U.S. Fish and Wildlife Service

Spring/Summer Habitat Use and Seasonal Movement Patterns of Predatory Fishes in the Lake Washington Ship Canal

Final Report, 2006-2009

September 2010 *By Roger A. Tabor, Scott T. Sanders, Mark T. Celedonia, Daniel W. Lantz, Steve Damm, Terence M. Lee, Zhuozhuo Li, and Benjamin E. Price*

Washington Fish & Wildlife Office
Lacey, Washington

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SPRING/SUMMER HABITAT USE AND SEASONAL MOVEMENT PATTERNS OF PREDATORY FISHES IN THE LAKE WASHINGTON SHIP CANAL

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to SEATTLE PUBLIC UTILITIES

by

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EXECUTIVE SUMMARY

Federally-protected Chinook salmon *Oncorhynchus tshawytscha* and other juvenile salmon in the Lake Washington basin must migrate through the Lake Washington Ship Canal (LWSC), a narrow, low-velocity artificial waterway. In this waterway, juvenile salmon are vulnerable to predatory fishes, including the non-native smallmouth bass *Micropterus dolomieu* and largemouth bass *M. salmoides*, and the native northern pikeminnow *Ptychocheilus oregonensis*. Some diet and abundance information on these predatory fish has been collected (e.g., Fayram and Sibley 2000; Tabor et al. 2004) but little is known about their habitat use and movement patterns. Chinook salmon habitat use patterns in the LWSC have been characterized in Celedonia et al. 2008b and Celedonia et al. 2010. The relationship between juvenile Chinook salmon habitat use and predator habitat use is important to understand for management of Chinook salmon in the Lake Washington system. This study used acoustic tracking methods to define habitat use and movement of these juvenile salmon predatory fishes.

The objectives of this study were to 1) describe the habitat use patterns of smallmouth bass, largemouth bass, and northern pikeminnow and determine their relationship to existing overwater and in-water structures; and, 2) determine seasonal movement patterns of these species, with particular emphasis on if and when they move between the LWSC and Lake Washington.

To address these objectives, we conducted an acoustic tracking study to determine the spring and summer habitat use and seasonal movement patterns of predatory fishes in the LWSC in 2006-2009. We used two separate systems to address our objectives: a fine-scale system to track

fish over a small area in the LWSC and a course-scale system to track fish over a large area within the LWSC, Union Bay, and Lake Washington for a longer time period.

The most intensive, fine-scale tracking was conducted at Gas Works Park and under the I-5 and University Bridges. Most tagged fish were smallmouth bass. Results showed smallmouth bass inhabiting these sites areas commonly used overwater structures, areas of sparse vegetation, vegetation edges, and areas with gravel and sand substrate. Smallmouth bass use primarily used 2-4 m deep water and were rarely in water that was more than 12 m deep. These are also areas used occasionally by juvenile Chinook salmon during outmigration (Celedonia et al 2008b; Celedonia et al. 2010).

Course-scale tracking revealed that predatory fish species exhibit varying movement patterns. During most of the year, northern pikeminnow inhabit Lake Washington. However, from May through August some of the tagged northern pikeminnow moved into the LWSC. Here, they were concentrated close to shore during the day and were often associated with vegetation. At night, northerm pikeminnow occupy a wide range of depths. It is possible that northern pikeminnown in the LWSC may overlap with outmigrating juvenile Chinook salmon habitats. However, because of the small number of northern pikeminnow moving into the LWSC and their varied behaviors, this study implies that northern pikeminnow are generally not a major predator of juvenile salmonids in the LWSC.

Course-scale tracking showed smallmouth bass have strong seasonal migration patterns. A large portion of smallmouth bass in the LWSC migrate into Lake Washington between June and

October and remain there until early spring. Smallmouth bass size is linked to these migrations, with smaller fish being less likely to migrate into Lake Washington for overwintering. Smallmouth bass return to the LWSC from Lake Washington between March and mid-April. While smallmouth bass migrations may be partially driven by spawning behavior, their return to the LWSC each year ensures that smallmouth bass inhabit the LWSC during the juvenile Chinook salmon outmigration period.

The five largemouth bass tagged in the LWSC generally stayed in the LWSC or made occasional forays into Union Bay. Their overlap with juvenile Chinook salmon in the LWSC is still unknown. However, due the small number of largemouth bass successfully tagged and tracked, more research is necessary on this predatory fish.

In improving habitat conditions for juvenile Chinook salmon in the LWSC, managers should look to avoid improving habitat for predatory fishes, if possible. Efforts should focus on reducing habitat for smallmouth bass. Unfortunately, smallmouth bass use a variety of habitat types from open beaches to areas with overwater structures. However, large offshore, deep structures like the University Bridge appear to attract smallmouth bass and probably increase the overlap between smallmouth bass and juvenile salmonids. Because smallmouth bass appear to have a discrete population in the LWSC, efforts to remove them could have positive effects on salmonid populations. However, a high removal rate may be impractical and a removal program may have to be continued over a long time period. Additional research is needed to look at the density of smallmouth bass in different areas of the LWSC and in different habitats as well as examine differences in diet.

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INTRODUCTION

The Lake Washington Ship Canal (LWSC) is a narrow, low-velocity artificial waterway at the downstream end of the Lake Washington basin that juvenile salmonids must pass through to reach the marine environment. Juvenile salmonids that pass through this waterway include Chinook salmon *Oncorhynchus tshawytscha* which is part of the Puget Sound evolutionarily significant unit and are considered threatened under the federal Endangered Species Act. The LWSC is in a highly urbanized area with numerous commercial and recreational activities and information on the relationship between these activities and juvenile Chinook salmon is needed to improve shoreline management. Part of the basic information needed on juvenile Chinook salmon is information on their predators. For example, there are several proposed development projects in the LWSC, and in planning for these projects, shoreline and land use planners and fishery managers also need to assess how the projects will influence predators of juvenile Chinook salmon. Also, planners need to look for potential restoration projects in the LWSC that could improve juvenile salmonid habitat and reduce predator habitat.

As salmon smolts outmigrate to the marine environment, they are vulnerable to a variety of predators including birds, mammals, and fishes. Predation levels can be high because the high abundance of salmon smolts can alter the functional (increase in predation rates) and numerical (increase in predator abundance) responses of predators. Additionally, anthropogenic changes such as dams and streamflow changes can exacerbate the vulnerability of smolts to predation.

As juvenile salmonids pass through the LWSC they are vulnerable to a variety of predators. Principal predators include two species of introduced black bass (smallmouth bass *Micropterus dolomieu*, and largemouth bass *M. salmoides*) and a native cyprinid (northern pikeminnow *Ptychocheilus oregonensis)*(Tabor et al. 2004). Other predators such as cutthroat trout and piscivorous birds are abundant in nearby Lake Washington but their abundance in the LWSC is not well known. Anecdotally, they appear to be present in the LWSC but not abundant and may have a minimal impact on salmon populations in this area.

The habitat use and movement patterns of predatory fishes in the LWSC are not well known. Initial research was conducted in 2004 and 2005 but few fish were successfully tracked (Celedonia et al. 2008b). Additionally, the movement patterns of predatory fishes between Lake Washington and the LWSC are not known.

Smallmouth bass are native to the Great Lakes and Mississippi River basins and have been introduced widely throughout temperate North America including the Pacific Northwest (MacCrimmon and Robbins 1975). In some cases, they have been shown to have serious negative impacts on native fish populations (Vander Zanden et al. 1999; MacRae and Jackson 2001; Jackson 2002; Weidel et al. 2007). In rivers and lakes of the Pacific Northwest, they often consume juvenile salmonids. However, their overall impact on salmonid populations is usually not well understood (Bennett et al. 1991; Fayram and Sibley 2000). In the LWSC, salmonids comprise approximately half of their overall diet from May through July (Tabor et al. 2007). An estimated 11,550 Chinook salmon *Oncorhynchus tshawytscha*, 10,700 coho salmon *O. kisutch*, and 9,150 sockeye salmon *O. nerka* are consumed annually by smallmouth bass in the LWSC (Tabor et al. 2007).

Largemouth bass are native to much of eastern North America and have been widely introduced in North America including the Pacific Northwest (MacCrimmon and Robbins 1975). Because they are not common in rivers of the Pacific Northwest, their overlap with juvenile salmonids is generally much less than that of smallmouth bass. Their greatest impact appears to be in rearing lakes of juvenile coho salmon (Reimers 1989; Bonar et al. 2005). In the LWSC, nonsalmonid fishes make up most of the diet of largemouth bass with juvenile salmonids comprising less than 20% of the overall diet from May to July. An estimated 650 Chinook salmon, 2,050 coho salmon, and 3,900 sockeye salmon are consumed annually by largemouth bass in the LWSC (Tabor et al. 2007).

Because northern pikeminnow are abundant in Lake Washington (Brocksmith 1999) and known congregate in areas where juvenile salmonids are abundant, they may be an important predator in the LWSC. Northern pikeminnow are a native piscivore that inhabits lakes and large rivers in the Pacific Northwest. Because they can be abundant and often prey heavily on juvenile salmonids, they are considered the principal predator of juvenile salmonids is many areas. They have been shown to especially congregate around dams (Beamesderfer and Reiman 1991) and at the outlets of hatchery facilities (Collis et al. 1995) to prey on juvenile salmonids. Northern pikeminnow are an opportunistic predator that consumes a wide variety of prey types including fish, invertebrates, plant material, and dead animals (Tabor et al. 1993; Petersen et al. 1994; Shively et al 1996). In the LWSC, their diet consists primarily of either signal crayfish *Pacifastacus leniusculus* or juvenile salmonids (Tabor et al. 2004). However, little information is available on their abundance in the LWSC and their overall consumption of smolts is not known (Tabor et al. 2004; Beauchamp et al. 2007).

Objectives: Our objectives of this study were to 1) describe the habitat use patterns of smallmouth bass, largemouth bass, and northern pikeminnow and determine their relationship to existing overwater and in-water structures; and, 2) determine seasonal movement patterns of these species, with particular emphasis on if and when they move between the LWSC and Lake Washington. To answer these questions, we tagged predatory fishes in 2006-2008 with acoustic tags and documented their spring/summer habitat use and seasonal movements.

STUDY SITE

The LWSC and Lake Washington comprise the lower portion of the Lake Washington basin, which is approximately 1,570 km^2 and ranges in elevation from 6 to 1,650 m. The eastern 14% (by area) of the basin lies within the Cascade Range, while the western 86% is part of the Puget Sound lowlands. Much of the basin is heavily urbanized with over a million people inhabiting the basin. Much of the City of Seattle is within the basin. The basin has undergone numerous anthropogenic changes over the past 150 years.

The LWSC is a 13.8-km-long artificial waterway that is located between Lake Washington and Puget Sound. The LWSC consists of five sections: Montlake Cut, Portage Bay, Lake Union, Fremont Cut, and the Salmon Bay waterway (Figure 1). The largest part of the LWSC is Lake Union, which is 235 ha in size and has a mean depth of 9.8 m. The shorelines of Portage Bay, Lake Union, and Salmon Bay are highly developed with numerous marinas, commercial shipyards, and house boat communities. The Fremont Cut and Montlake Cut are narrow

channels with steep banks. The Ballard Locks, located at the downstream end of the LWSC, controls the water level of the LWSC as well as Lake Washington. During winter (December to February) the water level is kept low at an elevation of 6.1 m. Starting in late February the water level is slowly raised from 6.1 m in January to 6.6 m by May 1 and 6.7 m by June 1.

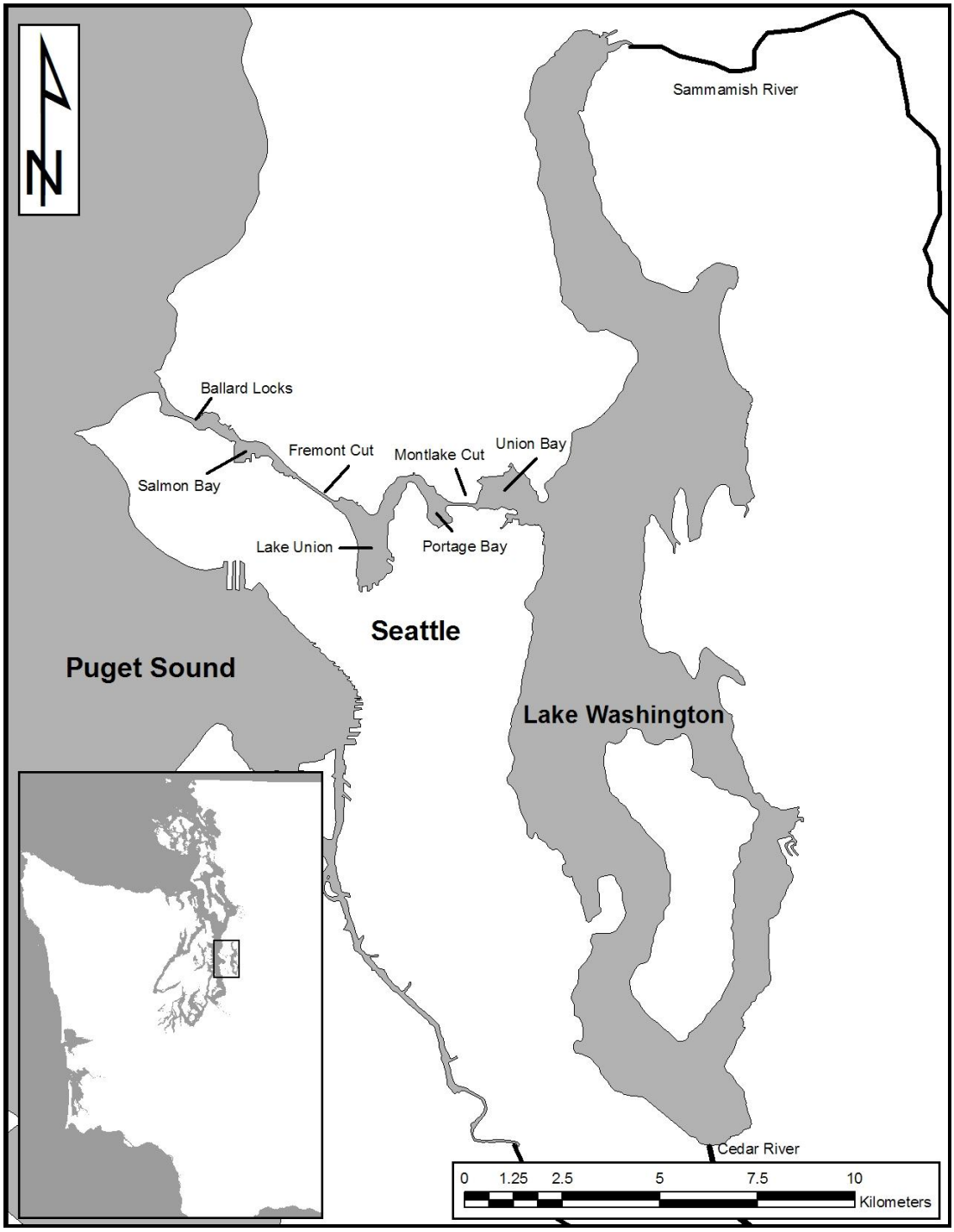


FIGURE 1. Map of lower Lake Washington basin displaying the various sections of the Lake Washington Ship Canal (LWSC). Location of study area in western Washington is also shown.

Upstream of the LWSC is Lake Washington, a large monomictic lake with a total surface area of 9,495 hectares and a mean depth of 33 m. The lake typically stratifies from June through October. Surface water temperatures range from 6-7°C in winter to over 20°C in summer. Over 78% of the shoreline is comprised of residential land use. The largest tributary to Lake Washington is the Cedar River which enters the lake at the south end. The other major tributary to Lake Washington is the Sammamish River, whose watershed includes Bear Creek, Lake Sammamish, Issaquah Creek, and several small tributaries.

Compared to other similar-sized basins in the Pacific Northwest, the Lake Washington basin is inhabited by a relatively large number of fish species, including 25 native species (primarily salmonids, cottids *Cottus* spp., and cyprinids) and at least 15 introduced species. Large populations of the native cyprinids, peamouth *Mylocheilus caurinus* and northern pikeminnow, occur in Lake Washington and Lake Sammamish. Largemouth bass were initially planted in the system in 1890 (Stein 1970). The history of smallmouth bass planting in Lake Washington is less clear, but records suggest that smallmouth bass have been present since at least 1930 (Lampman 1946).

Anadromous salmonids in the Lake Washington basin include sockeye salmon, Chinook salmon, coho salmon, and steelhead. Sockeye salmon are by far the most abundant anadromous salmonid in the basin with adult returns of sockeye salmon exceeding 350,000 fish in some years (Fresh and Lucchetti 2000). The major source of natural production is the Cedar River with additional production from smaller tributaries in the north end of the basin. The sockeye salmon run is also supplemented with fry production from the Washington Department of Fish and Wildlife (WDFW) Cedar River Hatchery. The largest run of naturally-produced Chinook salmon in the Lake Washington basin also occurs in the Cedar River. Adult fish also spawn in Bear Creek. Adult coho salmon spawn in numerous small tributaries as well as all the major streams. Hatchery-produced juvenile Chinook salmon and coho salmon are released from the WDFW Issaquah Creek Hatchery, located near the south end of Lake Sammamish, and from the University of Washington (UW) Hatchery, located on Portage Bay of the LWSC.

Historically, the Duwamish River watershed, which included the Cedar River, provided both riverine and estuarine habitat for indigenous anadromous salmonids. Beginning in 1912, drainage patterns of the Cedar River and Lake Washington were extensively altered (Weitkamp and Ruggerone 2000). Most importantly, the Cedar River was diverted into Lake Washington from the Duwamish River watershed, and the outlet of the lake was rerouted through the LWSC. These activities changed fish migration routes and environmental conditions encountered by migrants.

METHODS

To determine the spring/summer habitat use and seasonal movement patterns of smallmouth bass, largemouth bass, and northern pikeminnow in the LWSC, we used two separate tracking systems. Spring/summer habitat use was determined with a fine-scale tracking system (HTI tracking system). This system allowed us to obtain exact fish positions (sub-meter resolution) throughout the day and night. However, because of cost constraints and system limitations, we

could only track fish in a relatively small area (maximum, approximately 28 ha) over a short period (1-2 months). A separate system (Vemco receivers) was used to determine seasonal movement patterns. The use of long-lasting tags (6 months – 2 years) and several independent receivers placed strategically in the LWSC and Lake Washington enabled us to determine large-scale movement patterns over a much longer period.

HTI tracking system

Predators were tracked in the LWSC at two locations: 1) I-5/University Bridge area and 2) Gas Works Park (Figure 2). These sites were chosen because these sites were also Chinook salmon smolt tracking sites (Celedonia et al. 2010), predators were known to be common, and they encompassed a relatively large area. 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 omnidirectional 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.

All of the hydrophones in a given array are cabled into a shared receiver (HTI Model 290 Acoustic Tag System) which processes tag pings and other acoustic signals detected by the hydrophones. Each receiver is connected to a personal computer that logs the acoustic data.

We either used HTI Model 795E tags (20 day; 1.5 g) or Model 795M tags (12 day; 0.75 g) to tag small-sized bass (< 200 mm FL). For larger bass and northern pikeminnow, we primarily used HTI Model 795G tags (60 day; 4.4 g). In 2007, tags were single-pulsed; whereas, in 2008 they were double-pulsed. Double-pulsing the tags reduces the battery life approximately 30-40% but the data files can be processed reliably with HTI autotracking software, which significantly reduces the amount of data processing. Data files for single-pulse tags generally need to be processed manually, especially for an area like LWSC, which has a large amount of background noise due to boating activity. The HTI autotracking software searched data files from both sites for all smallmouth bass tagged in the LWSC, regardless of where they were tagged. Additionally, we also searched for predatory fish captured and released at the west end of the SR 520 bridge (Celedonia et al. 2009). In 2007, we searched for tagged fish released at Gas Works Park in the I-5/University Bridge data files, but due to time constraints, we did not look for I-5/University Bridge fish in Gas Works Park data files.

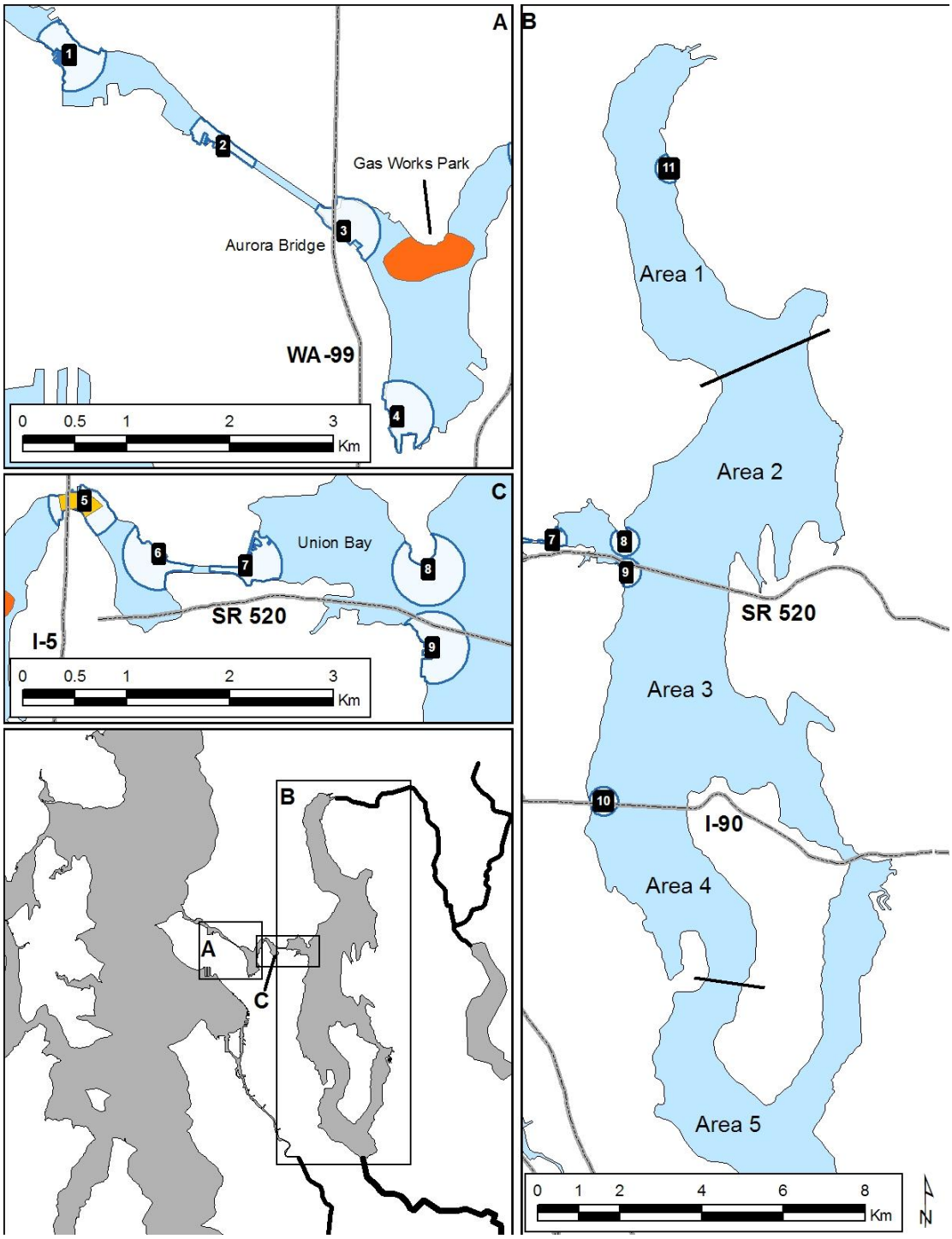


FIGURE 2. Maps of lower Lake Washington basin displaying HTI tracking sites (Gas Works Park [orange] and I-5/University Bridge site [yellow]) and Vemco receiver sites (numbers 1-11). The area around each Vemco receiver indicates the approximate coverage area (approximately 350 m from receiver). Description of each Vemco site is given in Table 1. Five areas of Lake Washington are also shown.

Vemco hydrophones/receivers

To track the seasonal movements of predatory fishes and movement between the LWSC and Lake Washington, we deployed Vemco VR2 receivers. The VR2 is a self-contained, submersible unit with a built-in omni-directional hydrophone and has a lithium battery that lasts approximately 15 months. Receivers logged the date, time, identification code, and depth of any acoustic tag in its listening range. In general, the VR2s can detect tags that are within 300-400 m. We deployed six receivers throughout the LWSC (Table 1; Figure 2). Another receiver was deployed at the west end of Union Bay, which is a transition area between Lake Washington and the LWSC. Two additional receivers were deployed in Lake Washington at the east end of Union Bay (Figure 2). The VR2s were typically downloaded once every one to two months. The VR2 in Salmon Bay was removed in 2007 because few fish were detected at this site. As part of an adult sockeye salmon tracking project, the Muckleshoot Indian Tribe (MIT) also had two additional VR2s in Lake Washington (Table 1) which could also detect our tags. These data were added to our dataset.

TABLE 1. List of locations where a Vemco VR2 fixed receiver was deployed. The receiver numbers correspond to the locations shown in Figure 2. LWSC = Lake Washington Ship Canal; USFWS = U.S. Fish and Wildlife Service, MIT = Muckleshoot Indian Tribe.

Number	Site name	Water body	Agency	Start date	End date	Days (Dates) not functioning
1	Fishermen's Terminal	LWSC - Salmon Bay	USFWS	20-Apr-06	5-Feb-07	
2	King County Lab	LWSC - Fremont Cut	USFWS	2-May-06	27-Apr-09	15 (18-Apr to 3-May-07)
3	Northwest Lake Union	LWSC - Lake Union	USFWS	20-Apr-06	27-Apr-09	20 (18-Apr to 8-May-07)
4	South Lake Union	LWSC - Lake Union	USFWS	8-May-06	4-Sep-08	
5	University Bridge	LWSC - Lake Union	USFWS	21-Jun-06	15-Sep-09	
6	UW Hatchery	LWSC - Portage Bay	USFWS	2-May-06	15-Sep-09	
7	UW Rowing Center	Transition - L. Washington/LWSC	USFWS	1-May-06	22-Jun-09	59 (20-Nov-07 to 18-Jan-08)
8	Webster Point	Lake Washington	USFWS	31-May-06	15-Sep-09	13 (11 to 24-Apr-07)
9	Lakeshore Condos	Lake Washington	USFWS	2-May-06	15-Sep-09	14 (11 to 25-Apr-07)
10	West I-90 Bridge	Lake Washington	MIT	20-Apr-06	15-Sep-09	253 (1-Jan to 10-Sep-08)
11	St. Edwards Park	Lake Washington	MIT	21-Jul-06	5-Nov-07	180 (11-Nov-06 to 10-May-07)

To supplement data from the fixed VR2s, we periodically conducted mobile surveys of LWSC and Lake Washington. In most cases, we slowly boated along the shoreline (approximately 30 m from shore) of the LWSC and Lake Washington. We attempted to survey at least once every three months (January-March; April-June; July-September; October-December). We typically did not survey Salmon Bay in the LWSC and the north (north of St. Edwards Park) and south (south of Mercer Island) end of Lake Washington because of time constraints and few fish were detected. Each time a fish was detected, a GPS location was obtained. The boat location was used as the approximate location of the fish. The mobile receiver and omni-directional hydrophone have a listening range of approximately 300 m. The MIT also conducted weekly mobile surveys of the LWSC and Lake Washington from July to October in 2006 and 2007. Detections of our fish by their mobile receiver were incorporated into our dataset.

We used both regular Vemco coded tags and depth (pressure) tags (Table 2). We used coded Vemco tags that were programmed to emit an identification signal at random intervals (most tags were set at 30-90 seconds). Each tag had a unique code. All Vemco tags were on the same frequency: 69.0 kHz. Depth tags had an accuracy of ± 0.3 m. Depth tags used in 2007 had two alternating identification codes; the first code provided the depth information and the second code provided the unique code. In general, bass < 300 mm FL and northern pikeminnow < 400 mm FL were implanted with V9 and V9P (depth) tags, while larger fish were often implanted with V13 and V13P tags. Because of tag availability and several fish were implanted with two tags (a Vemco and a HTI tag), the exact tag size used varied. Except for a few fish, the total tag weight was less than 3% of the body weight.

TABLE 2. Vemco acoustic tag specifications and the number deployed. Weight is the weight in air. Delay is the minimum and maximum number of seconds between when an identification signal was emitted. Battery life is the minimum tag life listed by the manufacturer; in some cases, the actual battery life was substantially longer.

Type	Diameter	Length	Weight	Output	Delay	Battery life	Number deployed		
model	(mm)	(mm)	(g)	(dB at 1 m)	(s)	(days)	2006	2007	2008
Regular coded tags									
V9-1L	9	24	3.6	142	30-90	157	8	0	0
V9-2L	9	29	4.7	142	20-60	156	5	0	0
					30-90	290	0	11	0
					60-120	417	0	4	3
V9-6L	9	21	2.9	142	30-90	79	5	0	0
V13-1L	13	36	11.0	147	20-60	334	24	1	0
					30-90	616	0	13	7
Totals							42	29	10
Depth tags									
V9P-1L	9	40	5.2	143	20-60	72	5	0	0
V9P-2L	9	47	6.4	143	30-90	249	0	10	0
V13P-1L	13	45	12.0	150	20-60	280	0	12	0
					30-90	518	1	2	0
Totals							6	24	0

Fish collection and tagging

A variety of techniques were used to collect predatory fishes. Fish were collected through angling, gill nets, beach seines, or baited trot lines. Smallmouth bass were collected primarily through angling, while northern pikeminnow were collected primarily with gill nets. Catch rates of largemouth bass were low for each gear type; however, most were collected during beach seining.

We used variable-mesh, monofilament nylon gill 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 at dusk or night and retrieved 1.5 to 2 h later to minimize the amount of time fish were in the net. Nets were set in approximately 5 to 10 m deep water. To minimize stress to fish, we slowly brought the nets to the boat. When we observed a

predatory fish in the net, we left the net in the water and put a landing net under the fish. The gill-net mesh around the fish was then cut to free the fish.

Additionally, we used a beach seine that was 30-m long and 3.7 m deep with 38-mm stretch mesh in the wings and 9-mm stretch mesh in the wings. We identified four locations where we could effectively use a beach seine: 1) east side of Gas Works Park, 2) south shoreline under I-5 Bridge, 3) North Portage Bay along UW shoreline, and 4) West Montlake Park. Beach seining was done at night to increase the probability of encircling large predatory fish. In 2006, we also attempted to increase our catch of northern pikeminnow by setting a baited trot line. The trot line consisted of a series of baited hooks that were attached to lead line and set on the bottom where the depth was 5-10 m deep. Earthworms were used as bait.

Collection efforts for fish to be implanted with HTI tags were conducted within the coverage area of the HTI hydrophone array. For fish to be implanted with Vemco tags, most collection efforts occurred in the LWSC between Fremont Cut and Montlake Cut; however, to increase our sample size of northern pikeminnow, we did tag some that were caught in Lake Washington near Union Bay as part of another study (Celedonia et al. 2008b).

After capture, fish were placed in an aerated cooler and transported to the University of Washington (UW) pier where they were tagged. 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. Fish were placed in a customized surgical platform with their ventral side facing upwards. During the surgery, the gills were irrigated with MS-222 solution at 15-30 s intervals. An incision approximately 10-20 mm long was made between the pectoral and pelvic fins. One or two tags were then inserted into the peritoneal cavity through the incision. Two or three sutures of 3-0 coated Vicryl® braided suture material were used to close the incision. Fish were then placed in a recovery tank of fresh water. The entire operation was usually completed in 5-8 min. Fish were allowed to recover before being released at their approximate capture location.

Macrophyte surveys

To assess habitat use of predatory fishes, we also collected field data on aquatic macrophytes in 2007 and 2008. We used a point-intercept method 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 pre-established 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. Transects were surveyed to a depth of 10-11 m, which was the maximum depth macrophytes

were expected. When presence/absence of macrophytes differed between two sequential points (e.g., present at one point, but not at the next), we attempted to locate a more precise location for the edge. The following numbers of points were surveyed: University Bridge, n_{2007} = 117, n_{2008}= 175; Gas Works Park, n_{2007} = 170, n_{2008}= 188. We used the Spatial Analyst Spline tool in ArcGIS 9.2 to generate macrophyte density contours based on survey point data. For splining, we used n = 5 points and regularized with a weight value of 0.1.

In 2007, macrophyte surveys were conducted July 17-18 at the Gas Works Park site and August 7-8 at the I-5/University Bridge site. In 2008, surveys were conducted August 12-13 at the Gas Works Park site and July 22 and 28 at the I-5/University Bridge site. Additionally, macrophyte distribution and growth was monitored at a few locations at the I-5/University Bridge site. This sampling was conducted once per week in 2008 from June 19 to July 16. This monitoring as well as monitoring at a site on the west end of the SR 520 bridge (Celedonia et al. 2009), indicated there was limited horizontal change in the size of macrophtye beds from mid-June to late-July. There was no discernable change in macrophyte density during the study period. At both sites, aquatic macrophytes grew 0.4-1.2 m closer to the surface of the water during the study period. Overall, we felt macrophyte growth may have some effect of habitat selection but its effect would be small in comparison to the main habitat effects and could be easily confounded by other variables (e.g., spawning activity, prey availability, water temperature and other environmental conditions); therefore, we pooled data across the sampling period.

Data analysis-HTI

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. Orthophoto and bathymetry data were obtained from Seattle Public Utilities (SPU). Bathymetry was checked against depth measurements collected during aquatic macrophyte surveys. SPU bathymetry data were generally accurate; however, some adjustments were necessary at depths ≤ 4 m.

The total horizontal area of each habitat category contained within the tracking area was considered the availability of that category. 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.

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 various habitat features (habitat type, shoreline type, substrate, and depth selection) was estimated by comparing the number of

data points observed in each habitat category to the amount that was available. Selection ratios (Manly et al. 2002) were calculated for each fish 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 feature in category i relative to all available habitats at the study site.

For depth selection (inshore versus offshore), the tracking area was segregated into water column depths at 2 m intervals (i.e., 0-2 m, 2-4 m, etc.; Figure 3). The water level in the LWSC remains the same in May and June and then slowly decreases by 0.1 m during July. We assumed that water level fluctuations had a minimal effect on our depth selection calculations. Habitat selection was determined by dividing the tracking areas into various habitat types based on density of aquatic macrophytes and proximity to overwater structures (Tables 3 and 4; Figures 4 and 5). We also determined substrate selection for the Gas Works Park site. We used data collected by Floyd/Snider and SPU. We combined their data into four categories (silt, sand/silt, gravel/sand, and cobble/boulder; Figure 6). For habitat and substrate selection, we only included areas where the depth was 0-10 m deep; smallmouth bass were rarely in areas outside of this depth interval. No substrate information was available for the I-5/University site.

TABLE 3. Five littoral (< 10 m deep) habitat types used to determine habitat selection at the Gas Works Park site, May-August, 2007 and 2008. The total area of these habitats was 2.73 ha in 2007 and 3.42 ha in 2008. The large, open offshore area (> 10 m deep) within our coverage area was not considered in our analysis because smallmouth bass rarely used that area.

		Area (ha)		Percent	
Habitat type	**Description**	**2007**	**2008**	**2007**	**2008**
Dense vegetation	Area of dense macrophytes	0.061	0.260	2.23	7.61
Moderate vegetation	Area of moderate macrophytes	0.126	0.208	4.61	6.09
Sparse vegetation	Area of sparse macrophytes	0.218	0.285	7.97	8.34
Vegetation edge	Area that is within 5 m of macrophytes	0.239	0.327	8.74	9.57
Open areas	Open area that is not near vegetation	2.090	2.336	76.44	68.38

TABLE 4. Nine habitat types used to determine habitat selection at the I-5/University Bridge site, May-August, 2007 and 2008. The total coverage area was 6.14 ha.

Habitat type	Abbreviation	Description	Area (ha)	Percent
University Bridge structures	UB-S	Area within 5 m of the two large support structures, (including wing walls) and bridge columns	0.358	5.83
University Bridge - other areas	UB-O	Other areas directly under or within 5m of the University Bridge	0.266	4.34
Overwater structures	OWS	Area that is directly under or within 5 m of nearshore structures	0.679	11.06
I-5 Bridge - vegetation	I-5 B-V	Vegetated areas directly under or with 5 m of the I-5 Bridge	0.280	4.57
I-5 Bridge - open areas	I-5 B-O	Open area directly under or with 5 m of the I-5 Bridge	0.469	7.65
Moderate/dense vegetation	M/D Veg	Area of moderate and dense macrophytes not including areas near structures	0.232	3.77
Sparse vegetation	Sp Veg	Area of sparse macrophytes not including areas near structures	0.749	12.21
Vegetation edge	Veg edge	Area that is within 5 m of macrophytes not including areas near structures	0.360	5.87
Open areas	Open	Open area that is not near structures or vegetation	2.745	44.71

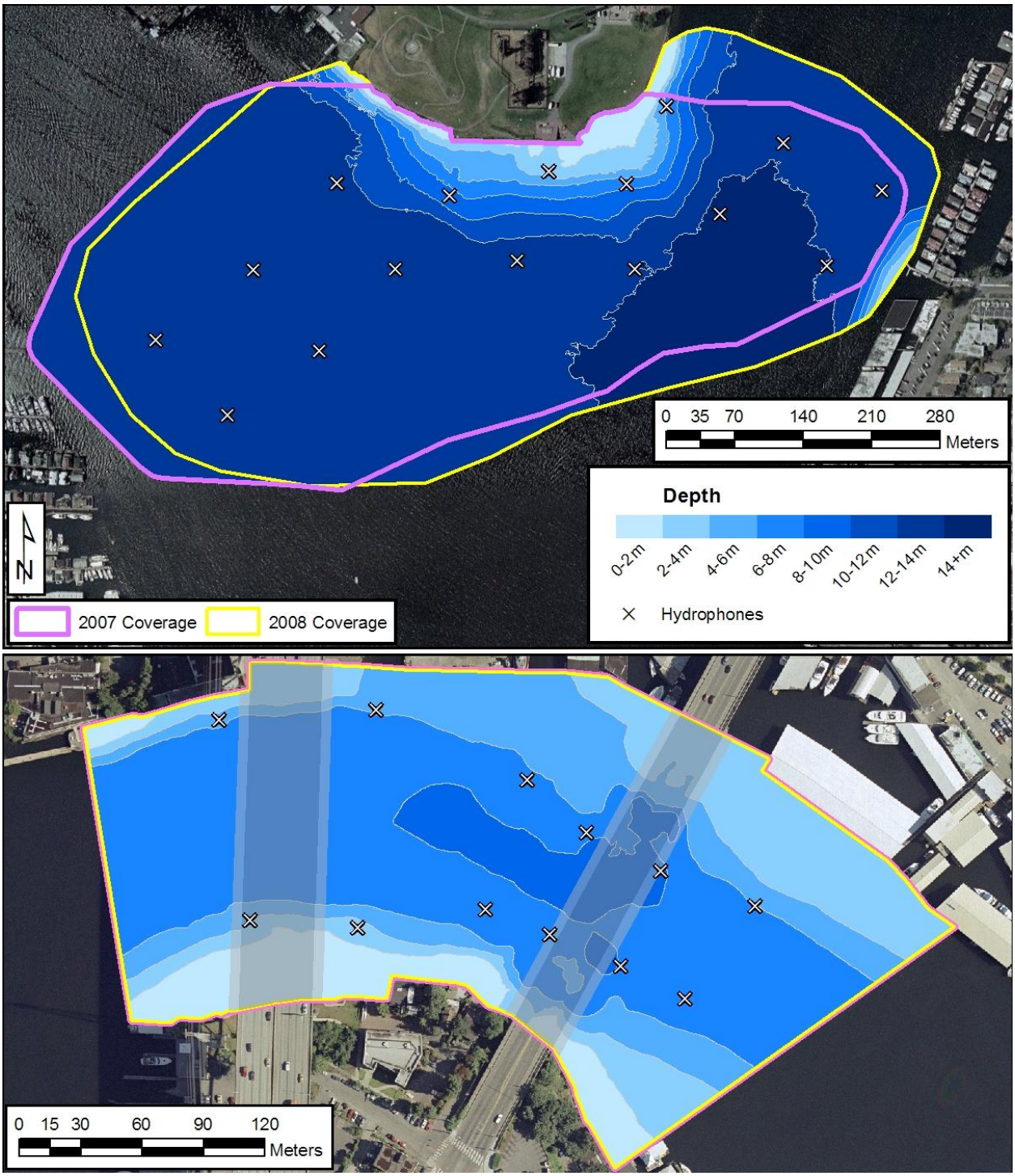


FIGURE 3. Map of Gas Works Park site (top panel) and I-5/University Bridge site (bottom panel) showing depth intervals (2-m contours) and hydrophone locations (X's), May to August, 2007 and 2008.

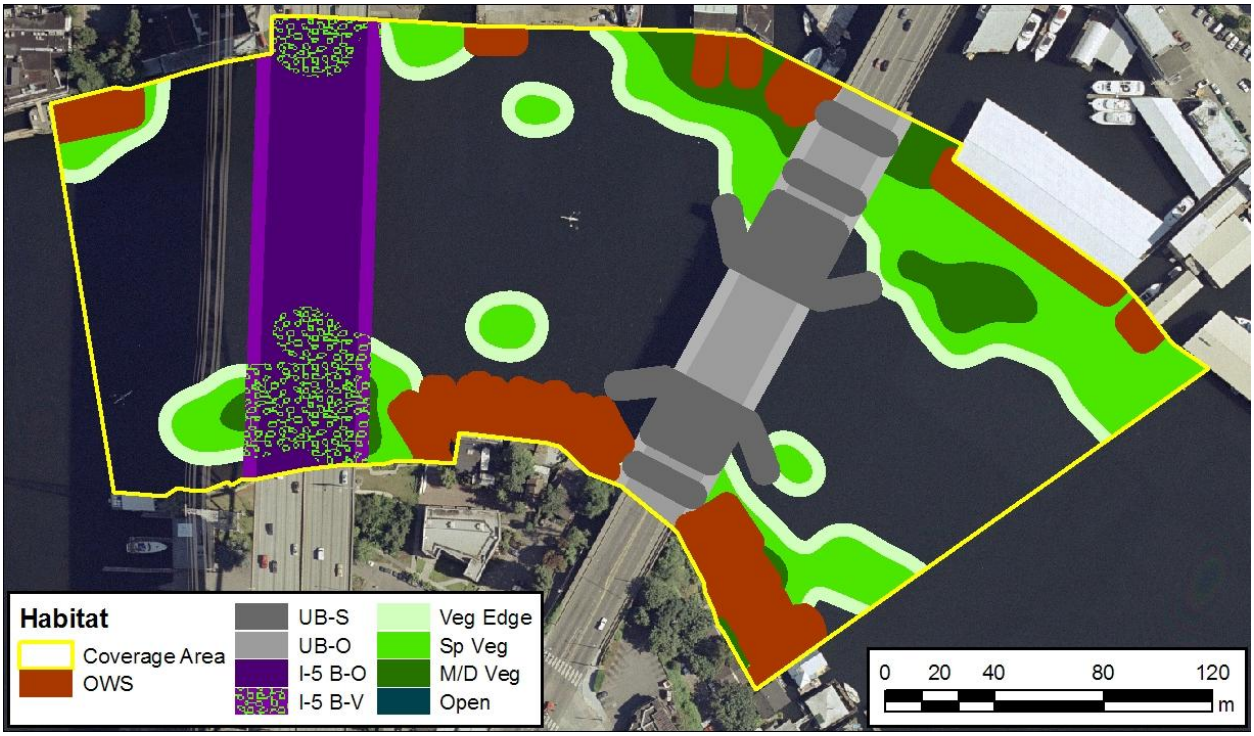


FIGURE 4. Map of the I-5/University Bridge site showing the various habitat types, May to August, 2007 and 2008. Descriptions of habitat types are given in Table 4.

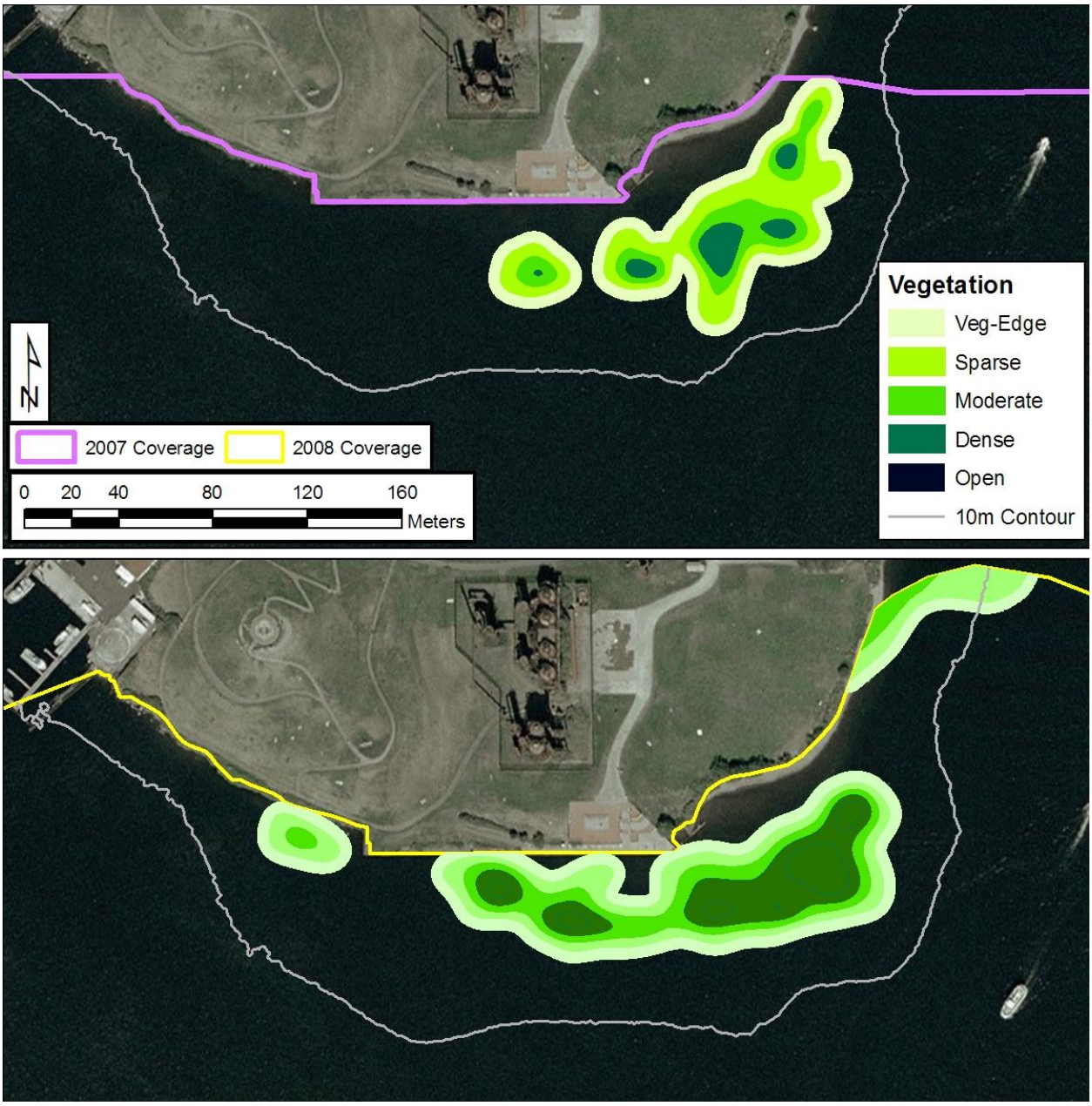


FIGURE 5. Map of the Gas Works Park site showing various habitat types, May to August, 2007 (top panel) and 2008 (bottom panel). Descriptions of habitat types are given in Table 3. Habitat selection analysis only included areas where the depth was 0-10 m deep (offshore contour line) because smallmouth bass were rarely in areas deeper than this depth interval.

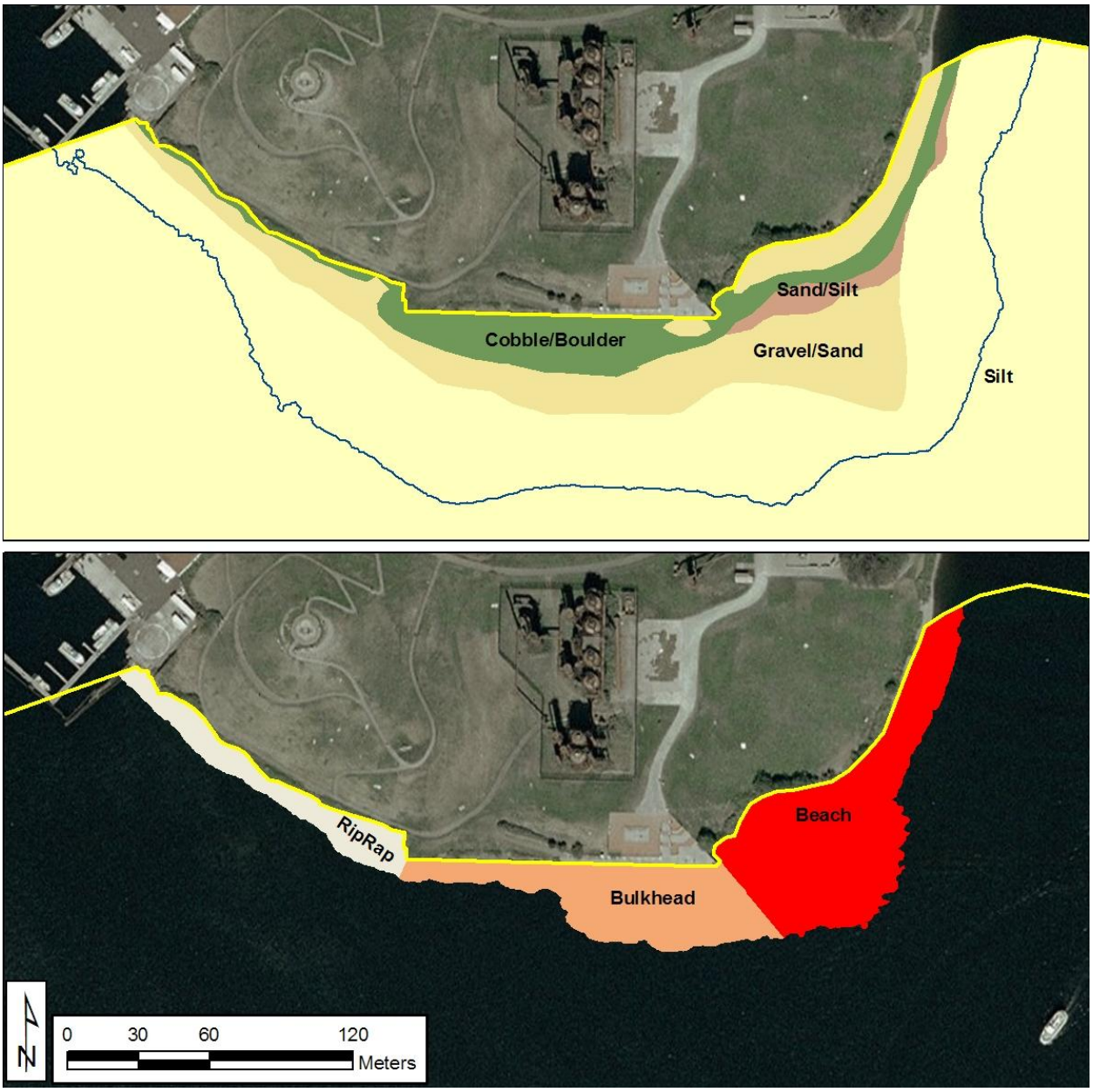


FIGURE 6. Map of the Gas Works Park site showing substrate (top panel) and shoreline types (bottom panel), May to August, 2007 and 2008. Both panels only show the inshore part of the coverage area. Substrate in the offshore area of the coverage area (not shown) was all silt. Substrate selection analysis only included areas where the depth was 0-10 m deep (blue contour line) because smallmouth bass were rarely in areas outside of this depth interval. In the bottom panel, the offshore contour line is at 4-m depth. The area between 0 and 4 m depth was used to determine selection of the three shoreline types (rip rap, bulkhead, and beach).

To estimate shoreline type selection, we divided Gas Works Park shoreline into three shoreline types: beach, rip rap, and bulkhead (Figure 6). We only included detection points that were in water less than 4 m deep. Fish in deeper water were considered as being offshore and not in close contact with the shoreline. Shoreline availability was based on the area between 0 and 4 m depth. Shoreline analysis was not done for the I-5/University site because most of the shoreline in our coverage area was relatively uniform (mostly overwater structures).

Differences in use between habitat categories for habitat type, shoreline type (Gas Works Park only), substrate type (Gas Works Park only), and depth selection were compared with a non-parametric Friedman test and multiple comparisons procedure (Conover 1999). Individual fish were used as the blocking variable. This statistical test allowed us to combine results of 2007 and 2008 (different habitat availability) and have a larger sample size. For each diel period, we only included the results of fish that had more than 200 data points.

Data analysis-Vemco

All data from VR2s were combined into an Access database and subsequently queried to produce the number of detections per hour at each receiver for each fish. We evaluated tracking information for each fish and categorized their seasonal movements as either 1) resident fish that remained in the LWSC; 2) left the LWSC and moved into Lake Washington; 3) not enough data to determine their seasonal movement; 4) fish died or tag was expelled; tag remained in one location over an extended period of time; and 5) other, movement pattern unclear. Resident fish were defined as fish that remained in the LWSC throughout the summer and were still present on October 15 (water temperature at 1 m depth was approximately 12°C). To define when fish left or entered the LWSC, we used the UW Rowing Center VR2 (west end of Union Bay) as the boundary between LWSC and Lake Washington. Data points from this site and nearby VR2s at UW Hatchery, Webster Point, and Lakeshore Condos were used to determine which direction the fish was moving. If the fish was moving to Lake Washington, we used the date of the first detection at the UW Rowing Center VR2 and if the fish was moving into the LWSC we used the date of the last detection at the UW Rowing Center. Regression analysis was used determine if there was a relationship between smallmouth bass size and when they left the LWSC. Also, we determined the percent of smallmouth bass that left the LWSC based on three capture and release categories: Portage Bay, Gas Works Park, and Aurora Bridge area. Hourly detections of northern pikeminnow were also used to determine their diel movement in and out the LWSC.

Depth information was examined for both seasonal use and diel patterns (dawn, day, dusk and night). Seasonal depth use was overlaid with temperature data from King County monitoring stations.

Each mobile-tracking detection in Lake Washington was assigned to one of the five standard sampling areas of Lake Washington (Figure 2). For each fish, the primary lake area was defined as the area that had the majority of detections. Secondary areas were other lake areas where each fish was found. Mobile-tracking detections in the LWSC were used in combination with fixed-receiver data to determine if there was any site fidelity between years of smallmouth bass

returning to the LWSC from Lake Washington. We examined the furthest west each fish was detected and compared that to their capture and release location.

RESULTS

Spring/summer habitat use – smallmouth bass

A total of 57 fish were tagged with HTI acoustic tags (Table 5). Fifty of the fish were smallmouth bass. All but two of the smallmouth bass were collected by angling. Smallmouth bass collected at the I-5/University Bridge site (n = 28; mean, 358.2 mm FL) were significantly larger than those collected at the Gas Works Park site (n = 22; mean, 302.2 mm FL; Mann-Whitney *U* test; $P = 0.05$; Figure 7). Thirty smallmouth bass were tagged in 2007 and 20 were tagged in 2008 (Figure 8). The mean length tagged was smaller in 2007 (mean, 316.6 mm FL) than 2008 (mean, 342.3 mm FL) but there was no statistical difference in fish size between years (Mann-Whitney *U* test; $P = 0.17$).

Four northern pikeminnow (range, 314-360 mm FL; mean, 339.8 mm FL) were implanted with HTI acoustic tags. Northern pikeminnow were collected through either angling ($n = 1$) or gill nets ($n = 3$). We also tagged three largemouth bass; all were relatively small fish (range, 113-170 mm FL; mean, 168.2 mm FL). Two were collected with beach seines at the I-5/University Bridge site and the other fish was collected through angling at the Gas Works Park site.

During the tagging on June 28, 2007 at both sites, a different tag encoding was accidentally used than the setting used on the tracking receiver system. Four northern pikeminnow, three smallmouth bass, and one largemouth bass were tagged on that date. Although these tags were detected, the signal was weak and we obtained few positions. Therefore, these fish were not used in any analysis. For 2007 and 2008 combined, all of our northern pikeminnow were tagged on this date and thus we did not obtain any useful northern pikeminnow tracking data.

TABLE 5. Number of predatory fish that were tagged with HTI acoustic tags at two study sites in the Lake Washington Ship Canal, May-July 2007-2008.

Location	Year		
Species	2007	2008	Total
I-5/University Bridges			
Northern pikeminnow	1		1
Largemouth bass	2		2
Smallmouth bass	14	8	22
Gas Works Park			
Northern pikeminnow	3		3
Largemouth bass	1		1
Smallmouth bass	16	12	28

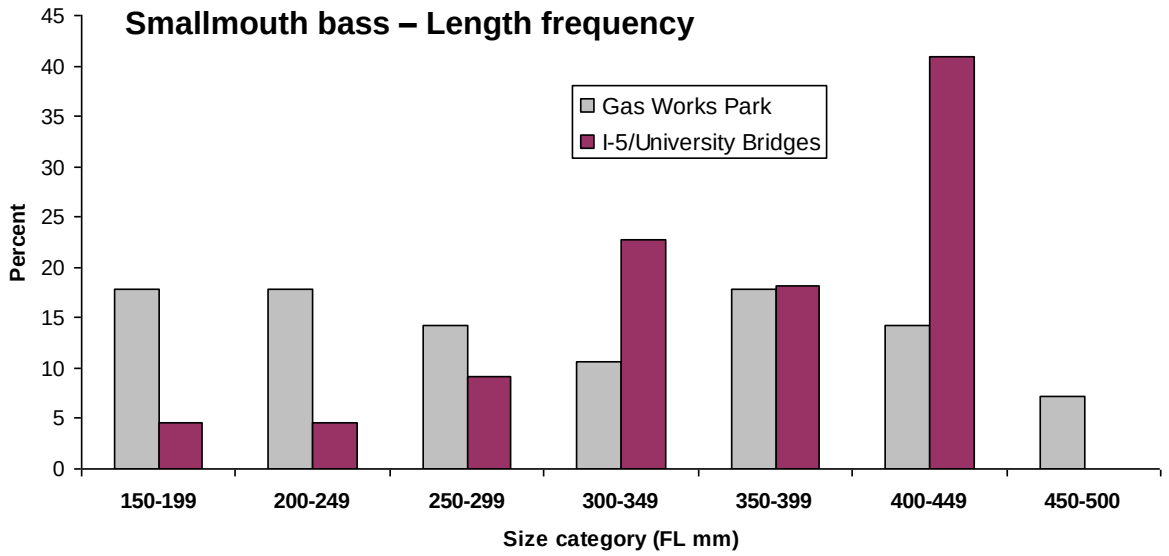


FIGURE 7. Length frequency (50-mm FL increments) of smallmouth bass collected and tagged (HTI acoustic tags) at two sites in the Lake Washington Ship Canal, May-July 2007-2008. $N = 50$.

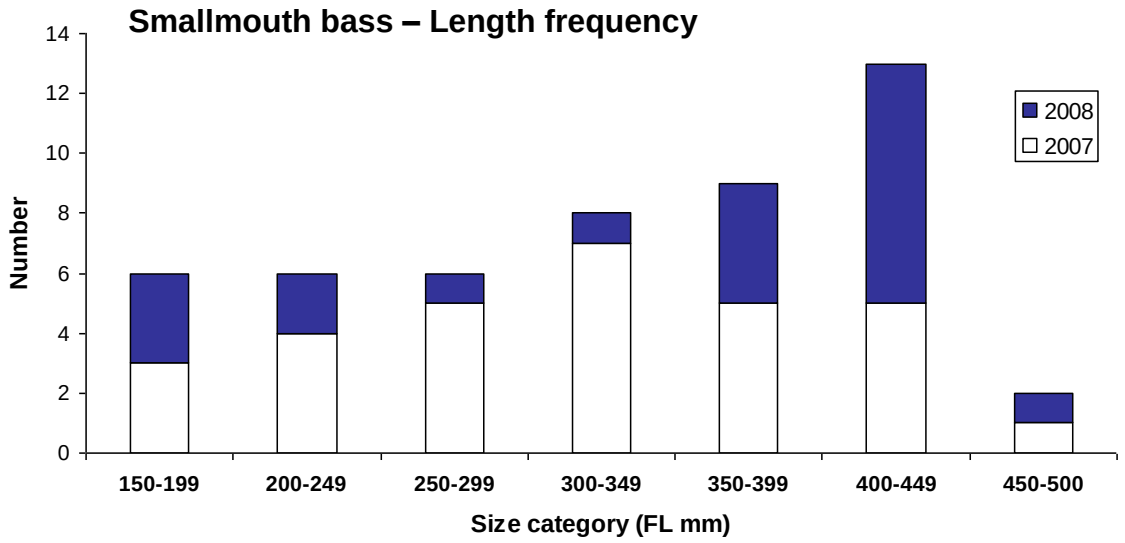


FIGURE 8. Number and size category of acoustic-tagged smallmouth bass collected for two different years. Smallmouth bass were tagged with HTI acoustic tags at two study sites in the Lake Washington Ship Canal, May-July 2007-2008.

We were able to effectively track 84% (42 of 50 fish) of the smallmouth bass at the site they were released. We obtained at least 10,000 data points for 35 fish (Appendix 1). One smallmouth bass from our SR 520 bridge tracking project was tracked at the I-5/University Bridge site for seven days and briefly at the Gas Works Park. Also some smallmouth bass from Gas Works Park were tracked at the I-5/University Bridge site. Only one I-5/University Bridge fish was extensively tracked at Gas Works Park.

At both tracking sites, smallmouth bass 250-349 and > 350 mm FL were concentrated in areas that were 2-4 m deep (Figures 9 and 10); however, at the I-5/University Bridge site they were commonly in deeper areas. Smallmouth bass 150-249 mm FL at Gas Works Park were spread out over a wide range of bottom depths (0-12 m bottom depth). At the I-5/University Bridge site, we only tracked two smallmouth bass 150-249 mm FL and both were rarely outside of the area that was 2-6 m deep. There was no noticeable change in depth between diel periods for all three size categories at either site.

During each diel period, smallmouth bass at Gas Works Park primarily selected areas of the study site that were 2-4 m deep (Figure 11). Areas that were 0-2 and 4-6 m also had a positive selection for most fish. Areas that were more than 12 m deep were rarely used. This area represented 83.1% of the coverage area but only 0.14% of the smallmouth bass positions. Smallmouth bass 150-249 mm FL generally had a higher selection of areas that were 0-2 m; however, the overall bottom depth selection was similar between the three size classes.

Bottom depth use at the I-5/University Bridge site was generally similar to Gas Works Park. The 2-4 m depth interval was the highest ranked depth interval for dawn, dusk, and night (Figure 11). However, during the day there was a tendency for smallmouth bass to use areas with deeper water than at Gas Works Park. During the day, all bottom depth categories were similar except the 0-2 m interval which was little used. At night, smallmouth bass were primarily in the 2-4 and 4-6 m bottom depth intervals.

Overall, we observed little difference in the use of the five habitat categories at Gas Works Park (Figure 12). No significant difference was observed during dawn, day, and night periods (Friedman test, $P > 0.05$). At dusk, the use of dense and moderate vegetation was higher than in the open water area (Friedman test, $P < 0.05$).

At the I-5/University Bridge site there were significant differences in habitat selection for all diel periods (Friedman test, $P < 0.05$). The highest ranked habitat types at the I-5/University Bridge site were the University Bridge structures, sparse vegetation, and vegetation edge (Figure 13). This was particularly evident during the day (Figures 14 and 15). Fifty-four percent of smallmouth bass had a positive selection ratio for nearshore overwater structures (OWS) during at least one diel period. This was most evident at night when 41% had a positive selection ratio. Use of nearshore overwater structures (OWS) was most evident in smaller fish during the day. Forty percent of bass 150-349 mm FL exhibited a positive selection ratio during day, while at night only 19% of bass 350-470 mm FL had a positive selection. Both fish 150-249 mm FL strongly selected nearshore overwater structures (OWS) during the day. Habitat types generally not used in relation to their availability were open areas and the two I-5 Bridge habitats.

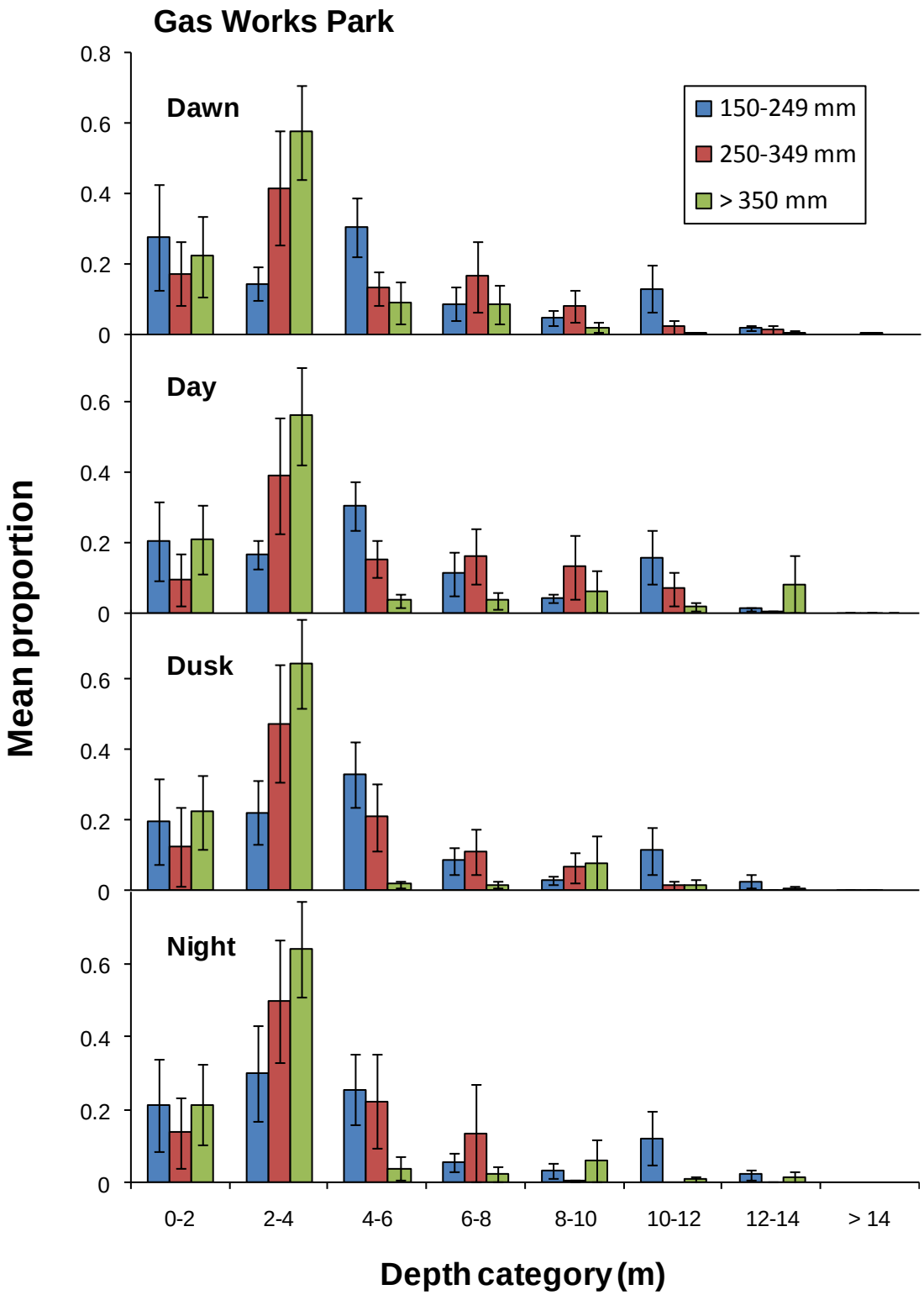


FIGURE 9. Mean proportion (± SE) of eight bottom depth categories (m) used by three size classes (mm FL) of smallmouth bass at Gas Works Park, May-August 2007 and 2008. Sample sizes: A) 150-249 mm: n = 7 for each diel period; B) 250-349 mm: n = 6 for day and night, n = 5 for dawn and dusk; C) < 350 mm: n = 9 for each diel period.

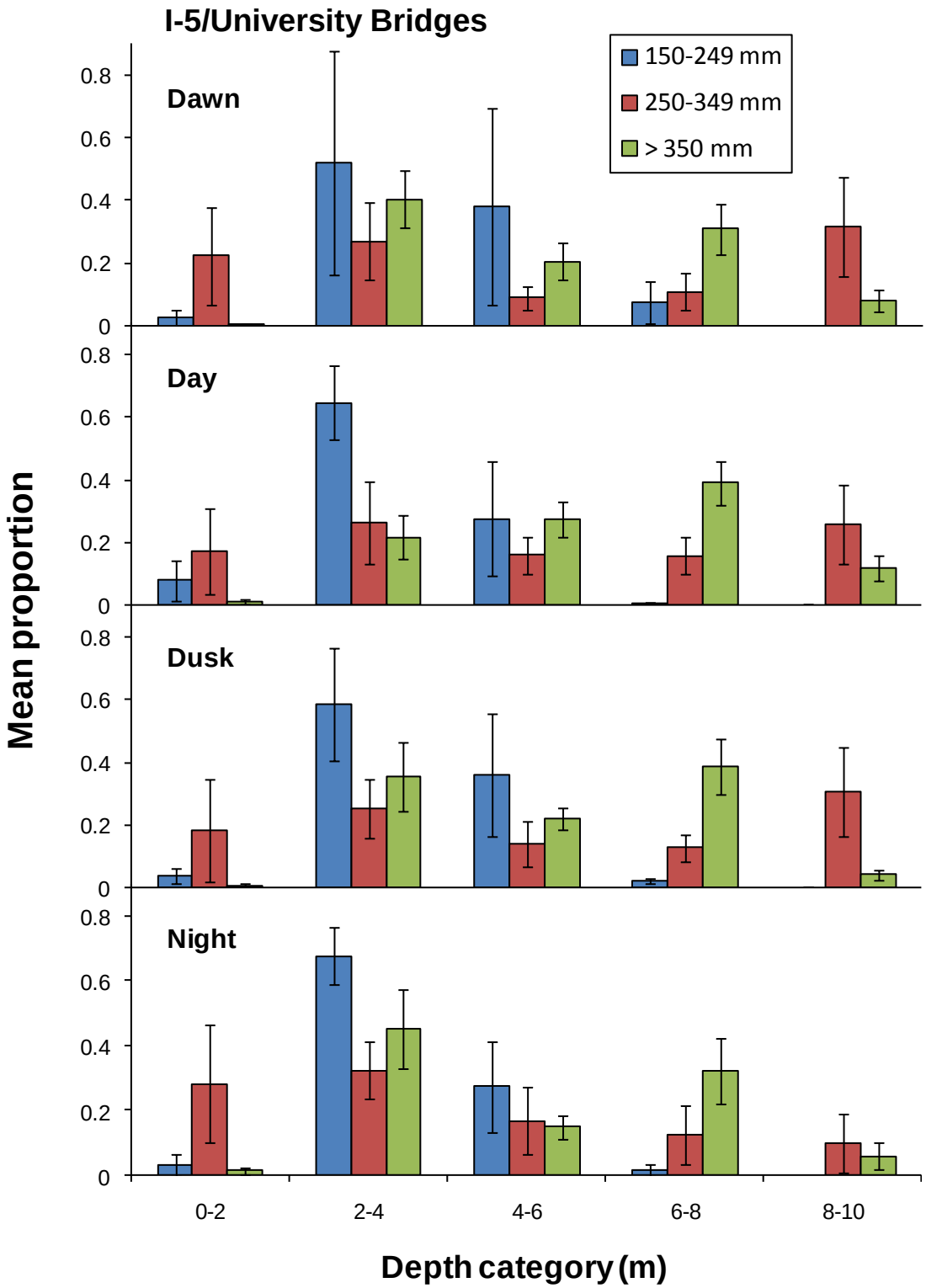
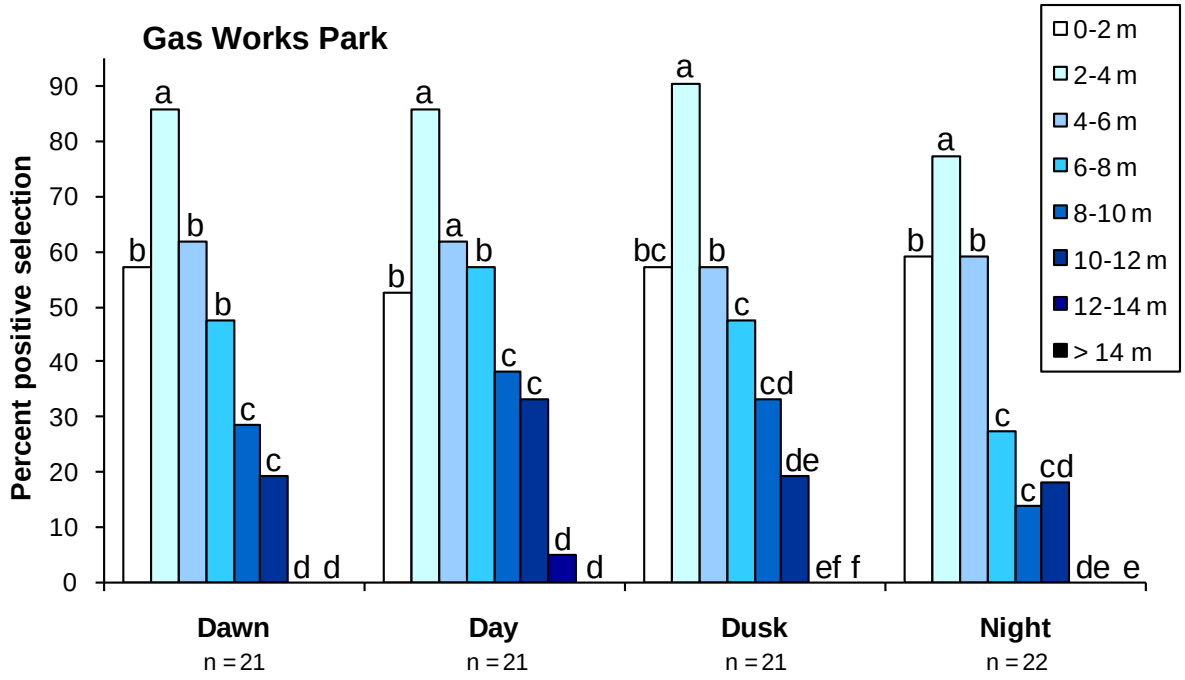


FIGURE 10. Mean proportion (± SE) of five bottom depth categories (m) used by three size classes (mm FL) of smallmouth bass at the I-5/University Bridge site, May-August 2007 and 2008. Sample sizes: A) 150-249 mm: *n* = 2 for each diel period; B) 250-349 mm: *n* = 7 for day, *n* = 6 for dawn and dusk, *n* = 5 for night; C) < 350 mm: *n* = 9 for dawn, *n* = 16 for day, *n* = 8 for dusk, *n* = 10 for night.



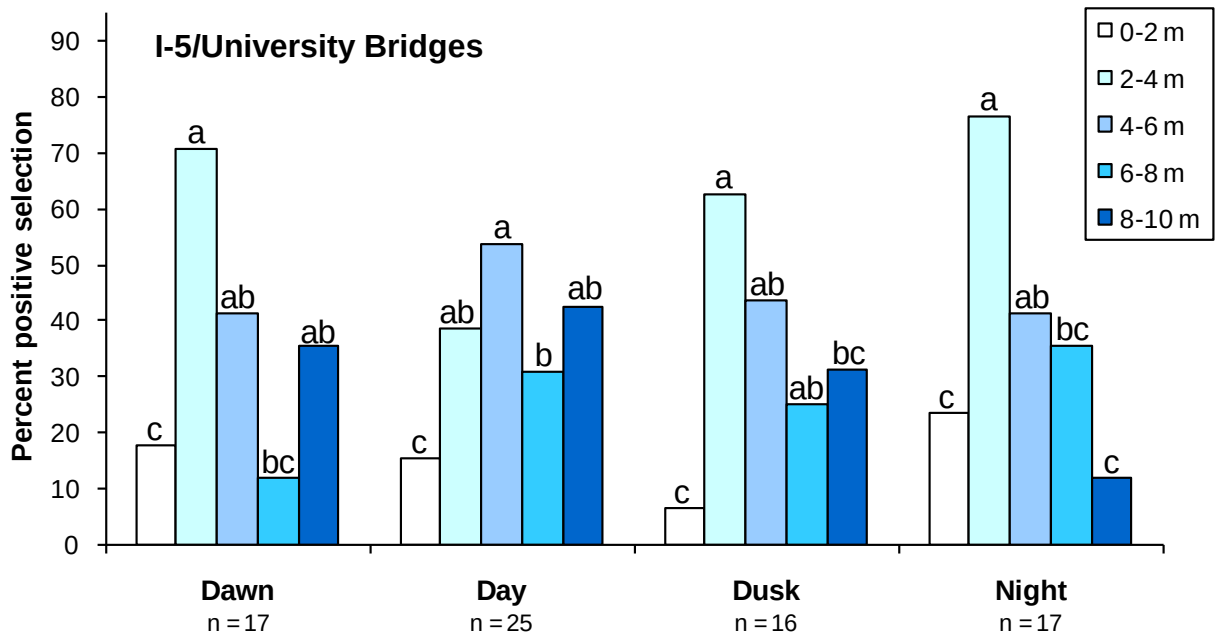


FIGURE 11. Percent of smallmouth bass with a positive selection ratio ($\hat{w}_i > 1$) for different depth categories (m) at Gas Works Park and the I-5/University Bridge site, May-August 2007 and 2008. Selection ratios were calculated within each diel period and thus statistical comparisons were only made within each diel period. Letters above bars are the results of Friedman multiple comparisons procedure within each diel period; bars with different letters are significantly different; n = the number of tagged smallmouth bass available (> 200 data points) within each diel period. Fish from both years were combined.

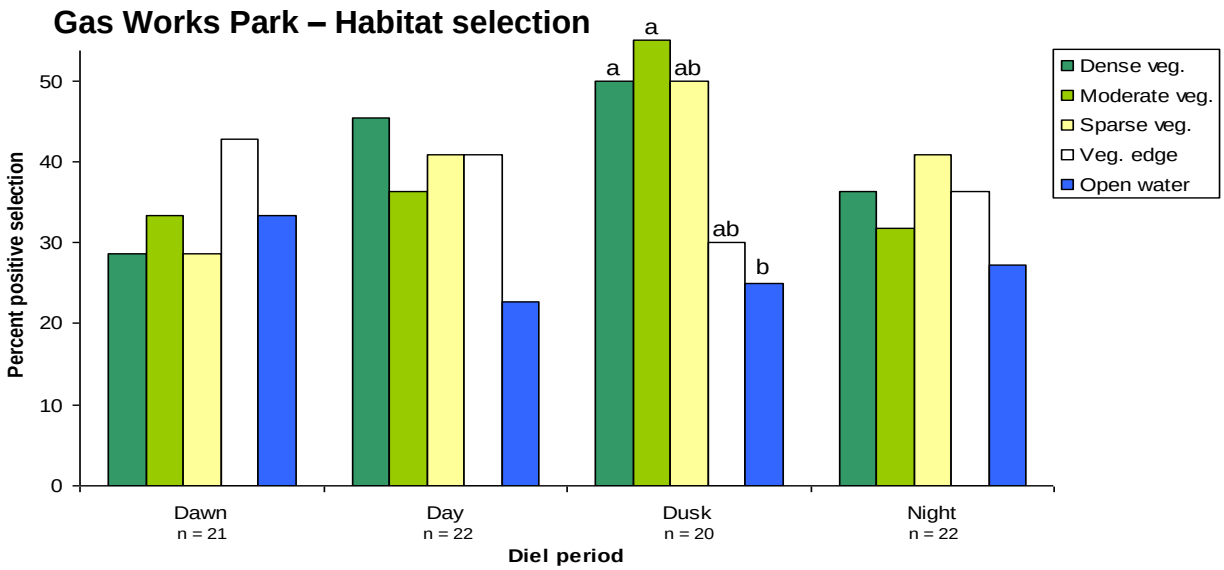


FIGURE 12. Percent of smallmouth bass with a positive selection ratio ($\hat{w}_i > 1$) for five habitat types at Gas Works Park, May-August 2007 and 2008. Selection ratios were calculated within each diel period and thus statistical comparisons were only made within each diel period. Letters above bars are the results of Friedman multiple comparisons procedure within each diel period; bars with different letters are significantly different; no letters indicate there was no significant difference for that diel period; n = the number of tagged smallmouth bass available (> 200 data points) within each diel period. Fish from both years were combined. Veg. = vegetation.

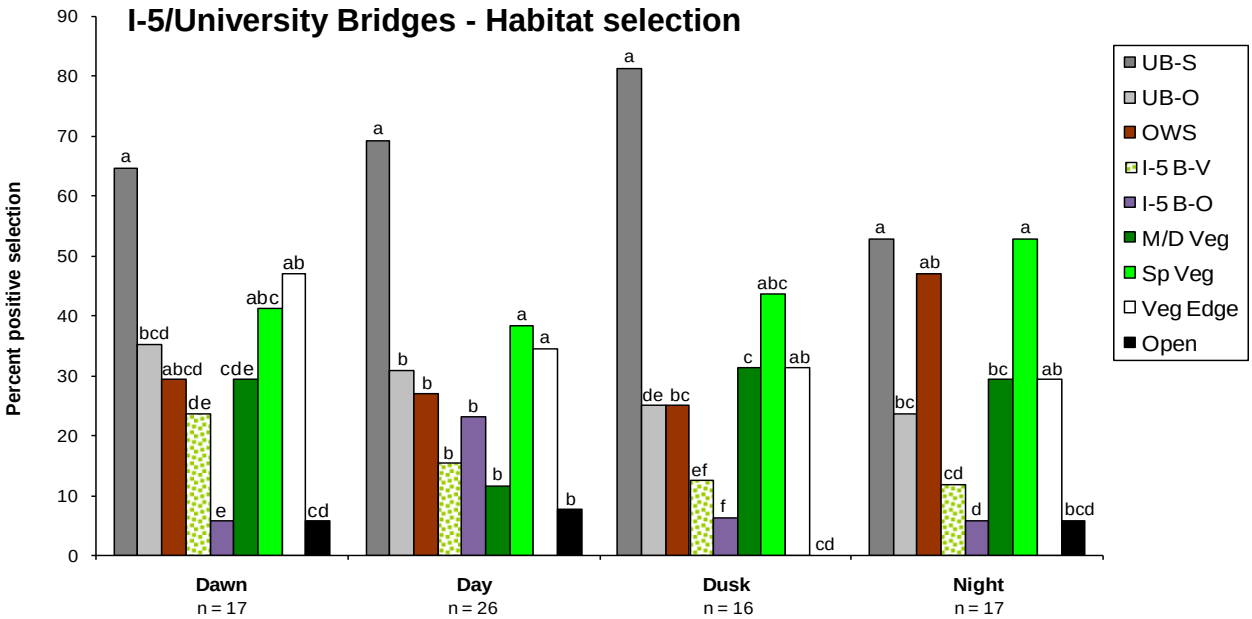


FIGURE 13. Percent of smallmouth bass with a positive selection ratio ($\hat{w}_i > 1$) for nine habitat types at the I-5/University Bridge site, May-August 2007 and 2008. Selection ratios were calculated within each diel period and thus statistical comparisons were only made within each diel period. Letters above bars are the results of Friedman multiple comparisons procedure within each diel period; bars with different letters are significantly different; n = the number of tagged smallmouth bass available (> 200 data points) within each diel period. Fish from both years were combined. UB-S = University Bridge structures; UB-O = University Bridge – other areas; OWS = overwater structures; I-5 B-V = I- 5 Bridge – vegetation; I-5 B-O = I-5 Bridge – open areas; M/D Veg = moderate/dense vegetation; Sp Veg = sparse vegetation; Veg Edge = vegetation edge; and Open = open areas. Habitat descriptions are listed in Table 4.

Smallmouth bass 150-349 mm FL

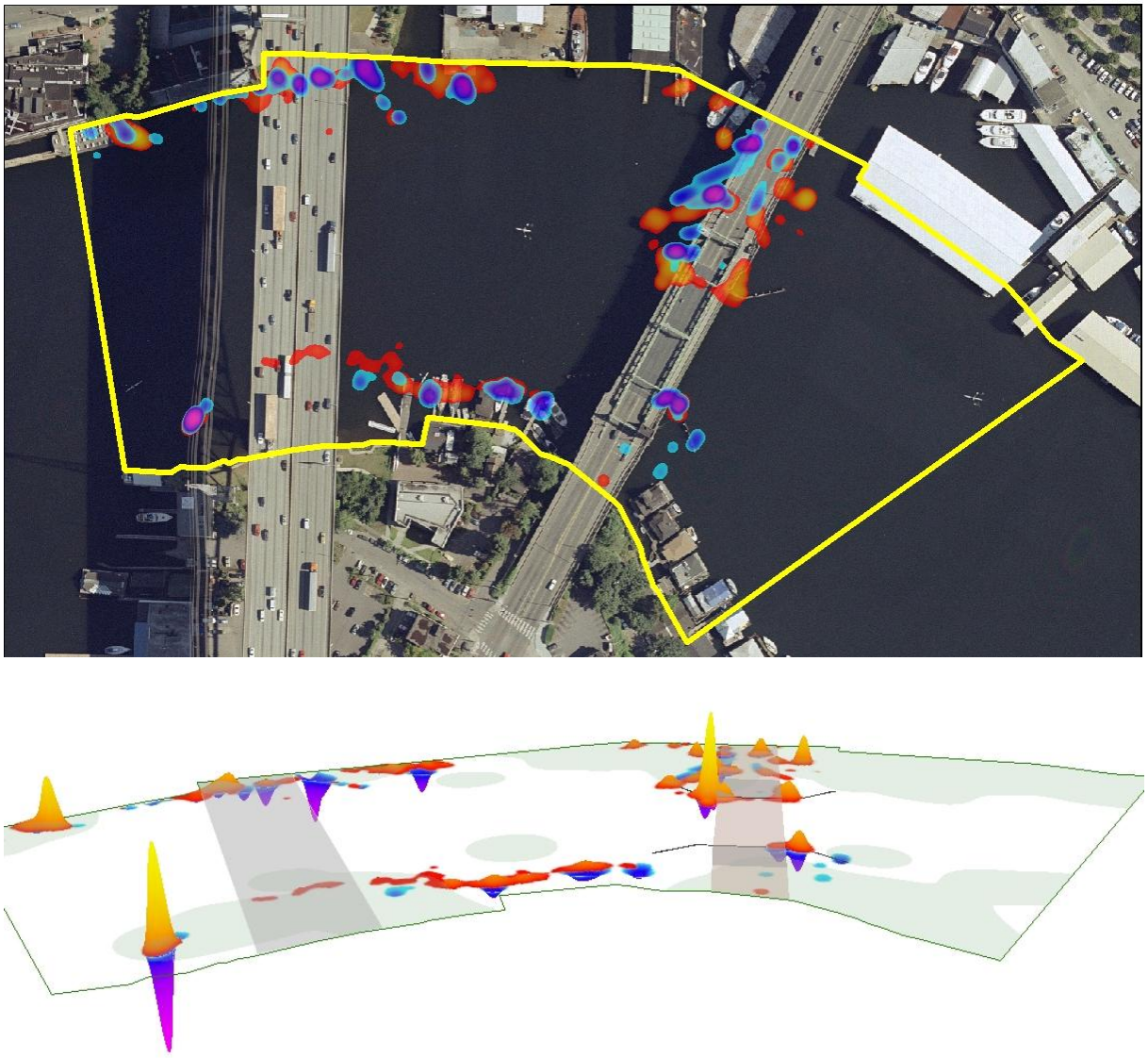


FIGURE 14. Day (yellow-red) and night (blue-purple) density plots of smallmouth bass 150-349 mm FL (day, *n* = 10; night, *n* = 7) at the I-5/University Bridge site, May-August 2007 and 2008. Each bass was weighted equally for the density plot calculation. The yellow (top) and green (bottom) lines are the coverage areas of the hydrophone array. The data presented on the two images are the same but are displayed in 2D on the top and 3D on the bottom. On the 3D image, daylight values are positive and night values are negative. Light green area on the 3D image is the macrophyte beds.

Smallmouth bass 350-470 mm FL

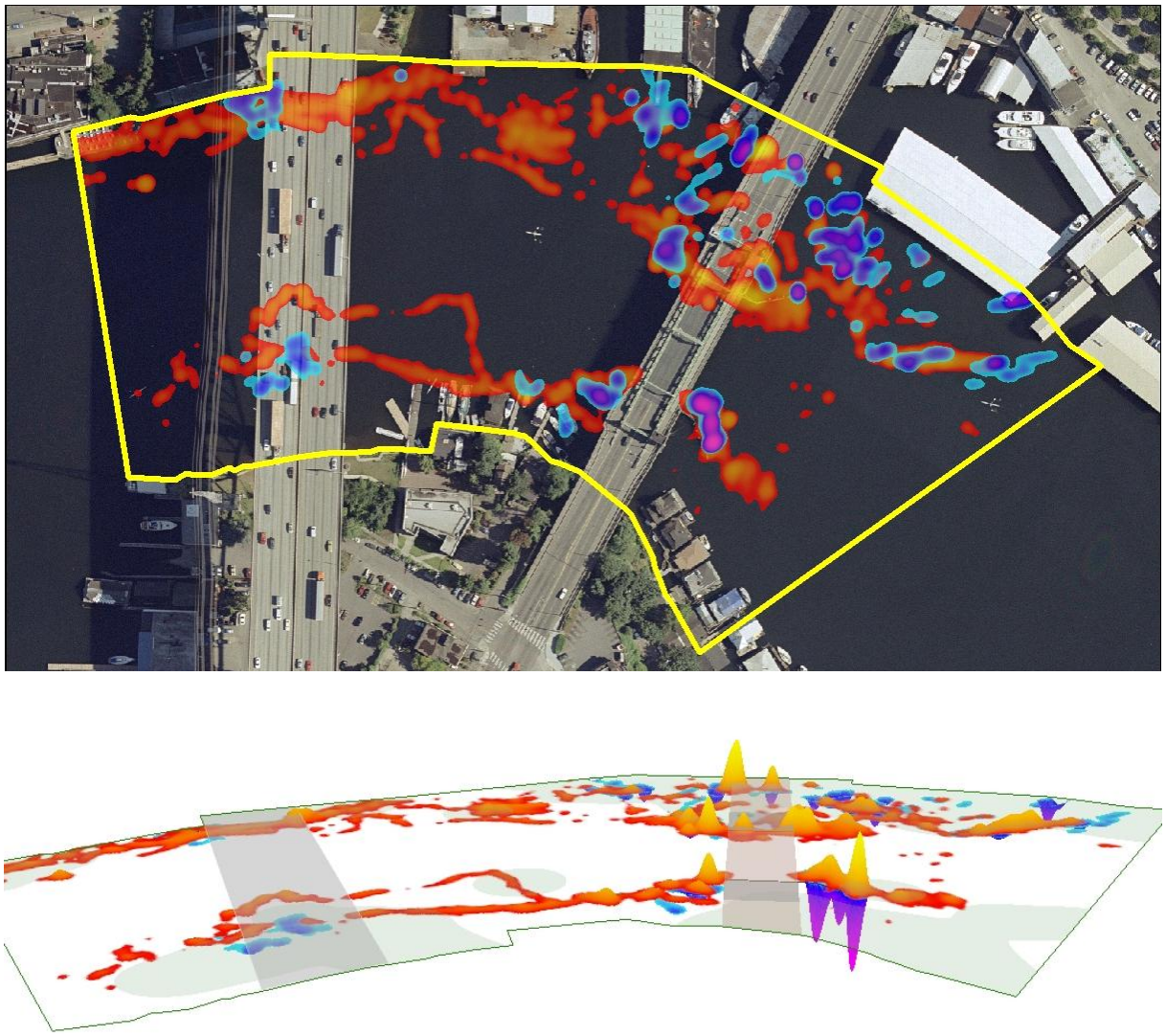


FIGURE 15. Day (yellow-red) and night (blue-purple) density plots of smallmouth bass 350-470 mm FL (day, *n* = 16; night, *n* = 10) at the I-5/University Bridge site, May-August 2007 and 2008. Each bass was weighted equally for the density plot calculation. The yellow (top) and green (bottom) lines are the coverage areas of the hydrophone array. The data presented on the two images are the same but are displayed in 2D on the top and 3D on the bottom. On the 3D image, daylight values are positive and night values are negative. Light green area on the 3D image is the macrophyte beds.

At Gas Works Park, gravel/sand areas were strongly selected over the other substrate types during dawn and night (Figure 16). During the day, gravel/sand areas were significantly different than sand/silt and cobble/boulders areas but not silt areas. At dusk, gravel/sand was the highest ranked substrate category but differences were not significant (Friedman test, $P = 0.055$).

Density plots of smallmouth bass at Gas Works Park indicated they were primarily located in two areas: at the southeast corner where the shore is a beach or at the western end where the shoreline is rip rap (Figure 17). Smallmouth bass showed a strong positive selection for beach shoreline during all diel periods (Friedman test, $P < 0.05$; Figure 18). Four smallmouth bass showed a strong positive selection for rip rap during the day, all of these fish were 150-250 mm FL. One of these fish moved to bulkhead or beach shoreline during the other three diel periods. The other three fish remained closely associated with rip rap throughout all diel periods.

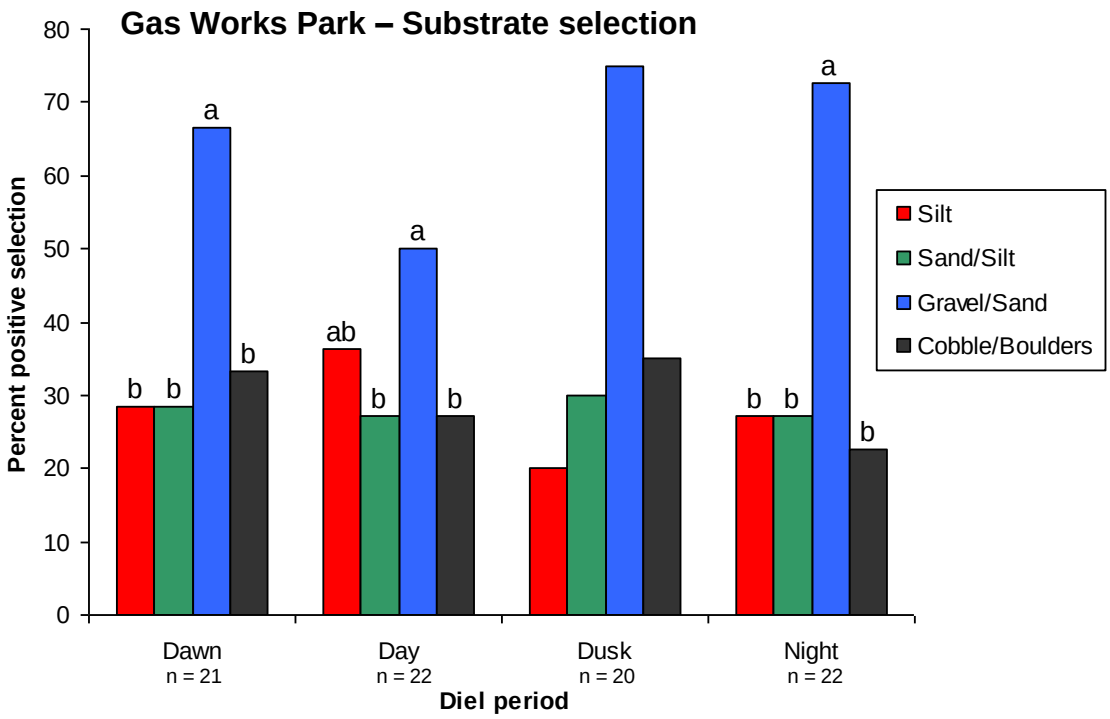


FIGURE 16. Percent of smallmouth bass with a positive selection ratio ($\hat{w}_i > 1$) for four substrate types at Gas Works Park, May-August 2007 and 2008. Selection ratios were calculated within each diel period and thus statistical comparisons were only made within each diel period. Letters above bars are the results of Friedman multiple comparisons procedure within each diel period; bars with different letters are significantly different; no letters indicate there was no significant difference within that diel period. Fish from both years were combined. n = the number of tagged smallmouth bass available (> 200 data points) during each diel period.

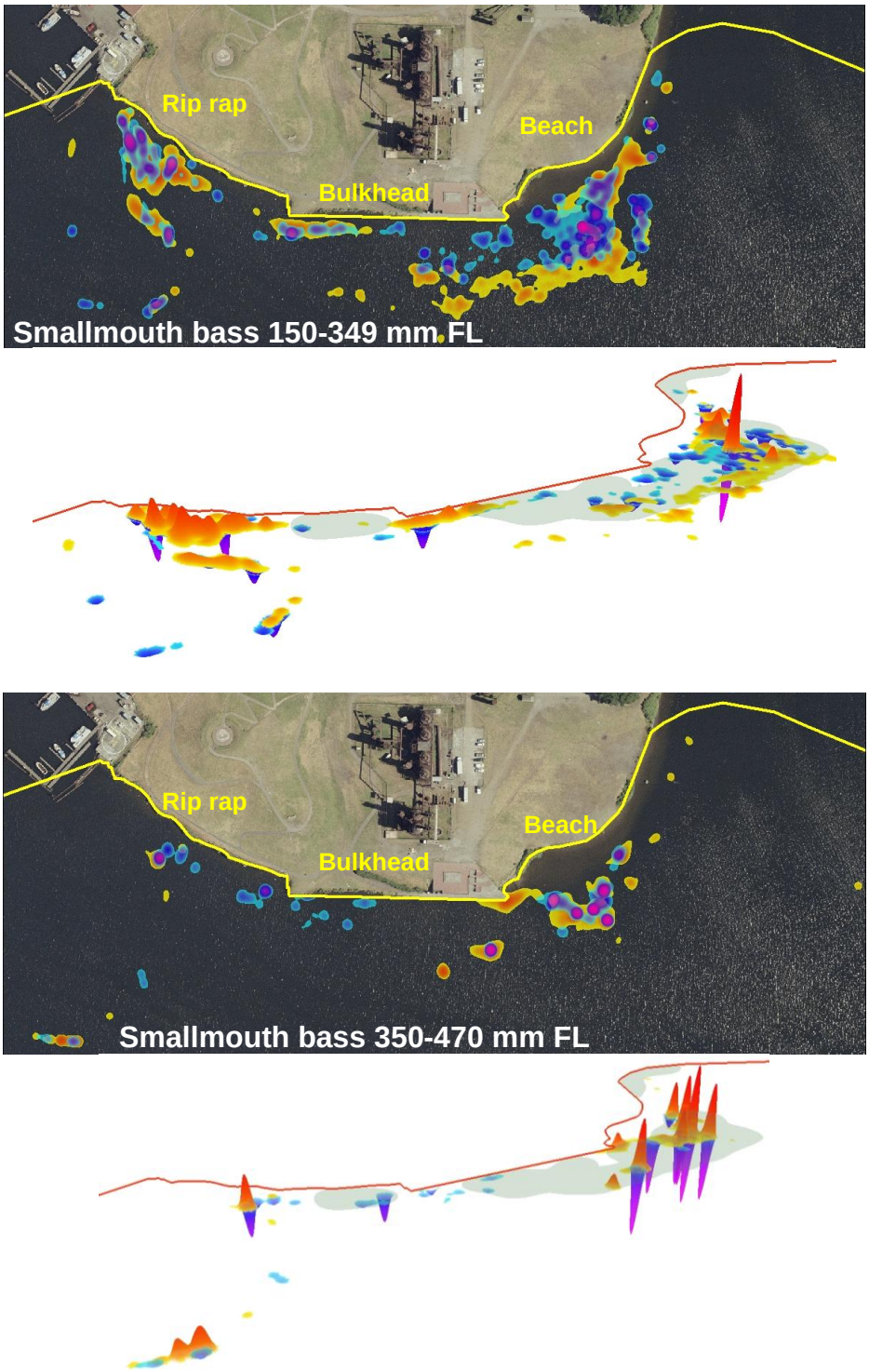


FIGURE 17. Day (yellow-red) and night (blue-purple) density plots of two sizes of smallmouth bass at Gas Works Park site, May-August 2007 and 2008. The top two images (2D and 3D) are for bass 150-349 mm FL and the bottom two images (2D and 3D) are for bass 350-470 mm FL. Each bass was weighted equally for the density plot calculation. The yellow (2D images) and orange (3D images) lines are the coverage areas of the hydrophone array. The coverage area extends substantially to the south; however, smallmouth bass rarely used this area and had a density value of 0. On the 3D image, daylight values are positive and night values are negative. Light green area on the 3D images is the macrophyte beds. The three shoreline types are shown on the 2D images.

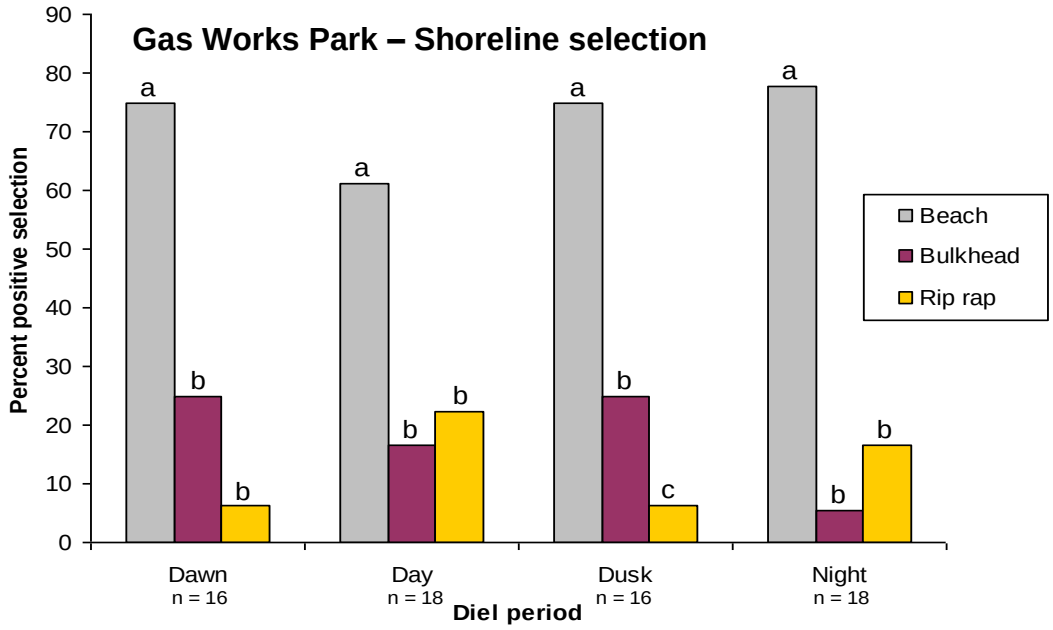


FIGURE 18. Percent of smallmouth bass with a positive selection ratio ($\hat{w}i > 1$) for three shoreline types at Gas Works Park, May-August 2007 and 2008. Selection ratios were calculated within each diel period and thus statistical comparisons were only made within each diel period. Letters above bars are the results of Friedman multiple comparisons procedure within each diel period; bars with different letters are significantly different. Fish from both years were combined. n = the number of tagged smallmouth bass available (> 200 data points) during each diel period. Data only represents fish that are in less than 4 m depth; fish in deeper water were not considered in close association with the shoreline.

Three small largemouth bass were tagged with HTI acoustic tags (Table 6); however, we were only able to get useful tracking data on one fish (#5127; 113 mm FL). This fish was captured under the I-5 Bridge and appeared to remain in this area for the duration of the tag life. The fish was closely associated with macrophytes; either macrophyte areas under the bridge (72.9% of all data points) or macrophyte areas close to the bridge (23.8% of all data points). This fish was never tracked at night; it may have retreated to some protective area (e.g., next to a large boulder) where we were unable to effectively receive the tag signal or perhaps its nighttime habitats were outside of our coverage area.

TABLE 6. Largemouth bass tagged with HTI acoustic tags in the LWSC in 2007. Release site is the area where the fish were captured and released. GWP = Gas Works Park; I-5/UB = I-5 and University Bridges. E tags are 20-day, 1.5 g tags and M tags are 12-day, 0.75 g tags. The number of days tracked is the number of days at least one data point was obtained. The first 24 hours after release was not used.

Date released	Release site	Tag type	Tag period (msec)	Fork length (mm)	Weight (g)	Date of first data point	Date of last data point	Number of days tracked	Number of data points
28-Jun	I-5/UB	E	5097	170	61	30-Jun	2-Jul	3	8
29-Jun	I-5/UB	M	5127	113	21	30-Jun	11-Jul	12	3,526
9-Jul	GWP	E	5297	161	68	--	--	0	0

Seasonal movement patterns

Northern pikeminnow

A total of 22 northern pikeminnow was captured, tagged, and released in the LWSC (Appendix 2). An additional 12 northern pikeminnow were captured and released at the west end of the SR 520 bridge in Lake Washington close to the Vemco receiver at the Lakeshore Condominium building. Half of the tagged northern pikeminnow (n = 34) were between 400 and 449 mm FL (Figure 19). All but seven fish were > 350 mm FL.

Of the 22 northern pikeminnow released in LWSC, 11 moved to Lake Washington within four days after release (Figure 20). Of the remaining 11 fish released in LWSC, five moved to the lake between 10 and 32 days after tagging, three appeared to die or expelled their tag (based on lack of movement - horizontally and vertically), and three were not detected long enough to obtain seasonal movement information. Overall 16 fish moved to Lake Washington and only three returned to the LWSC (Figure 20).

Overall, we obtained useful tracking results on six of the 22 northern pikeminnow released in the LWSC. Three of them appeared to make several forays back and forth between Lake Washington and the LWSC. Fish #17222 moved to Lake Washington shortly after release and did not return to the LWSC until the following year in 2007, when it moved back and forth between Lake Washington and the LWSC from May 20 and August 17 (Figure 21). Approximately 28 times this fish moved either into or out of the LWSC (Figure 21). Fish #22507 was observed moving back and forth between the LWSC and Lake Washington in both 2008 and 2009 (Figure 22). In 2008, movements between the two water bodies were observed from June 5 to July 12 (18 forays) and in 2009 from May 21 to July 26 (16 forays; Figure 22). Fish #22506 appeared to make 11 forays (either into or out of LWSC) between June 7 and 22, 2008 (Figure 23). Fish #17222 moved into Lake Union and was detected at both the south Lake Union and northwest Lake Union receivers, while the other two fish were only detected as far west as the University Bridge receiver. The duration of each foray into the LWSC for these three northern pikeminnow varied widely from 1 hour to 18 days.

The other three pikeminnow were in the LWSC for 11 to 25 days (excluding one-week recovery period) before moving to Lake Washington. Two fish (#221 and #4355) were only detected at the UW Hatchery and University Bridge receivers until they left for the lake (Figure 24). The other fish (#22505) was released at Gas Works Park on July 17, 2008 and was not detected at any receiver until it left the LWSC on August 9, 2008; presumably it was somewhere in Lake Union during that time interval. The three fish that made numerous forays between the LWSC and Lake Washington ranged in size from 425-475 mm FL, while the other three fish that remained in the LWSC ranged in size from 330-418 mm FL.

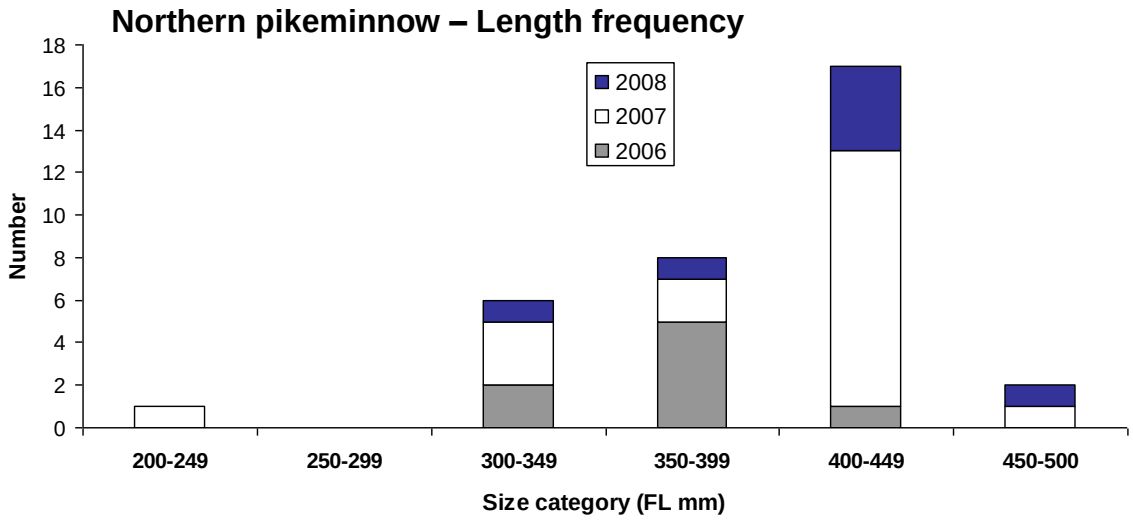


FIGURE 19. Number and size category of acoustic-tagged northern pikeminnow collected for three different years. Northern pikeminnow were tagged with Vemco acoustic tags at several sites in the Lake Washington Ship Canal as well as at the west end of the SR 520 bridge, May-July 2006-2008.

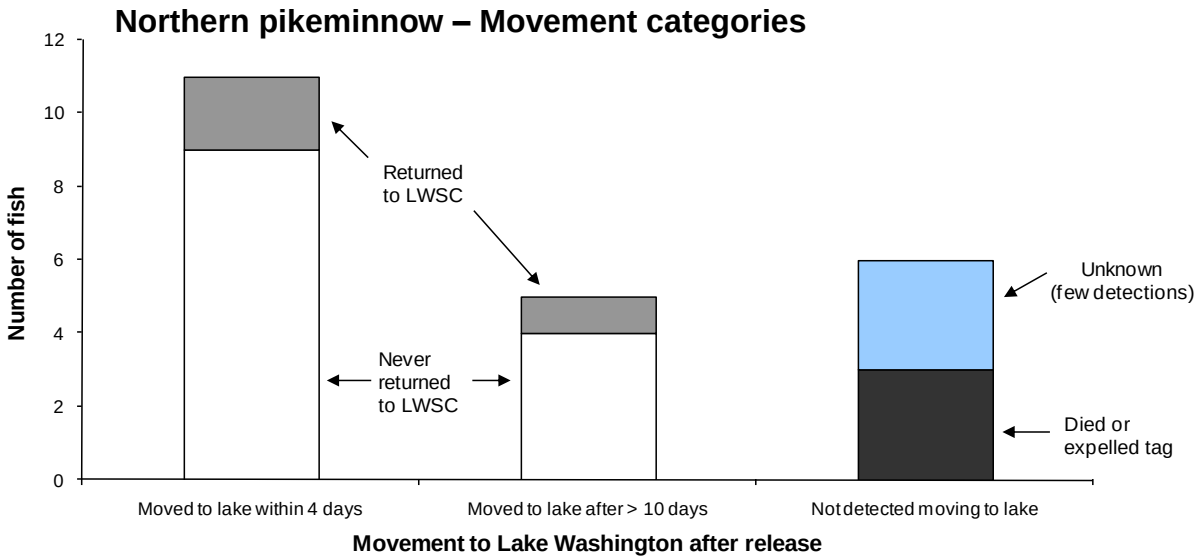


FIGURE 20. Number of tagged northern pikeminnow that moved to Lake Washington after release. All fish (*n* = 22) displayed were captured and released in the Lake Washington Ship Canal (LWSC), May-July 2006-2008 and implanted with Vemco acoustic tags.

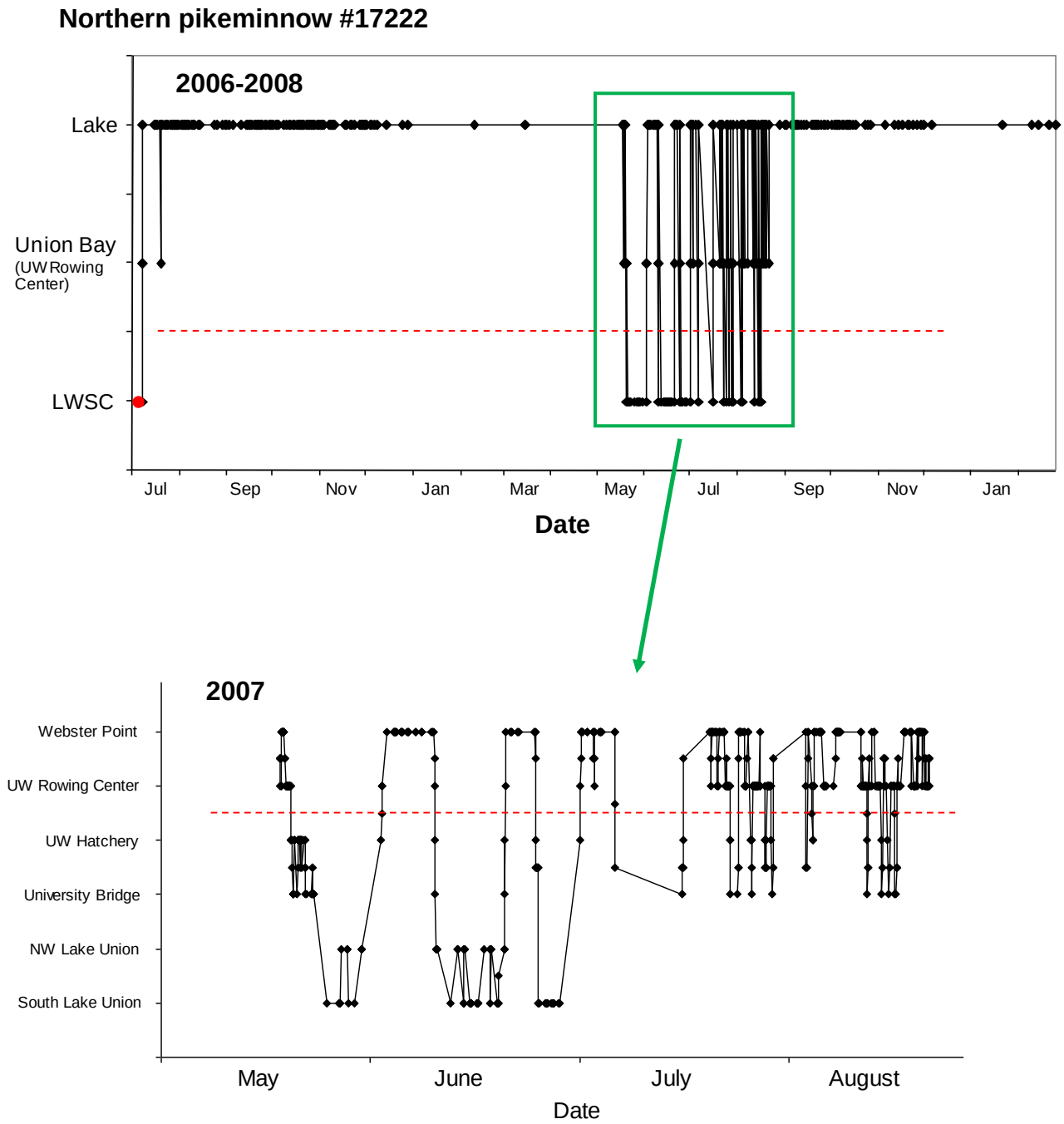


FIGURE 21. Daily (top panel) and hourly (bottom panel) movement of northern pikeminnow #17222 between Lake Washington and the LWSC, July 2006 – February 2008. Fish # 17222 was released on July 6, 2006 (red circle) in the LWSC and was 425 mm FL. The dashed red line represents the boundary between Lake Washington and the LWSC. Lake detections represent Webster Point detections as well as other detections in Lake Washington. LWSC detections are the combined results of four receivers (UW Hatchery, University Bridge, NW Lake Union, and South Lake Union). The Webster Point detections represent the combined results of two receivers at the eastern edge of Union Bay. The receiver locations are arranged (top to bottom) based on their distance from Lake Washington. See Figure 2 for receiver locations.

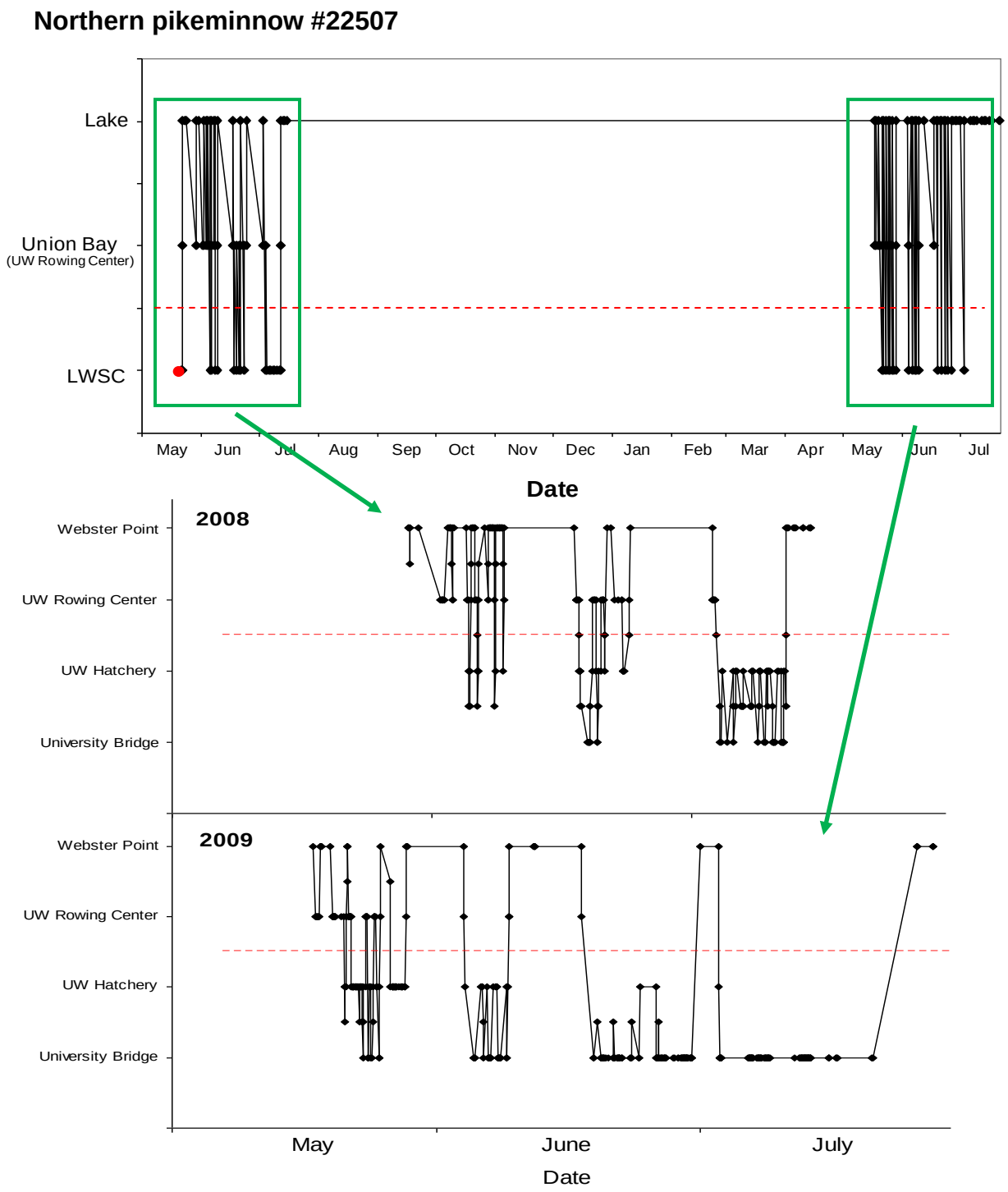


FIGURE 22. Daily (top panel) and hourly (bottom two panels) movement of northern pikeminnow #22507 between Lake Washington and the LWSC, May 2008 – July 2009. Fish #22507 was released on May 21, 2008 (red circle) in the LWSC and was 475 mm FL. The dashed red line represents the boundary between Lake Washington and the LWSC. Lake detections represent Webster Point detections as well as other detections in Lake Washington. LWSC detections are the combined results of two receivers (UW Hatchery and University Bridge). The Webster Point detections represent the combined results of two receivers at the eastern edge of Union Bay. The receiver locations are arranged (top to bottom) based on their distance from Lake Washington. See Figure 2 for receiver locations.

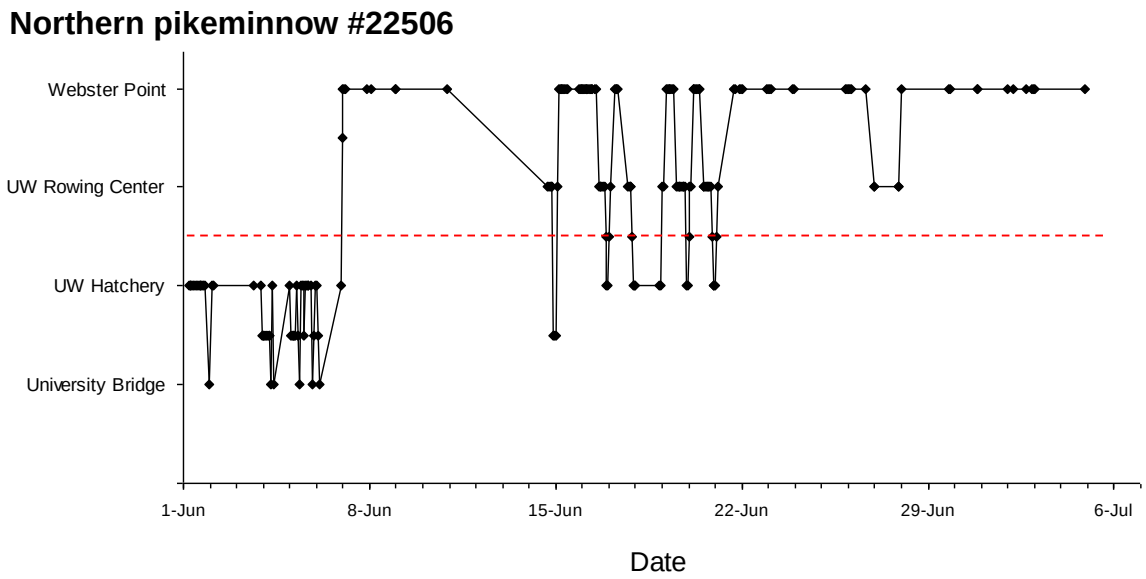


FIGURE 23. Hourly locations of northern pikeminnow #22506 based on four fixed receivers, June-July 2008. The receiver locations are arranged (top to bottom) from the furthest east to furthest west. If the fish was detected at two receivers during the same hour, the detections are indicated by a value midway between the receivers. The dashed red line represents the boundary between Lake Washington and the LWSC. See Figure 2 for receiver locations.

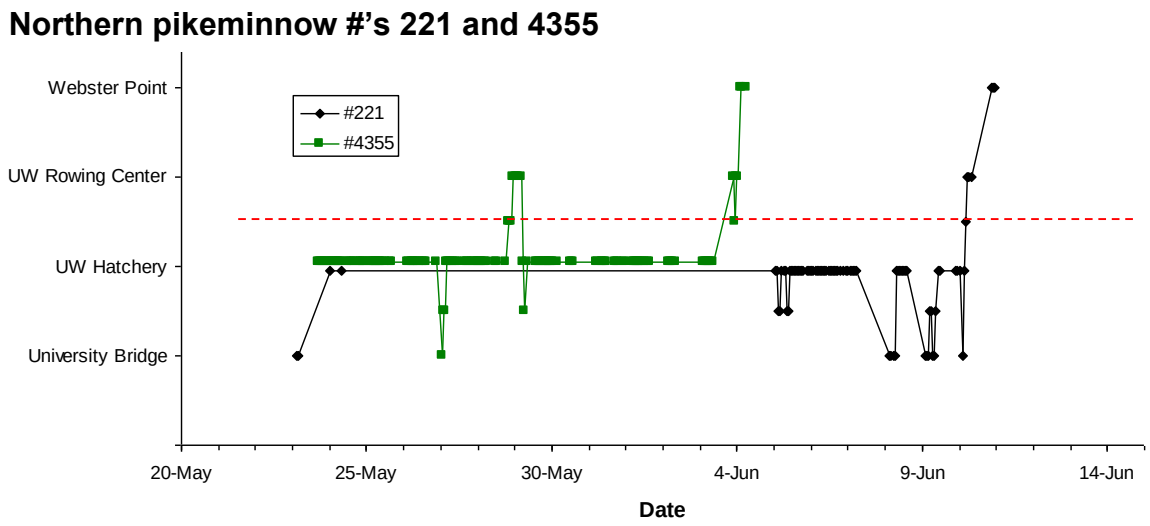


FIGURE 24. Hourly locations of northern pikeminnow #221 and #4355 based on four fixed receivers, May-June 2007. The receiver locations are arranged (top to bottom) from the furthest east to furthest west. The Webster Point detections represent the combined results of two receivers at the eastern edge of Union Bay. If a fish was detected at two receivers during the same hour, the detections are indicated by a value midway between the receivers. The dashed red line represents the boundary between Lake Washington and the LWSC. See Figure 2 for receiver locations.

The vast majority of movements into and out of the LWSC were at night. The three fish that moved back and forth typically moved into the LWSC in the late evening and returned shortly before dawn (Figure 25). The other three fish, which remained in the LWSC after release, all moved to Lake Washington at night.

Three of the 12 northern pikeminnow released at the SR 520 Bridge were detected in the LWSC. One appeared to have entered the LWSC and either died or expelled the tag (lack of horizontal and vertical movements). The other two entered the LWSC within 3 days of release and were only present for a short time period and thus were not considered part of their normal behavior.

From the end of August to mid-May, we did not detect any northern pikeminnow in the LWSC; thus we found no evidence that northern pikeminnow overwinter in the LWSC.

Overall, 15 northern pikeminnow from LWSC were detected moving to Lake Washington. Six of the 15 were tagged in 2008 when mobile tracking surveys were not frequently conducted and the St. Edwards receiver was not functioning. Therefore, we were only able to get limited information on their movements in Lake Washington. However, two fish tagged in 2008 were detected on the east side of Mercer Island near the I-90 Bridge. Of the remaining nine fish (tagged before 2008), five were rarely detected in the lake; three appeared to reside within a confined area (all were somewhere along the west shoreline between I-90 bridge and SR 520 bridge), and one fish (#17222) was found at various locations between I-90 bridge and St. Edwards Park. Fish#17222 was primarily detected at the Lakeshore Condominium receiver but appeared to made long forays to various places in the lake. In one case, it moved from the west I-90 bridge receiver to the St. Edwards Park receiver (approximately 16 km) in a little over two days (August 12-14, 2006).

We also obtained relatively few detections of SR 520 Bridge fish. Only two fish were extensively detected (> 14 days) at either the Webster Point or Lakeshore Condos receivers. Seven fish were detected at the west I-90 receiver and one was detected at the St. Edwards Park receiver.

Overall, we were only able to find seven of the 20 tagged northern pikeminnow (combined Lake Washington and LWSC fish) in Lake Washington in 2006 and 2007 with mobile tracking. Two encounters were recorded in Area 1, one in Area 2, four in Area 3, two in Area 4, and two in Area 5.

During the first two weeks in June 2007, 15 tagged northern pikeminnow were present (10 from SR 520 bridge and 5 from LWSC) in Lake Washington. Of those, eight were detected at the receiver on the west end of the I-90 Bridge between June 5 and 11. Most of the detections at the west end of the I-90 Bridge were at night. Movement of a large percent of the tagged population suggests some type of spawning aggregation. However, detections of four fish were made less than one week after release and thus we are unsure if this movement was indicative of normal behavior.

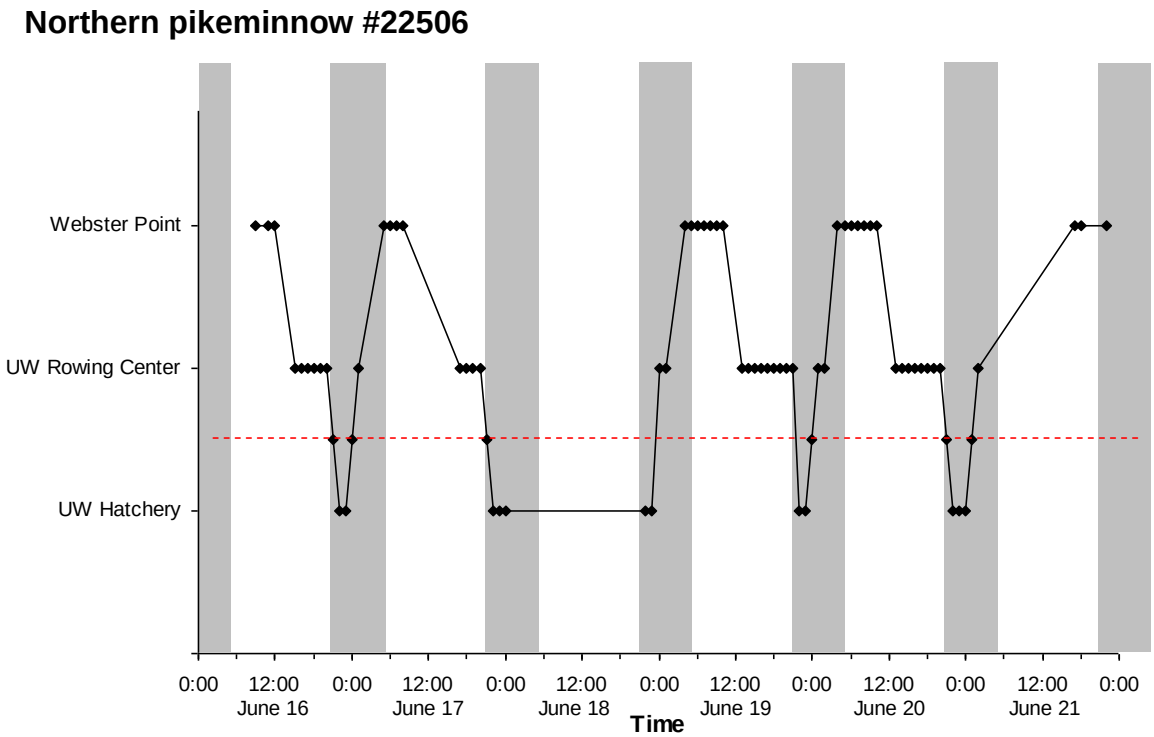


FIGURE 25. Hourly movements of northern pikeminnow #22506 based on three fixed receivers, June 16-June 21, 2008. Shaded bars indicate times of low light conditions (dusk to dawn). The receiver locations are arranged (top to bottom) from the furthest east to furthest west. If the fish was detected at two receivers during the same hour, the detections are indicated by a value midway between the receivers. The dashed red line represents the boundary between Lake Washington and the LWSC. See Figure 2 for receiver locations.

Because most northern pikeminnow left the LWSC shortly after release, we were only able to obtain depth information on one northern pikeminnow (fish #221) in the LWSC. While in the LWSC, fish #221 was generally in water less than 3 m deep (Figure 26). A few other depth tags were detected but they were always at the same general location and the depth did not vary and we assumed the fish had either died or expelled the tag.

Northern pikeminnow in Lake Washington were in shallow water (0-8 m) during the summer and moved to deeper water (10-18 m deep) in the fall (Figure 27). Fish #119 was also detected during mobile tracking on February 21, 2008 and was at a depth of 41 m. From October to December, fish #119 was frequently detected; however, most detections were at night. For example, during the month of November, fish #119 was detected on 29 of 30 nights (2,475 detections); however, it was only detected on three other dates during other diel periods (21 detections).

We obtained extensive depth data on three fish in 2007: fish #111 (June 14-26; 4,897 data points), fish #112 (July 16-22; 1,313 data points), and fish #119 (June 1 – December 9; 37,039 data points). Fish #111 and #112 were usually within a narrow depth range (0-5 m deep) during the day; whereas at night they occurred over a much broader depth range (Figure 28). In June-August, fish # 119 inhabited a boarder depth range during the day than at night. In September, it inhabited a narrow range during day and a board range at night. Unlike the other two northern

pikeminnow, fish #119 was usually in deeper water during the day than at night in June and July (Figure 29).

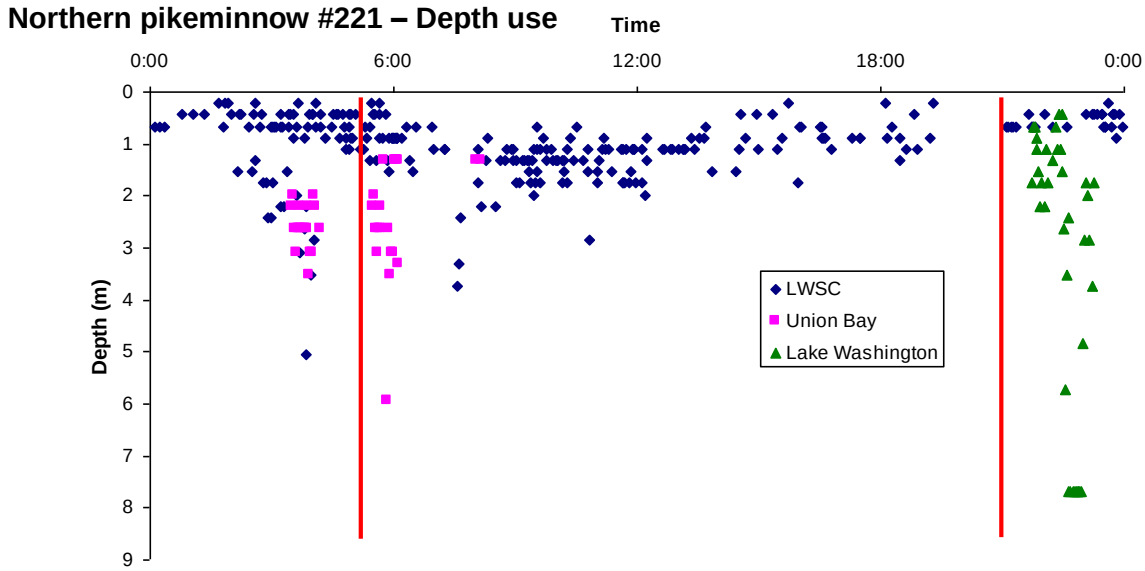


FIGURE 26. Depth distribution (m) of northern pikeminnow #221, May 30 – June 10, 2007. Red lines indicate the average time for dawn and dusk during these dates.

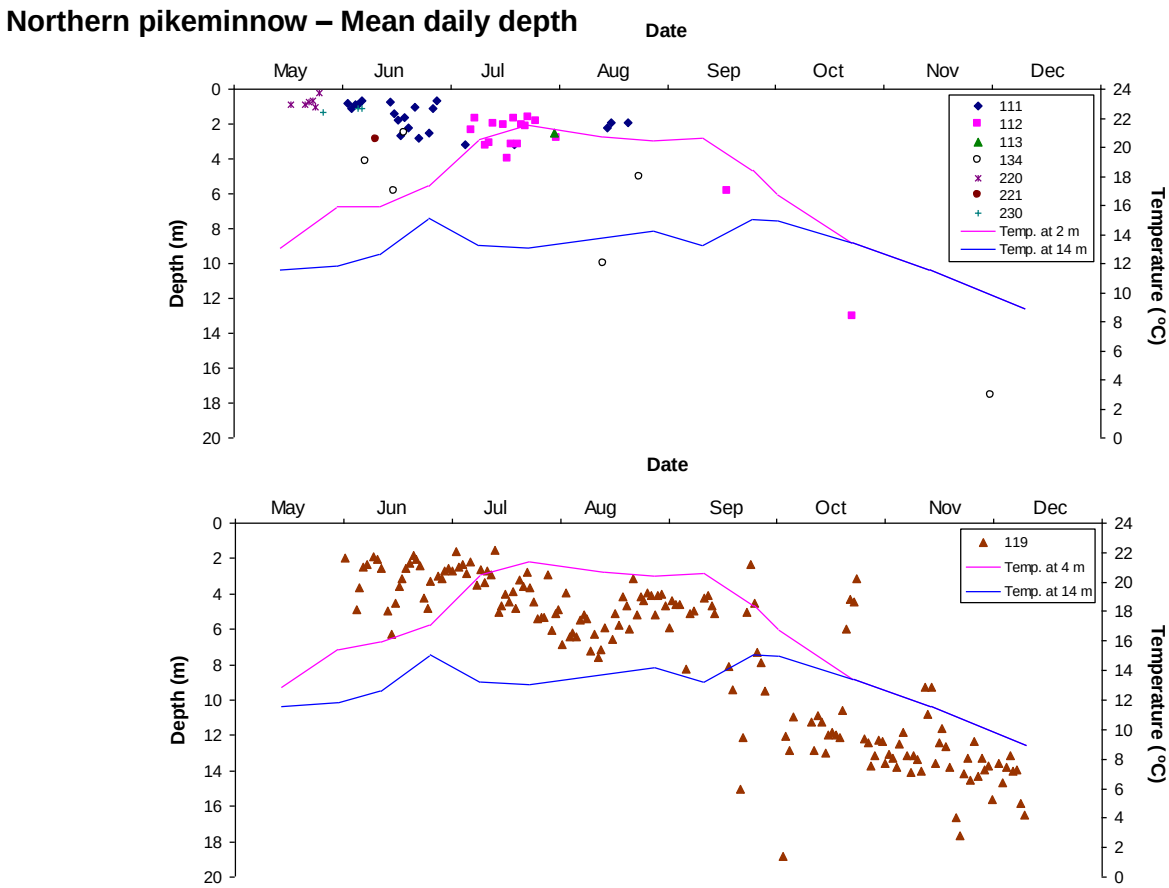


FIGURE 27. Mean daily depth (m) of northern pikeminnow in Lake Washington, May – December 2007. Most data are from fixed receivers at Webster Point and Lakeshore Condos.

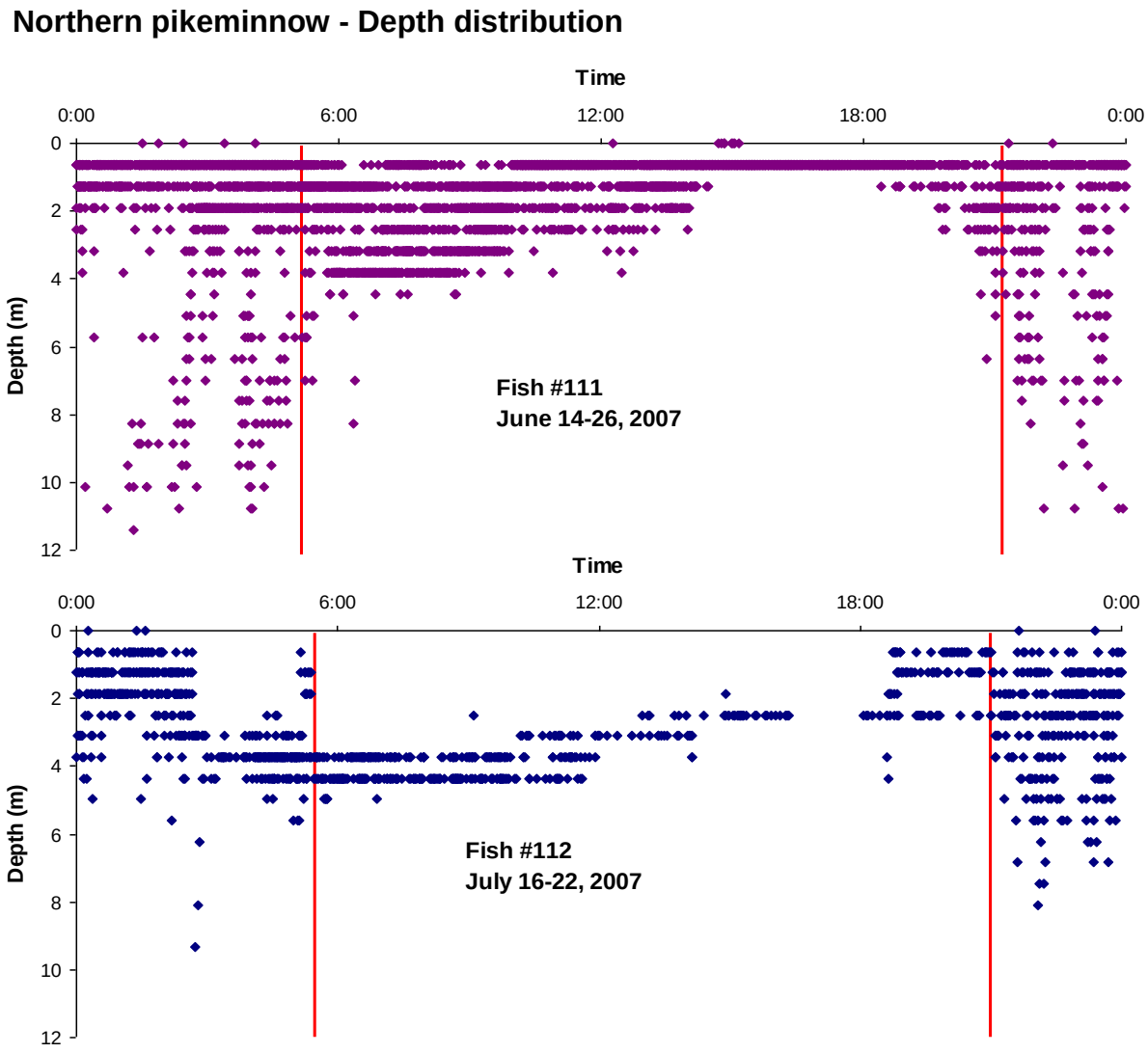


FIGURE 28. Depth distribution (m) of northern pikeminnow #111 and #112 in Lake Washington, 2007. Red lines indicate the average time for dawn and dusk during these dates.

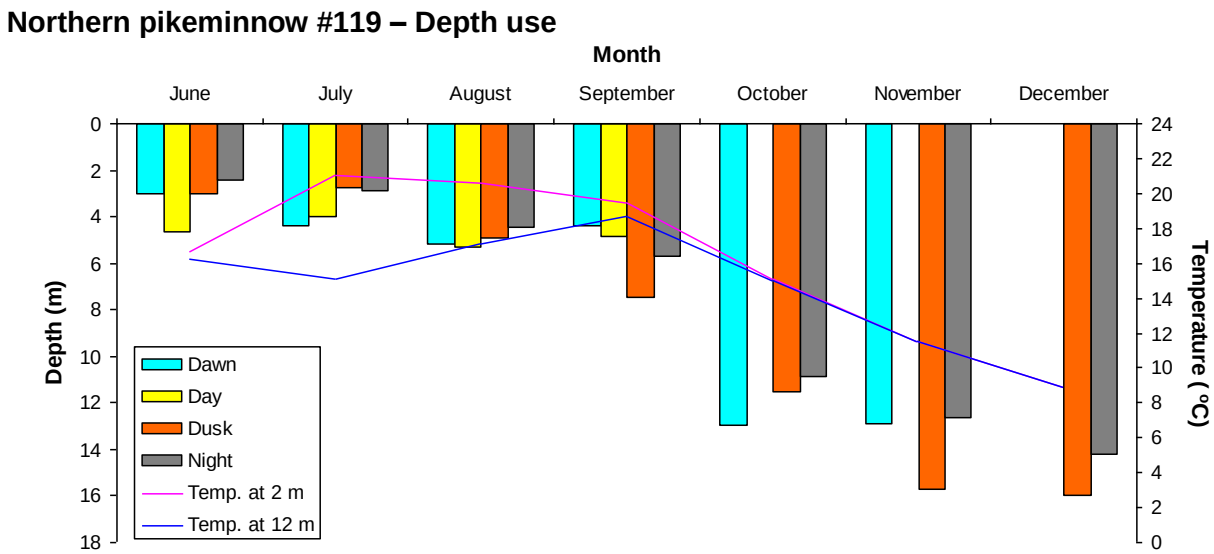


FIGURE 29. Mean monthly depth (m) of northern pikeminnow #119 in Lake Washington, 2007. Data are from fixed receivers at Webster Point and Lakeshore Condos.

Smallmouth bass

A total of 72 smallmouth bass were captured, implanted with Vemco acoustic tags, and released in the LWSC (Appendices 3 and 4). Fourteen percent of the tagged fish were 150-249 mm FL, 50% were 249-350, and 36% were > 350 mm FL (Figure 30). Smallmouth bass were collected in three areas of the LWSC: 1) Aurora Bridge (n = 9), 2) Gas Works Park (n = 35), and 3) Portage Bay (n = 28).

We were unable to get any seasonal movement data on 15 of the tagged fish because we were only able to track them for a short time, or they did not move and we considered them dead or had expelled their tag. Of the remaining 57 fish, 47 (82%) left the LWSC and moved into Lake Washington and 10 (18%) remained in the LWSC and appeared to overwinter there. The percent of fish that remained in the LWSC appeared to be related to the location where they were captured. Fifty-six percent of those captured near the Aurora Bridge migrated to the lake, 79% of those from Gas Works Park migrated, and all of the Portage Bay fish migrated to the lake (Figure 31). For Lake Union and Aurora Bridge fish combined, the mean length of resident fish (n = 10; mean, 296 mm FL) was significantly smaller than migrating fish (n = 27; mean, 337 mm FL)(t-test; P = 0.017).

Timing of smallmouth bass departure from the LWSC appeared to be related to their size and location (Figure 32). Smallmouth bass from Portage Bay generally moved out earlier than other smallmouth bass from other locations but there was no relation between fish size and departure date. Date of departure of fish from Gas Works Park was related to fish size with larger fish leaving much earlier than smaller fish. Overall, the median date to leave the LWSC was July 8th for fish > 350 mm FL and August 31th for fish < 350 mm FL.

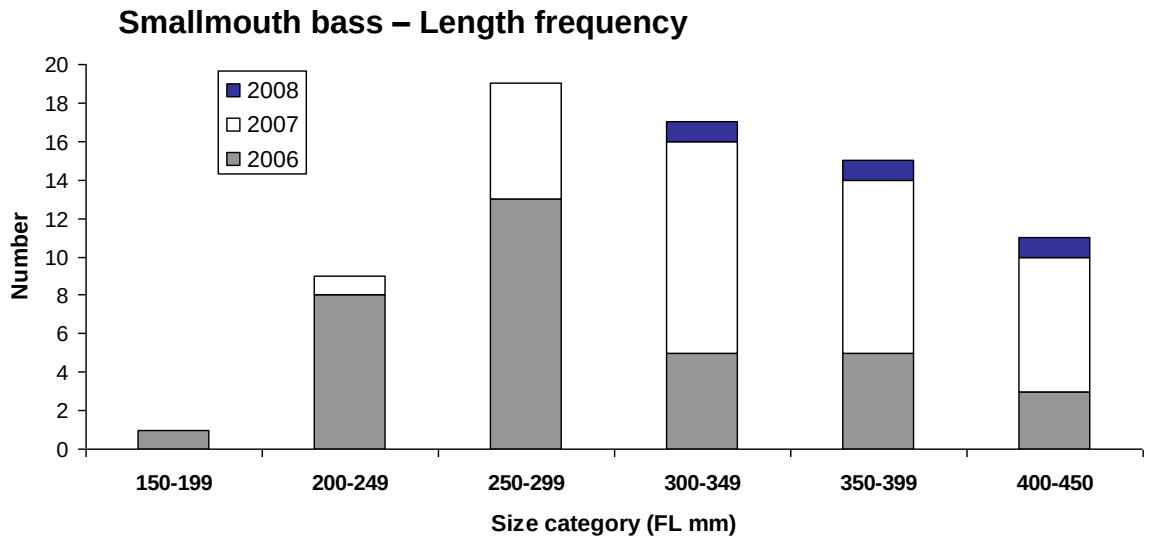


FIGURE 30. Number and size category of acoustic-tagged smallmouth bass collected for three different years. Smallmouth bass were tagged with Vemco acoustic tags at several sites in the Lake Washington Ship Canal, May-July 2006-2008.

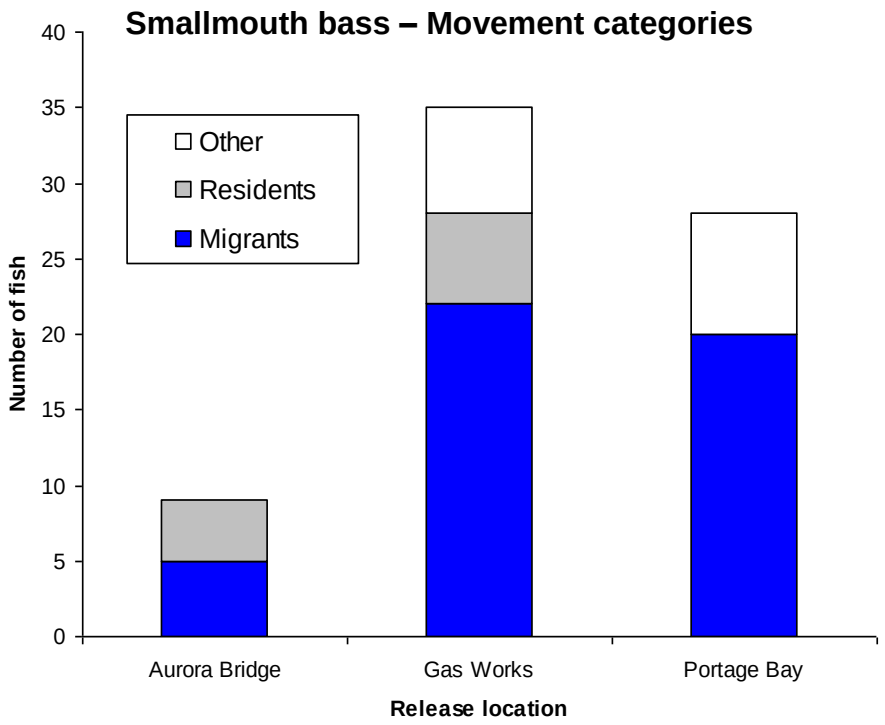


FIGURE 31. Number of tagged LWSC smallmouth bass (n = 72) that either migrated to Lake Washington (migrants), remained in the LWSC (residents), or their seasonal movements could not be determined (other). Migrants are fish that left the LWSC in the late-spring, summer, or early-fall and migrated to Lake Washington. Residents are fish that were still in the LWSC as of October 15 and most likely overwintered in the LWSC. Other includes fish that not enough data was collected to determine their movement patterns or are fish that never moved and are likely from fish that died or expelled their tag. Fish were divided into three areas of the LWSC where they were captured and released.

Overall, movement of smallmouth bass was generally towards Lake Washington. However, we observed 10 fish that moved downstream from their release site at either Lake Union or Aurora Bridge to the receiver at the west of Fremont Cut. Six of those 10 fish were also detected in Salmon Bay, either through mobile tracking or the fixed receiver at Fisherman's Terminal (only operated in 2006). Three smallmouth bass (#118 and #252 and #4363) were observed in the vicinity of Ballard Locks. None of the 25 smallmouth bass from Portage Bay were ever observed at the Fremont Cut or northwest Lake Union receivers. Detections of these fish in Lake Union were rare; three fish were occasionally detected at either Gas Works Park or south Lake Union.

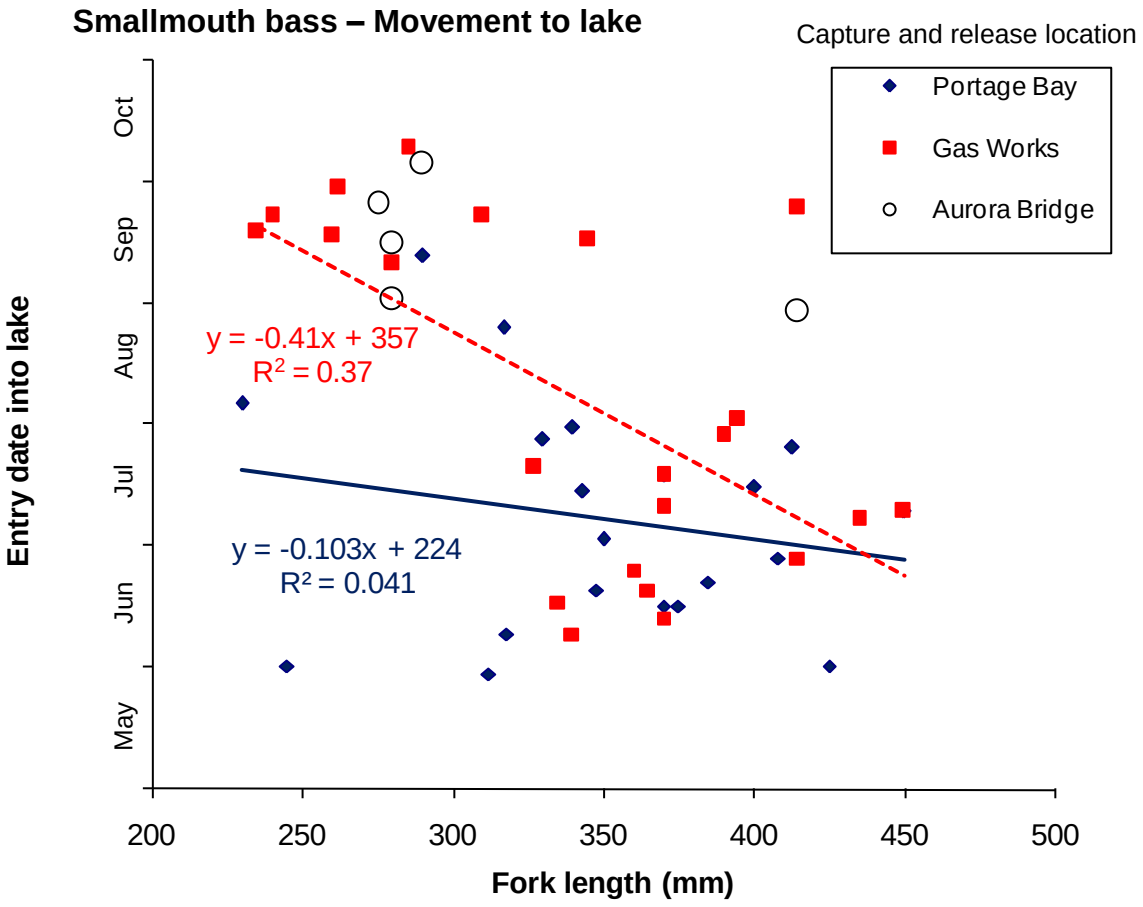


FIGURE 32. Relationship between smallmouth bass fork length (mm) and date they left the LWSC and migrated to Lake Washington. Fish were divided into the three areas where they were captured and released. A regression line was not developed for Aurora Bridge fish because there were only five data points.

We were able to detect 23 smallmouth bass returning to the LWSC. One fish (#117) moved back into the LWSC in October and appeared to spend much of the winter in the LWSC. The other 22 fish did not return to the LWSC until the next spring. Overall, the median date to return to the LWSC was April 2 for fish > 350 mm FL (size at tagging) and April 4 for fish < 350 mm FL. Date of return ranged from March 4 to May 23. Most smallmouth bass returned to the LWSC when water temperatures were 6-9°C, which was just before the spring warming phase (Figure 33).

Eleven smallmouth bass were observed to migrate back to Lake Washington a second time. The median second return date was July 11th, which was similar to July 8th observed for the first return date of fish > 350 mm FL. Only two of the 11 fish were observed to return to the LWSC a second time (Figure 34); these fish were detected 685 and 758 days from the date of release.

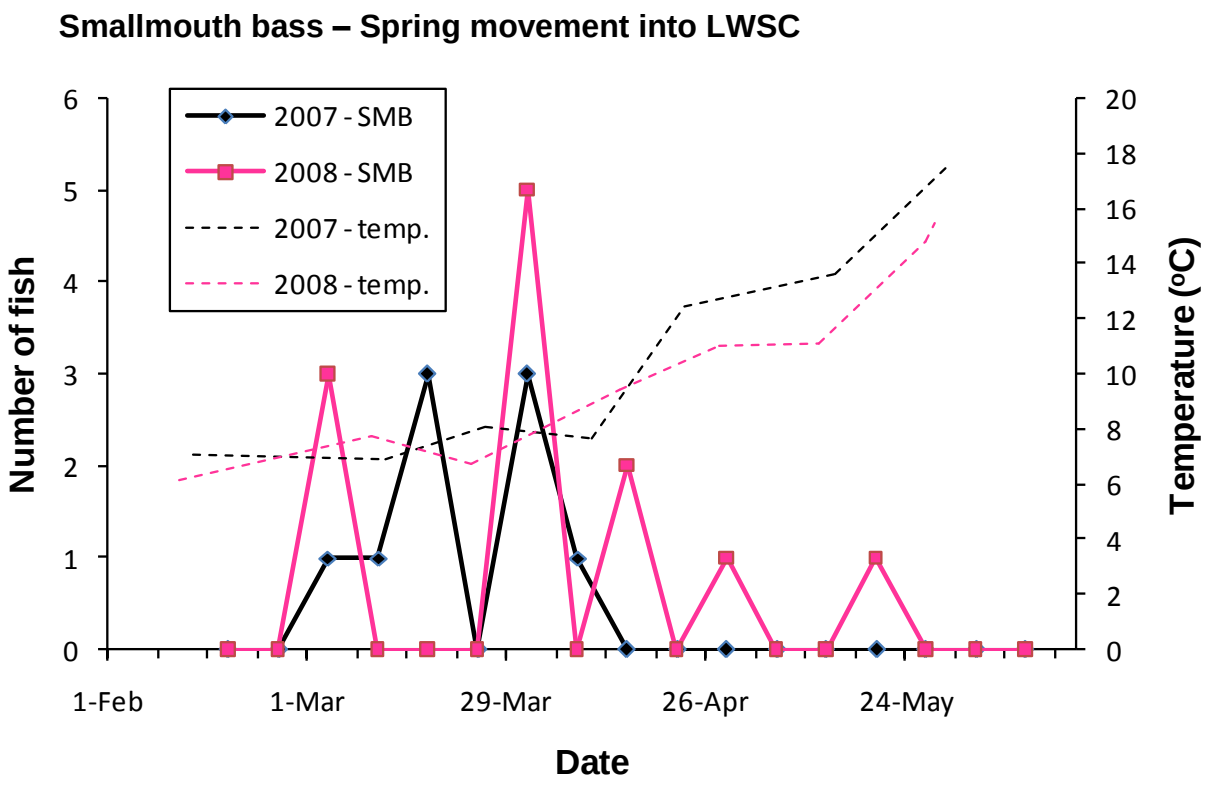


FIGURE 33. Weekly number of tagged smallmouth bass (SMB, solid lines) that returned to the LWSC and water temperatures (temp., dashed lines) in Montlake Cut (1 m depth; King County water quality station). Smallmouth bass that returned in 2007 were tagged in 2006 (May-July) and those that returned in 2008 were tagged in either 2007 or 2006 (May-July). These smallmouth bass spent the fall and winter in Lake Washington before returning to the LWSC.

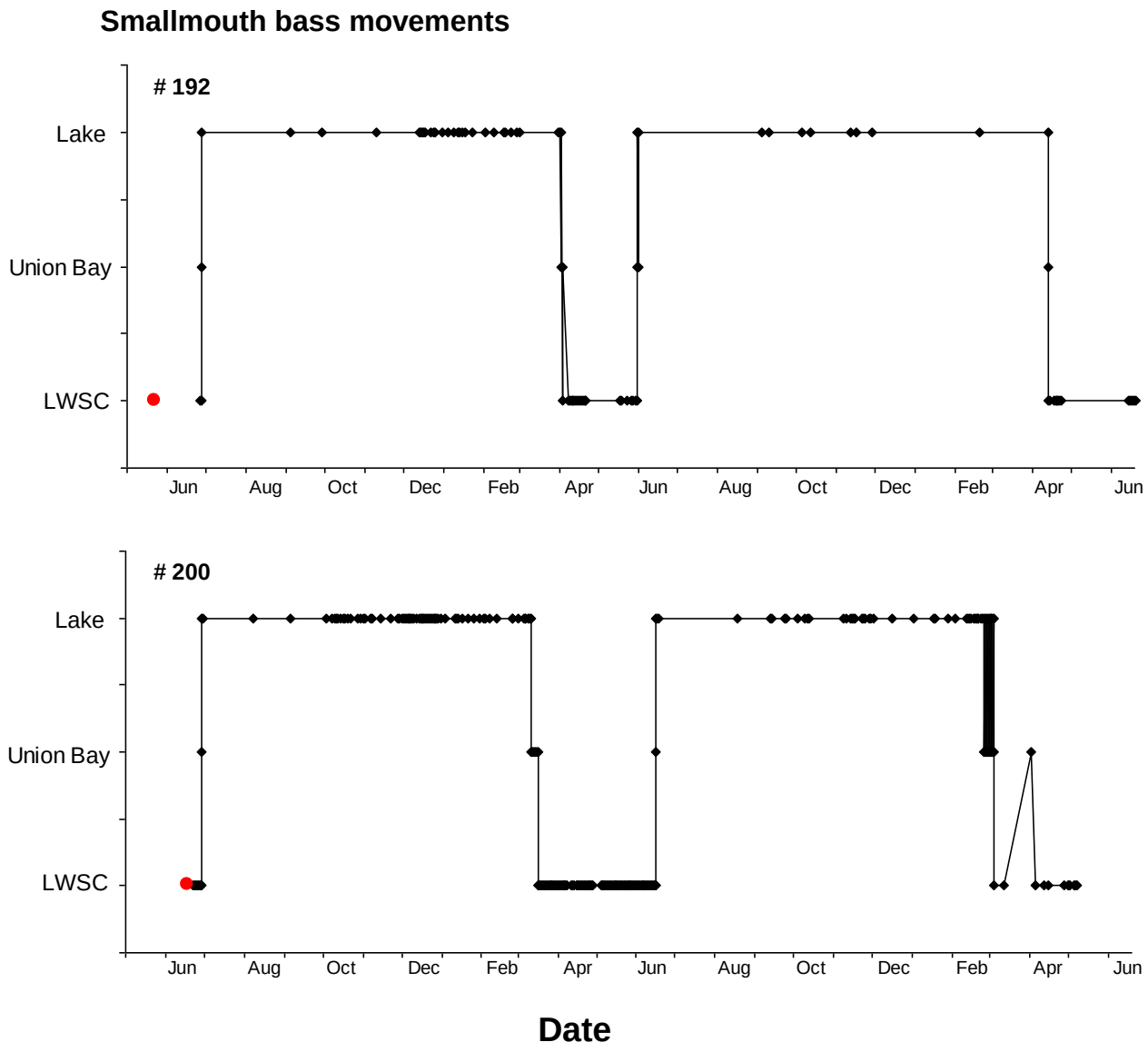


FIGURE 34. Daily movement of two smallmouth bass between Lake Washington and the LWSC, May 2006 – June 2008. Union Bay denotes that the fish was detected at the west end of Union Bay. Red circles are the date of release in the LWSC; Fish #192 was 415 mm FL at release and #200 was 408 mm FL. Each data point indicates at least one detection was made for a particular date. Both fish appeared to inhabit Portage Bay when they were in the LWSC; #192 was usually found near Stan Sayres Park when it was in Lake Washington while #200 was often detected by the Lakeshore Condominium receiver as well as near Sand Point.

Smallmouth bass appeared to return to the same general area of the LWSC as they were captured the previous year. Ten of eleven returning fish that were captured in Portage Bay were not detected further west than the University Bridge receiver; whereas, those captured at Gas Works all moved past the University Bridge and most were found at Gas Works Park (Figure 35). Also, two smallmouth bass (# 192 and # 210; Figure 36) that overwintered in Lake Washington and then were recaptured by anglers in 2007 were found at the same exact location in the LWSC as they were captured in 2006.

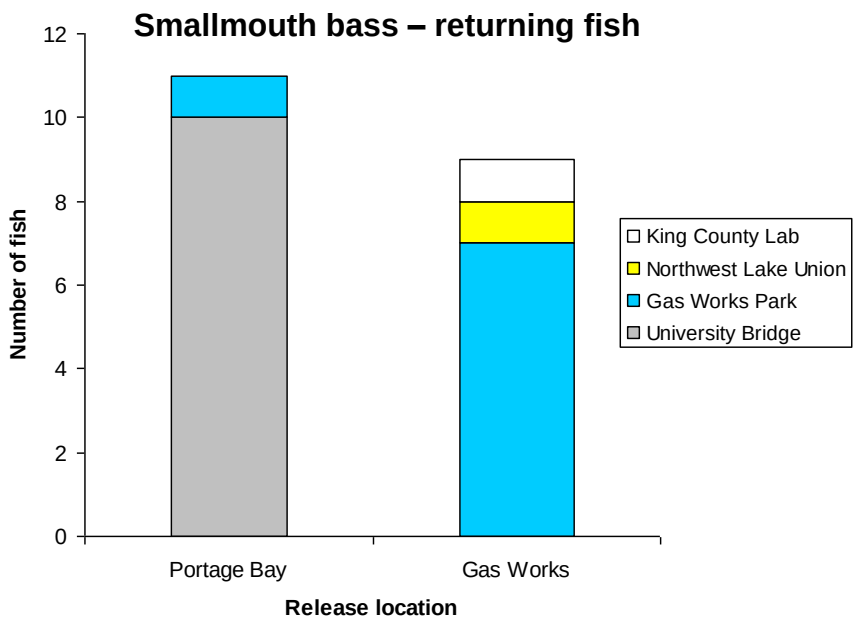


FIGURE 35. Furthest west detection of smallmouth bass (2007 and 2008) that returned to the LWSC from tagging the previous year. These fish were captured (tagged with Vemco acoustic tags) and released in the LWSC and then spent the fall and winter in Lake Washington and returned to the LWSC in the spring. Size at tagging ranged from 260-450 mm FL (mean, 362 mm FL). The return locations are arranged from east (University Bridge is furthest east) to west (King County Lab is furthest west). Release and return locations are shown in Figure 2.

FIGURE 36. Photo of smallmouth bass #210 that was recaptured in north Portage Bay, LWSC, June 4, 2007. This fish was recaptured within a few meters of where it was caught and released on May 15, 2006. Between July 9, 2006 and March 4, 2007 this fish was in Lake Washington. The large red scar near the pelvic fins is the location of the incision where the tag was implanted (note the sutures were still present).

Within Lake Washington, smallmouth bass from LWSC were found in numerous locations throughout the lake. For example, fish # 212 and #3873 were found at the extreme north end of the lake, and fish # 196 and #3896 were found in the south end of the lake (#196 near Coleman Point and fish #3896 at the mouth of Taylor Creek).

Although we did not closely monitor the movements of smallmouth bass in Lake Washington, we did obtain some general information on their locations and movements. During the time when both the south (west I-90 Bridge) and north (St. Edwards Park) lake receivers were operational, 44 tagged smallmouth bass entered the lake from the LWSC. Of those, 16 were never detected at either receiver, five were detected at both receivers, 13 were only detected at the west I-90 Bridge receiver and 10 were detected just at the St. Edwards Park receiver. The number of fish at the St. Edwards Park receiver may be underestimated because the receiver was not operational from Nov 11, 2006 to May 10, 2007.

Results of mobile tracking also indicated smallmouth bass were widespread throughout the lake. However, most fish were found in either Area 1 or 2 (Figure 37 [see Figure 2 for map]). The number of fish in areas 1 and 5 is probably underestimated because these areas were not always surveyed due to time constraints. Two areas of the lake where we found several fish were the northwest shoreline from Wolf Bay to the north side of Sand Point and the southwest shoreline from Stan Sayres Park to Seward Park. There was no apparent relation between where in the lake smallmouth bass were found and their release location or size class.

Combining results of stationary and mobile receivers, each smallmouth bass was often within a localized area of Lake Washington; however, in some cases they moved a relatively long distance in a short period of time. For example, fish #4360 moved a distance of approximately 10 km in five days; from Hunts Point (February 21, 2008) to east I-90 Bridge (February 26, 2008). Fish #200 was usually near the Lakeshore Condominium receiver; however, on one occasion (November 1, 2006) it moved to the west I-90 receiver (approximately 5 km) in less than one day and then returned to the Lakeshore Condominium receiver five days later.

Of the 11 smallmouth bass we detected migrating back to Lake Washington on the second year after release, six showed some degree of site fidelity within the lake between years, one did not, and for the other four we had few lake detections the second year.

Results of Vemco depth tags indicated smallmouth bass generally inhabit shallow water (0-8 m) from May to September. As water temperatures cool, they move to deeper waters. Smallmouth bass in both the LWSC (Figure 38) and Lake Washington (Figure 39) displayed this general trend. Fall and winter depth ranged from 10 to 35 m deep.

Based on HTI and Vemco tracking, smallmouth bass appear to often be inactive at night and remain at the same depth. At dawn, they appear to be more active and range across a wide range of depths (Figure 40). Most fish occupied a wide range of depths during dawn, day, and dusk; however, we did observe one fish (#222) that almost always occupied the same depth (Figure 40). This may be indicative of a nest-guarding male.

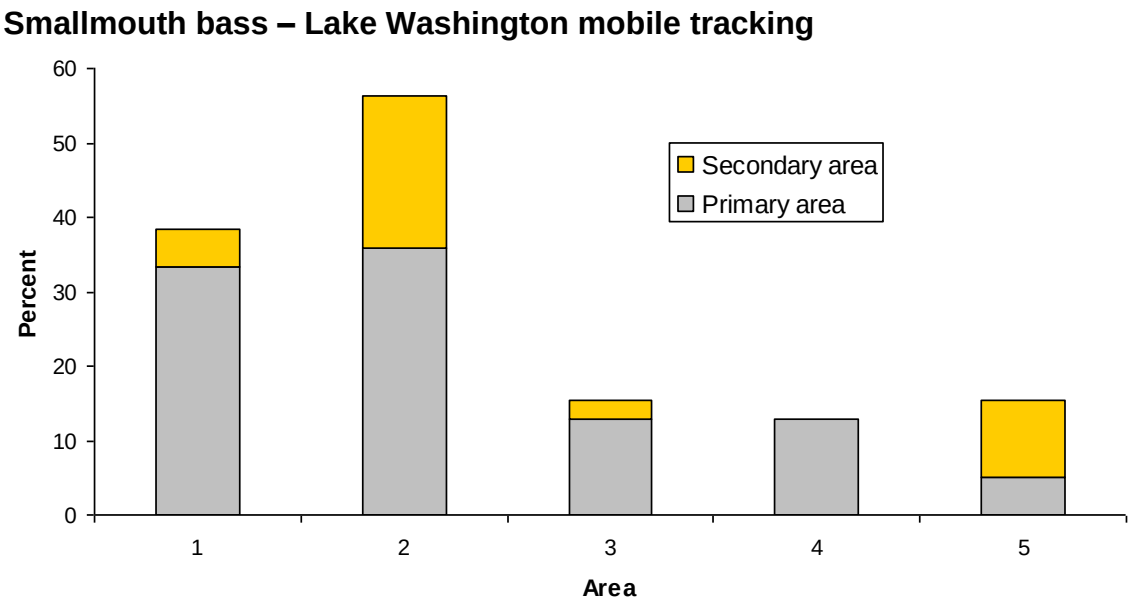


FIGURE 37. Percent of smallmouth bass (n = 39) that were located (mobile tracking) in different areas of Lake Washington, 2006 and 2007. The primary area is the area of the majority of detections for each fish. Secondary area is the other lake areas where each fish was found. Area locations are shown in Figure 2.

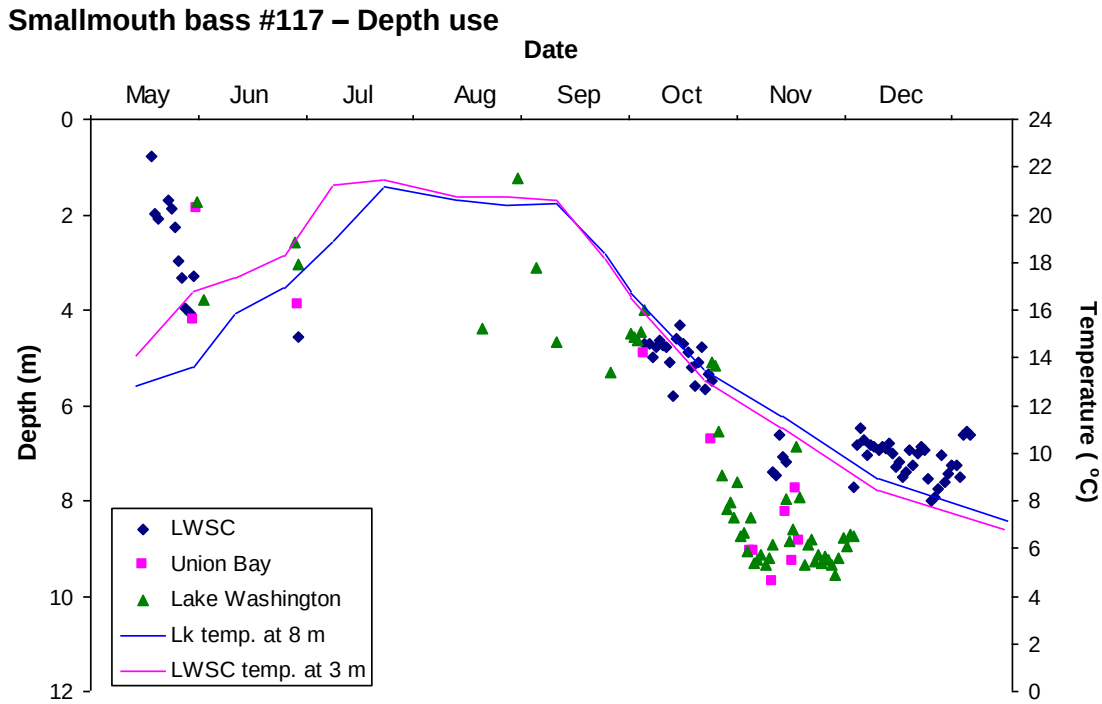


FIGURE 38. Mean daily depth (m) of smallmouth bass #117 in three areas of the lower Lake Washington basin, May – December 2007.

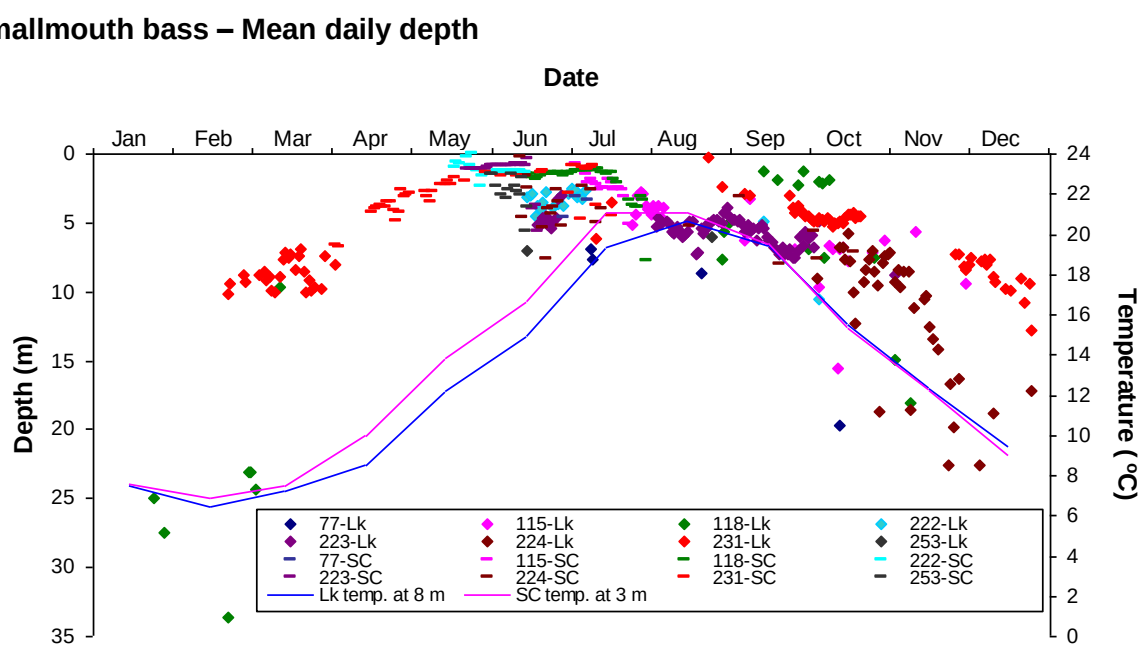


FIGURE 39. Mean daily depth (m) of eight smallmouth bass in the Lake Washington Ship Canal (SC; dashes) and Lake Washington (Lk; diamonds). Data from 2006-2008 were combined.

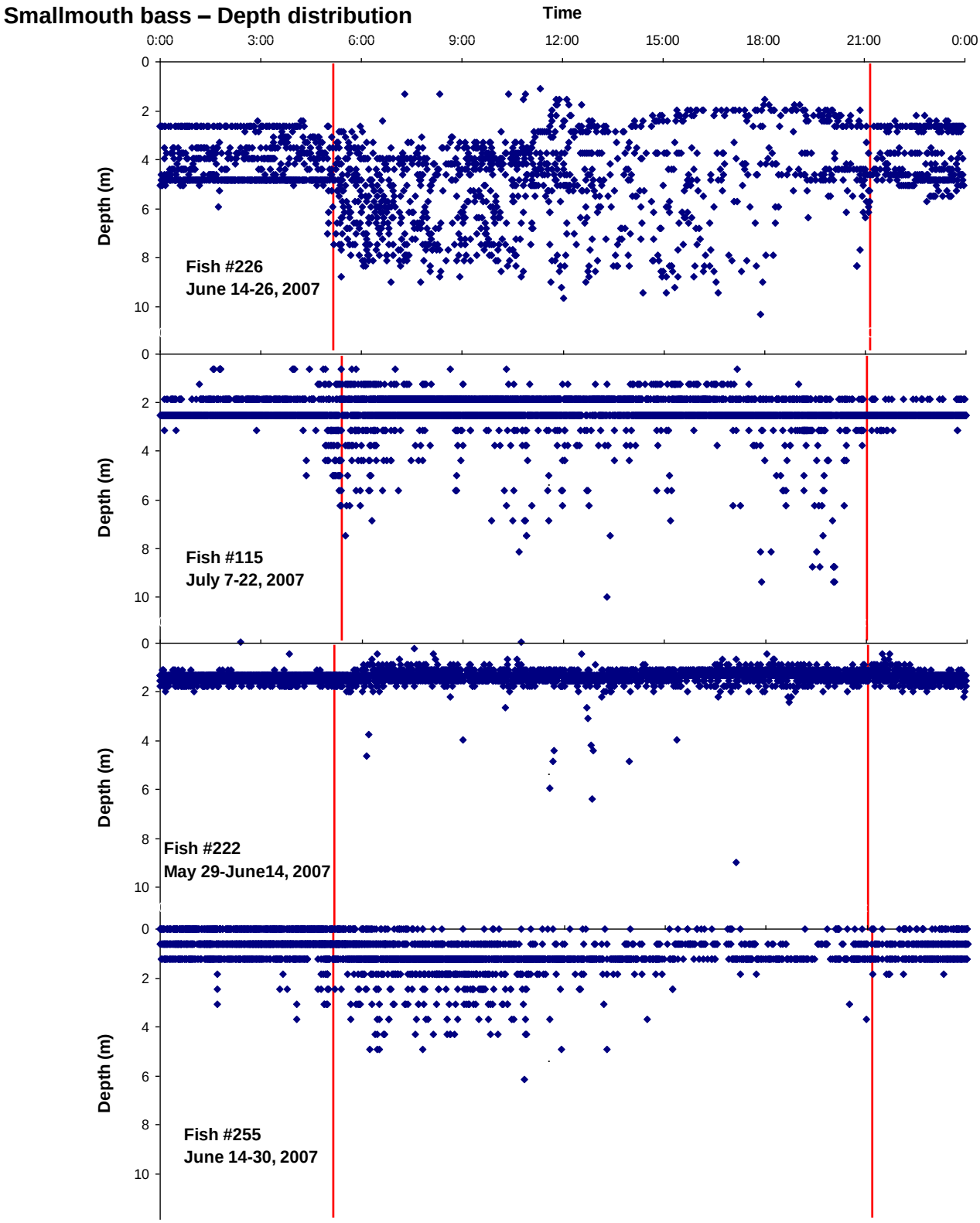


FIGURE 40. Depth distribution (m) of four smallmouth bass in the Lake Washington Ship Canal, 2007. Red lines indicate the average time for dawn and dusk during the dates shown.

Largemouth bass

All Vemco tagging of largemouth bass was done in 2006 (Table 7). In 2007 and 2008, no largemouth bass collected were large enough to be tagged. All tagged largemouth bass were detected at least 97 days (maximum, 743 days) from the date of release. Unlike smallmouth bass, largemouth bass were never detected in the lake except at the Webster Point and Lakeshore Condo receivers. Lack of detections in the lake may indicate that they did not move further east than Union Bay and they rarely moved into other areas of Lake Washington. The three small largemouth bass from Portage Bay (#215, #3890, and #3894) were primarily detected in Portage Bay, mostly at the UW Hatchery but occasionally at the University Bridge receiver. The largest largemouth bass (#197) was captured in Portage Bay and moved to Union Bay six days after release. It was usually detected at one of the three receivers in the Union Bay area. Although it occasionally moved back into the LWSC, it was usually only there for a few hours. The other largemouth bass (#17188) was from Gas Works Park and was detected primarily in Lake Union (Figure 41). Fish #17188 was detected at each LWSC receiver except the Salmon Bay receiver over a 743-day period (July 19, 2006 to July 31, 2008). For both 2006 and 2007, detections of fish #17188 in May to November were widespread across the receivers. In November-March, when water temperatures were low, almost all detections were only at one receiver, northwest Lake Union (Figure 41).

TABLE 7. Largemouth bass tagged with Vemco acoustic tags in the LWSC in 2006. Location is the area where the fish were captured and released. Tag model specifications are given in Table 2. Percent body weight is the tag weight to fish weight percent.

Date released	Location	Tag model	Tag ID	Fork length (mm)	Weight (g)	Percent body weight
14-Jun	West Montlake Park	V13-1L	197	410	1,350	0.81
14-Jun	North Portage Bay	V9-2L	215	201	123	3.82
21-Jun	West Montlake Park	V9-1L	3890	215	130	2.77
30-Jun	West Montlake Park	V9-1L	3894	192	112	3.21
19-Jul	Gas Works Park	V13-1L	17188	290		

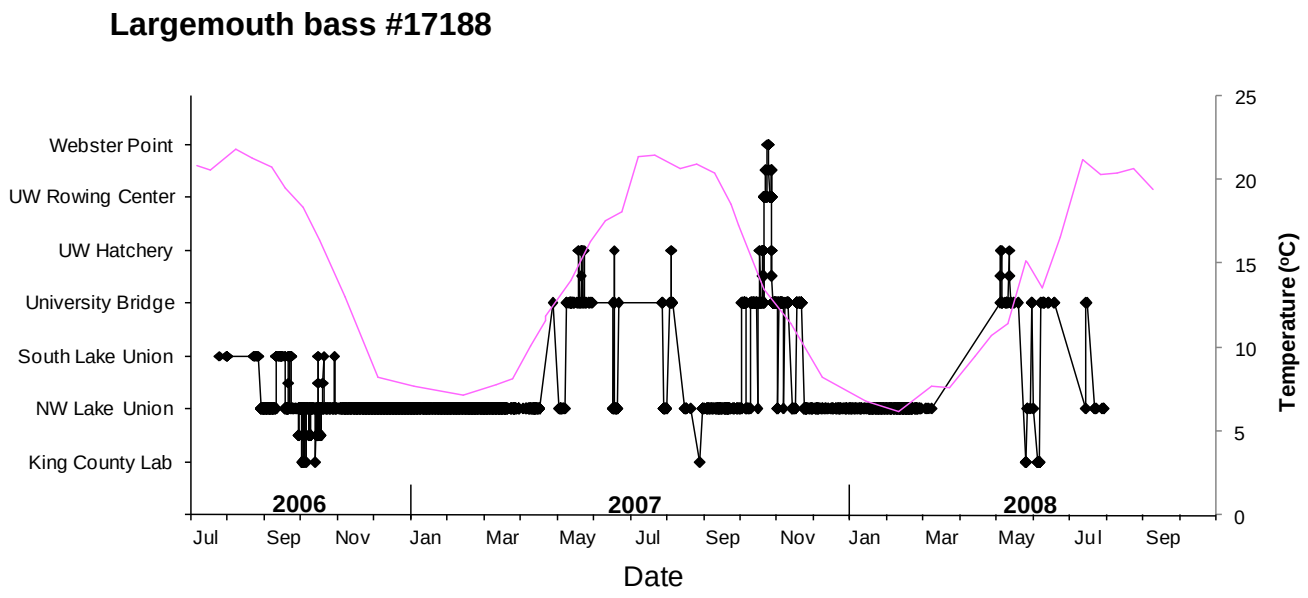


FIGURE 41. Hourly locations (black line) of largemouth bass #17188 based on seven fixed receivers, July 2006 – September 2008. The receiver locations are arranged (top to bottom) from the furthest east to furthest west. If a fish was detected at two receivers during the same hour, the detections are indicated by a value midway between the receivers. See Figure 2 for receiver locations. Temperature data (pink line; 1 m depth) were from a King County water quality station at the east end of the Fremont Cut.

DISCUSSION

Acoustic tracking techniques proved to be an effective method to determine habitat use and movement patterns of predatory fish in the LWSC. Due to low catch rates of northern pikeminnow and largemouth bass, fine-scale tracking was done primarily with smallmouth bass. For the two tracking sites combined, we obtained fine-scale tracking results for 43 smallmouth bass, which comprised over 4.9 million data points. For course-scale tracking, we tagged 111 fish, which included 72 smallmouth bass, 34 northern pikeminnow, and 5 largemouth bass. We were able to get seasonal movement patterns of 57 of 72 (79%) smallmouth bass. Most northern pikeminnow moved to Lake Washington after tagging and we obtained limited movement information. Overall, we only obtained good tracking results for six northern pikeminnow, of which only two produced good long-term (> 3 months) movement data. All largemouth bass were tracked for at least three months, largely because they remained in the LWSC or only moved a short distance to Union Bay.

Spring/summer habitat use - smallmouth bass

At the Gas Works Park site, we found smallmouth bass strongly selected gravel/sand substrate; however, this relationship may be confounded by depth selection. Gravel/sand substrate at Gas Works Park was generally the dominant substrate type within the 2-6 m depth range, which is often the preferred depth of smallmouth bass. Larger substrates such as cobbles and boulders are commonly selected by smallmouth bass (Coble 1975; Fresh et al. 2001) but because large substrates were primarily in shallow water at Gas Works Park, smallmouth bass probably did not select large substrates. At our SR 520 bridge site, cobble and boulder substrates are in deeper waters (4-6 m deep) and smallmouth bass showed a strong positive selection these substrates (Celedonia et al. 2009). Also, deeper areas at Gas Works Park consisted primarily of silt. These areas may be avoided because they are either too deep or because of the fine sediments.

The selection of gravel substrates may also be partly related to spawning. Smallmouth bass often construct their nests in gravel substrate (Bozek et al. 2002; Orth and Newcomb 2002). The large area at the southeast point of Gas Works Park may be ideal for spawning because of the substrate type, slope, and perhaps other factors such as water velocity.

Based on our previous work in the LWSC and Lake Washington (Celedonia et al. 2008b) and work of other researchers (Sammons and Bettoli 1999), we expected the rip rap area of Gas Works Park to be selected over other shoreline types. However, we found only 4 of 22 fish showed any selection for rip rap. Of the fish that selected rip rap, they were all 150-250 mm FL. The size and depth of the rip rap may create better habitat conditions for smaller bass. Similarly, smallmouth bass that were closely associated with small, shallow rip rap at the Seattle Tennis Club shoreline in Lake Washington were also 150-250 mm FL (Celedonia et al. 2008b). Cole and Moring (1997) found large smallmouth bass (> 400 mm FL) in Green Lake, Maine were often located in the areas with no cover; whereas smaller fish were usually closely associated with some type of cover. Sammons and Bettoli (1999) did not find any effect of fish size in the use of rip rap in a Tennessee reservoir. Larger smallmouth bass may prefer rip rap that extends

into deeper waters and has larger interstitial spaces. Spawning site selection and prey availability may also cause some smallmouth bass to prefer other shoreline areas over rip rap.

In reviews of smallmouth bass literature, authors have generally concluded that smallmouth bass typically prefer rocky shorelines and avoid thick beds of aquatic macrophytes (Hubbs and Bailey; Coble 1975; Becker 1983). At both HTI tracking sites, we found smallmouth bass were commonly associated with macrophytes. Smallmouth bass commonly spawn near some type of cover and macrophytes may provide this cover if other more preferred types (e.g., large wood debris) are not available; however, macrophytes also provide cover for smaller-bodied nest predators on bass eggs, larvae, and fry. Additionally, the use of macrophytes may provide smallmouth bass an ideal location to observe and ambush juvenile salmonids that are in the open water. Other preferred prey, such as signal crayfish and sculpin *Cottus* spp., may be abundant in macrophyte beds.

At the west end of the SR 520 bridge, we found smallmouth bass preferred sparse vegetation and the offshore edge of vegetation and avoided dense and moderately dense areas of macrophytes (Celedonia et al. 2009). In contrast, we found few differences between the use of different densities of macrophytes at Gas Works Park or the I-5/University Bridge site. The macrophyte beds at the SR 520 bridge were substantially larger and often reached the surface. The foraging success of smallmouth bass may be greatly reduced in these large beds (Cooper and Crowder 1979, Wiley et al. 1984). In our LWSC sites, the macrophtye beds may be small enough that smallmouth bass can still forage effectively. Also, the substrate of the LWSC sites (i.e., gravel) may be more conducive for spawning than the substrate at the SR 520 bridge, which is predominantly silt.

At the I-5/University Bridge site, smallmouth bass inhabited somewhat deeper water than at Gas Works Park. Differences were largely due to the use of the large structures of the University Bridge which are mostly in water that is 8-10 m deep. Large deep structures such as the University Bridge may allow smallmouth bass to inhabit deeper water that is further from shore and have more overlap with juvenile salmonids. At I-5/University Bridge site as well as south Lake Union and the Lakeshore Condos near the SR 520 bridge, juvenile Chinook salmon have been observed using the offshore areas of large deep structures (Celedonia et al. 2010; Celedonia et al. 2009) and probably have some degree of overlap with smallmouth bass. At Gas Works Park, their overlap may be minimal because juvenile salmonids are offshore where water depths are > 10 m deep (Celedonia et al. 2010) and smallmouth bass are primarily close to shore in water that is 0-8 m deep.

Depth of smallmouth bass within the water column (vertical distribution) was unknown at our study sites. We attempted to reanalyze the I-5/University Bridge data to obtain 3D positions; however, we only obtained results for one smallmouth bass that was actively migrating through the middle of the tracking array. The other bass were close to the structures and could not be tracked in 3D, probably due to the tag signal bouncing off the structures and creating a large error in the vertical axis calculation. We did examine results from the SR 520 bridge study (Celedonia et al. 2009) where two double-tagged smallmouth bass were present (HTI tag for the horizontal axis and a Vemco tag for the vertical axis). Results did show that both smallmouth bass shifted their vertical distribution to shallower waters when they were close to the bridge

structures. If there was no effect of the structures on bass vertical distribution, we would have expected them to be in deeper water near the bridge because the density and height of macrophytes was substantially less under the bridge. Therefore, these smallmouth bass provide preliminary evidence that large structures may allow smallmouth bass to inhabit shallow waters and have greater overlap with salmonids. Under more natural conditions, smallmouth bass generally are close to the substrate (Emery 1973) but occasionally they may even be at the water surface (Munther 1970). Further tagging efforts with double-tagged smallmouth bass is probably needed to get a better picture of their vertical distribution.

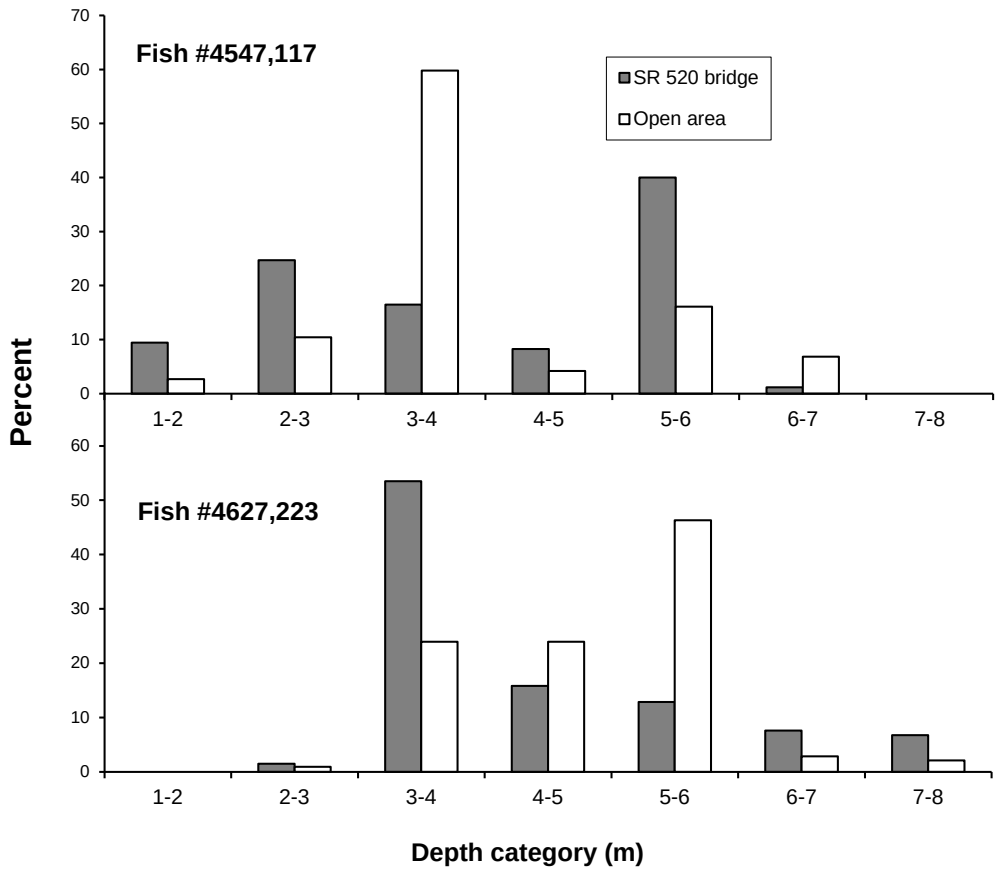


FIGURE 42. Water column depth distribution of two smallmouth bass near the west end of the SR 520 bridge, Lake Washington, May-June 2007. Shaded bars indicate when fish were directly under or within 5 m of the bridge; open bars indicate when fish were in areas away from the bridge. Each bass was tagged with a HTI acoustic tag (first number) and a Vemco depth tag (second number). Horizontal positions were obtained from the HTI tag, while the depth data was obtained from the Vemco tag. Both fish were primarily in water that was 4-6 m deep. See Celedonia et al. 2009 for a description of the study area and Appendix 4 for fish information.

Seasonal movements

Northern pikeminnow

Most northern pikeminnow released in the LWSC with Vemco transmitters moved to Lake Washington shortly after release and often 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). Martinelli and Shively (1997) also reported that radio-tagged northern pikeminnow in the Columbia River often were displaced several kilometers from their release site. Therefore, large numbers of northern pikeminnow may need to be tagged to obtain a reasonable sample size of fish that display typical movement patterns in and out of the LWSC. Most of our LWSC results were based on six fish out of the 22 fish tagged and released in the LWSC. Also, there appeared to be large variability in movement patterns between individuals. Therefore, a large sample is needed to account for post-tagging movements and natural variability is fish behavior. Perhaps 150-200 fish may be needed for tagging.

In contrast, tagging efforts in Cultus Lake, British Columbia found northern pikeminnow remained close to their release site and were often recaptured multiple times at that site (Bradford et al. 2007). In that study, fish were collected with a trap net and were subsequently externally tagged with a Floy-tag without the use of an anesthetic. Other studies including this study may have employed more intrusive capture techniques (i.e., gill nets and electrofishing). As well, surgical procedures and the use of an anesthetic could have profound effects on their short-term behavior. Martinelli and Shively (2007) suggested that it takes about seven days for internally-tagged northern pikeminnow to act naturally and forage the same as non-tagged fish.

One unanticipated element of our study was the difficulty collecting northern pikeminnow. Catch rates during angling and trot line efforts were generally low. The use of bait appeared to improve catch rates but often the hook was swallowed and the fish was not in good condition. Beach seining was labor intensive and catch rates were generally low. Also, there are few good seining sites in the LWSC and often underwater debris becomes entangled in the net. Gill nets appeared to be the most effective method but sometimes the fish became too entangled and the fish was injured and could not be tagged. Also, catch rates were generally low until July, which is the same time when adult anadromous salmonids are present, thus bycatch could be a problem. Improvements in the methodology of collecting northern pikeminnow need to be found before any large-scale tagging project is undertaken. For example, Bradford et al. (2007) were able to collect large numbers of northern pikeminnow in Cultus Lake, British Columbia with a trap net.

Following their initial movements after tagging, many of the northern pikeminnow appeared to move to a new area in Lake Washington and did not have any large-scale movement patterns. Results of tracking work at the SR 520 Bridge (Celedonia et al. 2008a; Celedonia et al. 2009) and other sites in Lake Washington (Brocksmith 1999) indicate northern pikeminnow often occupy a small, relatively defined area (e.g. 20 ha). In Cultus Lake, they also appear to have limited movements during the summer (Bradford et al. 2007). Although many northern pikeminnow appear to be move within a small area, there also appears to be another segment of

the population that is quite mobile. We documented three northern pikeminnow that made numerous trips in and out of the LWSC. We were also able to track one of them in the lake, where it was detected in a wide variety of locations. Gender differences during spawning could potentially account for this: females may only occupy spawning grounds long enough to spawn, and might need to return multiple times to spawn out completely; whereas males tend to remain on the spawning grounds throughout the spawning season.

We observed eight northern pikeminnow migrating from the SR 520 bridge area to the I-90 bridge within a one week period (June 5-11, 2007). Additionally, the northern pikeminnow that moved in and out of the LWSC all left the LWSC for the first two weeks of June. These movements could be related to spawning activity. Exact spawning timing is not well known. Based on a northern pikeminnow maturity index, Olney (1975) felt in Lake Washington they spawned from early June to early August with a peak in July. They may spawn periodically during this period based on certain environmental cues such as the lunar cycle.

The locations of northern pikeminnow spawning areas in Lake Washington are also not well known. Rubble, cobble, and gravel areas have been reported as northern pikeminnow spawning areas in lakes (Patten and Rodman 1969; Wydoski and Whitney 2003). In general, these substrate types are rare in the LWSC and therefore it is doubtful they spawn in the LWSC. Additionally, low catch rates of northern pikeminnow in the LWSC would suggest the LWSC is not a major spawning area. Because we observed several northern pikeminnow (10 of 21 that were tagged in or near the LWSC) in the south part of the lake near Mercer Island in June or July, there may be some major spawning areas in that part of the lake.

Movements of northern pikeminnow into the LWSC may be more related to foraging than spawning. Northern pikeminnow are known to concentrate in areas where juvenile salmonids or other prey are abundant (Collis et al. 1995; R. Tabor, unpublished data). Under lab conditions, northern pikeminnow prey heavily on juvenile salmonids at night and little predation occurs during the day (Petersen and Gadomski 1994). Therefore, our observed movements into the LWSC at night might be related to foraging activity.

Initial spring movements of northern pikeminnow into the LWSC were only documented for two fish; however, both entered about the same time of the year. Fish #17222 moved into the LWSC on May 20, 2007 and fish #22507 entered on May 21, 2009. Movement of these fish may have been related to the release of hatchery salmonids from the UW Hatchery which occurred on May 14 in both years. Similarly, Collis et al. (1995) found the abundance of northern pikeminnow near Columbia River hatcheries increased following the release of juvenile salmonids. Within Lake Washington, northern pikeminnow also aggregate in the south end on the lake at the mouth of the Cedar River in March when adult longfin smelt *Spirinchus thaleichthys* are moving upstream to spawn (R. Tabor, unpublished data).

It is unclear if conditions in the LWSC are optimal for northern pikeminnow. In Lake Washington, northern pikeminnow inhabit shallow water (4-6 m deep) during the day in late-spring and summer and prefer areas with aquatic macrophytes (Celedonia et al. 2008a; Celedonia et al. 2009). They do not show any preference for large overwater structures. In the LWSC, large overwater structures are numerous; in some areas, aquatic macrophtye abundance is

reduced due to shading from these structures. Also, the relative availability of prey may be lower in the LWSC than Lake Washington. Juvenile salmonids are abundant in the LWSC but other prey items (i.e., signal crayfish, longfin smelt, threespine stickleback, and sculpin) may be more available in Lake Washington than in the LWSC.

The three northern pikeminnow from which we obtained extensive depth information were all double-tagged with a HTI tag. Results of HTI tracking indicated that during the day, these northern pikeminnow were concentrated in shallow water close to shore (Celedonia et al. 2008a; Celedonia et al. 2009). At night, they dispersed over a large area and often moved offshore. Combining Vemco and HTI tracking data indicates that, at night, two of the fish inhabited mid-water and surface waters; while the other fish primarily inhabited surface waters. Location of prey resources may influence their vertical distribution at night.

Results of our tracking work suggest northern pikeminnow primarily inhabit Lake Washington and occasionally move into the LWSC to forage. Our results in combination with other studies suggest northern pikeminnow is not a major predator in the LWSC because they do not appear to be abundant. Gill net catches of northern pikeminnow during our study were generally low in comparison to catch rates in Lake Washington. During electrofishing sampling in 1999, catch rates were generally low (Tabor et al. 2004). Gill net catch rates by the Muckleshoot Indian Tribe in 1997 were also low (B. Footen, unpublished data). Northern pikeminnow may be at their spawning sites in Lake Washington during June and July when juvenile salmonids are abundant in the LWSC. Additional sampling (abundance estimates and additional tracking) is needed to reach more conclusive results but at present they do not appear to be a major predator of juvenile salmonids in the LWSC.

Smallmouth bass

On a yearly basis, adult smallmouth bass typically have three major phases: 1) spawning in the spring, 2) summer/fall rearing within a well-defined home range, and 3) overwintering (Ridgway et al. 2002). In some lakes and rivers, most fish inhabit the same area for all three phases and have a well-defined home range throughout the year (Todd and Rabeni 1989; Beam 1990). In other systems, major phases may not be in close proximity to each other, and thus, smallmouth bass make regular, predictable migrations. Smallmouth bass in Embarrass River, Wisconsin moved 30-100 km downstream in the fall from a small stream to a large deep river to overwinter (Langhurst and Schoenike 1990). Kraai et al. (1991) found they moved up to 6.5 km in Meredith Reservoir, Texas apparently to spawning areas. Some lake-dwelling populations move into tributaries to spawn (Webster 1954; Robbins and MacCrimmon 1977; Gerber and Haynes 1988) or to the confluence of a tributary (Garren et al. 2001). For example in Lake Simcoe, Ontario, smallmouth bass migrate upstream 3.5 km from the lake to reach their riverine spawning area (Robbins and MacCrimmon 1977). In a review of literature of seasonal movements of smallmouth bass in streams, Lyons and Kanehl (2002) found migration distance correlated with winter severity; in streams that do not freeze they tend to be sedentary but in systems with ice they often travel more than 5 km.

Smallmouth bass in a particular water body may often consist of a mixture of fish that are either sedentary or mobile. In Lake Sammamish, 81% were sedentary and 19% were mobile

(Pflug and Pauley 1983). VanArum et al. (2004) found that after spawning 57% were migratory (moved a mean of 5.3 km) and 42% were sedentary. Smallmouth bass in the LWSC appear to be primarily mobile fish; most left the LWSC in the summer and returned the following year after a summer/fall rearing phase and an overwintering phase in Lake Washington. Some fish (e.g. fish #206) that remained in the LWSC year-round were often quite mobile.

During spring and early summer, smallmouth bass in the LWSC appeared to establish defined home ranges. Results of our tracking research (HTI tags) and a mark-recapture study (Tabor et al. 2004) indicated that most smallmouth bass in the LWSC did not move substantially while in the LWSC. Spawning activity, especially nest guarding by males, probably reduces their movements. Also prey, such as juvenile salmonids, are abundant and bass may only need to forage over a small area (Savitz et al. 1983).

Although we were unable to determine the exact position of most returning smallmouth bass, many appeared to return to the same general area of the LWSC as the previous year. Two fish (#192 and #210) were caught in the LWSC in the same location as in 2006 after overwintering in Lake Washington. Returning to the same general area each year is probably an indication of nest site fidelity. In other studies, nest site fidelity has been observed in some proportion of the spawning population (Robbins and MacCrimmon 1977; Ridgway et al. 1991; Garren et al. 2001). Ridgway et al. (2002) found nesting males showed a high degree of nest site fidelity, with over 70% returning to within 100 m of the nest site from the previous year, even though their nesting site was not part of their summer home range.

Most returning smallmouth bass appeared to move into LWSC sometime from early March to mid-April. Timing of their return to the LWSC appears to correspond somewhat to the initial warming period in the spring. This appears to be consistent to movements observed by Montgomery et al. (1980) in Columbia River sloughs where smallmouth bass entered the sloughs from mid-March to April and returned to the main channel in August. Movements were believed to be directly related to spawning and the primary stimulus for moving into the sloughs was temperature. In the LWSC, some of their principal prey items (i.e., sculpin and signal crayfish) may not be available during this time because of the low water temperatures. Juvenile salmonids typically do move into the LWSC until late April and May. Also, smallmouth bass should have low consumption rates during early March to mid-April because of the low water temperatures (Wydoski and Whitney 2003). Therefore, timing of smallmouth bass entry into the LWSC may be more related to spawning than foraging.

Generally, smallmouth bass returned to the LWSC a few weeks to a few days before there was any noticeable increase in temperature. Suski and Ridgway (2009) found smallmouth bass move quickly from deep water to shallow water once the water temperature warms in the spring. The one returning smallmouth bass (#231) with a depth tag moved into the LWSC in relatively deep water (6-10 m) and did not move into shallow water (1-3 m) until the water temperature had risen substantially. Taken together, this suggests smallmouth bass move into the LWSC before the spring warming period and stage in deep water and wait until water temperatures warm (approximately 15°C) to move into shallow warm to spawn. Therefore, other environmental cues (e.g., day length) may also be important in influencing movement into the LWSC.

Within some lakes, smallmouth bass appear to have discrete populations (Stone et al. 1954; Webster 1954; Fry and Watt 1957). The populations can become reproductively isolated because spawning occurs in different areas of the lake and they have strong nest site fidelity. Genetic analyses have also shown that there are differences between spawning populations (Stepien et al. 2007). Although smallmouth bass have only been in Lake Washington for a limited number of generations, different spawning populations may exist between Lake Washington and the LWSC. Although they may intermingle in the summer in the lake, the LWSC and Lake Washington populations may be reproductively isolated.

Additionally, smallmouth bass in the LWSC may consist of two or more populations. One population may be an east population in Portage Bay and a west population in Lake Union and Fremont Cut. The size of smallmouth bass in the west section of the LWSC appears to be smaller than the east (Tabor et al. 2004), which may be a result of a higher percentage of fish remaining in the LWSC where foraging conditions during the late summer and fall may not be as good as in Lake Washington.

Because smallmouth bass populations in the LWSC may be discrete from populations that remain in Lake Washington year-round, bass removal efforts in the LWSC may have positive effects on salmonid populations. Smallmouth bass would certainly recolonize vacated habitats but this may take a few years. However for this to be feasible, a high removal rate would be necessary.

Most smallmouth bass appear to leave the LWSC between mid-June and September. Departure from the LWSC may be related to a variety of factors, such as cessation of spawning activity, water temperature, water quality, and prey availability. Smallmouth bass generally spawn from late April to June and therefore some fish may leave the LWSC after spawning has been completed.

Peak surface temperatures in the LWSC are approximately 22-24°C and it is unclear if these water temperatures would cause them to leave. Optimum temperature for smallmouth bass growth is 25-27°C (Moyle 2002) and under lab conditions, adults select water that is 27-31°C (Armour 1993). However, in many field studies, smallmouth bass occupy areas where temperatures were 20-22°C and avoid temperatures that exceed 25°C (Gerber and Haynes 1988). Savitz and Treat (2007) found summer movements in and out Lake Michigan harbors were related to water temperature. Smallmouth bass often appear to select coolwater habitats and it is unclear whether their use of these habitats is related to temperature or other factors.

Smallmouth bass often move to deeper water in the late summer (Cole and Moring 1997). Low dissolved oxygen levels in these deeper areas in the LWSC may reduce the amount of preferred habitat available. Other changes in water quality, such as water clarity, could also influence their preference to return to Lake Washington. Smallmouth bass generally prefer clear water (Moyle 2002) and because Lake Washington generally has better water clarity than the LWSC, they may prefer habitat conditions in Lake Washington.

The availability of principal prey items (juvenile salmonids, sculpin, and signal crayfish) for smallmouth bass in the LWSC may be greatly reduced in July and August. After mid-July, the abundance of juvenile salmonids in the LWSC is greatly reduced. Additionally, as water temperatures warm, prickly sculpin *Cottus asper* typically move into deeper waters (Rickard 1980) and may be less available to smallmouth bass. In Lake Washington, their summer diet consists of crayfish, sculpin, and threespine stickleback *Gasterosteus aculeatus* (Fayram and Sibley 2000; Mazur 2004). These prey types may be more abundant in Lake Washington than in the LWSC.

A population estimate of smallmouth bass in the LWSC was conducted in 1999 (Tabor et al. 2007). This estimate was based on a Schnabel multiple-pass mark-recapture effort. A key assumption of this estimate was that there is minimal immigration and emigration (Ricker 1975). Based on our observed timing of smallmouth bass returning to the LWSC, there does not appear to be a substantial amount of immigration from May and July. However, there does appear to be a substantial amount of emigration. The population estimate will need to be adjusted to take into account emigration in June and July. Changes in the population estimate will subsequently result in a change in the overall consumption estimate.

Largemouth bass

Of the three predator species we examined, largemouth bass seasonal movements occurred over a smaller area. Although we only tagged five largemouth bass, they all appeared to stay in the LWSC or close by in Union Bay. Home ranges of largemouth bass generally range from <0.1 to 50 ha. Often largemouth bass have a limited home range (Lewis and Flickinger 1967; Warden and Lorio 1975); however, home range size may vary depending on temperature (Sammons and Maciena 2005), prey availability (Savitz et al. 1983), prey location (Sammons and Maciena 2005), and habitat conditions (Sammons et al. 2003; Ahrenstorff et al. 2009). High availability of prey fishes, such as juvenile salmonids, and adequate habitat conditions (i.e., silt substrate with abundant macrophytes and in-water structures) in the LWSC and Union Bay may reduce their home range size. Because we only tagged five fish and all but one were < 300 mm FL, additional tagging is needed to reach more conclusive results.

Generally, largemouth bass appear to have restricted movements during the winter (Karchesky and Bennett 2004; Hunter and Maceina 2008). There is some moderate level of movement (Hanson et al. 2007) but their home range size is typically smaller than at other times of the year (Sammons and Maciena 2005). The one largemouth bass (#17188) for which we were able to obtain extensive seasonal information appeared to follow this general trend. This fish was consistently found near the northwest Lake Union receiver throughout the winter and nowhere else; whereas during other seasons it appeared to move to a variety of areas in the LWSC.

Conclusions

Smallmouth bass inhabited a wide range of depths between 0 and 10 m deep but were mostly found in the 2-4 m depth interval. The large area of the Gas Works Park site that was > 12 m deep was rarely used. Smallmouth bass strongly selected the bridge support structures at the I-5/University Bridge site but also showed some positive selection for sparse vegetation, vegetation edge, and nearshore overwater structures. At the Gas Works Park site, they showed a selection for the beach shoreline and gravel/sand substrate. Smallmouth bass inhabited deeper areas at the I-5/University Bridge site than at Gas Works Park; this was due largely to the use of the deep support structures of the University Bridge. Large offshore, deep structures like the University Bridge appear to allow smallmouth bass to inhabit offshore, deeper waters and probably have greater overlap with juvenile Chinook salmon.

Course-scale tracking of smallmouth bass showed they have a strong seasonal migration pattern between the LWSC and Lake Washington. Of the smallmouth bass we were able to obtain seasonal movement information, 82% migrated to Lake Washington sometime between June and October. Smallmouth bass < 350 mm FL were more likely to overwinter in the LWSC and if they did migrate to Lake Washington, they migrated later in August-October. Most returning smallmouth bass appeared to move into LWSC sometime from early March to mid-April. Timing of their return to the LWSC appears to correspond to the initial warming period in the spring and may be directly related to spawning. Smallmouth bass often showed some degree of site fidelity between years for both spring/summer locations in the LWSC and summer/fall/winter locations in Lake Washington. Because smallmouth bass often have a high degree of spawning site fidelity, there can be different populations within the same water body. Smallmouth bass in the LWSC may represent one perhaps two separate populations from smallmouth bass that inhabit Lake Washington year-round.

Results of course-scale tracking of northern pikeminnow showed they primarily inhabit Lake Washington and occasionally make forays into the LWSC lasting a few hours to several days. Movements in and out of the LWSC occur primarily at night. Our results and results of other studies suggest northern pikeminnow spend most of their time in Lake Washington and a small portion of the population move into the LWSC for short periods of time. Overall, northern pikeminnow do not appear to be a major predator of juvenile salmonids in the LWSC; however, because of our small sample size further tagging is needed.

Only five largemouth bass were implanted with Vemco tags; however, they all appeared to remain in the LWSC or were nearby in Union Bay. Each largemouth bass were tracked for at least three months. The one largemouth bass that was tracked for two years appeared to have restricted movements when water temperatures were cold (November-March) and moved to a variety of areas in the LWSC during other times of the year.

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APPENDICES

APPENDIX 1. Smallmouth bass tagged with HTI acoustic tags in the LWSC in 2007 and 2008. Release site is the area where the fish were captured and released. GWP = Gas Works Park; I-5/UB = I-5 and University Bridges. G tags are 60-day, 4.4 g tags and E tags are 20-day, 1.5 g tags. The number of days tracked is the number of days at least one data point was obtained. The first 24 hours after release was not used. The number of data points is the number recorded at the release site; other data points is the number at the other HTI fixed array site in LWSC (the last fish listed was tagged outside the LWSC and tracked at the I-5/UB site). Tracking was performed from May 18 to August 20 in 2007 and May 20 to August 20 in 2008.

Year Date released	Release site	Tag type	Tag period (msec)	Fork length (mm)	Weight (g)	Date of first data point	Date of last data point	Number of days tracked	Number of data points	Other data points
2007										
18-May	GWP	G	4557	435	1,580	19-May	15-Jul	54	347,506	0
22-May	GWP	G	4567	365	760	23-May	16-Jun	22	76,913	15
22-May	GWP	G	4577	370	800	23-May	17-Jul	51	247,959	427
22-May	GWP	G	4587	310	520	23-May	20-Jul	41	110,674	1,599
22-May	GWP	G	4597	340	720	23-May	7-Jun	9	3,346	2
23-May	I-5/UB	G	4607	340	700	24-May	23-Jun	8	10,067	0
23-May	I-5/UB	G	4617	318	500	24-May	8-Jun	12	10,994	0
23-May	I-5/UB	G	4627	348	720	24-May	19-Jun	20	59,087	0
23-May	I-5/UB	E	4637	235	210	24-May	12-Jun	5	9,087	0
23-May	I-5/UB	E	4647	183	76	24-May	12-Jun	18	72,817	0
11-Jun	I-5/UB	G	4897	375	920	12-Jun	13-Jun	2	2,664	0
11-Jun	I-5/UB	G	4907	380	910	--	--	0	0	0
11-Jun	I-5/UB	G	4917	400	900	12-Jun	15-Jul	13	1,927	0
11-Jun	I-5/UB	E	4927	290	400	12-Jun	1-Jul	15	30,578	0
11-Jun	GWP	E	4937	360	700	--	--	0	0	136
20-Jun	GWP	E	4987	235	211	21-Jun	11-Jul	21	72,885	0
20-Jun	GWP	E	4997	238	206	--	--	0	0	0
25-Jun	GWP	G	5007	450	1,430	26-Jun	8-Jul	13	60,554	37
25-Jun	I-5/UB	G	5017	315	480	1-Jul	15-Jul	3	3,358	0
28-Jun	GWP	G	5067	400	1,100	--	--	0	0	0
28-Jun	I-5/UB	E	5077	321	470	29-Jun	29-Jun	1	1	0
28-Jun	GWP	E	5087	185	105	30-Jun	20-Jul	13	322	0
3-Jul	I-5/UB	G	5157	298	400	4-Jul	20-Aug	35	22,666	0
3-Jul	I-5/UB	G	5167	425	1,350	4-Jul	15-Jul	12	14,929	0
3-Jul	I-5/UB	G	5177	413	1,330	7-Jul	24-Jul	17	8,701	0
9-Jul	GWP	G	5197	283	380	10-Jul	14-Aug	35	87,318	0
9-Jul	GWP	G	5217	255	269	10-Jul	13-Aug	32	19,699	13
9-Jul	GWP	G	5237	250	263	19-Jul	14-Aug	11	22,993	0
9-Jul	GWP	E	5257	215	163	10-Jul	2-Aug	33	129,336	0
9-Jul	GWP	E	5277	165	71	10-Jul	29-Jul	20	34,526	0
2008										
20-May	I-5/UB	G	4508	400	1,050	21-May	26-Jun	25	328,489	149
20-May	I-5/UB	G	4518	420	1,250	21-May	1-Jun	27	45,505	13,780
20-May	I-5/UB	G	4528	380	1,050	21-May	7-Jul	29	12,158	0
20-May	I-5/UB	G	4538	420	1,600	21-May	6-Jul	42	189,761	269
21-May	I-5/UB	G	4548	410	1,400	22-May	5-Jul	26	37,133	0
22-May	GWP	E	4558	210	135	--	--	0	0	0
23-May	I-5/UB	G	4568	430	1,420	24-May	3-Jul	15	10,127	0
23-May	GWP	G	4578	275	355	12-Jun	10-Jul	7	2,168	56,962
23-May	GWP	G	4588	340	840	24-May	14-Jun	21	532,823	23
23-May	GWP	G	4598	385	1,080	24-May	14-Jun	21	580,318	19
28-May	I-5/UB	G	4608	430	1,364	29-May	7-Jul	34	212,321	33
29-May	GWP	E	4618	153	55	30-May	11-Jun	12	10,759	26
29-May	GWP	E	4628	160	66	30-May	11-Jun	12	14,559	12
3-Jun	GWP	G	4668	435	1,337	4-Jun	11-Jun	7	28,982	49
3-Jun	GWP	G	4678	385	952	4-Jun	11-Jun	7	34	256
3-Jun	GWP	G	4688	475	1,614	4-Jun	11-Jun	7	32,425	673
3-Jun	GWP	E	4698	211	147	4-Jun	16-Jun	8	10,973	14
3-Jun	GWP	E	4708	166	61	4-Jun	18-Jun	13	11,053	20
5-Jun	GWP	G	4718	410	1,167	6-Jun	28-Jul	52	1,342,742	307
5-Jun	I-5/UB	G	4728	350	744	8-Jun	28-Jul	11	2,179	42
12-Jun	SR 520	G	4808	470	1,865	14-Jun	17-Jul	7	--	1,884

APPENDIX 2. Northern pikeminnow tagged with Vemco acoustic tags in the LWSC, 2006-2008. Location is the area where the fish were captured and released. Tag model specifications are given in Table 2. Depth tags used in 2007 had two alternating identification codes; the first code (Tag ID A) provided the depth information and the second code (Tag ID B) provided the unique code. Percent body weight is the tag weight to fish weight percent, which includes HTI tags if two tags were used (bold numbers).

Year Date released	Location	Tag model	Tag ID A	Tag ID B	Fork length (mm)	Weight (g)	Percent body weight
2006							
9-Jun	Gas Works Park	V9-2L	211		355	500	**1.82**
14-Jun	West Montlake Park	V13-1L	193		385	528	2.08
14-Jun	West Montlake Park	V9P-1L	254		310	380	1.37
16-Jun	Gas Works Park	V13-1L	201		380	560	**2.23**
30-Jun	Gas Works Park	V13-1L	17223		395	740	1.49
6-Jul	Gas Works Park	V9P-1L	251		370	500	**1.92**
6-Jul	Gas Works Park	V13-1L	17222		425	800	**1.93**
19-Jul	Aurora Bridge	V13P-1L	246		325		
2007							
10-May	North Portage Bay	V13P-1L	230	12467	445	1,100	**1.49**
10-May	North Portage Bay	V9P-2L	221	12458	390	750	**1.44**
10-May	North Portage Bay	V9P-2L	220	12457	325	329	1.95
17-May	North Portage Bay	V9-2L	4355		330	400	**2.28**
18-May	West Montlake Park	V9-2L	4353		220	106	4.43
22-May	North Portage Bay	V13P-1L	136		435	920	1.30
24-May	SR 520 bridge	V13P-1L	119		430	1,060	**1.55**
24-May	SR 520 bridge	V13P-1L	111		427	1,020	**1.61**
24-May	SR 520 bridge	V13P-1L	134		413	920	**1.78**
31-May	SR 520 bridge	V9P-2L	225	12462	400	700	**1.54**
31-May	SR 520 bridge	V9P-2L	228	12465	340	530	**2.04**
6-Jun	SR 520 bridge	V13P-1L	112		460	1,280	**1.28**
6-Jun	SR 520 bridge	V13-1L	4366		425	1,020	**1.61**
6-Jun	SR 520 bridge	V13P-1L	113		415	840	**1.83**
6-Jun	SR 520 bridge	V9-2L	4354		420	930	**0.98**
6-Jun	SR 520 bridge	V13P-1L	116		435	1,040	**1.58**
6-Jun	SR 520 bridge	V9-2L	5271		441	1,020	**0.89**
15-Jun	SR 520 bridge	V13-1L	5272		410	890	**1.73**
28-Jun	University Bridge	V13-1L	17187		360	510	**2.45**
2008							
21-May	North Portage Bay	V13-1L	22508		380	750	1.47
21-May	North Portage Bay	V13-1L	22509		445	1,100	1.00
21-May	North Portage Bay	V13-1L	22507		475	1,580	0.70
21-May	North Portage Bay	V13-1L	22506		435	1,120	0.98
28-May	North Portage Bay	V13-1L	22510		430	1,171	0.94
17-Jul	Gas Works Park	V13-1L	22505		418	800	1.38
17-Jul	Gas Works Park	V9-2L	22513		328	370	1.27

APPENDIX 3. Smallmouth bass tagged with Vemco acoustic tags in the LWSC in 2006. Location is the area where the fish were captured and released. Tag model specifications are given in Table 2. Percent body weight is the tag weight to fish weight percent, which includes HTI tags if two tags were used (bold numbers).

Date released	Location	Tag model	Tag ID	Fork length (mm)	Weight (g)	Percent body weight
2-May	North Portage Bay	V13-1L	208	370	1,020	1.08
4-May	North Portage Bay	V13-1L	202	385	1,090	1.01
4-May	University Bridge	V9-2L	213	245	200	2.35
15-May	North Portage Bay	V13-1L	210	450	1,400	0.79
23-May	Gas Works Park	V13-1L	192	415	1,440	**1.07**
23-May	Gas Works Park	V9-2L	212	327	600	**1.52**
23-May	Gas Works Park	V13-1L	205	370	900	**1.71**
23-May	Gas Works Park	V9P-1L	253	335	800	**0.84**
1-Jun	Gas Works Park	V13-1L	204	370	924	**1.35**
14-Jun	West Montlake Park	V9P-1L	255	245	212	2.45
14-Jun	North Portage Bay	V9-2L	214	193	128	3.67
16-Jun	I-5 Bridge	V9-1L	3891	250	260	**1.96**
16-Jun	I-5 Bridge	V9-1L	3893	230	179	**2.44**
16-Jun	I-5 Bridge	V9-1L	3873	230	196	1.84
21-Jun	West Montlake Park	V13-1L	196	343	580	1.90
21-Jun	I-5 Bridge	V13-1L	200	408	1,260	**1.23**
27-Jun	Gas Works Park	V13-1L	194	340	520	**2.40**
27-Jun	Gas Works Park	V13-1L	198	285	376	2.93
27-Jun	Gas Works Park	V13-1L	206	275	372	2.96
27-Jun	Gas Works Park	V13-1L	209	285	351	3.13
27-Jun	Gas Works Park	V13-1L	17192	265	325	3.38
27-Jun	Gas Works Park	V9P-1L	252	265	272	1.91
27-Jun	Gas Works Park	V9-1L	3895	260	286	1.26
27-Jun	Gas Works Park	V9-1L	3898	230	194	1.86
27-Jun	Northeast Lake Union	V9-1L	3896	262	276	1.30
30-Jun	Gas Works Park	V9-6L	817	255	278	1.04
30-Jun	Gas Works Park	V13-1L	17191	270	324	3.40
6-Jul	I-5 Bridge	V9-6L	825	225	185	**2.38**
6-Jul	I-5 Bridge	V13-1L	17190	330	600	**2.57**
6-Jul	Gas Works Park	V9-6L	822	280	300	**1.47**
6-Jul	Gas Works Park	V9-6L	816	235	221	**1.99**
6-Jul	Gas Works Park	V13-1L	17189	395	1,200	**1.28**
6-Jul	Gas Works Park	V9-6L	815	290	375	**1.17**
19-Jul	Gas Works Park	V13-1L	17186	255		
19-Jul	Gas Works Park	V13-1L	17185	227	733	1.50

APPENDIX 4. Smallmouth bass tagged with Vemco acoustic tags in the LWSC in 2007 and 2008. Location is the area where the fish were captured and released. Tag model specifications are given in Table 2. Depth tags used in 2007 had two alternating identification codes; the first code (Tag ID A) provided the depth information and the second code (Tag ID B) provided the unique code. Percent body weight is the tag weight to fish weight percent, which includes HTI tags if two tags were used (bold numbers).

Year Date released	Location	Tag model	Tag ID A	Tag ID B	Fork length (mm)	Weight (g)	Percent body weight
2007							
18-May	West Montlake Park	V9P-2L	222	12459	370	940	**0.84**
18-May	West Montlake Park	V13P-1L	117		425	1,520	**1.08**
18-May	Gas Works Park	V13P-1L	231	12468	435	1,580	**1.04**
22-May	North Portage Bay	V9P-2L	229	12466	330	520	1.23
22-May	Gas Works Park	V13-1L	4364		365	760	**2.03**
22-May	Gas Works Park	V13-1L	4362		370	800	**1.93**
22-May	Gas Works Park	V9-2L	4349		310	520	**1.75**
22-May	Gas Works Park	V13-1L	4361		340	720	**2.14**
22-May	Gas Works Park	V9-2L	4352		240	209	2.25
23-May	University Bridge	V13-1L	4360		340	700	**2.20**
23-May	University Bridge	V9-2L	4351		318	500	**1.82**
23-May	I-5 Bridge	V9P-2L	223	12460	348	720	**1.50**
24-May	North Portage Bay	V13-1L	4358		312	480	2.29
24-May	North Portage Bay	V13-1L	4365		350		
7-Jun	West Montlake Park	V9-2L	4347		265	297	1.58
11-Jun	University Bridge	V9-2L	4348		375	920	**0.99**
11-Jun	University Bridge	V9-2L	5268		380	910	**1.00**
11-Jun	University Bridge	V13-1L	5273		400	900	**1.71**
11-Jun	University Bridge	V9-2L	4356		290	400	**1.55**
11-Jun	Gas Works Park	V13-1L	5274		360	700	**1.79**
11-Jun	Aurora Bridge	V13P-1L	118		415	1,250	0.96
11-Jun	Aurora Bridge	V9P-2L	224	12461	290	350	1.83
11-Jun	Aurora Bridge	V9P-2L	226	12463	300	400	1.60
11-Jun	Aurora Bridge	V9-2L	4350		275	250	1.88
11-Jun	Aurora Bridge	V9-2L	4357		280		
11-Jun	Aurora Bridge	V13-1L	4363		320	450	2.44
11-Jun	Aurora Bridge	V9-2L	5269		310	400	1.18
11-Jun	Aurora Bridge	V9-2L	5270		280		
11-Jun	Aurora Bridge	V13-1L	5275		350	600	1.83
21-Jun	North Portage Bay	V13-1L	4359		317	610	1.80
25-Jun	Gas Works Park	V13P-1L	77		450	1,430	**1.15**
25-Jun	East Lake Union	V9P-2L	227	12464	395	920	0.70
28-Jun	Gas Works Park	V13P-1L	120		400	1,100	**1.49**
3-Jul	University Bridge	V13P-1L	115		413	1,330	**1.23**
2008							
2-Jul	Gas Works Park	V9-2L	22512		415	1168	0.40
17-Jul	Gas Works Park	V13-1L	22511		390	1110	0.99
17-Jul	Gas Works Park	V9-2L	22514		345	733	0.64

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