400
520 Bridge	15-Jun	Gill Net	4957	318	380
520 Bridge	15-Jun	Gill Net	4967	410	890
520 Bridge	15-Jun	Gill Net	4977	362	500

TABLE 9. Detection of tagged northern pikeminnow at the SR 520 study site, May-August, 2007. The list only includes fish that were released at the SR 520 site. The first 24 hours after release was not used. The percent of days detected includes days when the fish was detected on a least one hydrophone. Shaded fish are the six fish we obtained extensive tracking results and were used for most of the analyses.

Tag period (msec)	Date released	Date of first data point	Date of last data point	Percent of days detected	Number of data points North	Number of data points South
4657	24-May	29-May	20-Jul	59.3	13,481	62,733
4667	24-May	29-May	23-Jul	78.0	115,533	64,364
4677	24-May	7-Jun	17-Jul	5.1	91	237
4687	24-May	4-Jun	8-Jun	10.2	170	369
4727	31-May	--	--	5.1	0	0
4737	31-May	--	--	0	0	0
4747	31-May	2-Jun	7-Jun	10.2	4,904	261
4777	6-Jun	10-Jun	5-Aug	84.7	46,566	71,448
4787	6-Jun	7-Jul	22-Jul	20.3	882	2,830
4797	6-Jun	7-Jun	4-Jul	16.9	1,937	24,226
4807	6-Jun	--	--	0	0	0
4817	6-Jun	8-Jun	9-Jun	3.4	0	3,103
4827	6-Jun	--	--	1.7	0	0
4837	6-Jun	10-Jun	10-Jun	6.8	32	0
4847	6-Jun	7-Jun	7-Jun	1.7	0	391
4857	6-Jun	9-Jun	9-Jun	5.1	4	1,079
4867	6-Jun	--	--	0	0	0
4877	6-Jun	--	--	0	0	0
4957	15-Jun	16-Jun	16-Jun	1.7	0	1,764
4967	15-Jun	17-Jun	24-Jun	3.4	213	568
4977	15-Jun	16-Jun	16-Jun	1.7	220	310

Density plots indicated pikeminnow were less active during the day than at night (Figure 25). During the day, data points were concentrated in a few localized areas. At night, data points were spread out over a large area, including areas offshore outside the coverage area. Tracks of individual fish indicated they were often close to shore during the day and spread out over a broad area both near- and offshore during dusk and night (Figure 27). Although pikeminnow were spread out over a large area at night, they were still concentrated in nearshore areas where the water was 4-6 m deep. Depth selection analysis indicated the water column depth of 4-6 m was the only depth interval significantly selected for each time period (Figure 28). Seventy percent of all detections (time periods combined) were between 4 and 6 m deep (water column depth) while this depth interval only comprised 30% of the coverage area. On some occasions,

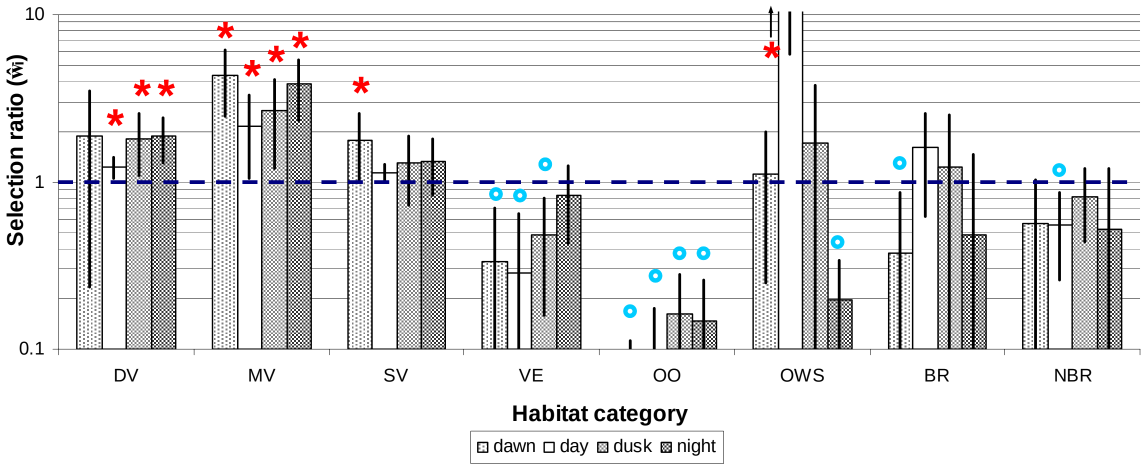


FIGURE 22. Habitat selection ($\hat{w}_i$, selection ratio; log scale) of six northern pikeminnow at the SR 520 bridge study site, May-August 2007. Error bars represent Bonferroni-adjusted 90% confidence intervals. Errors bars indicate if selection for (lower bar >1) or against (upper bar <1) a habitat type occurred. A red asterisk (*) indicates if the habitat type was selected for and a blue circle (o) indicates if the habitat type was selected against. Habitat categories are described in Table 1.

pikeminnow moved into shallow water (0-2 m) at dawn (Figure 29). Otherwise, they were rarely observed in this area.

In addition to the six pikeminnow we tracked extensively, we also obtain some movement information on 11 other pikeminnow that were tracked on three or fewer days. In general, the overall behavior of this group of fish was similar to the six extensively-tracked pikeminnow. Of the 11 briefly-tracked pikeminnow, most were close to shore and were often located at the Madison Point pier during the day or a few meters just north of the pier (Figure 30). One fish (#4977) was tracked as it moved along the SR 520 bridge during the daytime. Otherwise, little association with the bridge structure was observed in this group of fish.

Of the eight double-tagged pikeminnow, we obtained a large number of detections for only two fish (HTI tag #'s 4657 and 4667) (Table 10). Fish #4657 was detected from June 2 to 26 and was in shallow water during the day and moved to deeper water at night

(Figure 31). The other pikeminnow (HTI tag 4667) was detected on every day from June 1 to August 13 except seven days. We separated this data into two periods: June and late July-August. In June, this pikeminnow used a wide-range of depths throughout the day; whereas, in late-July-August it was rarely in water less than 4 m deep during the day (Figure 32). Merged Vemco and HTI data of these two pikeminnow indicated they were usually present in the upper half of the water column during the day and close to shore (Figure 33). During the day, fish # 4667 was also located close to the substrate where the water was 6-10 m deep. At night, fish # 4667 moved up in the water column and was usually in water that was less than 4 m deep. This fish did not show any appreciable offshore movements at night. In contrast, fish #4657 appeared to move offshore at night and often inhabited mid-column depths.

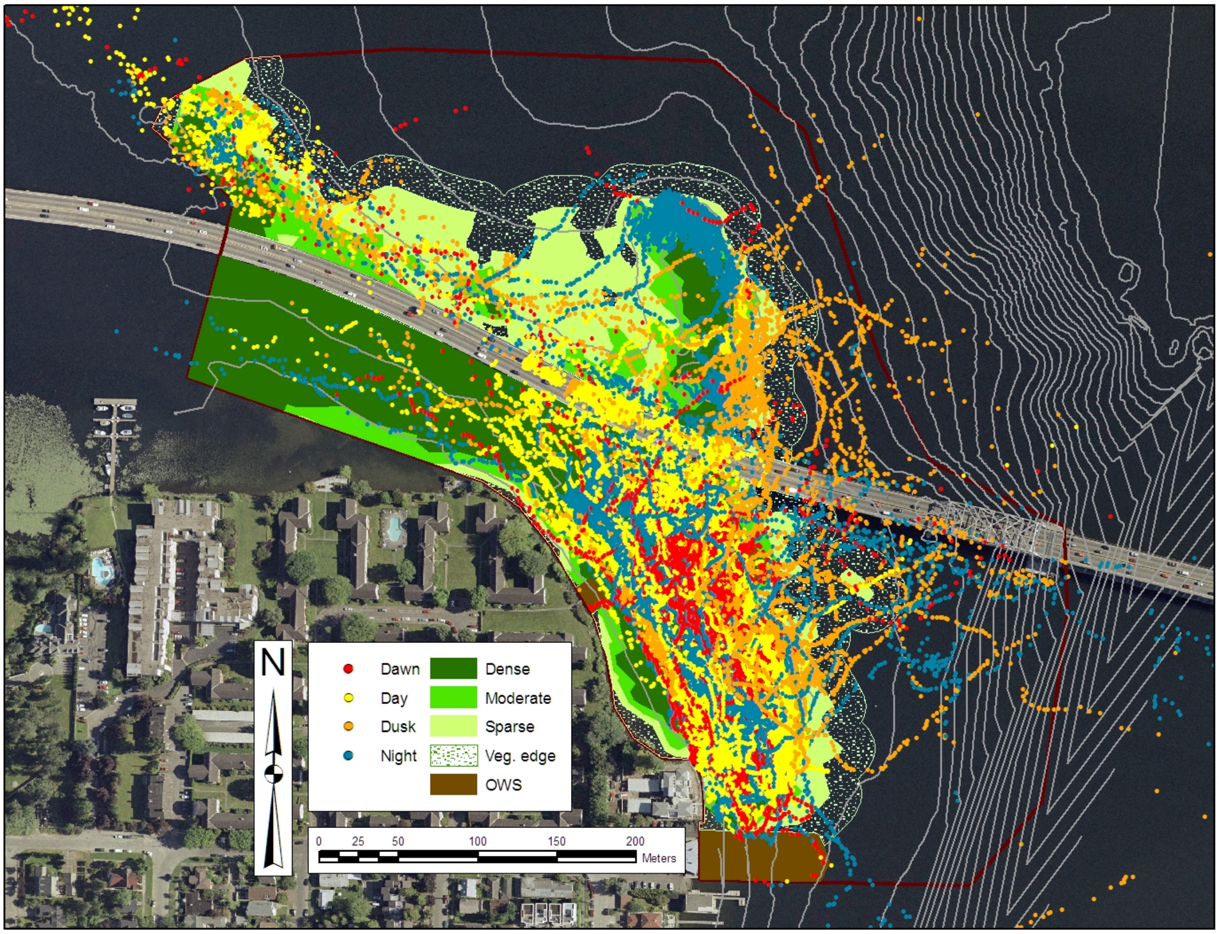


FIGURE 23. Data points of northern pikeminnow #4657 during different time periods at the SR 520 bridge study site, May 29-July 20, 2007 showing its relationship to aquatic macrophyte (three density levels and the offshore edge) distribution. The dark red line is the coverage area of the hydrophone array. White lines are depth contours in 2-m intervals. OWS = overwater structures (not including the SR 520 bridge).

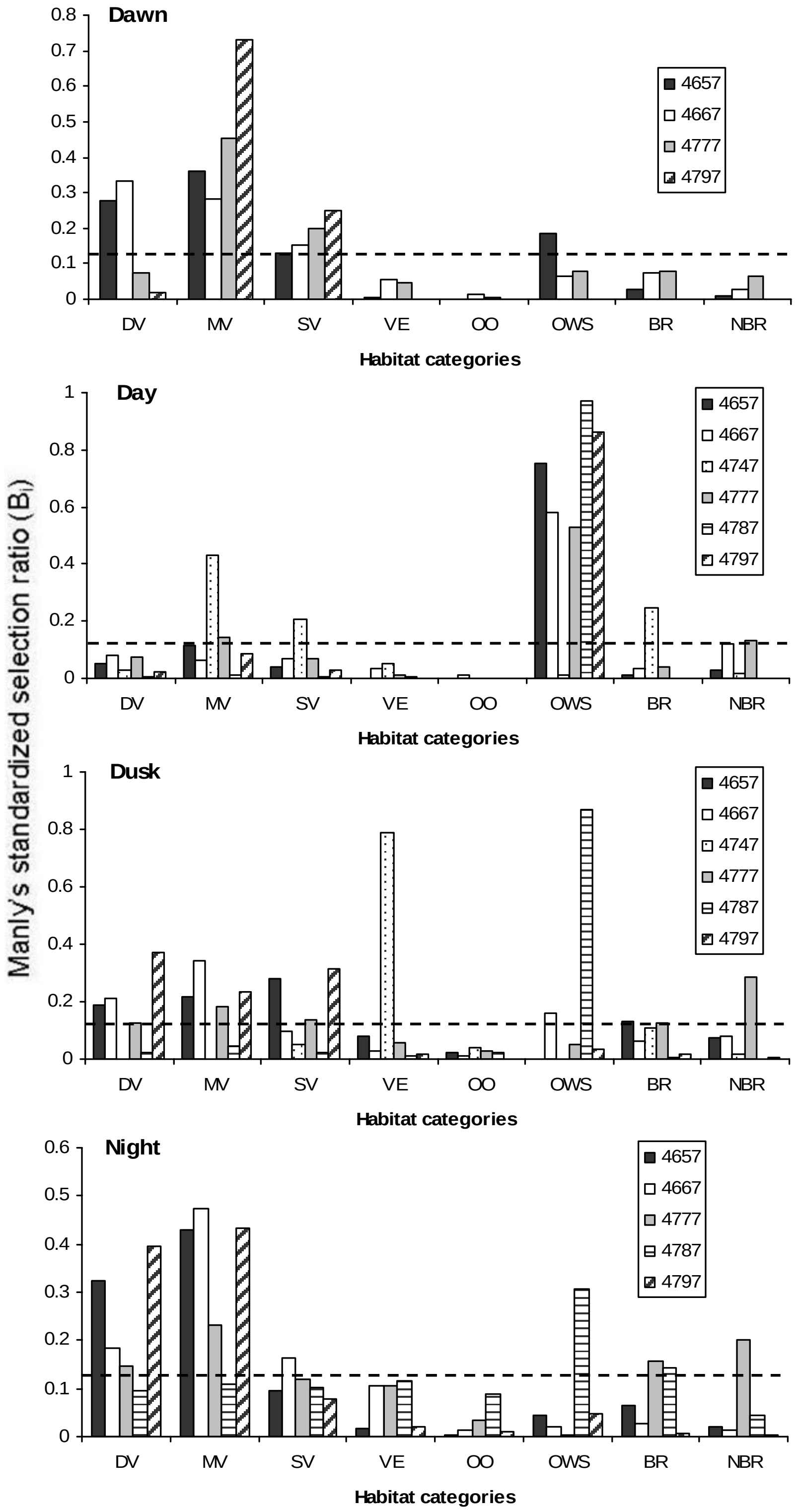


FIGURE 24. Habitat selection (B_i, Manly's standardized selection ratio) of six northern pikeminnow at the SR 520 bridge study site, May-August 2007. Habitat categories are described in Table 1. The dashed lines indicate the level of selectivity if all habitat types were used proportionally. Not every fish was present during each time period.

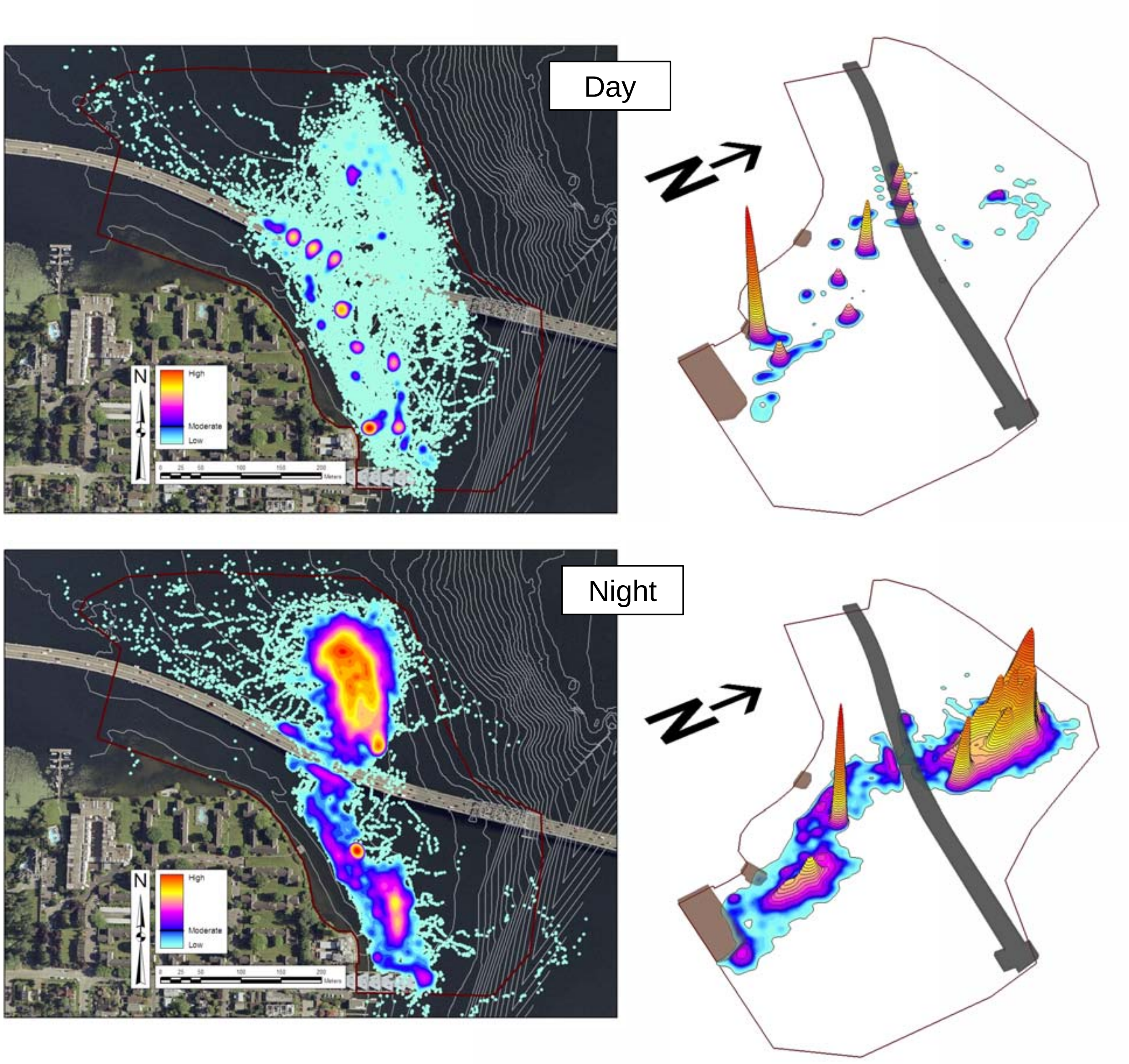


FIGURE 25. Day and night density plots of northern pikeminnow #4667 at the SR 520 bridge study site, May-August 2007. The pictures on the right side are the same pictures as on the left side just displayed in 3D. Representation of lowest density was altered to enhance clarity: size of lowest density was made smaller in the plot 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.

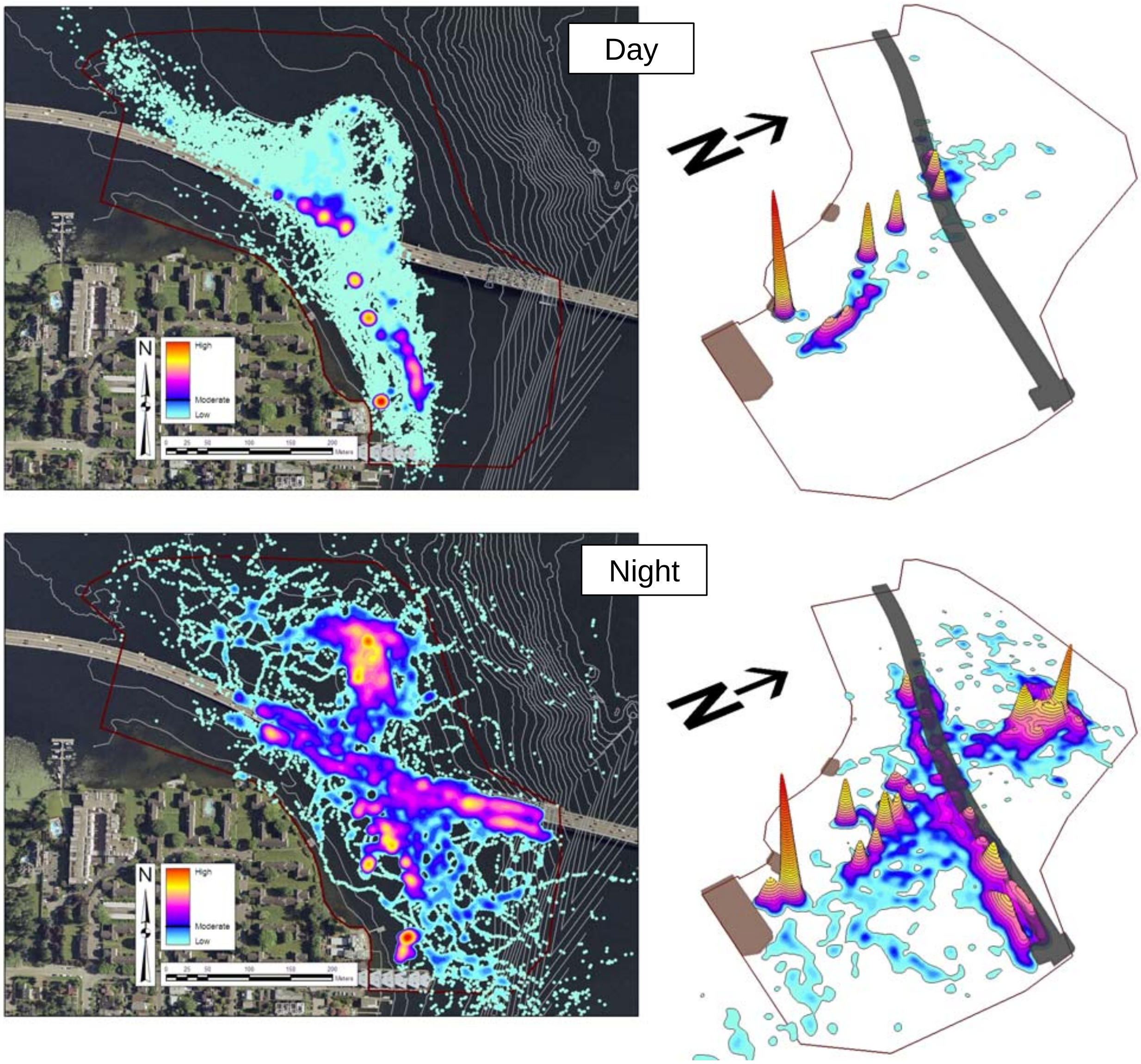


FIGURE 26. Day and night density plots of northern pikeminnow #4777 at the SR 520 bridge study site, May-August 2007. The pictures on the right side are the same pictures as on the left side just displayed in 3D. Representation of lowest density was altered to enhance clarity: size of lowest density was made smaller in the plot 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.

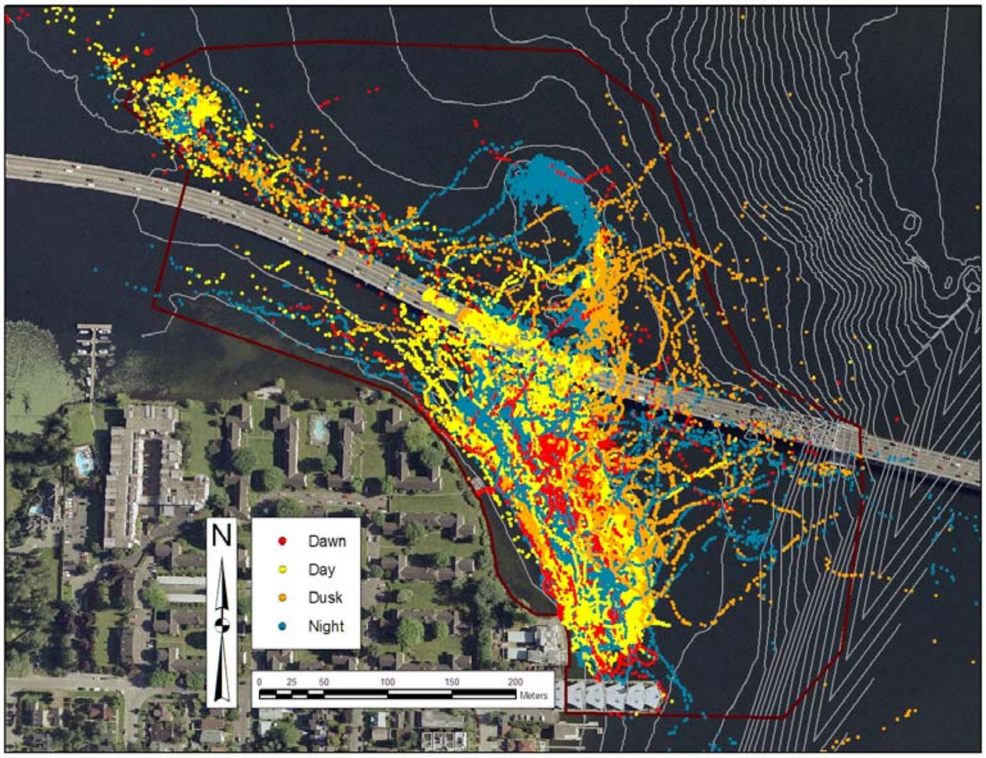


FIGURE 27. Data points of northern pikeminnow #4657 during different time periods at the SR 520 bridge study site, May 29-July 20, 2007. White lines are depth contours in 2-m intervals. The dark red line is the coverage area of the hydrophone array.

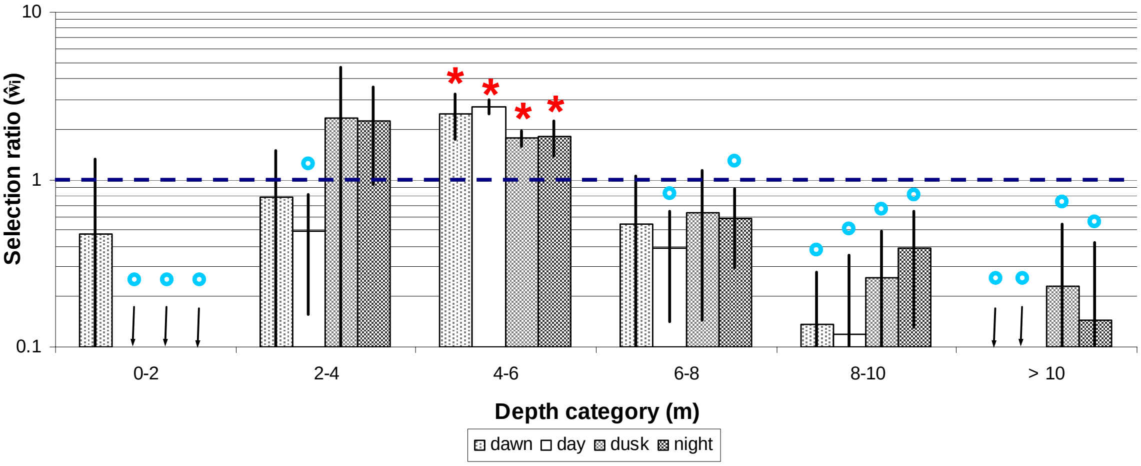


FIGURE 28. Depth selection ($\hat{w}_i$, selection ratio; log scale) of six northern pikeminnow at the SR 520 bridge study site, May-August 2007. Selection is for the entire water column (inshore versus offshore) and not for the position of the fish within the water column. Error bars represent Bonferroni-adjusted 90% confidence intervals. Errors bas indicate if selection for (lower bar >1, dashed line) or against (upper bar <1, dashed line) a habitat type occurred. A red asterisk (*) indicates if the habitat type was selected for and a blue circle (o) indicates if the habitat type was selected against.

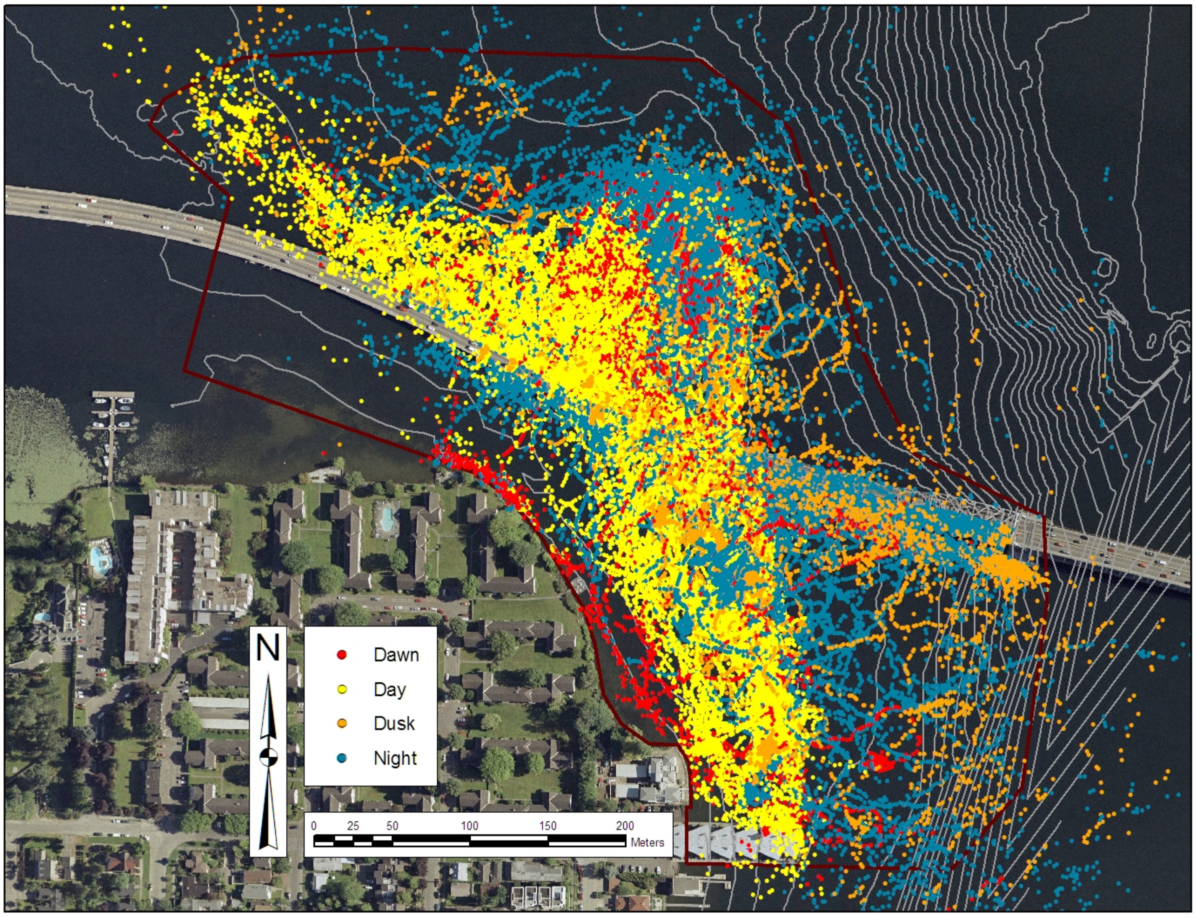


FIGURE 29. Data points of northern pikeminnow #4777 during different time periods at the SR 520 bridge study site, May 29-July 20, 2007. White lines are depth contours in 2-m intervals. The dark red line is the coverage area of the hydrophone array.

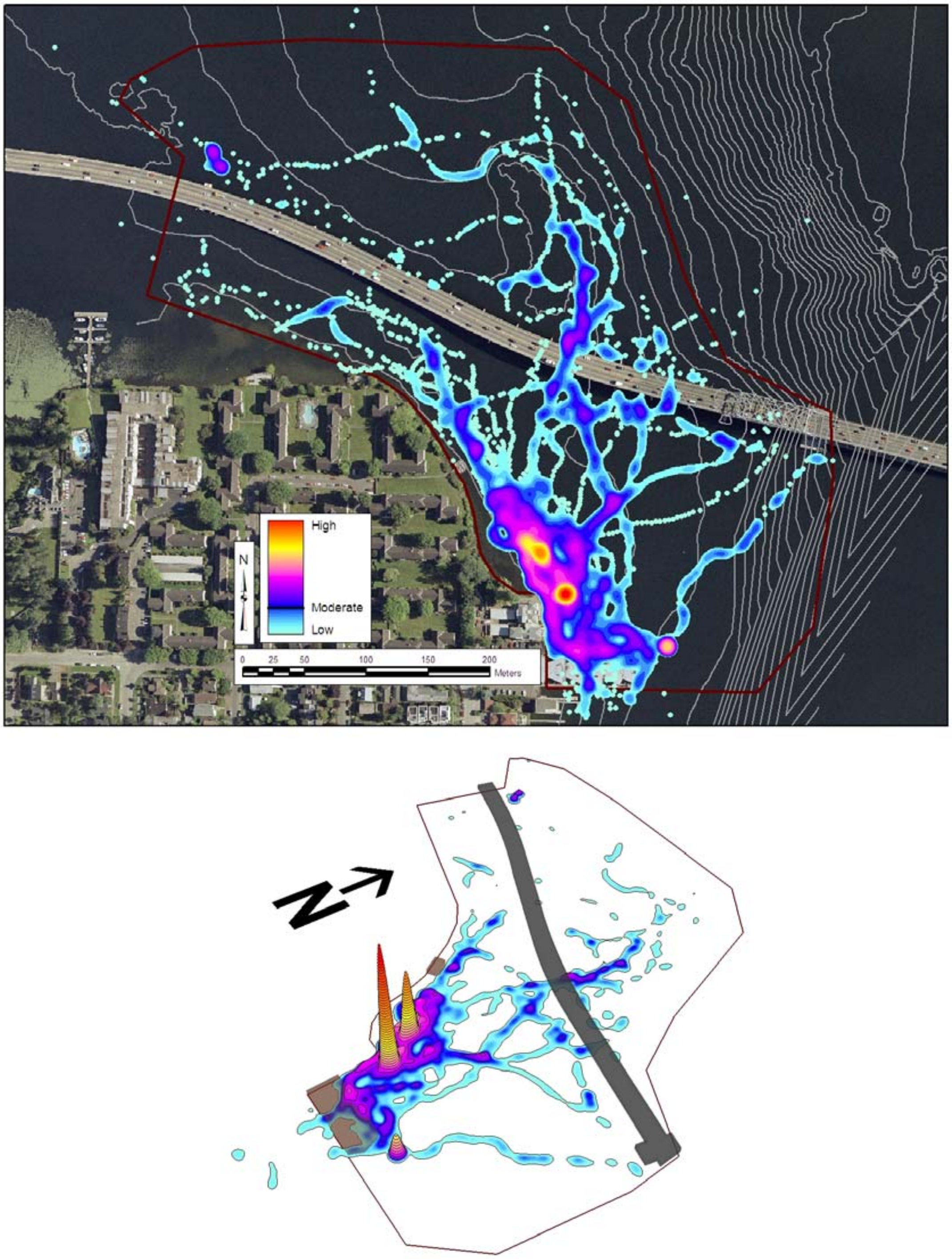


FIGURE 30. Density plot of 11 briefly-tracked northern pikeminnow at the SR 520 bridge study site, May-August 2007. These pikeminnow were only present in the array for a short period of time (three or fewer days) and relatively few data points were obtained. Each pikeminnow was weighted equally for the density plot calculation. The bottom picture is the same picture as the top just displayed in 3D. Representation of lowest density was altered to enhance clarity: size of lowest density was made smaller in the plot on the top, and lowest density was eliminated from plot on the bottom. The dark red line is the coverage area of the hydrophone array in both the 2D and 3D pictures. White lines in the 2D picture are depth contours in 2-m intervals.

TABLE 10. Detections of double-tagged northern pikeminnow by the Vemco receiver located on the offshore edge of the Lakeshore West Condominiums, May-August, 2007. All pikeminnow were caught and released at the SR 520 study site.

				Vemco detections		
Vemco tag ID	HTI tag period	Fork length (mm)	Date released	Date of first data point	Date of last data point	Total # of detections
111	4657	427	5/24	6/2	6/26	4,440
112	4787	460	6/6	7/7	7/31	375
113	4837	415	6/6	6/11	7/30	11
116	4867	435	6/6	--	--	0
119	4667	430	5/24	5/29	8/13	10,198
134	4677	413	5/24	6/7	8/13	29
225	4737	400	5/31	--	--	0
228	4747	340	5/31	6/3	6/7	24

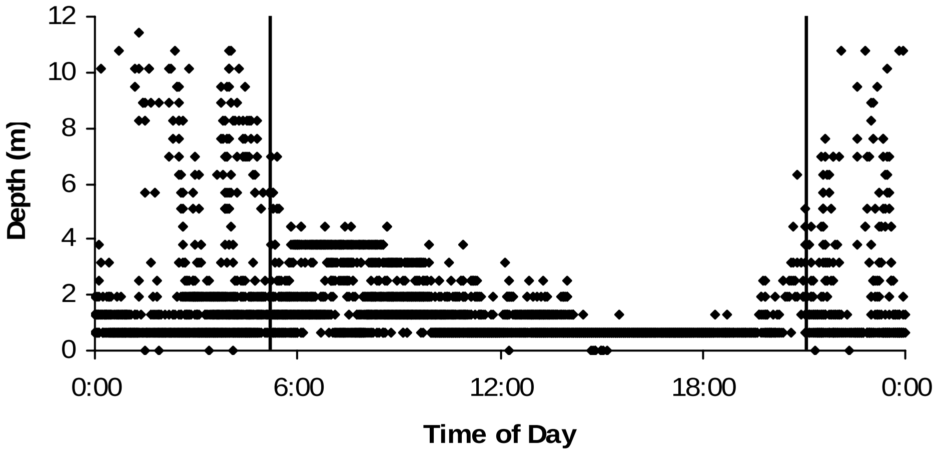


FIGURE 31. Depth use of northern pikeminnow #4657 (Vemco tag #111) near the Lakeshore West Condominiums, June 2-26, 2007. All dates were combined. Vertical lines indicate the average sunrise and sunset during the time period.

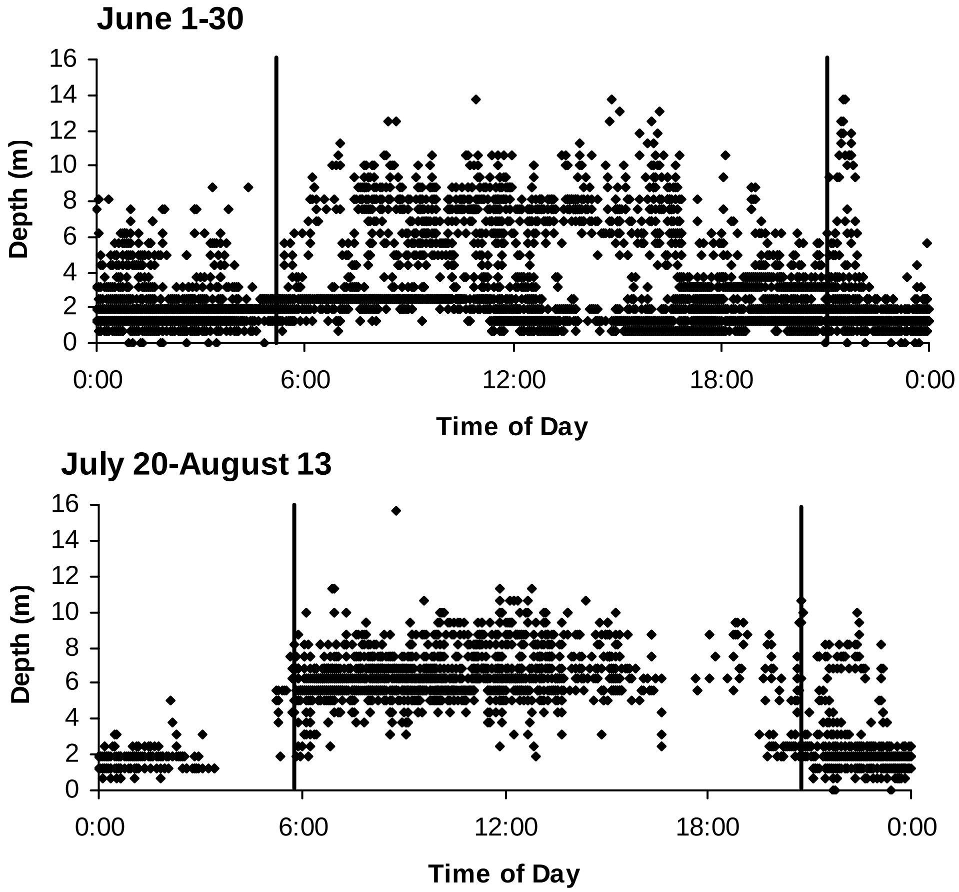


FIGURE 32. Depth use of northern pikeminnow #4667 (Vemco tag #119) near the Lakeshore West Condominiums, June 1-30 and July 25-August 13, 2007. All dates were combined. Vertical lines indicate the average sunrise and sunset during the time period.

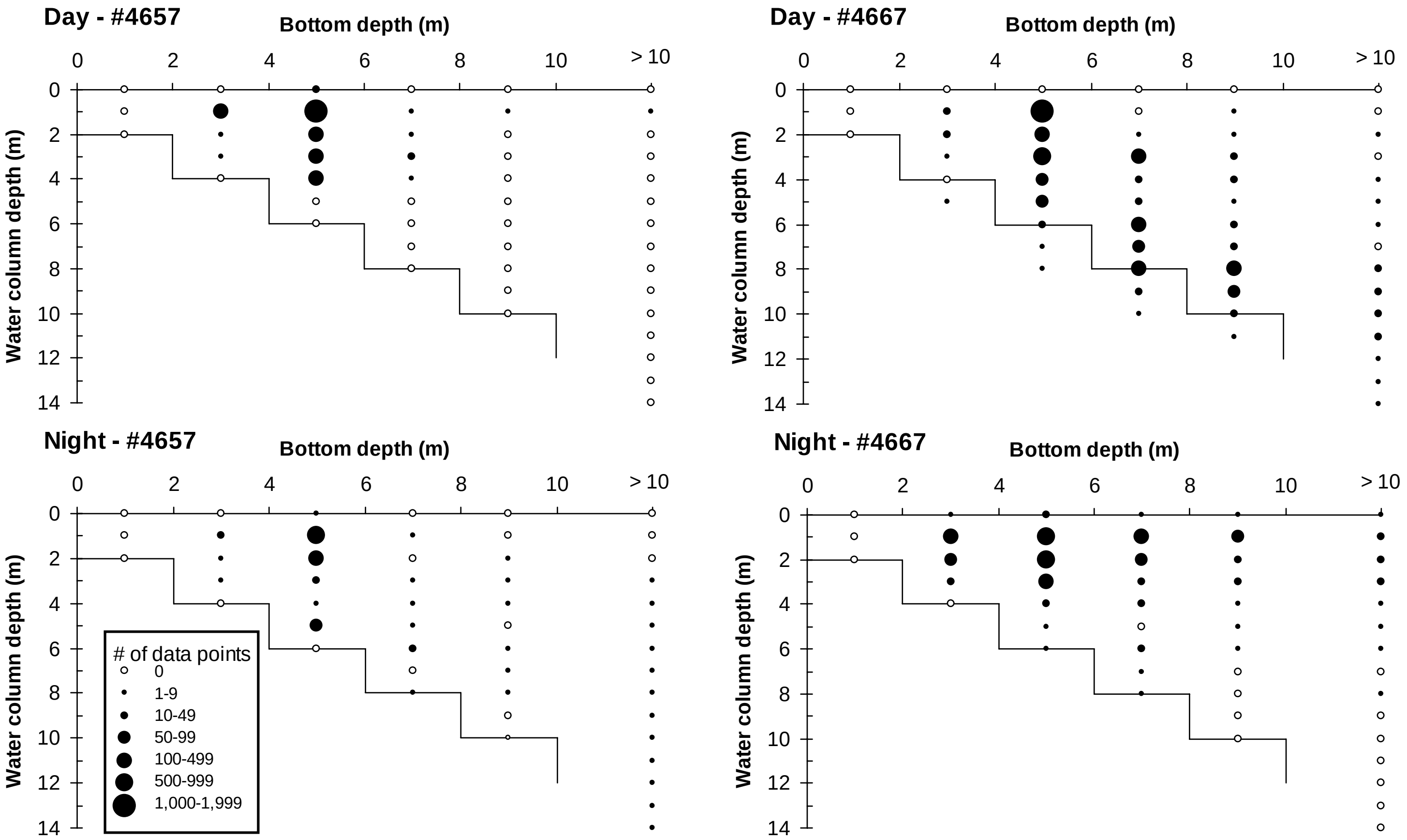


FIGURE 33. Day and night depth distribution of two double-tagged northern pikeminnow at the SR 520 study site, 2007. Fish #4657 was tracked from June 2-26 and Fish # 4667 was tracked from June 1 to July 25. Data for the fishes' depth in the water column was obtained from the Vemco tag and the location of the fish and the corresponding water column depth was obtained from HTI tag information. The line represents the lake bottom for each depth interval.

Smallmouth bass

Of the six smallmouth bass released at the study site, two weighed less than 100 g and E tags (20 days; 1.5 g) were used. The other bass (including double-tagged bass from LWSC) weighed more than 200 g and G tags were used (Table 11). The double-tagged bass from the LWSC were primarily large adult bass ranging in size from 318 to 425 mm FL (mean, 373 mm FL). In contrast to pikeminnow, all of the smallmouth bass released at the study site were tracked for an extended period of time. The two smallmouth bass tagged with E tags (20 day) were tracked over a 15 and 19 day period and the four bass tagged with G tags (60 day) were tracked over a time period ranging from 37 to 60 days (Table 12). For fish released at the site, the mean percentage of days we detected smallmouth bass was 76.4%; whereas it was only 15.0% for northern pikeminnow. We obtained over 987,000 data points for the six smallmouth bass combined; whereas, only 420,000 were obtained for the 25 tagged northern pikeminnow.

TABLE 11. 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, expect the first smallmouth bass listed which was captured in Portage Bay and released at the SR 520 bridge site. G tags are 60-day, 4.4 g tags and E tags are 20-day, 1.5 g tags.

Location	Date released	Capture method	Tag period (msec)	Tag type	Fork length (mm)	Weight (g)
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

TABLE 12. Detection of tagged smallmouth bass at the SR 520 study site, May-August, 2007. The first 24 hours after release was not used. The first group listed was released at the study site. Whereas, the second group was released in the LWSC and only their first three days at the study site was processed. The percent of days detected includes days when the fish was detected on a least one hydrophone. ND = not determined.

Tag period (msec)	Date released	Date of first data point	Date of last data point	Percent of days detected	Number of data points North	South
4697	24-May	25-May	9-Jun	89.5	0	103,897
4707	31-May	2-Jun	30-Jul	96.6	65,246	299,514
4717	31-May	2-Jun	22-Jul	28.8	2,199	7,297
4757	6-Jun	7-Jun	6-Aug	100	85,428	122,270
4767	6-Jun	7-Jun	26-Jun	100	78	116,309
4947	15-Jun	16-Jun	23-Jul	62.7	104,910	80,214
4547	17-May	28-Jun	29-Jun	ND	651	4,255
4577	22-May	6-Jul	9-Jul	ND	8,590	3,822
4567	22-May	18-Jul	21-Jul	ND	2,170	10,799
4617	23-May	8-Jun	9-Jun	ND	273	9,803
4627	23-May	19-Jun	22-Jun	ND	19,392	11,455
4897	11-Jun	15-Jun	18-Jun	ND	12,869	7,033
5177	3-Jul	25-Jul	28-Jul	ND	270	1,411

The two small smallmouth bass (173, 185 mm FL) were closely associated with nearshore overwater structures (Figures 34 and 35). All three nearshore structures were used extensively. Selection of overwater structures did not appear to vary substantially between the time periods (Figure 34). Few data points were under or near the SR 520 bridge (fish #4697, 0.01% of data points; fish #4767, 0.15% of data points). Both fish showed a strong preference for water that was 0-2 m deep. Seventy-two percent of all data points in the coverage area of fish # 4697 were close to shore in water 0-2 m deep and 57% were 0-2 m deep for fish # 4767. The area of the coverage area that was 0-2 m deep was only 3.3% of the total area. Additionally, 19% of all data points combined for these two fish were outside the coverage area. The vast majority of these points were slightly on shore and were not used in our calculations. However, if these points were included, the overall selection for shallow water (0-2 m) would be increased.

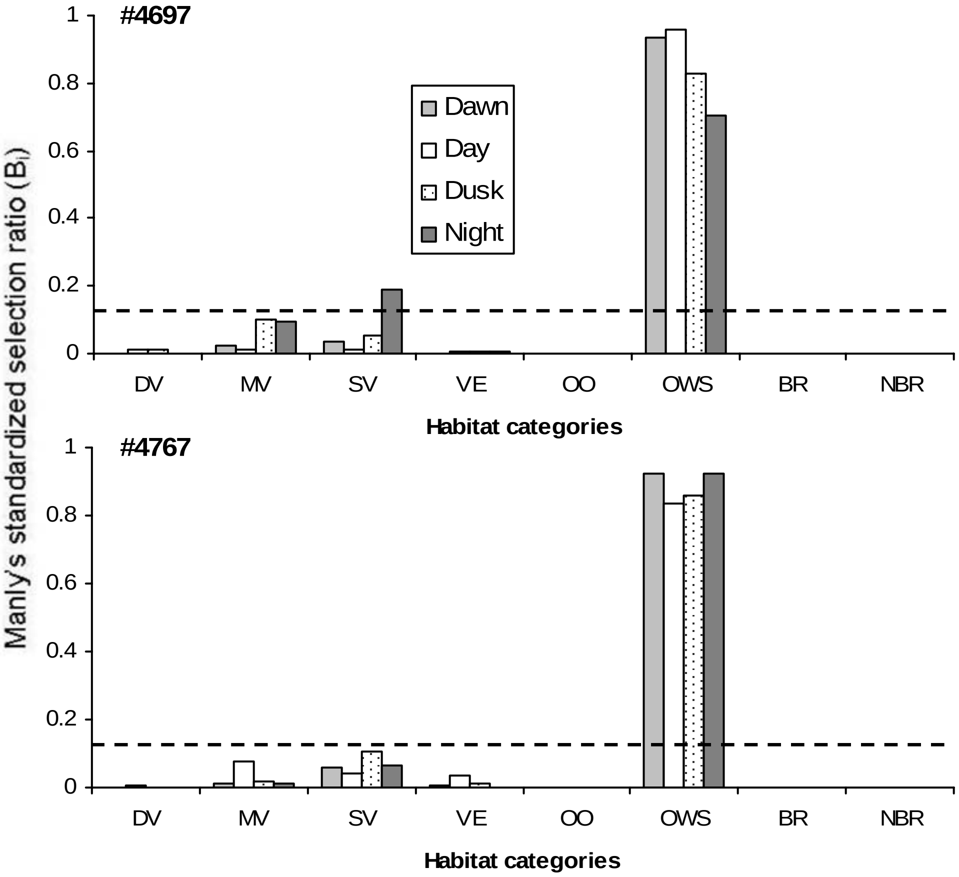


FIGURE 34. Habitat selection (B_i, Manly's standardized selection ratio) of two small smallmouth bass at the SR 520 bridge study site, May-August 2007. Habitat categories are described in Table 1. The dashed lines indicate the level of selectivity if all habitat types were used proportionally.

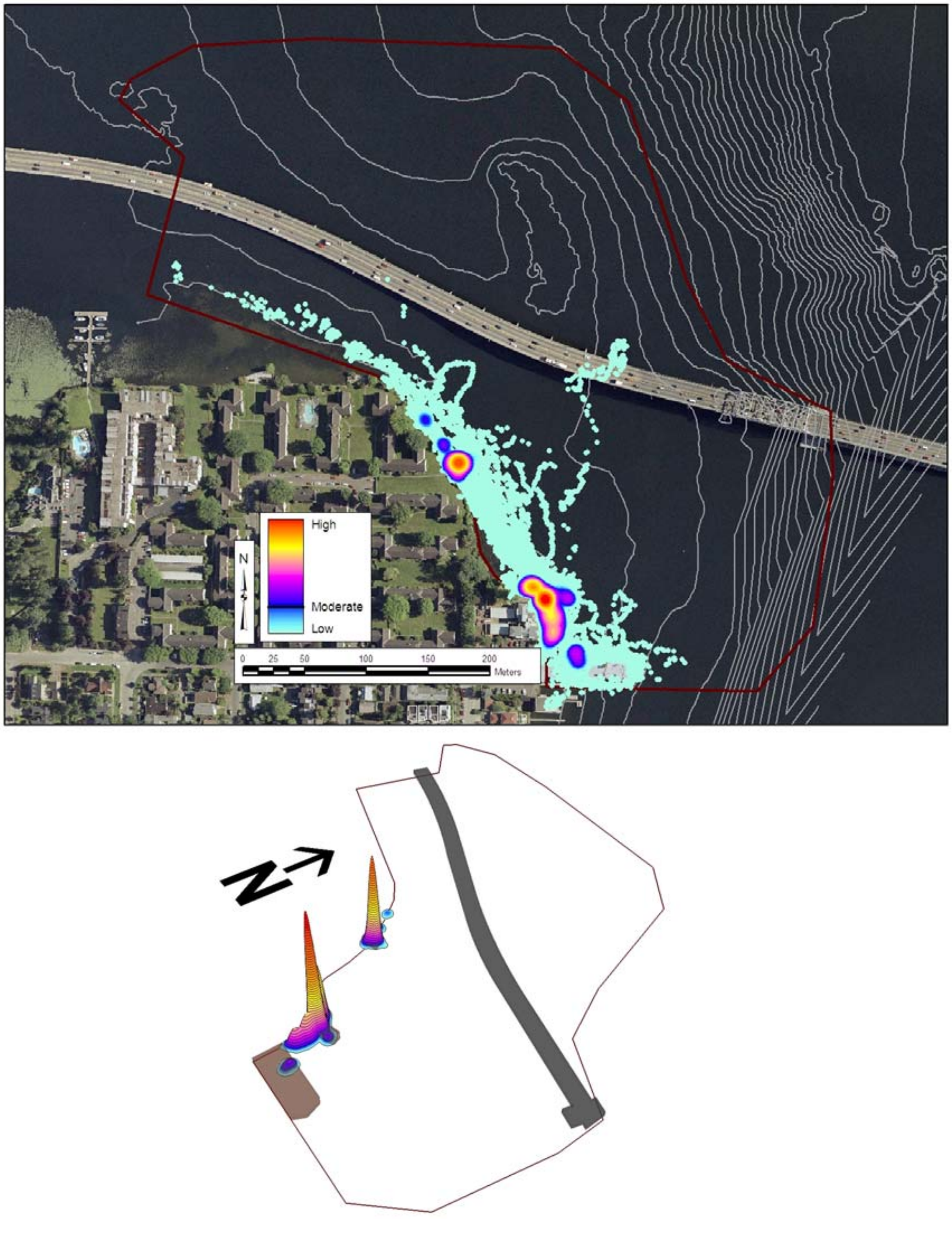


FIGURE 35. Density plot of two small smallmouth bass (fish #'s 4697 and 4767) at the SR 520 bridge study site, May-June 2007. Each bass was weighted equally for the density plot calculation. The calculations include all time periods (dawn, day, dusk, and night). Both bass were tagged with 20-day tags. The bottom picture is the same picture as the top just displayed in 3D. Representation of lowest density was altered to enhance clarity: size of lowest density was made smaller in the plot on the top, and lowest density was eliminated from plot on the bottom. The dark red line is the coverage area of the hydrophone array in both the 2D and 3D pictures. White lines in the 2D picture are depth contours in 2-m intervals.

The other four smallmouth bass released at the SR 520 study site also showed a strong preference for overwater structures (Figures 36, 37, and 38). Similar to the small bass, the nearshore overwater structures were commonly used except the shallowest of the three structures (pier at the Edgewater Apartments) was not used. However, unlike the small bass, they extensively used the SR 520 bridge (Figures 36 and 37). Three of the four bass showed a selection for the bridge. Overall, the four bass had a significant selection for the bridge for day, dusk, and night time periods (Figure 37). Selection for the bridge was generally strongest during the day and night and weakest at dawn. Density plots indicated some bass were often closely associated with the bridge columns (Figure 39). Selection of the macrophyte edge and sparse vegetation increased at dawn and dusk; however, no significant selection was observed. For the most part, open offshore areas and dense and moderate vegetation were selected against (Figures 37 and 40). Smallmouth bass were usually located in water that was 4 to 8 m deep (Figures 41 and 42). They tended to be in shallower water at night, selecting water that was 4-6 m deep; whereas selection ratios for dawn, day, and dusk were highest for the 6-8 m deep area.

In general, the seven smallmouth bass that were tagged in the LWSC appeared to have similar distribution patterns as the four large smallmouth bass tagged and released at the SR 520 bridge site (Figure 43). The seven LWSC bass often used overwater structures but it was often quite variable between individuals. The bridge was only significantly selected during the day (Figures 44 and 45). The only other significant selection was for sparse vegetation at dawn. Unlike all other bass tracked at the SR 520 bridge site, bass # 4577 selected the open offshore area during the day (Figure 46). This fish moved inshore at night and was located near an overwater structure. Similar to the other large smallmouth bass, the LWSC bass were usually located in water that was 4 to 8 m deep (Figure 47). Three of the seven bass were also tagged with Vemco depth tags (Table 13). Both fish appeared to be primarily in shallow water at night. At dawn and dusk, they both occupied a wide range of depths indicating they were active during crepuscular periods. One fish appeared to move into deeper water at dawn and dusk while the other moved into both shallower and deeper water at dawn (Figure 48).

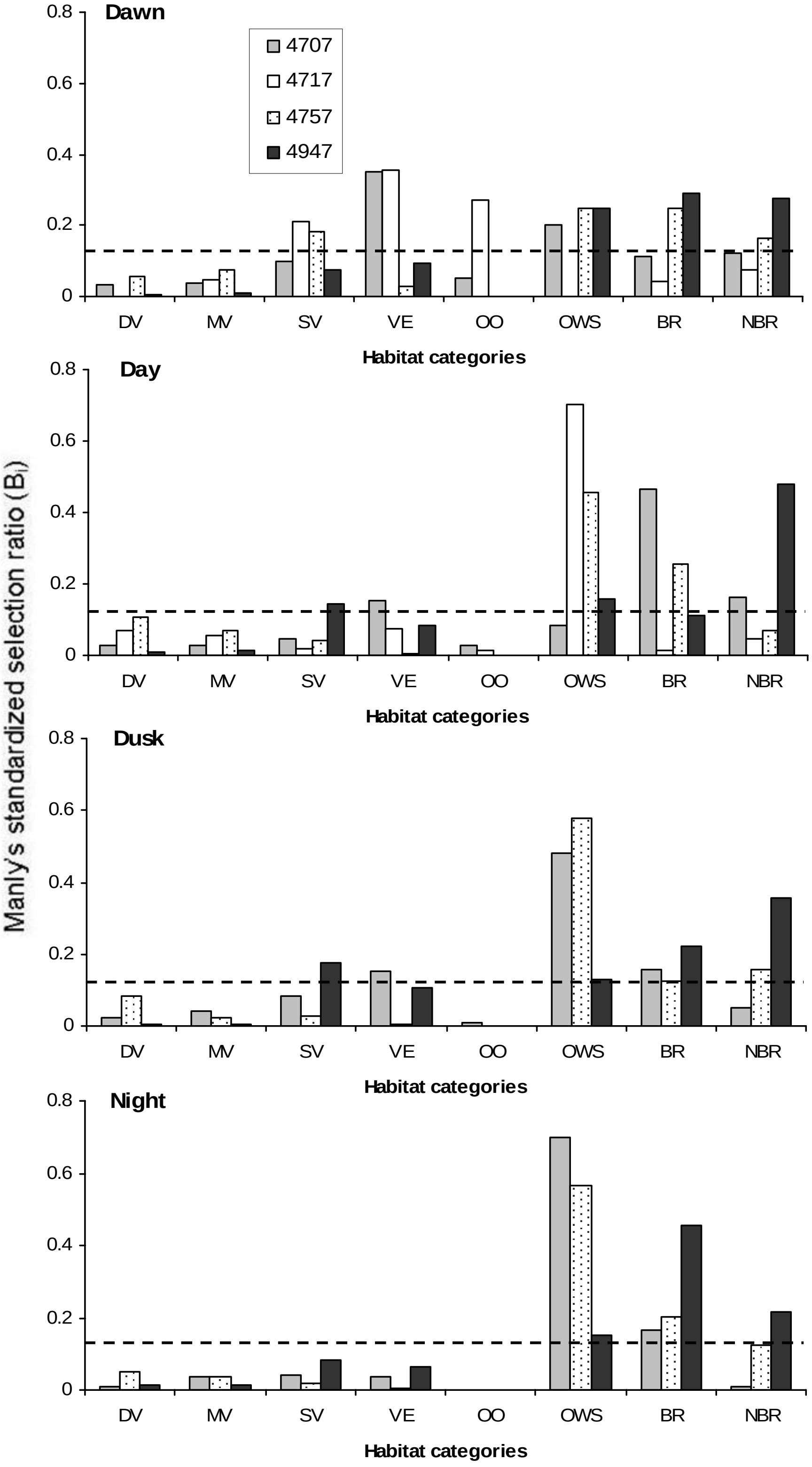


FIGURE 36. Habitat selection (B_i, Manly's standardized selection ratio) of four smallmouth bass released at the SR 520 bridge study site, May-August 2007. Habitat categories are described in Table 1. The dashed lines indicate the level of selectivity if all habitat types were used proportionally.

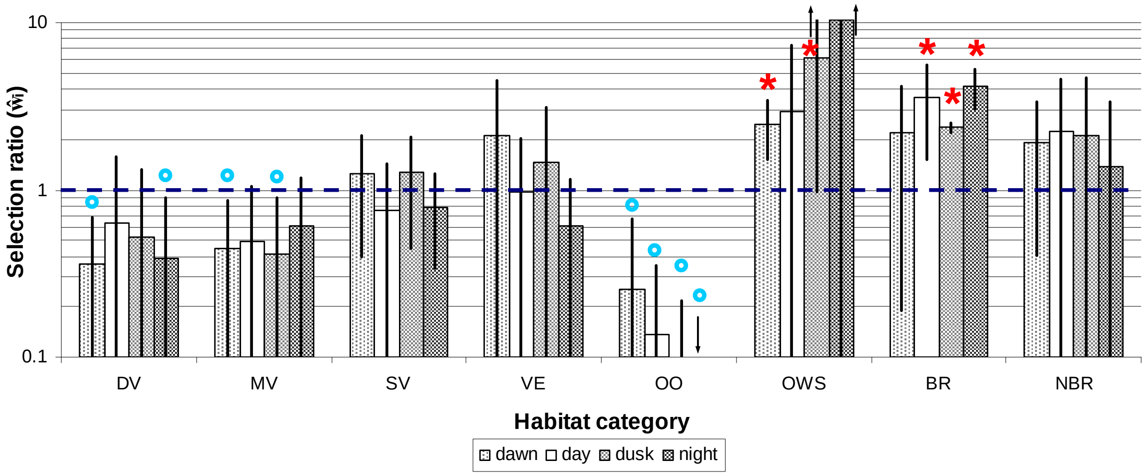


FIGURE 37. Habitat selection ($\hat{w}_i$, selection ratio; log scale) of four adult smallmouth bass (#'s 4707, 4717, 4757 and 4947) released at the SR 520 bridge study site, May-August 2007. Error bars represent Bonferroni-adjusted 90% confidence intervals. Errors bars indicate if selection for (lower bar >1, dashed line) or against (upper bar <1, dashed line) a habitat type occurred. A red asterisk (*) indicates if the habitat type was selected for and a blue circle (o) indicates if the habitat type was selected against. Habitat categories are described in Table 1.

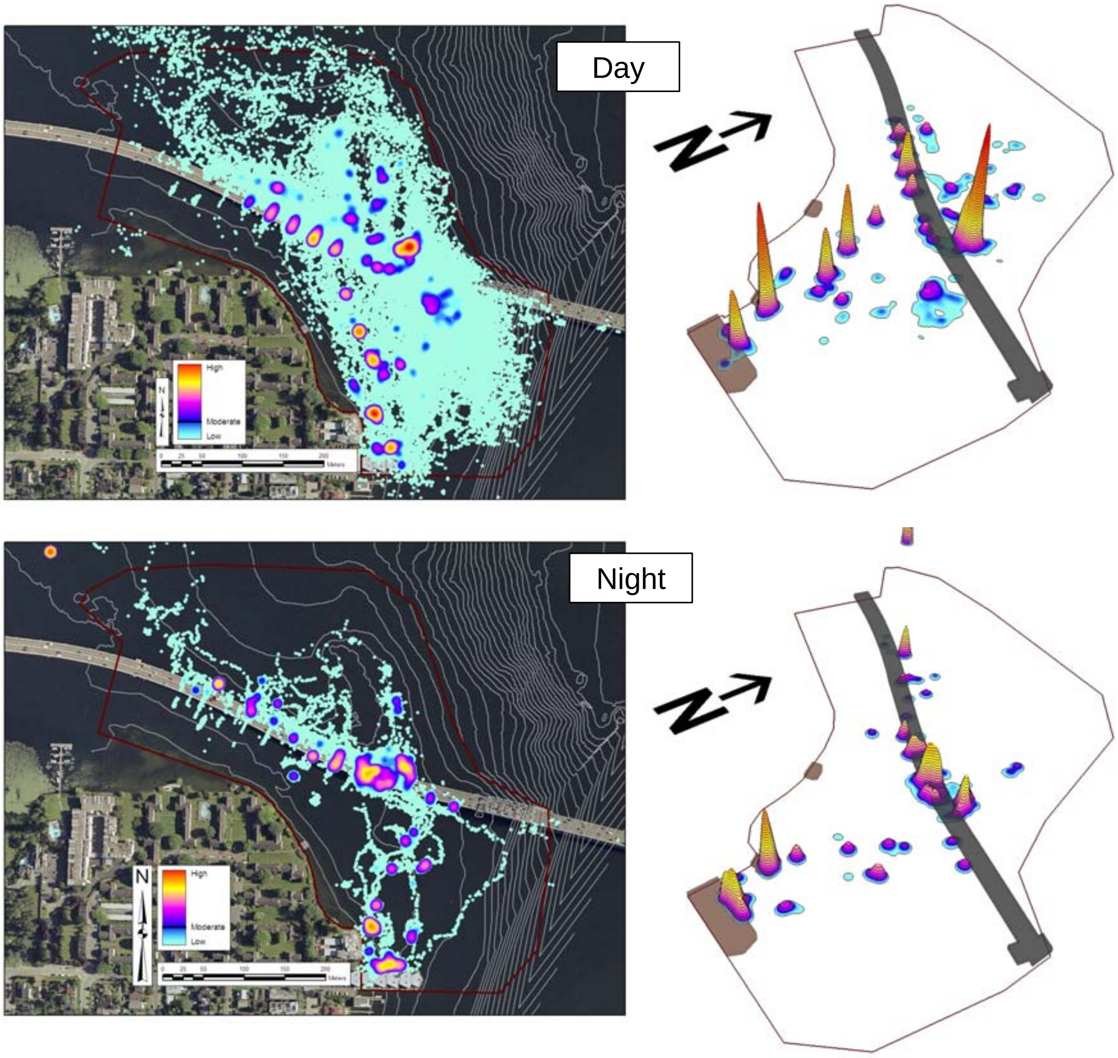


FIGURE 38. Day and night density plots of four adult smallmouth bass (#'s 4707, 4717, 4757 and 4947) at the SR 520 bridge study site, May-August 2007. Each bass was weighted equally for the density plot calculation. The pictures on the right side are the same pictures as on the left side just displayed in 3D. 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.

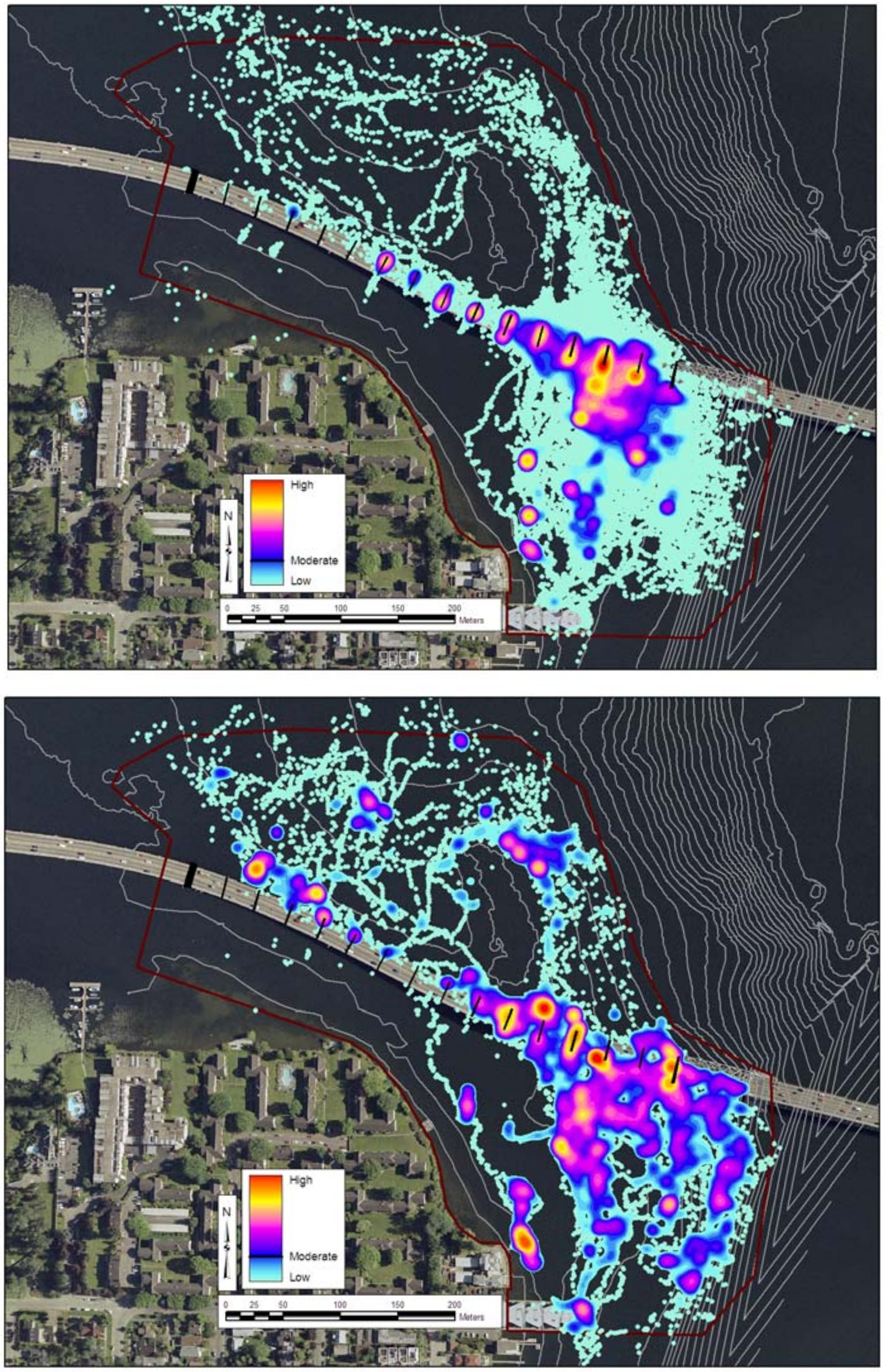


FIGURE 39. Density plots of smallmouth bass at the SR 520 bridge study site, May-August 2007. Black lines along the bridge are the locations of the columns which support the bridge. The top plot is of a single fish (tag period 4707) and the bottom plot is a combination of seven bass tagged in the LWSC. Each bass was weighted equally for the density plot calculation of the bottom photo. 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.

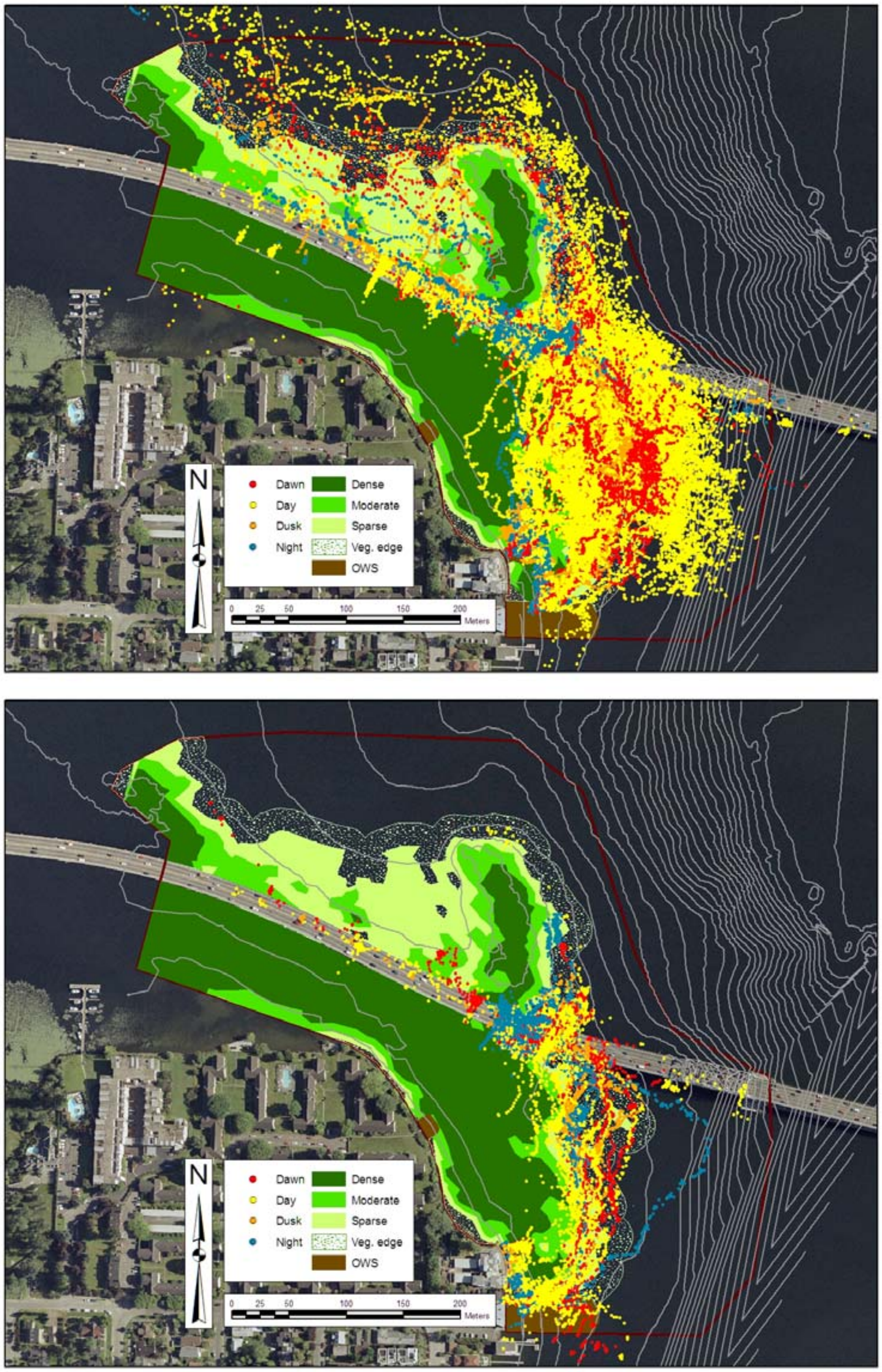


FIGURE 40. Data points of two smallmouth bass (top panel is fish #4707 and bottom panel is fish #4947) at the SR 520 bridge study site, (June-July 2007) showing their relationship to aquatic macrophyte (three density levels and the offshore edge) distribution. The dark red line is the coverage area of the hydrophone array. White lines are depth contours in 2-m intervals. OWS = overwater structures (not including the SR 520 bridge).

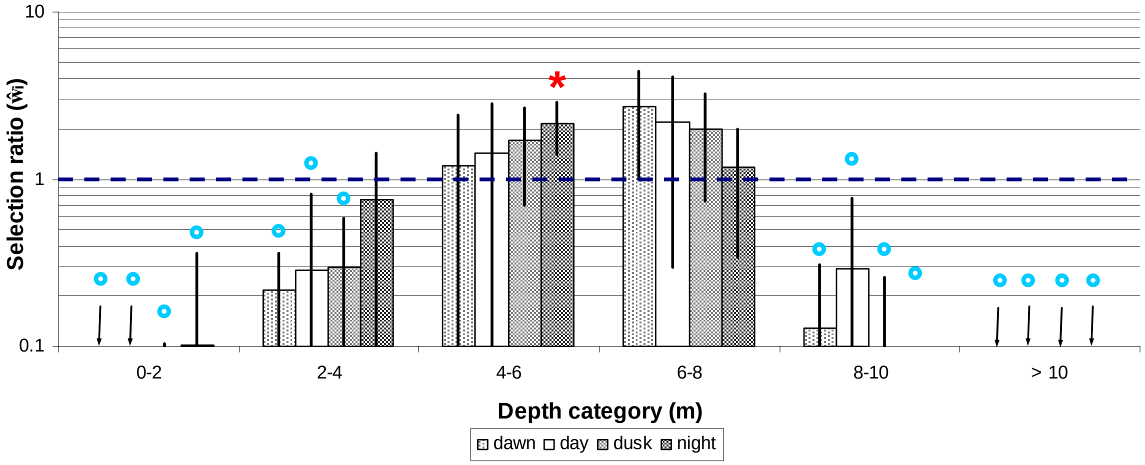


FIGURE 41. Depth selection (ŵ$_i$, selection ratio; log scale) of four smallmouth bass released at the SR 520 bridge study site, May-August 2007. Selection is for the entire water column (inshore versus offshore) and not for the position of the fish within the water column. Error bars represent Bonferroni-adjusted 90% confidence intervals. Errors bas indicate if selection for (lower bar >1, dashed line) or against (upper bar <1, dashed line) a habitat type occurred. A red asterisk (*) indicates if the habitat type was selected for and a blue circle (o) indicates if the habitat type was selected against.

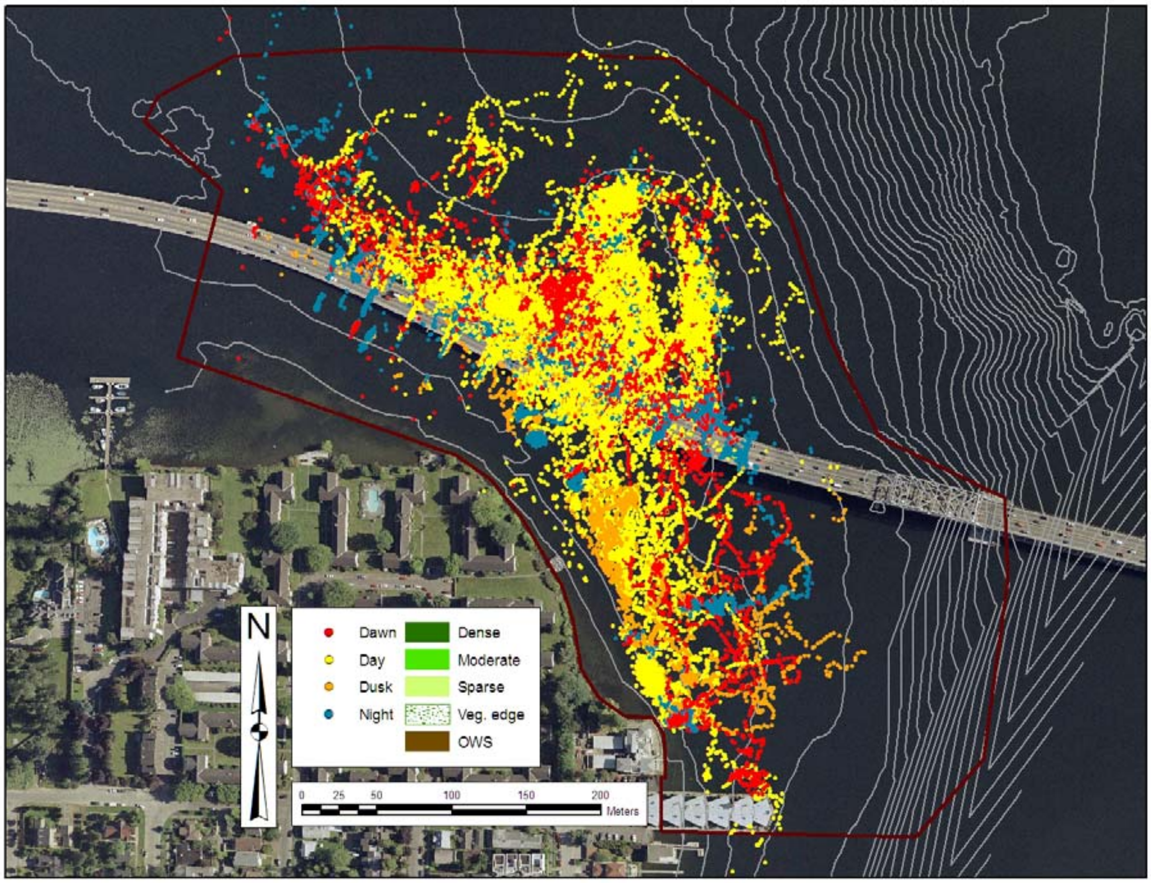


FIGURE 42. Data points of smallmouth bass #4757 at the SR 520 bridge study site, June 6–August 6, 2007. White lines are depth contours in 2-m intervals. The dark red line is the coverage area of the hydrophone array.

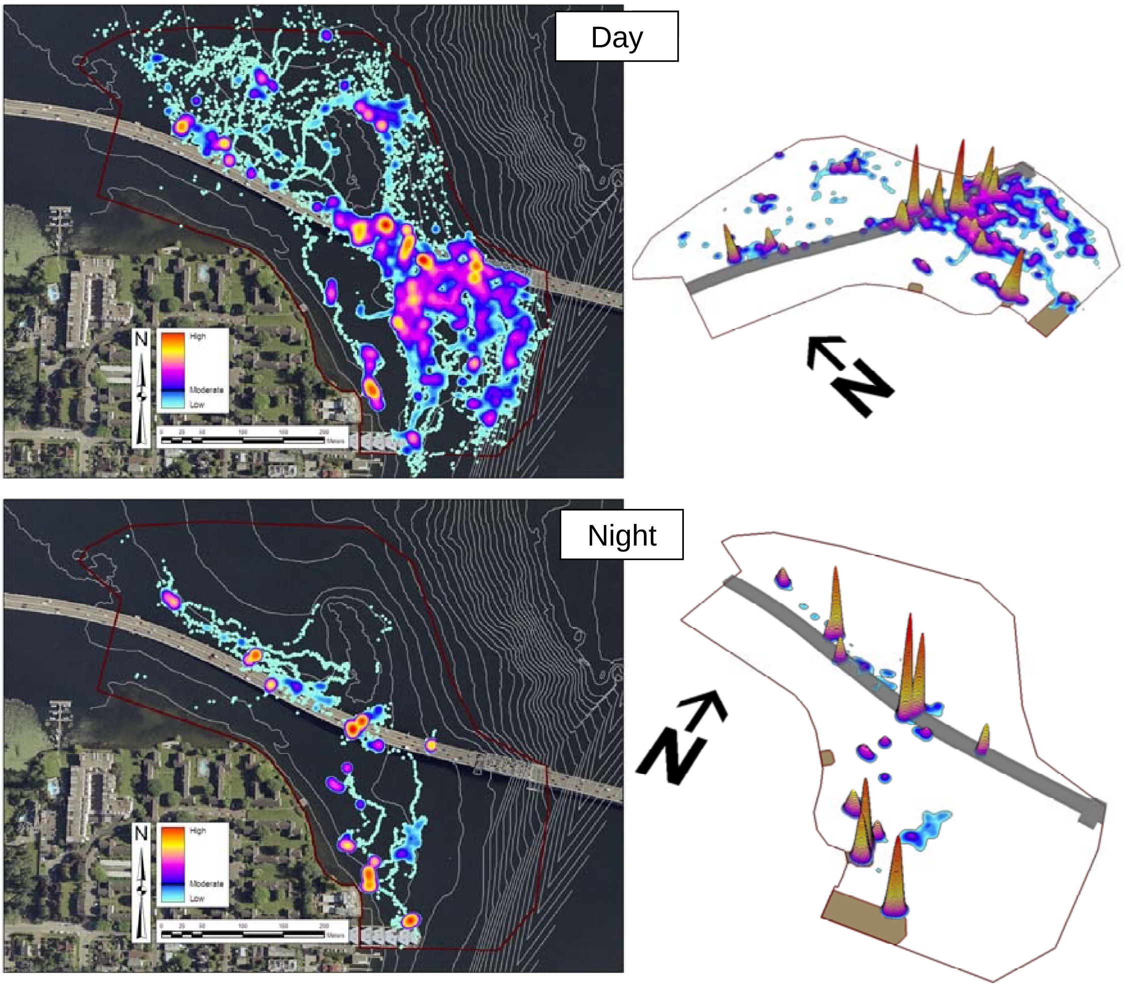


FIGURE 43. Day and night density plot of seven smallmouth bass from LWSC at the SR 520 bridge study site, May-August 2007. Each bass was weighted equally for the density plot calculation. The pictures on the right side are the same pictures as on the left side just displayed in 3D. Representation of 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.

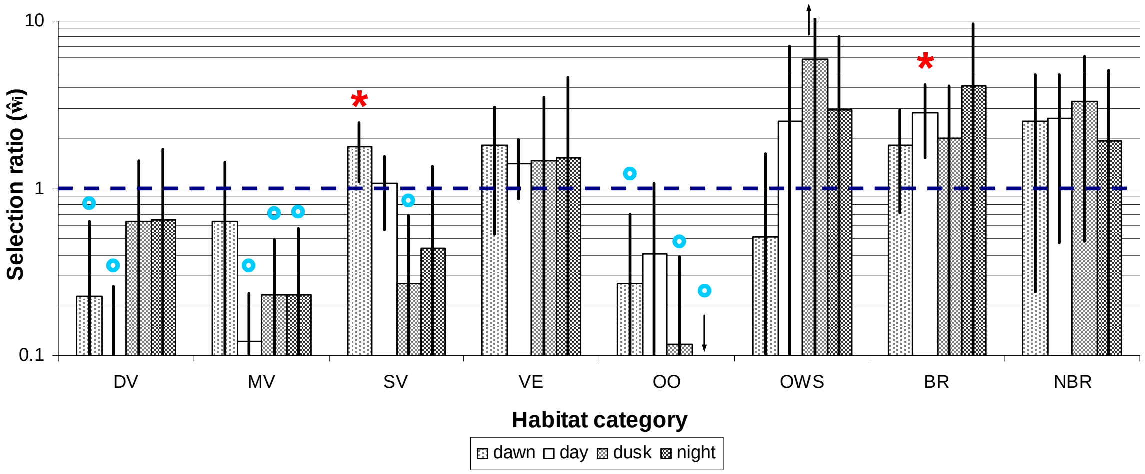


FIGURE 44. Habitat selection ($\hat{w}_i$, selection ratio; log scale) of seven smallmouth bass (tagged in LWSC) at the SR 520 bridge study site, June-July 2007. Error bars represent Bonferroni-adjusted 90% confidence intervals. Errors bars indicate if selection for (lower bar >1, dashed line) or against (upper bar <1, dashed line) a habitat type occurred. A red asterisk (*) indicates if the habitat type was selected for and a blue circle (o) indicates if the habitat type was selected against. Habitat categories are described in Table 1.

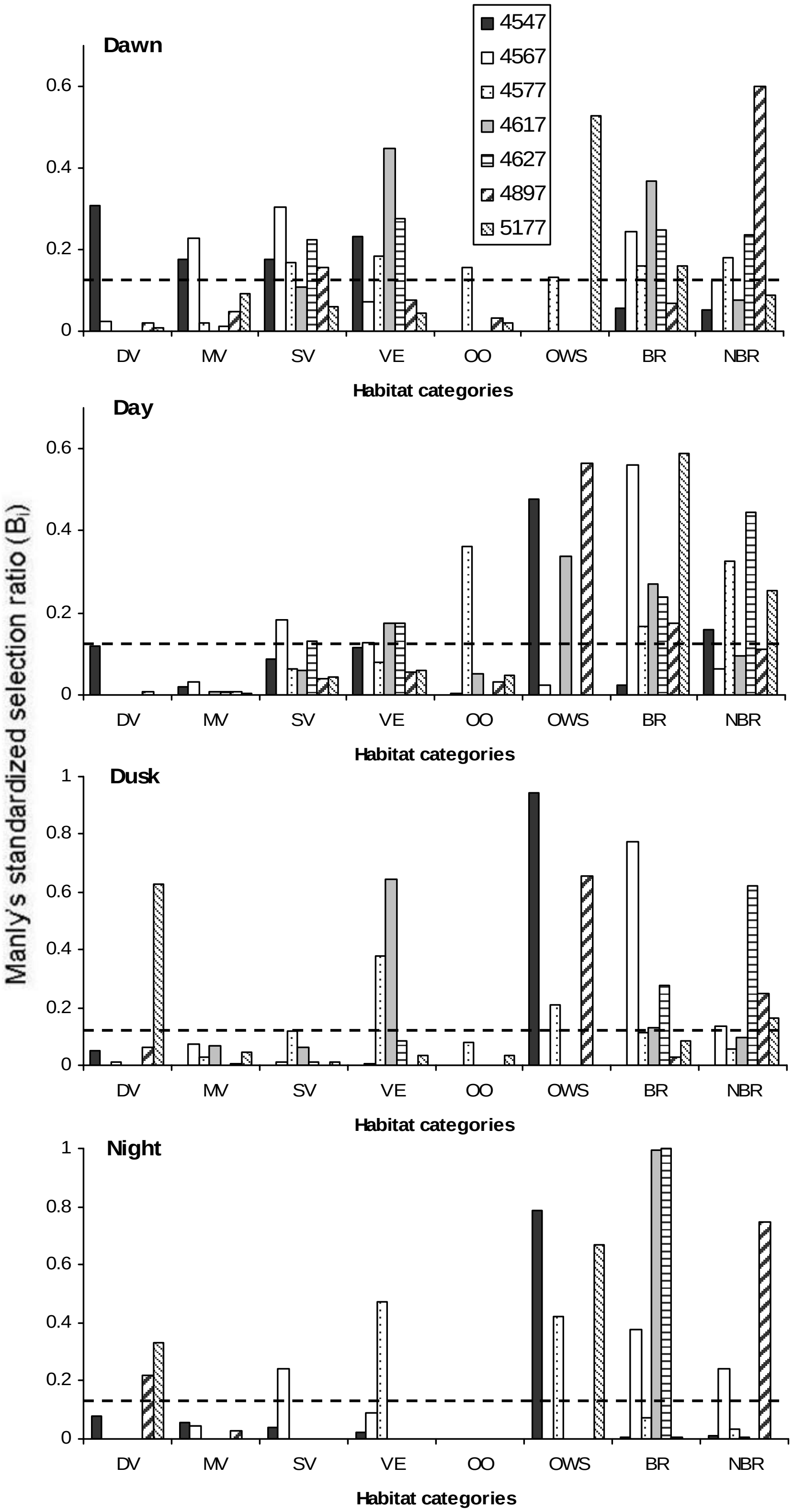


FIGURE 45. Habitat selection (B_i, Manly's standardized selection ratio) of seven smallmouth bass (tagged in LWSC) at the SR 520 bridge study site, June-July 2007. Habitat categories are described in Table 1. The dashed lines indicate the level of selectivity if all habitat types were used proportionally.

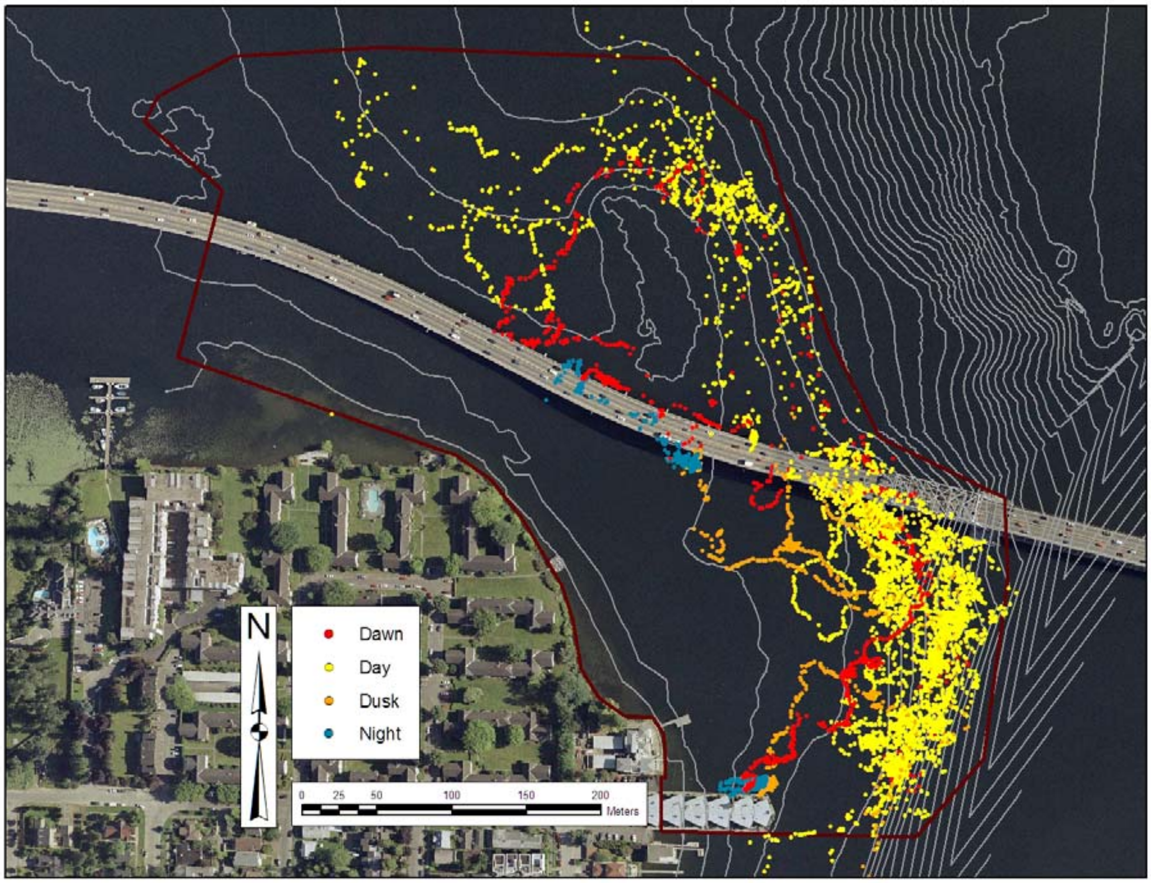


FIGURE 46. Data points of smallmouth bass #4577 at the SR 520 bridge study site, July 19-21, 2007. This fish was tagged and released at Gas Works Park, LWSC. White lines are depth contours in 2-m intervals. The dark red line is the coverage area of the hydrophone array.

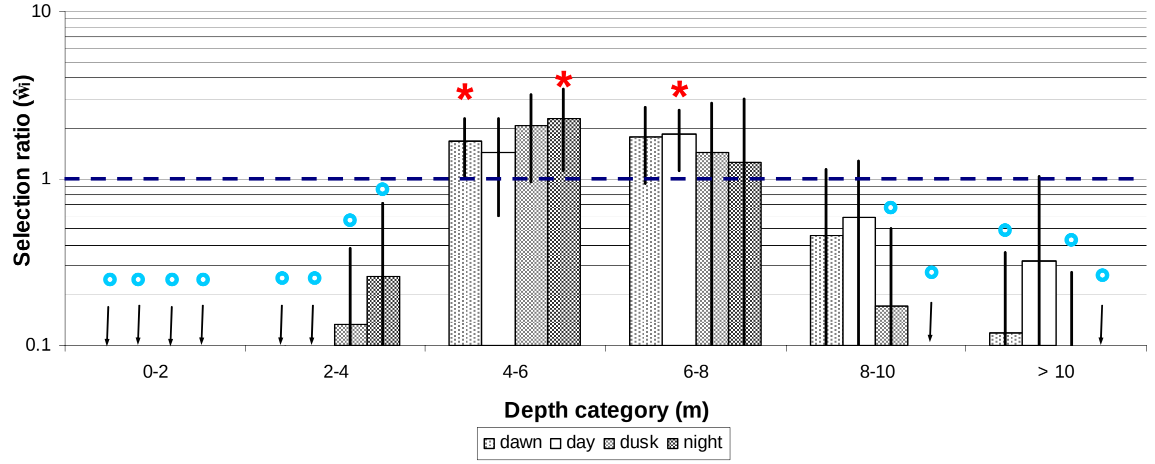
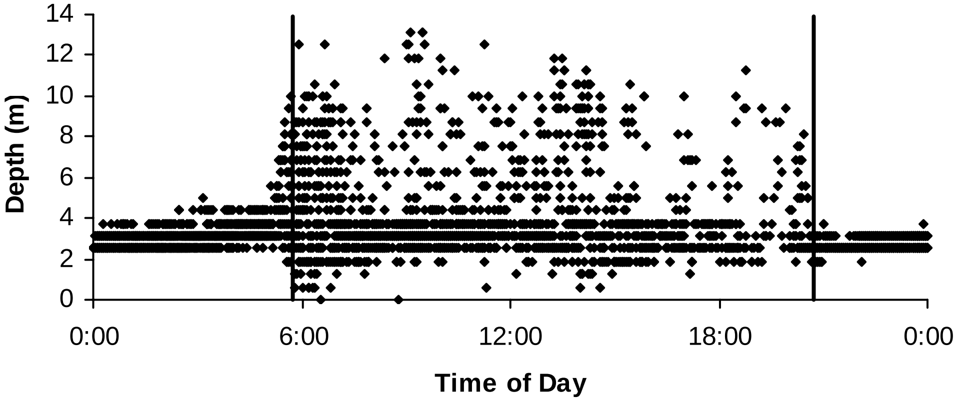


FIGURE 47. Depth selection ($\hat{w}_i$, selection ratio; log scale) of seven smallmouth bass (tagged in LWSC) at the SR 520 bridge study site, June-July 2007. Selection is for the entire water column (inshore versus offshore) and not for the position of the fish within the water column. Error bars represent Bonferroni-adjusted 90% confidence intervals. Errors bars indicate if selection for (lower bar >1, dashed line) or against (upper bar <1, dashed line) a habitat type occurred. A red asterisk (*) indicates if the habitat type was selected for and a blue circle (o) indicates if the habitat type was selected against.

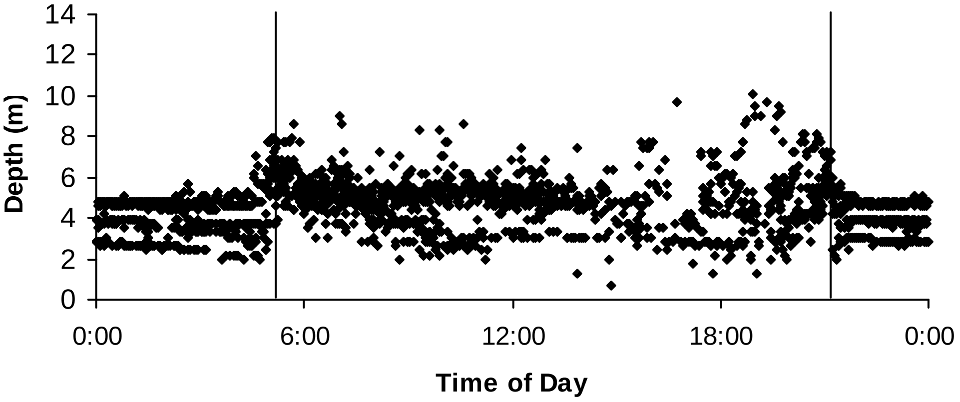
TABLE 13. Detections of double-tagged smallmouth bass by the Vemco receiver located on the offshore edge of the Lakeshore West Condominiums, May-August, 2007.

					Vemco detections		
Release location	Vemco tag ID	HTI tag period	Fork length (mm)	Date released	Date of first data point	Date of last data point	Total # of detections
I-5/University Bridge	115	5177	413	7/3	7/25	8/5	3,958
Portage Bay	117	4547	425	5/17	6/2	6/29	1,172
I-5/University Bridge	223	4627	348	5/17	6/19	8/14	3,500

Tag 115 - July 25 - Aug 5



Tag 223 - June 19-28



Tag 223 - Aug 3-14

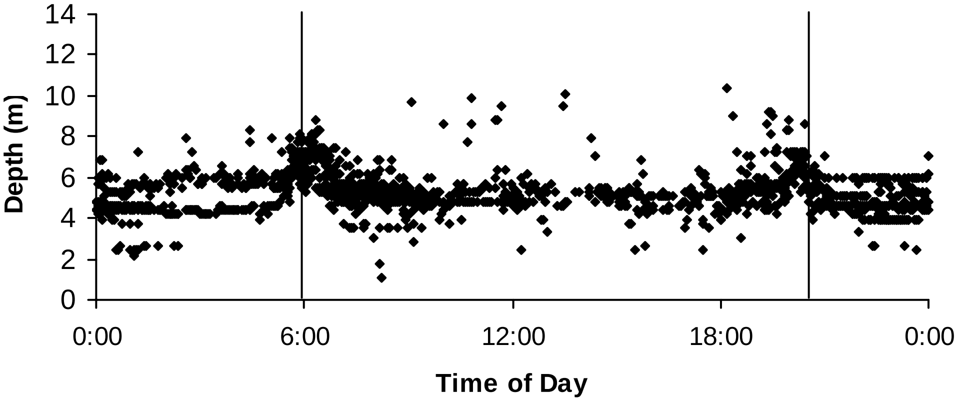


FIGURE 48. Depth use of smallmouth bass #5177 (Vemco tag #115) and #4627 (Vemco tag #223) near the Lakeshore West Condominiums, June-August 2007. All dates were combined. Vertical lines indicate the average sunrise and sunset during the time period.

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 appear infrequently used relative to resting habitat. Furthermore, less preferred habitats may become frequently used if animals are forced into them due to external factors such as habitat configuration or predation risk. Thus, habitat selection itself does not necessarily indicate preference, nor does it provide an indicator of how various habitats contribute to overall fitness and survival.

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

Chinook salmon smolts

Results suggest that Chinook salmon smolts engage in two fundamentally different migrational behaviors in the general area of the SR 520 bridge, and the effect of the SR 520 bridge depends on which behavior the fish are engaged in at the time. Chinook salmon smolts exhibited two principal migrational behaviors, both of which correspond with previous acoustic tracking work in Lake Washington. Celedonia et al. (2006) observed two primary migrational phases or behaviors in Lake Washington Chinook salmon smolts: an active migration phase, and a holding/resting/rearing phase. The active migration phase was characterized by rapid, direct movement through an area with little or no meandering or milling. In contrast, the holding/resting/rearing phase was characterized by long general area residence times and often substantial meandering and milling through the site. These categorizations described our observations at the SR 520 site. The active migration phase identified by Celedonia et al. (2006) described the overarching patterns observed in fish released on June 1, and holding/resting/rearing described patterns observed in fish released on June 14 and 28.

Reasons underlying the observed differences in behaviors between release groups cannot be identified with absolute certainty, but some possibilities appear likely. Differences in Chinook salmon smolt movements may be related to site conditions, physiological conditions, external cues, or a combination of these factors. Timing of Chinook salmon smolt migration is the product of complex interactions between a variety of physiological, ecological and environmental elements. The dynamic and shifting nature of these elements may contribute to differential behavioral and habitat use patterns at a particular site through time. For example, smolts at the Celedonia et al. (2006) Portage Bay LWSC site in 2004 were largely holding/resting/rearing here, spending anywhere from several hours to ≥ 2 d meandering and milling around the general site area prior to continuing their migration. In contrast, smolts tracked in 2005 actively migrated through the same site, spending little time - mostly < 1 h - and generally showing a direct path of travel through the site with little if any meandering or milling. One factor that appeared to contribute to this disparity was timing of smolt release and site presence relative to lunar apogee. Lunar apogee can function as a strong migrational cue in Chinook salmon smolts (DeVries et al. 2004). In the Celedonia et al. (2006) study, 2004 fish were released between apogees and most 2005 fish were released on or near apogee.

Timing of smolt release relative to lunar apogee may partially explain the variation in movement timing observed at the SR 520 bridge. Two apogees occurred near or during the study: one on May 27, the other on June 24. The close proximity of the June 1 release to the May 27 apogee was likely a dominant factor contributing to the rapid movement of these fish from release to the study site, through the study site, and from the study site to the University Bridge. In contrast, the June 14 study fish were released between apogees - 18 d after the May 27 apogee and 12 d prior to the June 24 apogee. This may partially explain the slower movement of these fish from release to the study site and to the University Bridge. Chinook salmon migration timing is not always associated with lunar apogee, however, and other factors may take precedence at times (DeVries et al. 2007). Thus, although the June 28 release was only four days after apogee - similar to the June 1 release - the slow movement of these fish from release to the University Bridge suggested that other factors took precedence over lunar apogee.

Temperature is another factor that may have influenced movement timing and habitat use. Specifically, elevated surface water temperature may contribute to desmolting and residualism, and may also present a migratory barrier in the LWSC (DeVries et al. 2007). Desmolting, or parr-reversion, is a loss of physiological adaptations to seawater that may occur in salmonid smolts. The timing and severity of desmolting is at least partially temperature-dependent (Clarke and Hirano 1995). Stefansson et al. (1998) found that desmolting in Atlantic salmon was a function of thermal sum, or degree-days, and that fish held at lower temperatures maintained smolt-like characteristics, but fish held at higher temperatures quickly passed through the "smolt window." Residualism in Lake Washington Chinook salmon has been observed in other studies (DeVries et al. 2005; DeVries et al. 2007). DeVries et al. (2007) observed that Chinook salmon appeared to residualize later in the outmigration season and also during years with warmer water temperatures in the LWSC during the outmigration season. The effects of desmoltification on movement and habitat use of Chinook salmon are uncertain. Typical smolt characteristics (i.e., elevated gill Na^+,K^+-ATPase) are not always a predictor of seaward movement in Chinook salmon (Ewing et al. 1980; Tiffan et al. 2000). Conversely, Aarestrup at al. (2000) observed a notable switch from a migratory mode to residency in desmolting anadromous brown trout. Also, Giorgi et al. (1988) observed that susceptibility of Chinook salmon smolts to bypass systems at two Columbia River dams was influenced by degree of smoltification, suggesting that habitat use characteristics may be partially dependent on smolt status. Thus, differences in degree of smoltification or desmoltification resulting from prolonged exposure to elevated water temperatures may have contributed to the variation in movement patterns between groups observed in our study. Future studies should consider measuring physiological parameters related to smoltification such as gill Na^+,K^+-ATPase to better evaluate these influences.

A barrier or hindrance to migration between the SR 520 bridge and University Bridge study sites may have contributed to the patterns observed. We observed a steady decline in the proportion of fish detected in the LWSC: 83%, 46% and 38 % of the fish tracked at the SR 520 bridge site from the June 1, 14 and 28 release groups respectively were detected in the LWSC (Table 2). This may have been partially attributed to the relatively short nominal 12 d battery life of the tags used in this study: some fish may have moved into the LWSC after the tag battery expired. However, other studies corroborate a possible decline in proportion of fish entering the LWSC during June. PIT tagging data presented by DeVries et al. (2005) showed that Chinook salmon released on the east end of Montlake Cut and detected migrating through the Ballard Locks and into Puget Sound showed a declining temporal trend from mid-May through late-June. Conversely, Chinook salmon released into Lake Union in the middle of the LWSC showed no such decline.

One hypothesis put forth that may partially explain a declining trend in Chinook salmon successfully entering and passing through the Montlake Cut is that of a thermal barrier (DeVries et al. 2007). Montlake Cut is much shallower than Lake Washington, and increasing surface water temperatures may warm the entire Montlake Cut so completely that Chinook salmon would be inhibited from entering. It is uncertain if this was a factor in our observations, but indications are that it is unlikely. Chinook salmon smolts from both the June 14 and 28 release groups consistently selected for 4-6 m water column depth during the day (Figures 19 and 21). It is uncertain, though doubtful, that temperature throughout the 10 m-deep Montlake Cut would be greater than 4-6 m deep at our study site. These fish were mostly holding rather than actively migrating, and depth selection by holding fish may differ from actively migrating fish. We observed 18 fish from these two releases that displayed behaviors consistent with active migration, and these fish generally appeared in similar depths as the holding fish although we did not perform separate depth selection calculations. Celedonia et al. (2006) also observed actively migrating Chinook salmon at a site 2 km south of the SR 520 bridge selecting for 2-4 m water column depth at temperatures 17-20^{o}C during June. These temperatures closely matched those in the LWSC, thus suggesting that some factor other than a thermal barrier was responsible for the low proportion of fish detected in the LWSC.

The behavior of Chinook salmon smolts suggested that an ecological barrier or hindrance inhibiting entrance into the LWSC was possible, although it is uncertain exactly what this barrier may have been or where it occurred. Chinook salmon smolts from both the June 14 and 28 releases both had general site area residence times that were generally much larger than the travel times from the study site to the University Bridge. This implies that fish were holding/resting/rearing in and near the study site area, and then moving relatively quickly through the Montlake Cut and into Lake Union. A barrier or hindrance to migration would explain these behaviors. For example, migrating

Chinook salmon smolts encountering one Snake River dam delayed for several days in the forebay where they milled around and occasionally moved back upstream (Venditti et al. 2000).

One hypothesis that may explain a decline, reluctance, and delay in entering the LWSC may be temporal changes in the migratory corridor related to water clarity. Actively migrating Chinook salmon smolts in this study selected for 4-6 m water column depths. This closely corresponds with other studies showing that Chinook salmon migrating north along the western shore of Lake Washington are generally close to shore in shallow water 1-5 m deep (Celedonia et al. 2006; Tabor et al. 2006). In contrast to the apparent nearshore and shallow water preference in Lake Washington, observations in the LWSC have found Chinook salmon smolts broadly distributed across open-water areas at water column depths > 8-10 m (Celedonia et al. 2006). One possible explanation for this disparity is differences in water clarity and predation risk. Turbidity and light intensity can substantially alter juvenile fish habitat use patterns (Gregory 1993; Miner and Stein 1996; Abrahams and Kattenfeld 1997; Reebs 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. Variations in turbidity between Lake Washington and the LWSC may partially explain the dramatic difference in juvenile Chinook salmon spatial distribution between these two areas. Although Celedonia et al. (2006) did not sample water quality, King County water quality monitoring data indicated that water clarity was generally lower in the LWSC than along the western shore of Lake Washington during the study period. Decreased clarity in the LWSC may have allowed the tracked 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 this study, water clarity steadily increased during the study period, and there was a subtle shift to shallower daytime depth selection from the June 14 to the June 28 release. No such shift was observed from the June 1 to the June 14 release, although depth selection shifts from one release to the next may have been obscured by increasing height of macrophyte canopy. If Chinook salmon in Lake Washington select for shallow water in general, and progressively select for shallower water as clarity increases, it is conceivable that lack of an appropriate shallow water migrational corridor may inhibit migration. One characteristic of the Montlake Cut is that it is steep sided – there essentially is no shallow water migrational corridor. The hypothesis then is that under conditions of relatively low clarity Chinook salmon migrants are not inhibited from entering into the Montlake Cut, but that under conditions of increasing clarity Chinook salmon are reluctant to move into the steeply banked, deep water Montlake Cut.

There was no evidence to suggest that the bridge at any time presented a complete barrier to Chinook salmon smolt migration. Instead, common behaviors included: 1) fish passing beneath the bridge with no apparent delay; 2) fish passing beneath the bridge after delays of a few seconds up to 46 minutes; 3) fish passing beneath the bridge on multiple occasions; and, 4) fish passing beneath the bridge to the north, returning to the south, and selectively residing beneath and near the bridge for a few minutes up to 24 hours. The fundamental differences in migrational behavior (active migration versus holding/resting/rearing) between the June 1 release and the June 14 and 28 releases contributed to substantial differences in habitat use and apparent influence of the bridge. Many actively migrating fish - about one third - appeared unhindered by the presence of the bridge. Slightly less than one third were delayed for ≤ 1 min, and slightly more than one third were delayed 3-46 min (median 15 min). The reluctance to pass beneath the bridge in this latter group appeared to trigger a holding behavior in many whereby they appeared to cease searching for a favorable route to pass and instead moved away from the bridge and milled or meandered for prolonged periods. Depth and macrophytes were confounding factors: depth contours paralleled the bridge on the western side of the site, and there was an abrupt difference in macrophyte density between the north and south sides of the bridge for much of the bridge length. Nonetheless, the closeness with which fish moved along the edge of the bridge strongly suggests that the bridge played an important role in directing some migrating Chinook salmon. The most favorable location to pass beneath the bridge was likely related to some combination of macrophyte density beneath and beyond the bridge, water column depth, light levels beneath the bridge, and perhaps also presence of predators.

In contrast to actively migrating fish, holding/resting/rearing fish selected for areas near the bridge (5-20 m from edge) for prolonged periods of time. The fact that fish selected for these areas, spent considerable lengths of time here and returned repeatedly suggested that this area was a preferred habitat for holding Chinook salmon smolts. Celedonia et al. (2006) similarly observed Chinook salmon smolts spending considerable amounts of time near a dock structure in Portage Bay and near an overwater boardwalk in south Lake Washington. One possible reason for selecting the near-bridge habitat may lie in the apparent shift of Chinook salmon smolts to deeper water near the bridge. The structure and/or shadow cast by the bridge may have provided a desirable source of nearby cover that allowed fish to move into deeper cooler water and perhaps better foraging territory.

Chinook salmon selected for deeper water > 6 m near the bridge during the day and away from the bridge at night. The nighttime shift to deeper water corresponds with observations of Celedonia et al. (2006). Such movement is typical of planktivorous fishes in lacustrine habitats, and is generally attributed to food availability and predation risk (Hall et al. 1979; Tabor and Wurtsbaugh 1991; Jacobsen and Berg 1998; Shoup et al. 2003). Open water limnetic areas often provide the best foraging opportunities (i.e., larger and more abundant zooplankton), but also present the greatest predation risk from piscivorous fishes. Therefore, planktivores often use these areas during crepuscular periods and at night when low light levels diminish predation risk from visual predators, and take cover in shallow littoral areas often near macrophyte beds during the day when predation risk is higher. 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. Also, Koehler et al.

(2006) found that Chinook salmon in Lake Washington selectively feed on the zooplankter *Daphnia* during June which corresponds with peak *Daphnia* abundance in the lake (Edmondson and Litt 1982; Shepherd et al. 2000; Winder and Schindler 2004). That we observed daytime depth selection near the bridge that was similar to nighttime selection suggests that the bridge may have facilitated access to better daytime foraging opportunities for preferred prey perhaps by providing a source of cover.

Although migrating Chinook salmon in this study selected for water 4-6 m deep, these results were likely confounded by the swath of macrophytes along the shoreline. Aquatic macrophytes appear to function as a false bottom to migrating salmonids, effectively shortening the perceived water column depth (Tabor et al. 2006). Thus, when utilizing areas above macrophytes, fish may be observed at deeper overall water column depths than they would be observed in areas without macrophytes. Tabor et al. (2006) observed that water column depth above milfoil where juvenile Chinook were present was equivalent to total water column depth when milfoil was absent. This may partially explain why we observed juvenile Chinook salmon migrating in deeper water compared to visual observations in areas free of macrophytes (1.0-2.5 m water column depth; Tabor et al. 2006). Celedonia et al. (2006) also observed deeper water column selection (2-4 m) in the presence of macrophytes.

It is uncertain how the size of Chinook salmon smolts used in this study compared with untagged smolts in the area during the same time period. Tagged fish may have been larger particularly earlier in the study given the accelerated growth regimen used during rearing of the tagged smolts. However, size may not be a critical factor in determining movement patterns and habitat use for fish at the same ontogenetic stage (i.e., the smolt stage). That is, size differences within an ontogenetic stage may contribute to variations in movement and habitat use patterns that are relatively minor compared with the overarching patterns established by ontogenetic stage. For example, Celedonia et al. (2006) observed generally minimal differences in movement timing and habitat use between smaller naturally-reared Chinook smolts (106-108 mm FL) and larger hatchery-reared fish (117-119 mm FL). Smaller Chinook salmon at the fry and presmolt stages appear to reside primarily in the south end of Lake Washington, and move north toward the SR 520 bridge as they grow larger and enter the smolt stage (Tabor et al. 2006). Thus, it appears likely that many naturally-reared fish in Lake Washington would encounter the SR 520 bridge at a similar ontogenetic stage as the fish used in this study. Future studies might consider sampling naturally-produced fish near the SR 520 bridge to compare with study fish in order to confirm these suppositions.

Macrophytes can obscure and dampen acoustic signals and this may have biased our results. Our experience with fine-scale acoustic tracking in Lake Washington and the LWSC (e.g., Celedonia et al. 2006) suggests an inverse relationship between macrophyte density and data continuity: the denser the macrophytes the sparser the data. This manifests as fish tracks that are comprised of fewer data points and larger gaps between data points. These effects have appeared mostly minimal except under conditions of very high macrophyte density. We have not performed a formal survey to verify or quantify these anecdotal observations, nor are we aware of any such attempts by others. Any degradation to data quality in the presence of macrophytes could yield results suggesting less use and selection of these areas than what actually occurred. In this study, habitat and depth selection ratios may be reduced and spatial frequency distribution diagrams may show lower frequency of occurrence in areas with dense macrophytes. We do not believe that this affected the overarching conclusions of the study. Areas with dense macrophytes had some of the highest selection ratios and frequencies of occurrence. If macrophytes degraded data in these areas, selection ratios and frequencies of occurrence would actually be greater than what we determined. There was, however, a conspicuous wholesale lack of fish tracks from the June 28 release in the area immediately south of the bridge in the western part of the site where macrophytes appeared particularly dense (Figure 19). This data void was smaller in the June 14 release (Figure 17), and minimal if non-existent in the June 1 release (Figure 14). Lack of data in this area was likely due to fish avoidance rather than excessive acoustic dampening. We anecdotally observed that macrophytes in this area progressively neared the water surface throughout the study period, and were at or near the water surface by the end of the study period. Tabor et al. (2006) observed few migrating Chinook salmon in areas where milfoil neared the water surface. Also, in our other studies in Lake Washington and the LWSC, even very dense vegetation has not so completely dampened or obstructed acoustic signals that no data points were obtained, although the macrophyte data collected does not allow for any quantitative comparisons of density. Future studies should consider more rigorously quantifying macrophyte density, and also tracking temporal increases in density and canopy height. Sparse data on the westernmost part of the site did adversely affect our ability to conclusively determine the location of where some fish passed beneath the bridge, and may have led to some fish being categorized as passing beneath the bridge off-site to the west rather than on-site at the very western edge of the site. Given the small numbers of fish categorized as off-site, effects of any such incorrect categorizations were minimal.

The ratio of tag weight to Chinook salmon body weight in this study was ≤ 6%. Brown et al. (1999) argued that the 2% rule commonly advocated for biotelemetry studies is based primarily on theory and has little empirical basis, and found that a ratio of up to 12% did not affect swimming performance of juvenile rainbow trout *O. mykiss* (5-10 g). Similarly, Anglea et al. (2004) found that tags weighing up to 6.7% of juvenile Chinook salmon body weight (approximately 36 g) did not adversely affect swimming performance or susceptibility to predation. Adams et al. (1998a) observed that feeding activity and overall health was not impaired by tagging juvenile Chinook salmon (114-159 mm FL) with tags that weighed 2.3-5.5% of body weight, the only range of tag sizes used in the study. Conversely, Adams et al. (1998b) observed that swimming performance and susceptibility to predation were adversely affected by tagging juvenile Chinook salmon (< 120 mm FL) with tags weighing 4.6-10.4% of body weight. However, the tags used in the study had an antenna that was external to the body of the fish, and it is not clear whether the effects observed were due to the tag weight or the presence of an external antenna. The HTI tags used in our study had no external antenna, and were thus more comparable to those used by Anglea et al. (2004). These findings suggest that the 6% ratio used in this study was appropriate, although there is still uncertainly regarding the full affects of tagging and tag weight on study fish.

Northern pikeminnow

We were only able to effectively track less than 30% 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 moved 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 tracking duration (1-5 months). Therefore, large numbers of pikeminnow may need to be tagged to obtain a reasonable sample size of fish in our study area. Most of our results were based on six fish. Additional samples are needed to reach more conclusive results. For example, behavioral differences between size groups can not be determined with our small sample size.

Although we extensively tracked only six northern pikeminnow, we did obtain valuable information on their habitat use and depth selection. Overall our results were remarkably consistent between individual fish. For example, the depth selection was similar between the six fish. At least 60% (range, 61-86%) of the detections were in the 4-6 m depth category for each fish. Habitat use patterns were more variable then depth selection but we were able to document some significant positive and negative selections.

In general, all tagged northern pikeminnow remained in the nearshore area during the day and spread out at night and often moved to deeper areas. 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).

The diel distribution of northern pikeminnow appears to be similar to that of juvenile Chinook salmon. Both species were often close to shore during the day and appeared to disperse at dusk and during the night. Additionally, the one Vemco-tagged pikeminnow we tracked in July and August appeared to inhabit deeper and more offshore waters after the abundance of Chinook salmon had declined. It is unclear if the diel movements of northern pikeminnow we observed were influenced by the movement patterns of juvenile Chinook salmon. Northern pikeminnow diel behavior is probably influenced largely by their diel feeding patterns but other factors such as predator avoidance and thermoregulation may be more important during some times of the day.

Exactly when northern pikeminnow feed and what they consume at the study site is not known. The summer diet of northern pikeminnow in Lake Washington consists primarily of longfin smelt *Spirinchus thaleichthys*, salmonids, cottids *Cottus* spp., and crayfish (Olney 1975; Brocksmith 1999). Cottids, longfin smelt, and crayfish are nocturnally active and probably more available during that time period. Juvenile Chinook salmon appear to be active throughout the day and night and it's unclear when they would be most vulnerable to predation. Usually piscivorous fishes have their greatest advantage over forage fishes under low light conditions. Tagged pikeminnow covered a larger area at night than during the day, which could indicate they were more actively searching for prey. Of the two Vemco-tagged pikeminnow, one was close to the surface at night and the other was in mid-water depths at night, thus indicating they may have been trying to feed on juvenile salmonids, longfin smelt, or other open water fish and not benthic prey like cottids and crayfish. Laboratory feeding experiments have indicated northern pikeminnow feed primarily under low light conditions (Petersen and Gadomski 1994). Also, Steigenberger and Larkin (1974) found pikeminnow in two lakes in British Columbia feed primarily at dusk and at night. In areas close to dams on the Columbia River, they fed at night and during the morning from 0600-1000 hours and diel feeding patterns were related to the abundance of juvenile salmonids (Vigg et al. 1991).

In contrast, pikeminnow in areas away from the dams fed primarily from dawn to late in the afternoon (0400-1600 hours). The authors felt the difference between the two areas was due to differences in prey availability. Information on the diet of pikeminnow at our study site would help us better understand their diel behavior.

Based on our results of six northern pikeminnow, we were unable to demonstrate a positive selection for the SR 520 bridge. For some time periods, we observed a negative selection for the bridge or the area near the bridge. However, four of the six pikeminnow showed some positive selection for either the bridge or the area near the bridge during at least one time period. Therefore, the use of the bridge appears to vary between individuals. Because our sample sizes were small, further samples are needed to reach more conclusive results. At present, the bridge does not appear to be a major foraging site for northern pikeminnow.

We did, however, demonstrate that northern pikeminnow strongly selected the other overwater structures. In particular, pikeminnow were often present near the small pier in front of the Madison Point Condominiums. 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 water to attract pikeminnow. The Madison Point 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. Perhaps, this site may attract 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. 2004). 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.

Another important question is whether pikeminnow congregate around the SR 520 bridge structure. Our sampling did not allow us to assess this question because our collection methods were different than other projects and thus we can't compare catch rates. Even if we could compare catch rates it might be difficult to assess whether pikeminnow congregate at this site due to the bridge structure or may naturally congregate at this site because of the close proximity to the LWSC and abundance of juvenile salmonids. Northern pikeminnow have been shown to congregate in areas where prey fish are concentrated. In Lake Washington, they appear to congregate at the mouth of the Cedar River in March when longfin smelt are moving upstream to spawn (Olney 1975; K. Fresh, NOAA Fisheries, unpublished data). In the Columbia River, northern pikeminnow often move to areas where juvenile salmonids are concentrated, such as hatchery release sites (Collis et al. 1995) or near dams (Beamesderfer and Rieman 1991).

The habitat types most strongly selected by northern pikeminnow at our study site were moderately dense and dense vegetation. These levels of vegetation occurred between 2 and 6 m deep, which corresponded with depth selection results. Therefore, it is difficult to determine whether pikeminnow were selecting the vegetation, or whether the apparent selection for vegetation was simply an artifact of their depth preference. It may also be a combination of the two variables. The complexity of the macrophytes may provide 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.

Smallmouth bass

Unlike northern pikeminnow, we were able to effectively track each 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 are probably not 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 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 (Brocksmith 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 site.

Our results clearly showed that the bridge structure provides suitable habitat for smallmouth bass. However, the abundance and diet of bass near the bridge is unknown and further sampling of smallmouth bass is needed. 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 water column depth of smallmouth bass. The bridge may also provide an ideal location for bass to ambush outmigrating juvenile salmonids. Alternatively, the bridge structure may not support a large smallmouth bass population because the structure is not very complex, the substrate consists of fine sediments, and the bottom has a gentle slope where the preferred depth is 4-8 m deep (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.

Smallmouth bass typically prefer rocky shorelines and avoid thick beds of aquatic macrophytes (Becker 1983). Similar to other studies, we found smallmouth bass spent little time in areas where macrophytes were dense or moderately dense. However, we found they were present in areas of sparse vegetation and along the offshore edge of the macrophyte beds. The offshore edge and areas of sparse vegetation appeared to be used primarily at dawn and thus may have been related to foraging since smallmouth bass often have a crepuscular feeding pattern (Vigg et al. 1991). This may be a valuable location to locate their preferred prey: crayfish and cottids. Dense aquatic vegetation generally decreases the foraging success of piscivores (Werner et al. 1983; Gotceitas and Colgan 1989) but they may be able to effectively forage in areas where the vegetation is sparse and along the edges. In a laboratory experiment, Gotceitas and Colgan (1983) found densities of macrophytes (simulated by green polypropylene rope) greater than 276 stems/m^2 significantly reduced the foraging success of largemouth bass. This level of complexity may be similar to the density of Eurasian milfoil we categorized as sparse. The equivalent complexity of Eurasian milfoil may be substantially less than 276 stems/m^2 because it is much taller and more complex on a per stem basis than strands of polypropylene rope. 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. Also, the use of sparse vegetation and the offshore edge may be somewhat related to depth preference since this area is usually 6-8 m deep.

Previous studies have found smallmouth bass are commonly associated with steep slopes (Hubert and Lackey 1980). Of the 11 smallmouth bass we tracked, only one showed a strong preference for the steep slope. Smallmouth bass may not select this area because the steep slope area is in relatively deep water (10-30 m). In lakes, smallmouth bass occur almost exclusively in the epilimnion (Becker 1983) and are usually in water that is less than 12 m deep (Coble 1975). The one smallmouth bass that did select the steep slope area may have been in the epiliminion and may not have been associated with the substrate.

The two groups of smallmouth bass (SR 520 caught fish and LWSC fish) we tracked at the study site appeared to behave quite differently. Those caught at the study site tended to be present for a long period of time; whereas the LWSC fish were often only present for a few days. Of the seven LWSC fish, three were present for three days or less and the other four were present between 9 and 25 days. The SR 520 bass probably had a well-defined home range which included the study site and may use their home range throughout the year. In contrast, the LWSC bass were probably in the process of moving between their spring/early summer home range in the LWSC to another home range located somewhere in another part of Lake Washington. Results of our Vemco tracking in 2006 indicated most smallmouth bass leave the LWSC in the late summer and move to various locations in the lake (Tabor, USFWS, unpublished data). The habitat use of the two groups of bass was similar but the SR 520 bass were somewhat more likely to use the bridge structure than the LWSC bass. This may be because there were several smallmouth bass at the bridge that already had established home ranges and there was little available space for other bass.

The two small smallmouth bass we tagged were both < 190 mm FL and were primarily in shallow water < 2 m deep. The other smallmouth bass we tagged were at least 245 mm FL and all but one was over 300 mm FL. These bass were primarily in water between 4 and 8 m deep. Although there was a large difference in depth selection between the two smallest bass and the other bass, further sampling is needed because of the small sample size of small bass. For many fish species, there is a progression for fish to inhabit deeper waters as they increase in size to reduce predation risk from piscivorous birds (Power 1987). In Lake Washington, smallmouth bass less than 250 mm FL generally inhabit shallower water that larger smallmouth bass (Fresh et al. 2001).

At dawn and dusk, some smallmouth bass appeared to make 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. In the Columbia River, smallmouth bass showed a crepuscular feeding pattern, but it was not pronounced (Vigg et al. 1991). An extended period of morning feeding was also 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) 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 encounter smallmouth bass that were motionless and appeared to be resting on the bottom. Some smallmouth bass appeared to be active at night and had relatively large night home ranges. Nighttime activity may be related to artificial lighting or moonlight. Some of the night-active smallmouth bass in Portage Bay and at the tennis club were near artificial lighting. 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 indicative of resting behavior; whereas restricted movement throughout the day may be related to spawning activity. During the spring, male smallmouth bass build a nest and after the female has laid the eggs, the male will guard the nest for several days. These male bass 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 and did not appear to be nest guarding. Spawning activity occurs in the spring and our tracking may have been after spawning season was over. The bass caught in the LWSC may have spawned there and returned to the lake at the end of the spawning season. 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.

Implications of observations to bridge design

This study was intended to provide information regarding Chinook salmon smolt, smallmouth bass and northern pikeminnow movement and habitat use around a portion of the existing SR 520 bridge. The primary purpose of this information gathering was to evaluate influence of the current bridge structure on these species, and use these results to inform design of the future bridge so as to minimize impacts to Chinook salmon. Towards these ends, it is desirable to identify how specific aspects of the current bridge design interact with the fish species of interest, and how differences in these design parameters with the new bridge might alter such interactions. Design features of interest include: bridge height, bridge width, number of support columns, diameter of support columns, support column spacing, and location of the bridge structure. These are complex issues that are particularly difficult to address in the current setting due to the following:

1. Chinook salmon smolt behavior in lakes is not well researched, let alone behavior around large overwater structures in lakes. This lack of comparative data inhibits firm conclusions from being drawn.

2. Chinook salmon behavior observed in this study was highly variable. Smolts showed two primary migratory behaviors - active migration and holding. The bridge appeared to influence each of these groups differently. Furthermore, fish within each of these categories were variable in their behaviors around the bridge. Such variability severely complicates assessments of how bridge features influence fish behavior.

3. The study site and broader general area of interest is quite heterogeneous. This is a transitional area where three distinct bodies of water come together: Lake Washington proper, Union Bay, and the Montlake Cut. Some of the features that vary through this area include: shoreline orientation, shoreline features (e.g., overwater structures, riparian vegetation), presence of islands, aquatic

macrophytes, gradient, substrate, and maximum depths. The interaction between Chinook salmon and such habitat transitions is uncertain and complicates assessment of bridge influence, particularly with regards to bridge siting.

4. Several on-site features were correlated in a large portion of the site. Bridge directional orientation, offshore edge of aquatic macrophytes, and shoreline orientation were similar on the western side of the site. Also, bridge height decreased from east to west, concomitantly with water depth. Thus it is difficult to conclusively determine primary factors influencing behavior in these areas.

One aspect of bridge design that may influence Chinook salmon behavior is siting. The current bridge location spans a broad area - approximately 400 m wide - of the 4-6 m water column depth (Figure 49). This depth was selected for by Chinook salmon in this study, and a large proportion of Chinook smolts passed beneath the bridge at this depth. Moving the bridge to the north may drastically reduce the length of bridge that spans this depth. One consequence of such siting may be reduced Chinook delay at the bridge. Chinook smolts may spend less time paralleling the bridge if a shorter length of the bridge falls within desirable water column depths. This could effectively concentrate Chinook salmon presence along the bridge and locations of bridge crossing to a smaller area. To the extent that the bridge structure increases predator density and predation risk, this could have the effect of increasing or decreasing predation risk. Minimizing time and distance paralleling the bridge could reduce exposure to the number of predators that appear attracted to bridge columns, such as smallmouth bass. Conversely, focusing Chinook salmon to a smaller area may increase predation risk from such predators as northern pikeminnow, which can alter their feeding patterns in response to salmonid abundance (Vigg et al. 1991). These relationships and others related to bridge design should receive further study.

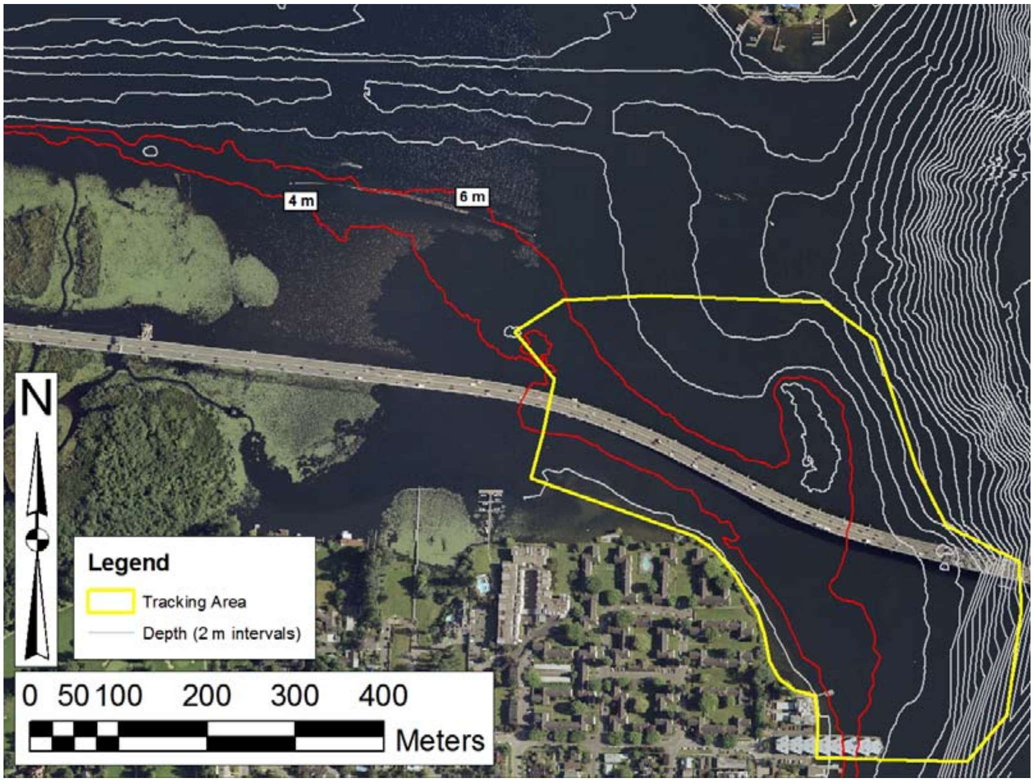


FIGURE 49. Existing SR 520 bridge span over the 4-6 m water column depths (shown in red) that were selected by Chinook salmon, June-July, 2007.

ACKNOWLEDGEMENTS

We wish to thank Becky Braley, Emily Dunklee, Tay Dunklee, Kevin Kennedy, Eric Tallman, Mathew Wynn, and Matthew Zimmer of the U.S. Fish and Wildlife Service (USFWS) for all their assistance with the data processing and field work. Jack Holbrook, Bob Clement, and Zuma Martin, USFWS provided technical support on data file transfer via a wireless cell phone connection. We also wish to thank Ken Berg, Bob Wunderlich, Brad Thompson, and Emily Teachout, USFWS; and Mike Grady and Kitty Nelson, NOAA Fisheries for input on the project proposal and providing technical support.

John Kugen, Mike Griffith, Darrin Coombs, Doug Hatfield, and John Kerwin of the Washington Department of Fish and Wildlife ensured we had plenty of juvenile Chinook salmon to tag from the Issaquah Creek State Hatchery. We also thank Gary Yoshida and Francis Sweeney, King County for all their help holding and acclimating the juvenile Chinook salmon fish and allowing us a place to tag them. We thank Jon Wittouck and Tom Rogers, University of Washington for use of their hatchery and dock facilities and providing logistical support. USFWS boats for this project were kept at either the Seattle Harbor Patrol or the University of Washington. Hydroacoustic Technology, Inc. (HTI) provided technical support for the equipment and tagging operation. We thank Chris Schultheiss, Lakeshore West Condominiums, for allowing us to place a Vemco receiver and a HTI hydrophone on their property. The Vemco receiver was provided by Fred Goetz of the U.S. Army Corps of Engineers. Julie Hall and Keith Kurko, Seattle Public Utilities (SPU) provided input on the original design of this project, the use of the tagging equipment, and provided financial support to the King County Environmental Lab.

Kurt Fresh and Steve Lindley, NOAA Fisheries; Eric Warner, Muckleshoot Indian Tribe; Paul DeVries, R2 Resource Consultants, and Michele Koehler, SPU provided valuable suggestions on this report.

Funding for this study was provided by the Washington State Department of Transportation (WSDOT) and administered by Phil Bloch and Rhonda Brooks. Phil Bloch was instrumental in designing this project and providing valuable comments on all aspects of this project. Our work near the bridge was coordinated with Tim Ditch, WSDOT maintenance supervisor. We also wish to thank WSDOT consultants, Shane Cherry and Chris Cziesla for their assistance with the design, review, and administration of this project.

REFERENCES

Aarestrup, K., C. Nielsen, and S.S. Madsen. 2000. Relationship between gill Na^+,K^+-ATPase activity and downstream movement in domesticated and first-generation offspring of wild anadromous brown trout (*Salmo trutta*). Canadian Journal of Fisheries and Aquatic Sciences 57:2086-2095.

Abrahams, M. and M. Kattenfeld. 1997. The role of turbidity as a constraint on predator-prey interactions in aquatic environments. Behavioral Ecology and Sociobiology 40:169-174.

Adams, N.S., D.W. Rondorf, S.D. Evans, and J.E. Kelley. 1998a. Effects of surgically and gastrically implanted radio transmitters on growth and feeding behavior of juvenile Chinook salmon. Transactions of the American Fisheries Society 127:128-136.

Adams, N.S., D.W. Rondorf, S.D. Evans, J.E. Kelley, and R.W. Perry. 1998b. Effects of surgically and gastrically implanted radio transmitters on swimming performance and predator avoidance of juvenile Chinook salmon (*Oncorhynchus tshawytscha*). Canadian Journal of Fisheries and Aquatic Sciences 55:781-787.

Aebischer, N.J., P.A. Robertson, and R.E. Kenward. 1993. Compositional analysis of habitat use from animal radio-tracking data. Ecology 74:1313-1325.

Alldredge, J.R., and J. Griswold. 2006. Design and analysis of resource selection studies for categorical resource variables. The Journal of Wildlife Management 70:337-346.

Anglea, S.M., D.R. Geist, R.S. Brown, K.A. Deters, and R.D. McDonald. 2004. Effects of acoustic transmitters on swimming performance and predator avoidance of juvenile Chinook salmon. North American Journal of Fisheries Management 24:162-170.

Beamesderfer, R.C. and B.E. Rieman. 1991. Abundance and distribution of northern squawfish, walleyes, and smallmouth bass in John Day Reservoir, Columbia River. Transactions of the American Fisheries Society 120:439-447.

Becker, G.C. 1983. Fishes of Wisconsin. University of Wisconsin Press, Madison, Wisconsin.

Brocksmith, R. 1999. Abundance, feeding ecology, and behavior of a native piscivore northern pikeminnow (*Ptychocheilus oregonensis*) in Lake Washington. Master's thesis, University of Washington, Seattle.

Brown, R.S., S.J. Cooke, W.G. Anderson, and R.S. McKinley. 1999. Evidence to challenge the "2% rule" for biotelemetry. North American Journal of Fisheries Management 19:867-871.

Celedonia, M.T., R.A. Tabor, S. Sanders, D.W. Lantz, and I. Grettenberger. 2006. Movement and habitat use of juvenile Chinook salmon and two predatory fishes in Lake Washington: 2004-05 acoustic tracking studies. Draft report. U.S. Fish and Wildlife Service, Western Washington Fish and Wildlife Office, Lacey, Washington.

Clarke, W.C., and T. Hirano. 1995. Osmoregulation. Pages 317-378 *in* C. Groot, L. Margolis and W.C. Clarke, editors. Physiological ecology of Pacific salmon. UBC Press, Vancouver, British Columia.

Coble, D.W. 1975. Smallmouth bass. Pages 21-33 *in* R.H. Stroud and H. Clepper, editors. Black bass biology and management. Sport Fishing Institute, Washington, D.C.

Cole, M.B. and J.R. Moring. 1997. Relation of adult size to movements of smallmouth bass in a central Maine lake. Transactions of the American Fisheries Society 126:815-821.

Collis, K, R. E. Beaty, and B. R. Crain. 1995. Changes in catch rate and diet of northern squawfish associated with the release of hatchery-reared juvenile salmonids in a Columbia River reservoir. North American Journal of Fisheries Management 15:346-357.

DeVries, P., F. Goetz, K. Fresh, and D. Seiler. 2004. Evidence of a lunar gravitation cue on timing of estuarine entry by Pacific salmon smolts. Transactions of the American Fisheries Society 133:1379-1395.

DeVries, P., F. and 18 others. 2005. PIT Tagging of Juvenile Salmon Smolts in the Lake Washington Basin: Fourth Year (2003) Pilot Study Results and Synopsis of 2000-2003 Findings. Prepared for U.S. Army Corps of Engineers. Contract Number DACW57-00-D-0003. R2 Resource Consultants, Inc., Redmond, Washington.

DeVries, P., F. and 14 others. 2007. PIT Tagging of Juvenile Salmon Smolts in the Lake Washington Basin: Fifth and Sixth Year (2004-2005) Pilot Study Results. Prepared for U.S. Army Corps of Engineers and Seattle Public Utilities. Contract Numbers DACW67-02-D-1013, W912DW-05-D-1001, and ROO-34-12. R2 Resource Consultants, Inc., Redmond, Washington.

Edmondson, W.T., and A.H. Litt. 1982. *Daphnia* in Lake Washington. Limnology and Oceanography 27:272-293.

Emery, A.R. 1973. Preliminary comparisons of day and night habits of freshwater fish in Ontario lakes. Journal of the Fisheries Research Board of Canada 30:761-774.

Ewing, R.D., C.A. Fustish, S.L. Johnson and H.J. Pribble. 1980. Seaward migration of juvenile Chinook salmon without elevated gill Na^+,K^+-ATPase activities. Transactions of the American Fisheries Society 109:349-356.

Fresh, K.L., D. Rothaus, K.W. Mueller, and C. Waldbillig. 2001. Habitat utilization by predators, with emphasis on smallmouth bass, in the littoral zone of Lake Washington. Draft report, Washington Department of Fish and Wildlife, Olympia.

Garshelis, D.L. 2000. Delusions in habitat evaluation: measuring use, selection and importance. Pages 111-164 *in* L. Boitani and T.K. Fuller, editors. Research techniques in animal ecology: controversies and consequences. Columbia University Press, New York, New York.

Garton, E.O., M.J. Wisdom, F.A. Leban, and B.K. Johnson. 2001. Experimental design for radiotelemtry studies. Pages 15-42 *in* J.J. Millspaugh and J.M. Marzluff, editors. Radio tracking and animal populations. Academic Press, San Diego, California.

Giorgi, A.E., G.A. Swan, W.S. Zaugg, T. Coley and T.Y. Barila. 1988. Susceptibility of Chinook salmon smolts to bypass systems at hydroelectric dams. North American Journal of Fisheries Management 8:25-29.

Gotceitas, V., and P. Colgan. 1989. Predator foraging success and habitat complexity: quantitative test of the threshold hypothesis. Oecologia 80: 158-166.

Gregory, R.S. 1993. Effect of turbidity on the predator avoidance behaviour of juvenile Chinook salmon (*Oncorhynchus tshawytscha*). Canadian Journal of Fisheries and Aquatic Sciences 50:241-246.

Hall, D.J., E.E. Werner, J.F. Gilliam, G.G. Mittelbach, D. Howard, C.G. Doner, J.A. Dickerman, and A.J. Stewart. 1979. Diel foraging behavior and prey selection in the golden shiner (*Notemigonus crysoleucas*). Journal of the Fisheries Research Board of Canada 36:1029-1039.

Hodgson, J.R., D.E. Schindler, and X. He. 1998. Homing tendency of three piscivorous fishes in a north temperate lake. Transactions of the American Fisheries Society 127:1078-1081.

Hubert, W.A. and R.T. Lackey. 1980. Habitat of adult smallmouth bass in a Tennessee River reservoir. Transactions of the American Fisheries Society 109:364-370.

Jacobsen, L., and S. Berg. 1998. Diel variation in habitat use by planktivores in field enclosure experiments: the effect of submerged macrophytes and predation. Journal of Fish Biology 53:1207-1219.

Kemp, P.S., M.H. Gessel and J.G. Williams. 2005. Seaward migrating subyearling Chinook salmon avoid overhead cover. Journal of Fish Biology 67:1381-1391.

Koehler, M.E., K.L. Fresh, D.A. Beauchamp, J.R. Cordell, C.A. Simenstad, and D.E. Seiler. 2006. Diet and bioenergetics of lake-rearing juvenile Chinook salmon in Lake Washington. Transactions of the American Fisheries Society 135:1580-1591.

Kraai, J. E., C. R. Munger, and W. E. Whitworth. 1991. Home range, movements, and habitat utilization of smallmouth bass in Meredith Reservoir, Texas. Pages 44-48 *in* D.C. Jackson, editor. The first international smallmouth bass symposium. Mississippi Agriculture and Forestry Experiment Station, Mississippi State University.

Manly, B.F.J., L.L. McDonald, D.L. Thomas, T.L. McDonald, and W.P. Erickson. 2002. Resource selection by animals: statistical design and analysis for field studies. Kluwer Academic Publishers, Boston.

McMahon, T.E. and S.H. Holanov. 1995. Foraging success of largemouth bass at different light intensities: Implications for time and depth of feeding. Journal of Fish Biology 46:759-767.

Miner, J.G., and R.A. Stein. 1996. Detection of predators and habitat choice by small bluegills: effects of turbidity and alternative prey. Transactions of the American Fisheries Society 125:97-103.

Munther, G.L. 1970. Movement and distribution of smallmouth bass in the middle Snake River. Transactions of the American Fisheries Society 99:44-53.

Nowak, G.M., and T.P. Quinn. 2002. Diel and seasonal patterns of horizontal and vertical movements of telemetered cutthroat trout in Lake Washington, Washington. Transactions of the American Fisheries Society 131:452-462.

Nowak, G.M., R.A. Tabor, E.J. Warner, K.L. Fresh, and T.P. Quinn. 2004. Ontogenetic shifts in habitat and diet of cutthroat trout in Lake Washington, Washington. North American Journal of Fisheries Management 24:624-635.

Olney, F.E. 1975. Life history and ecology of the northern squawfish *Ptychocheilus oregonensis* (Richardson) in Lake Washington. Master's thesis, University of Washington, Seattle, Washington.

Petersen. J.H. and D.M. Gadomski. 1994. Light-mediated predation by northern squawfish on juvenile chinook salmon. Journal of Fish Biology 45 (supplement A):227-242.

Petersen, J.H., D.M. Gadomski, and T.P. Poe. 1994. Differential predation by northern squawfish (*Ptychocheilus oregonensis*) on live and dead juvenile salmonids in the Bonneville Dam tailrace (Columbia River). Canadian Journal of Fisheries and Aquatic Sciences 51:1197-1204.

Pflug D. E. and G. B. Pauley. 1983. The movement and homing of smallmouth bass, *Micropterus dolomieui*, in Lake Sammamish, Washington. California Fish and Game 69:207-216.

Power, M.E. 1987. Predator avoidance by grazing fishes in temperate and tropical streams: importance of stream depth and prey size. Pages 333-351 *in* W.C. Kerfoot and A. Sih, editors. Predation: direct and indirect impacts on aquatic communities. University Press of New England, Hanover, New Hampshire.

Reebs, S.G. 2002. Plasticity of diel and circadian rhythms in fishes. Reviews in Fish Biology and Fisheries 12:349-371.

Reynolds, W. W., and M. E. Casterlin. 1976. Activity rhythms and light intensity preferences of *Micropterus salmoides* and *M. dolomieui*. Transactions of the American Fisheries Society 105:400-403.

Ridgway, M.S. and B.J. Shuter. 1996. Effects of displacement on the seasonal movements and home range characteristics of smallmouth bass in Lake Opeongo. North American Journal of Fisheries Management 16:371-377.

Rogers, K.B. and G. C. White. 2007. Analysis of movement and habitat use from telemetry data. Pages 625-676 *in* C.S. Guy and M.L. Brown, editors. Analysis and interpretation of freshwater fisheries data. American Fisheries Society, Bethesda, Maryland.

Savitz, J., L. G. Bardygula, T. Harder, and K. Stuecheli. 1993. Diel and seasonal utilization of home ranges in a small lake by smallmouth bass (*Micropterus dolomieui*). Ecology of Freshwater Fish 2:31-39.

Shepherd, J.H., A.H. Litt, S.E.B. Abella, J.M. Anson, W.T. Edmonson, and D.E. Schindler. 2000. Annual report: 1999 zooplankton abundances in Lake Washington. Department of Zoology, University of Washington, Seattle.

Shively R. S., T. P. Poe, and S. T. Sauter. 1996. Feeding response by northern squawfish to a hatchery release of juvenile salmonids in the Clearwater River, Idaho. Transactions of the American Fisheries Society 125:230-236.

Shoup, D.E., R.E. Carlson, and R.T. Heath. 2003. Effects of predation risk and foraging return on the diel use of vegetated habitat by two size-classes of bluegills. Transactions of the American Fisheries Society 132:590-597.

Stefansson, S.O., Å.I. Berge and G.S. Gunnarsson. 1998. Changes in seawater tolerance and gill Na^+,K^+-ATPase activity during desmoltification in Atlantic salmon kept in freshwater at different temperatures. Aquaculture 168:271-277.

Steigenberger, L.W. and P.A. Larkin. 1974. Feeding activity and rates of digestion of northern squawfish (*Ptychocheilus oregonensis*). Journal of the Fisheries Research Board of Canada 31:411-420.

Tabor, R.A., M.T. Celedonia, F. Mejia, R.M. Piaskowski, D.L. Low, B. Footen, and L. Park. 2004. Predation of juvenile Chinook salmon by predatory fishes in three areas of the Lake Washington basin. Miscellaneous report. U.S. Fish and Wildlife Service, Western Washington Fish and Wildlife Office, Lacey, Washington.

Tabor, R.A., B.A. Footen, K.L. Fresh, M.T. Celedonia, F. Mejia, D.L. Low, and L. Park. 2007. Predation of juvenile Chinook salmon and other salmonids by smallmouth bass and largemouth bass in the Lake Washington basin. North American Journal of Fisheries Management 27:1174-1188.

Tabor, R.A., H.A. Gearns, C.M. McCoy III, and S. Camacho. 2006. Nearshore habitat use by juvenile Chinook salmon in lentic systems of the Lake Washington basin, annual report, 2003 and 2004. U.S. Fish and Wildlife Service, Western Washington Fish and Wildlife Office, Lacey, Washington.

Tabor, R.A. and R.M. Piaskowski. 2002. Nearshore habitat use by juvenile Chinook salmon in lentic systems of the Lake Washington basin, annual report, 2001. U.S. Fish and Wildlife Service, Western Washington Fish and Wildlife Office, Lacey, Washington.

Tabor, R.A., R.S. Shively, and T.P. Poe. 1993. Predation on juvenile salmonids by smallmouth bass and northern squawfish in the Columbia River near Richland, Washington. North American Journal of Fisheries Management 13:831-838.

Tabor, R.A., and W.A. Wurtsbaugh. 1991. Predation risk and the imortance of cover for juvenile rainbow trout in lentic systems. Transactions of the American Fisheries Society 120:728-738.

Tiffan, K.F., D.W. Rondorf and P.G. Wagner. 2000. Physiological development and migratory behavior of subyearling fall Chinook salmon in the Columbia River. North American Journal of Fisheries Management 20:28-40.

Venditti, D.A., D.W. Rondorf and J.M. Kraut. 2000. Migratory behavior and forebay delay of radio-tagged juvenile fall Chinook salmon in a Lower Snake River impoundment. North American Journal of Fisheries Management 20:41-52.

Vigg, S., T.P. Poe, L.A. Prendergast, and H.C. Hansel. 1991. Rates of consumption of juvenile salmonids and alternative prey fish by northern squawfish, walleyes, smallmouth bass, and channel catfish in John Day Reservoir, Columbia River. Transactions of the American Fisheries Society 120:421-438.

Werner, E.E., J.F. Gilliam, D.J. Hall, and G.G. Mittelbach. 1983. An experimental test of the effects of predation risk on habitat use in fish. Ecology 64:1540-1548.

Winder, M., and D.E. Schindler. 2004. Climate change uncouples trophic interactions in an aquatic ecosystem. Ecology 85:2100-2106.

Winemiller, K.O. and D.H. Taylor. 1987. Predatory behavior and competition among laboratory-housed largemouth and smallmouth bass. American Midland Naturalist 117:148-166.

Winter, J.D. 1996. Advances in underwater biotelemetry. Pages 555-590 *in* B.R. Murhpy and D.W. Willis, editors. Fisheries techniques. American Fisheries Society, Bethesda, Maryland.

Wurtsbaugh, W.A. and D. Neverman. 1988. Post-feeding thermotaxis and daily vertical migration in a larval fish. Nature 333:846-848.

Zar, J.H. 1999. Biostatistical Analysis, 4th edition. Prentice-Hall, Upper Saddle River, New Jersey.

U.S. Fish and Wildlife Service
Western Washington Fish and Wildlife Office
Fisheries Division
510 Desmond Drive SE, Suite 102
Lacey, Washington 98503-1263
360/753-9440