Tabor RA, Lantz DW, Urgenson LS, Bosworth A, Warner EJ, Johnson JR. 2024. Seasonal and diel movements of adult yellow perch between two contrasting lakes (Lake Union and Lake Washington) in the Seattle metropolitan area. Northwest Science 98(1): *in press*.

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Seasonal and diel movements of adult yellow perch between two contrasting lakes (Lake Union and Lake Washington) in the Seattle metropolitan area/USFWS-SOTS

Running footer: Yellow perch movements

2 tables, 5 figures

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Abstract

We examined the seasonal movements of adult yellow perch (*Perca flavescens*) between a small, shallow lake (Lake Union) and a large, deep lake (Lake Washington). Lake Union is the largest part of the Lake Washington Ship Canal (LWSC), a narrow waterway between Lake Washington and Puget Sound. Yellow perch were implanted with acoustic tags that had a battery life of at least 460 days. All tagged yellow perch were captured and released in Lake Union in the summer of 2020 or 2021. Movements were monitored primarily with 14 stationary receivers that were deployed at key locations between the two lakes. Additional information was obtained from mobile tracking and other stationary receivers in Lake Washington. Of the 47 fish tagged, we were able to get seasonal movement data on 28 fish. Twenty-three (82%) of them left Lake Union and moved into Lake Washington while the other five (18%) remained in the LWSC. Most movements from Lake Union to Lake Washington occurred in September or October when water temperatures were decreasing. Return movements from Lake Washington to Lake Union had variable timing. Migrations between Lake Union and Lake Washington usually took just a few hours and took place day or night. The farthest observed distance moved from the release site was approximately 16 km. Within Lake Washington, tagged yellow perch were found over a broad area in the northern two/thirds of the lake. Overall, tracking results indicated yellow perch can make extensive migrations between the two lakes.

Key points:

1) Adult yellow perch from Lake Union were implanted with acoustic tags to monitor their seasonal and diel movement patterns.

2) Most yellow perch left Lake Union in the fall as temperatures were declining and migrated to Lake Washington where better overwintering conditions are present.
3) Migrations between Lake Union and Lake Washington usually took just a few hours and took place day or night.

Keywords: acoustic tags; adult yellow perch migrations; introduced species; urban lakes

Introduction

Potamodromous fishes of North America often make seasonal reproductive, feeding, and overwintering migrations (Thurow 2016). Like other fish migrations, potamodromous migratory behavior is thought to arise from separation of optimal habitats for growth, survival, and reproduction (Lucas and Baras 2001). In the Pacific Northwest, seasonal feeding migrations of piscivorous potamodromous fishes can occur in response to high abundance of migrating juvenile anadromous salmonids. This can be particularly noticeable near dams, at river mouths, and after hatchery releases because juvenile salmonids may be concentrated and vulnerable to predation. An understanding of the movements of these piscivores can help evaluate management options such as predator suppression efforts, dam operations, and hatchery release strategies.

Yellow perch (*Perca flavescens*) is a widespread introduced species in the Pacific Northwest, and their range appears to be expanding (McPhail 2007, Runciman and Leaf 2009). Because they can be abundant and consume a wide variety of prey types including small fishes, they may have important ecosystem effects (Post and Cucin 1984, Schindler and Carter 2006, Bradford et al. 2008). Although they are widespread and abundant in the Pacific Northwest, they have been understudied especially as a potential predator of juvenile salmonids (Schindler and Carter 2006). High predation rates of juvenile salmonids by yellow perch have been observed in a few instances (Dahle 1979, Miller 2012, Beck 2013) but most studies have observed little of no predation (Bonar et al. 2005). Yellow perch are considered secondary piscivores because they can take years to become piscivorous, are generally slow-moving, and are never more than 30-

40% piscivorous (Keast 1985). However, even low predation rates of salmonids may still be important if yellow perch are far more numerous than other predators.

Potamodromy in yellow perch is not well known. Reviews of yellow perch biology by Craig (2000), Lucas and Baras (2001), and Wydoski and Whitney (2003) concluded that annual distances moved by yellow perch are not extensive and most are localized. Generally, large adult yellow perch overwinter in offshore deep waters and move into shallow waters in the spring to spawn and then move farther from shore in the summer to feed (Bartoo 1972, Radabaugh et al. 2010, Feucht et al. 2023). These seasonal inshore/offshore movements can often take place in a localized area. Also, some yellow perch have relatively small home ranges (Fish and Savitz 1983, Helfman 1984). However, in some locations yellow perch appear to have extensive migrations. For example, Glover et al. (2008) found some yellow perch in Lake Michigan moved 10 to 40 km during both summer and non-summer months. In an earlier study in Lake Michigan, the maximum distance moved was 90 km (Smith and Van Oosten 1940).

For the most part, adult yellow perch in the warmer months (late spring to early fall) tend to be active during the day and inactive and rest on the bottom at night (Emery 1973, Helfman 1979, McCarty 1990, Bauer et al. 2009). At dawn, yellow perch move up in the water column and begin to feed. Some move offshore to feed on zooplankton and small fishes while others remain in the littoral zone to feed on a mixture of zooplankton and benthic prey (Scott 1955, McCarty 1990). Peak activity and feeding of yellow perch occurs primarily at dusk (Hasler and Bardach 1949, Keast and Welsh 1968, Costa 1979). During the day, individual adult yellow perch are often solitary while others are in schools and thus, they are considered facultative schoolers (Helfman 1984). Schooling by yellow perch appears to improve foraging efficiency when preying on small fishes (Nursall 1973). Although, yellow perch are primarily diurnally active, there are periods when they may be active at night. Spawning typically takes place during the night and early morning (Scott and Crossman 1973). Also, during ice conditions, yellow perch appear to be active at night, but their activity is reduced and are off the bottom and slowly swimming (Hergenrader and Hasler 1966).

In the Lake Washington basin in western Washington State, yellow perch are abundant and coexist with anadromous salmon populations. High levels of predation of migrating Chinook salmon (*Oncorhynchus tshawytscha*) by yellow perch has been documented in some widely separated areas of the Lake Washington basin (R. Tabor, unpublished data). One of these locations is the north part of Lake Union which is part of the Lake Washington Ship Canal (LWSC), a narrow-engineered waterway at the downstream end of the basin. Lake Union is a natural small shallow lake and is roughly 3.5 km from Lake Washington, a large, deep lake where large numbers of yellow perch are known to be present year-round. Large yellow perch (> 250 mm TL) have commonly been caught in Lake Union in June and July and often prey on emigrating Chinook salmon smolts during this period. It is unclear if Lake Union yellow perch represent a separate population from Lake Washington or if they represent a feeding migration from Lake Washington that could migrate to Lake Union in response to the emigration of Chinook salmon prey.

The overall objective of this study was to document the seasonal movement patterns of adult yellow perch in Lake Union and determine if they migrate to Lake Washington. Movement information of yellow perch is needed to help guide possible suppression efforts of this invasive fish species. Secondly, we were interested in determining if their seasonal migrations overlapped with emigration of Chinook salmon smolts through the LWSC. Because yellow perch are abundant and if their movements considerably overlap with Chinook salmon migrations, yellow perch have the potential to impact Chinook salmon populations. Lastly, we examined the diel movement of yellow perch when they moved between Lake Union and Lake Washington. To address these objectives, adult yellow perch in Lake Union were implanted with acoustic transmitters and their seasonal and diel movements monitored with stationary receivers.

Study Area

Lake Union and Lake Washington are in the lower portion of the Lake Washington basin, which is approximately 1,570 km^2. Lake Union is part of the Lake Washington Ship Canal (LWSC) which is a 10.8-km-long, narrow waterway that allows navigation between Lake Washington and Shilshole Bay in Puget Sound (Figure 1). The LWSC consists of five sections: Montlake Cut, Portage Bay, Lake Union, Fremont Cut, and the Salmon Bay waterway. The Fremont Cut and Montlake Cut of the LWSC are narrow channels with steep armored banks. Shorelines of the rest of the LWSC are highly developed and contain numerous marinas, commercial shipyards, and house-boat communities. The Ballard Locks located at the downstream end of the LWSC controls the water level of the LWSC and Lake Washington. Originally, Lake Union and Lake Washington were not connected. The LWSC and Ballard Locks were constructed in 1910-1920. Prior to construction of the LWSC, Lake Washington drained south to the Black and Duwamish rivers. A ridge separated Union Bay from Portage Bay and a small stream drained Lake Union into a tidally influenced Salmon Bay.

The largest part of the LWSC is Lake Union, which is 235 ha in size, has a mean depth of 10.5 m and maximum depth 16 m. Lake Union is a warm, monomictic lake that stratifies in summer. Surface water temperatures commonly exceed 21^{o}C. Water clarity is typically lower in

Lake Union than Lake Washington during the summer months (Celedonia et al. 2008). Saltwater typically intrudes into Lake Union every summer as lockages at the Ballard Locks increase and discharge levels decrease (King County 2018). The magnitude and duration of the intrusion varies from year to year but generally affects the area of the lake below 10 m depth. Besides elevated salinity, this deep area has increased temperature, sustained anoxia, and depressed pH (King County 2018). Montlake Cut, Portage Bay, and Fremont Cut have a mean depth of 9-11 m to allow for navigation of large vessels.

Upstream of the LWSC is Lake Washington, a large monomictic lake with a total surface area of 8,900 ha, mean depth of 33 m, and a maximum depth of 65 m. The lake typically stratifies from May to early November with a thermocline around 16 m. Surface water temperatures range from 6-7°C in winter to over 20°C in summer. The lake appears to have sufficient dissolved oxygen levels even in the deepest parts of the lake to support macroinvertebrate and fish communities (Thut 1969, Tabor et al. 2007). Over 78% of the shoreline is comprised of residential land use (Toft 2001).

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 20 introduced species. The history of yellow perch planting in the Lake Washington system is not clear, but they may have been present since the early 1900s (Lampman 1946). Yellow perch appear to be the most abundant of the introduced fish species in Lake Washington (Garrett et al. 2017). Anadromous salmonids in the Lake Washington system are comprised primarily of sockeye salmon (*O. nerka*), Chinook salmon, and coho salmon (*O. kisutch*). The Chinook salmon population is part of the Puget Sound Evolutionarily Significant Unit that is currently listed as threatened under the Endangered Species Act (ESA; Federal Register 64 FR

14208, March 24, 1999). Chinook salmon in the Lake Washington system outmigrate through the LWSC as subyearlings from late May through mid-July (DeVries et al. 2004) and may be particularly vulnerable to predation from predatory fishes such as yellow perch. Within the LWSC, Chinook salmon smolts typically move through most sections (e.g., Portage Bay and Fremont Cut) in less than 24 hours; however, in Lake Union, they spend one day to two weeks (Celedonia et al. 2011). Predation of Chinook salmon smolts by yellow perch in the LWSC has predominantly been documented in Lake Union with little predation observed in other sections (R. Tabor, unpublished data).

Methods

We used acoustic telemetry to determine the seasonal movements of Lake Union yellow perch. They were collected primarily through angling; however, a few were collected with gill nets (short sets of approximately 15 min). All collection efforts were conducted in north Lake Union; an area of the LWSC where large yellow perch were known to be common. After capture, fish were placed in a cooler and transported to a nearby tagging location. All tags were implanted surgically (Liedtke et al. 2012). All surgical instruments and tags were allowed to soak in a mixture of 2% Chlorhexidine disinfectant and sterile deionized water for at least 5 min and then rinsed in a 0.9% sterile saline bath immediately before implantation. Fish were anesthetized and then measured for total length (TL) and weighed (g). An incision approximately 10–20 mm long was made on the ventral side between the pectoral and pelvic fins. An acoustic tag was then inserted into the peritoneal cavity through the incision. Two or three sutures were used to close the incision. Fish were then placed in a recovery tank of fresh water. The entire operation was usually completed in 3–6 min. Fish were allowed to recover for 30-90 minutes before being released within 100 m of their capture location. A total of 47 yellow perch (mean TL = 245.3 mm; range 221–296 mm TL) were captured, implanted with acoustic tags, and released in the Lake Union (Figure 1). Twenty fish were tagged in 2020 (July–August) and 27 in 2021 (July). We used coded V9 Vemco tags that were each programmed to emit a unique identification signal at random intervals set at 80–200 seconds. All tags were on the same frequency: 69.0 kHz. The tag weight (4.7 g) was less than 3.2% of the body weight. Tag battery life was expected to be at least 460 days. Some tags had detections over 550 days after release.

Movements of tagged fish were primarily monitored with fixed receivers from July 2020 to December 2022. A total of 14 fixed Vemco VR2 receivers were deployed; nine in the LWSC, two at the west end of Union Bay (transition area between Lake Washington and the LWSC), and three in Lake Washington at the east end of Union Bay (Figure 1). Receivers provided presence/absence information and based on range tests they could typically detect tags within 300–500 m. Receivers were primarily placed in narrow gaps of the LWSC where detection probabilities would be higher. Except for the west end of Fremont Cut, we placed a receiver on both the north and south side of the LWSC to reduce the likelihood of a tagged yellow perch moving by without being detected. At each of these pairs of receivers, tags could be detected by both receivers at the same time depending on fish location; however, simultaneous detections between pairs of receivers were rare. Of the tagged yellow perch detected in Lake Washington, all were detected on multiple receivers in the LWSC.

To evaluate whether yellow perch from the LWSC were concentrated in one area of Lake Washington or occur over a broad area, we also collected some additional information from other stationary receivers as well as mobile tracking. The other stationary receivers consisted of nine receivers deployed around Lake Washington by the Muckleshoot Indian Tribe (October 2020 to May 2021) to track walleye (*Sander vitreus*) and adult anadromous salmon (*Oncorhynchus* spp.). We periodically conducted mobile surveys in Lake Washington along the central west shoreline from Sand Point to I-90 Bridge (Figure 1). We chose this shoreline because it was relatively close to the LWSC and we could conduct a survey within one day. We slowly boated along the shoreline (approximately 30 m from shore) of Lake Washington. The boat location was used as the approximate location of the fish. The mobile tracking system had a listening range of approximately 300 m. Mobile surveys were primarily conducted in the late fall and winter when yellow perch typically aggregate in deeper water. Altogether, four surveys were conducted, two in 2021 and two in 2022.

We evaluated tracking information for each fish and categorized their seasonal movements as either 1) resident fish that remained in Lake Union and other parts of the LWSC; 2) left Lake Union and moved into Lake Washington; 3) not enough data to determine their seasonal movement; or 4) fish died or tag was expelled (tag appeared to remain in one location over an extended period of time). Resident fish were defined as fish that remained in the LWSC throughout the summer and were still present on September 15 (approximate date when water temperature at 4 m depth decreases to < 20°C). To associate movements with changes in water temperatures, we deployed two temperature loggers (Hobo Tidbit model UTBI-001, Onset Computer Corporation, Bourne, MA) with one of our north Lake Union receivers. Loggers were deployed at 4-m depth. We chose this depth to be roughly the middle of the littoral zone. Yellow perch are typically found in the littoral zone during the spring and summer.

To help understand the movement pattern between the two lakes, we also calculated the numbers of hours to move between the two lakes by using the first or last detection (depending on direction moving) at I-5 Bridge receiver to first or last detection at Webster Point receiver. After accounting for the tag detection range, the distance between these two locations was roughly 2.5 km. To categorize movements between the two lakes as either day, night, or both, we used civil twilight time as the approximate time between day and night. We tested the effect of fish size at tagging on migratory pattern (migrated to Lake Washington versus remained in LWSC) and survival (category 1 and 2 versus category 3 and 4) by using Mann-Whitney *U* tests. Also, we tested size at tagging on date of migration to Lake Washington with a linear regression.

Results

We obtained seasonal movement data on 28 of the 47 tagged yellow perch (Table 1). Eleven of the other fish were detected from 4 to 45 days after tagging but were not detected or only detected once after September 15 and their seasonal movement pattern was not determined. We assumed these fish were removed by anglers or possibly birds (predators or scavengers). Eight tags never moved, and we assumed the fish died or expelled their tag. Size at tagging of yellow perch was similar between those that did not survive (n = 19; median length, 240 mm TL) to those that survived (n = 28, median length, 243.5 mm TL; Mann-Whitney U test; Z = 1.11; P = 0.27). Of the remaining 28 fish, 23 (82%) left the LWSC and moved into Lake Washington and 5 (18%) remained in the LWSC and appeared to overwinter there (Figure 2). Migration to Lake Washington was the predominant pattern for both tagging years; 81.9% (9 of 11) for the 2020 tag group and 82.4% (14 of 17) for the 2021 tag group. Of the 23 fish that moved to Lake Washington, two returned to Lake Union within a few weeks and appeared to overwinter there, eight overwintered in Lake Washington and returned to Lake Union the following late winter or spring, and the rest were only detected in Lake Washington after leaving the LWSC (Figure 2). A total of 32 movements (including some fish that moved more than once) from the LWSC to the lake were recorded. Seventy-eight percent (25 of 32) of these movements were in September or October (Figure 3) when water temperatures were decreasing (Figure 4). Timing of migrations back to the LWSC (n = 16) was variable but 44% occurred from March to May. Size at tagging of yellow perch was similar between those that remained in the LWSC (n = 5; median length, 243 mm TL; SD = 14.7) to those that migrated to Lake Washington (n = 23, median length, 244 mm TL; SD = 12.5; Mann-Whitney U test; Z = 0.03; P = 0.98). Also, there was no apparent effect of size at tagging on date of migration to Lake Washington (linear regression; r^2 = 0.008)

Movements between Lake Union and Lake Washington appeared to take a few hours, and time spent in Portage Bay, Montlake Cut, and east Union Bay appeared to be minimal. For movements from Lake Union to Lake Washington, the median time from the last detection at I-5 Bridge to first detection at Webster Point (roughly 2.5 km) was 3.85 hours (n = 32; range 0.82 to 46.4 hours). For movements from Lake Washington to Lake Union, the median time from the last detection at Webster Point to first detection at I-5 Bridge was 3.23 hours (n = 16; range 0.33 to 21.88 hours). Additionally, some movements between Lake Union and north Lake Washington were rapid. One tagged fish moved from St. Edwards Park in north Lake Washington to north Lake Union (approximately 14.5 km) in 50 hours, and this same fish moved from Lake Union to St. Edwards Park and back to Lake Union in 9 days (Table 2).

Movements between Lake Union and Lake Washington (last detection at I-5 Bridge to first detection at Webster Point and vice versa) occurred both day and night. Of the 48 movements, 16 were daylight only movements, 12 were nighttime only movements, 4 commenced during the daylight and ended that night, 13 commenced at night and ended during daylight hours, and 3 extended across more than two diel periods. Of the late summer-fall migrations (August–November; $n = 36$), 25% occurred just during the day, 28% completely at night, and 47% both day and night. For the winter and spring combined (December-May; $n = 12$), 58% occurred just during the day, 17% completely at night, and 25% both day and night (Figure 5).

Within Lake Washington, tagged yellow perch from the first-year releases were found over a broad area from St. Edwards Park in the north end to the north part of Mercer Island (Figure 1). When supplemental Lake Washington stationary receivers were operating (October 2020 to May 2021), three were detected north of Mercer Island, two at both St. Edwards and Sand Point receivers, and no detections were made on the south Lake Washington receivers. The farthest distance moved from the release site was approximately 16 km by two fish that migrated to St. Edwards Park in north Lake Washington. The range of mobile tracking detections from the second-year releases encompassed much of the survey distance (approximately 80%) from I-90 Bridge to Sand Point (Figure 1). Of these eight yellow perch, five were detected south of SR 520 bridge and three north of the bridge.

Discussion

Most yellow perch tagged in Lake Union migrated to Lake Washington. However, roughly a fifth of them remained in Lake Union and the LWSC and did not migrate to Lake Washington. Thus, there appears to be large variability among individuals on their seasonal movement patterns between the two lakes. Additionally, those that did migrate to Lake Washington were spread out over a large area and the distance migrated varied widely. Other studies of yellow perch movements have also found large variability among individuals. Mark-recapture studies of yellow perch have often found most of the recaptures are close to the tagging site, but some moved a considerable distance (Mraz 1952, Clady 1977, Glover et al. 2008). Lucchesi (1988) found there were discrete stocks in Lake Huron that returned to the same area to spawn but their movements away from the spawning area varied widely. At two sites, most fish were recaptured close to the original tag and release sites while at a third site, recaptures were over a large area. Lucas and Baras (2001) concluded that yellow perch do not exhibit substantial movements in most cases, but they may exhibit longer migrations where habitats for specific conditions are widely separated.

For most yellow perch that inhabit Lake Union during the summer, their summer foraging location may be Lake Union, but their overwinter location may be Lake Washington and thus, they undergo extensive migrations between the two water bodies. Migrations to Lake Washington primarily occurred in September and October with declining water temperatures. As water temperatures drop in the fall, yellow perch often move to deep overwinter locations (Reigle 1969, Schaefer 1977) and often inhabit the deepest parts of a lake during the winter (Becker 1983). Bartoo (1972) found yellow perch in Lake Washington in deep areas around 18 m. Also, large numbers of yellow perch were collected in Lake Washington during the winter with offshore bottom trawls (30–50 m deep; E. Warner, unpublished data). The maximum depth of Lake Union is only 16 m and water quality below 10 m depth may limit yellow perch use due to elevated salinity, low dissolved oxygen, and depressed pH (King County 2018). Water quality conditions during the winter in these deep areas of Lake Union can vary widely from year to year. In other systems, yellow perch have also shown a strong movement to overwinter sites. In a similar situation in two Iowa lakes, yellow perch moved from a shallow lake to an adjoining deep lake to overwinter (Schmitt and Hubert 1983). Also, yellow perch moved downstream out of Big Garlic River to Lake Superior in September and October as water temperatures decreased, presumably to overwinter (Manion 1977).

Movements back to Lake Union from Lake Washington were highly variable and may be related to various factors such as spawning and prey availability. Some occurred in the fall by fish that made multiple trips between the two lakes, and these migrations may have been related to locating suitable overwintering sites. Radabaugh et al. (2010) also found yellow perch movements were highest in the fall in an Iowa lake. A few of the movements we observed were in March and April which may have related to spawning. Yellow perch typically spawn in April in Lake Washington but the extent and timing of spawning in Lake Union and the LWSC is unknown. Also, there is some evidence that yellow perch home to the same spawning site year after year (Clady 1977, Lucchesi 1988), thus these may be returning to Lake Union to spawn after overwintering in Lake Washington. Post-spawning migrations in April and May may have also been related to prey availability. Major prey items of adult yellow perch in Lake Union and Lake Washington during the spring include threespine stickleback (*Gasterosteus aculeatus*; primarily eggs but also adult fish), sculpin (*Cottus* spp.), Chinook salmon smolts, longfin smelt (*Spirinchus thaleichthys*), zooplankton, and benthic invertebrates (Overman et al. 2009, R. Tabor, unpublished data). and the relative abundances and distributions of these prey items might influence movements to Lake Union. For example, yellow perch may follow the migrations of Chinook salmon smolts as the smolts emigrate from Lake Washington through the LWSC to Puget Sound. Abundances of threespine stickleback and longfin smelt vary widely from year to year (Moulton 1974, Peter Lisi, Washington Department of Fish and Wildlife, unpublished data) and yellow perch movements patterns may also vary in response to changes in prey availability.

Movement patterns and distribution of yellow perch in the LWSC often overlap with Chinook salmon smolts. These smolts migrate through the LWSC from late May through mid-July (DeVries et al. 2004), which is the same period when many yellow perch would be present in Lake Union. Within the LWSC, large yellow perch are predominately found in north Lake Union (Garrett et al. 2018), which is the same area where Chinook salmon spend most of their time while they are in the LWSC (Celedonia et al. 2011). Thus, there is substantial temporal and spatial overlap between the two species. However, it is unclear how much of yellow perch's behavior is in response to Chinook salmon smolts migrations. Chinook salmon comprises roughly 20% of the diet (mean proportion by weight) of yellow perch > 250 mm TL (R. Tabor, unpublished data). Perhaps there are also some other environmental conditions (e.g., habitat and prey availability) that attract large yellow perch to Lake Union. Another location where large yellow perch aggregate and prey on Chinook salmon smolts is Webster Point (R. Tabor, unpublished data). At both Lake Union and Webster Point, water currents change direction around a point and yellow perch may be able to take advantage of migrating or drifting prey more easily. In Lake Mendota, Wisconsin, yellow perch were attracted to areas near a point where *Daphnia* had accumulated (Hasler and Bardach 1949).

Migrations between Lake Union and Lake Washington usually just took a few hours. Based on the prolonged swimming performance of yellow perch calculated by Nelson (1989), we estimated that a 100 g individual could migrate the 2.5 km between our I-5 Bridge and Webster Point receivers in 1.8 h. Our tagged yellow perch averaged 194 g at time of tagging and would be expected to swim somewhat faster. The median time we observed between these two points was 3.85 hours. However, yellow perch may not have taken a direct route and may have rested or foraged. Overall, it does appear adult yellow perch moved rather quickly between Lake Union and Lake Washington.

To migrate between the two lakes, yellow perch must pass through Portage Bay, Montlake Cut, and the west part of Union Bay but do not appear to spend much time in these areas. Recent sampling efforts with variable-mesh gill nets in Portage Bay and the west part of Union Bay have caught yellow perch but most are relatively small (i.e., < 225 mm TL; Garrett et al. 2018). It appears large yellow perch only use this area as a migratory corridor. It is unclear why this area is not used more extensively. Perhaps because it is shallower than Lake Union or Lake Washington, or perhaps prey availability is lower. The south part of Portage Bay and much of Union Bay have extensive macrophyte beds which may limit available habitat. Chinook salmon smolts, an important prey item in May and June, also appear to migrate quickly through Union Bay and Portage Bay and spend considerably more time in Lake Union (Celedonia et al. 2011); however, this would only explain a small percentage of the yellow perch movements between Lake Union and Lake Washington. The relative abundance of other important prey items among different sections of the LWSC is not known.

Because yellow perch are considered to be diurnally active and rest on the bottom at night (Emery 1973, Helfman 1979, McCarty 1990), we expected migrations between Lake Union and Lake Washington to occur during the day. Instead, we found their movements occurred during both day and night. For many fish species, activity patterns can breakdown during migration due to an increase in predation risk (Reebs 2002). Adult yellow perch may be at risk from large cutthroat trout (*O. clarkii*) and large northern pikeminnow (*Ptychocheilus oregonensis*) but these fishes are uncommon in the LWSC (Garrett et al. 2018) and the overall predation risk for adult yellow perch is expected to be low. Diel activity patterns may also be influenced by season. Although our sample sizes were small, the percentage of yellow perch that migrated at least partially at night was higher in the fall (September-November) than during other times of the year. Switching from being diurnally active in the summer to being nocturnal has been observed in other temperate freshwater fish species (Reebs 2002) and thus yellow perch may switch to being more nocturnal as temperatures decrease in the fall and winter. Activity patterns of yellow perch in the LWSC and Lake Washington may also be quite different than other lakes because the LWSC migration corridor is in a highly urbanized area and has increased levels of artificial light at night (ALAN) which may allow yellow perch to be more active at night than in other systems. A higher percentage of movements at night during the fall compared to other seasons may have also been due to ALAN because these yellow perch would have started their migration in Lake Union where ALAN is more prevalent than in Lake Washington. Migration of Chinook salmon smolts in the LWSC has been shown to be impacted by ALAN (Celedonia et al. 2011). Some piscivorous fishes have also been shown to be more active at night with elevated ALAN (Becker et al. 2013, Nelson et al. 2021). Czarnecka et al. (2019) also found elevated levels of ALAN increased the feeding activity of the closely related Eurasian perch (*P. fluviatilis*) but its effect on the diel migration patterns of this species or yellow perch is unknown.

An important objective of this study was to provide information on yellow perch distribution to help guide possible suppression efforts and consequently reduce predation of Chinook salmon smolts. In Lake Union, suppression efforts would need to occur between May and September when yellow perch are more abundant. Yellow perch are often targeted by anglers in Lake Washington and Lake Sammamish in late fall and winter because yellow perch are in large aggregations. Similar angling efforts would likely be unproductive in Lake Union. Our tagged yellow perch from Lake Union were found over a broad area in Lake Washington and thus we were unable to identify primary locations where they overwintered and could be targeted. Additional tracking or hydroacoustic surveys are needed in Lake Washington to identify these primary locations where yellow perch aggregate and could be targeted.

In conclusion, large yellow perch appear to commonly migrate between Lake Union and Lake Washington. Most leave Lake Union in the fall as water temperatures are declining. Yellow perch likely migrate to Lake Washington where more favorable overwintering conditions such as deep water (i.e., > 15 m deep) habitats are present. Lake Washington is substantially deeper than Lake Union and water quality in Lake Union below 10 m depth can be poor. Timing of yellow perch movements from Lake Washington to Lake Union were not consistent; however, most migrations were between January to May, which may be related to either spawning or feeding.

Acknowledgements

This project was funded in part from grants by King County Cooperative Watershed Management (award number 4.8.20.016) and WRIA 8 Salmon Recovery Council. We wish to thank U.S. Fish and Wildlife Service (USFWS) employees (including Olivia Williams, Greg Byford, Keith Sweeney, Michael Elam, Marc Solano, Eric Klingberg, Hannah Ferwerda, Suzena Arias), Washington Department of Fish and Wildlife employees (Joe Short, George Chapman, Alanna Sutton, Katherine Gordon), Muckleshoot Indian Tribe employees (Eva Fuller, Jesse Nitz), Tom Friedman, and John Reese for their assistance with the field work. Suggestions by Regan McNatt and Benjamin Cross (USFWS) and three anonymous reviewers greatly improved an earlier version of this manuscript. We greatly appreciate all the assistance from the Seattle Harbor Patrol staff. The findings and conclusions in this report are those of the authors and do not necessarily represent the views of USFWS.

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Submitted 1 March 2024
Accepted 5 September 2024

Figure captions

Figure 1. Map of Lake Union and Lake Washington including other sections of the Lake Washington Ship Canal. Fixed receiver locations are shown: USFWS (U.S. Fish and Wildlife Service, solid diamonds) and MIT (Muckleshoot Indian Tribe, solid squares). Release site in north Lake Union is indicated with a star. Locations where tagged yellow perch were detected with mobile tracking equipment is also shown (open circles). Mobile tracking (dashed line) only occurred along the west shore of Lake Washington from I-90 Bridge to Sand Point.

Figure 2. Weekly presence data of tagged yellow perch from three areas of the lower Lake Washington system, June 2020 – November 2022. Lake Union area includes Lake Union, east Fremont Cut and west Portage Bay; Montlake Cut area includes east Portage Bay, Montlake Cut, and west Union Bay. All detections from stationary hydrophones and mobile tracking were included. Vertical lines indicate the release time (left lines) and expected end of tag life (right lines). Shaded areas indicate period (late May-mid July) when Chinook smolts would be expected to be migrating through the LWSC. Figure only includes the 28 tagged yellow perch that we were able to get seasonal movement data. Fish numbers correspond to fish numbers in Table 1.

Figure 3. Monthly percent of all yellow perch migrations between the Lake Union (LU) and Lake Washington (LW). Results are from 23 tagged fish that were tagged in Lake Union (July–August 2020 and July 2021) and migrated between Lake Union and Lake Washington; n = the number of all movements between the two water bodies; some fish undertook more than one

migration. Five additional fish were tagged in Lake Union but did not migrate to Lake Washington.

Figure 4. Mean daily temperatures in north Lake Union at 4-m depth (solid line) and temperatures at that site (symbols) when yellow perch migrated between Lake Union (LU) and Lake Washington (LW), July 2020 to December 2022. Solid symbols represent Lake Union to Lake Washington movements and open symbols represent Lake Washington to Lake Union movements. Different symbols were used for the two release groups (July-August 2020 and July 2021). Overlapping values were offset slightly for graphical purposes. No temperature data was available from November 11, 2020 to February 21, 2021.

Figure 5. Percent of yellow perch movements between Lake Union and Lake Washington that occurred in different diel categories, July 2020-November 2022. Diel categories: D only = occurred during the day, N only occurred at night, D / N = commenced during the daylight and ended that night, N / D = commenced at night and ended during daylight hours, D to D = commenced during the daylight and extended until daylight hours of the next day, N to N = commenced at night and extended until the next night. n = the number of all movements between the two water bodies; some fish undertook more than one migration.

Tables

Table 1. Tagging and detection information of yellow perch implanted with acoustic tags from Lake Union, July 2020-November 2022. Table only includes the 28 tagged yellow perch that we were able to get seasonal movement data. Yellow perch were caught and released on the same day. TL = total length. Tagged yellow perch with seasonal movement data were put into two categories: 1) resident fish that remained in Lake Union and other parts of the LWSC, or 2) left Lake Union and moved into Lake Washington. Detection information is from 14 stationary receivers located in the LWSC and in Lake Washington at the east end of Union Bay.

Fish number	Tag number	Release date	TL (mm)	Category	Number of detections	Number of days detected	Last detection: Date	Last detection: Location	Last detection: Days from release
1	40334	7/20/2020	255	2	71,196	338	9/21/2021	Webster Point	428
2	40335	7/20/2020	258	2	13,895	72	10/1/2020	Webster Point	73
3	40336	7/20/2020	235	2	27,041	164	7/14/2021	Lake Union	359
4	40337	7/20/2020	235	2	96,186	445	2/10/2022	Lake Union	570
5	40339	7/27/2020	240	2	33,606	181	2/9/2021	Fremont Cut	197
6	40341	7/27/2020	240	2	9,447	72	10/14/2020	Webster Point	79
7	40352	7/27/2020	263	1	88,357	471	2/1/2022	Lake Union	554
8	40353	7/27/2020	259	1	1,354	130	2/1/2022	Fremont Cut	554
9	40356	7/27/2020	241	2	61,192	427	2/1/2022	Webster Point	554
10	40359	8/14/2020	256	2	62,514	306	2/9/2022	Webster Point	544
11	40361	8/14/2020	234	2	38,845	142	1/14/2022	Webster Point	518
12	60569	7/14/2021	241	2	29,167	83	2/1/2022	Portage Bay	202
13	60570	7/14/2021	273	2	9,181	95	12/28/2021	Webster Point	167
14	60571	7/14/2021	234	1	9,559	95	10/20/2021	Lake Union	98
15	60572	7/14/2021	243	2	22,908	182	8/31/2022	Lake Union	413
16	60576	7/14/2021	244	1	23,214	165	1/5/2022	Lake Union	175
17	60579	7/14/2021	233	2	20,973	112	3/17/2022	Portage Bay	246
18	60581	7/19/2021	250	2	27,495	110	5/20/2022	Webster Point	305
19	60582	7/19/2021	230	1	27,925	203	3/5/2022	Lake Union	229
20	60583	7/26/2021	270	2	67,323	388	11/3/2022	Webster Point	465
21	60584	7/26/2021	246	2	30,250	132	5/13/2022	Webster Point	291
22	60585	7/26/2021	236	2	15,347	79	10/14/2021	Webster Point	80
23	60586	7/26/2021	250	2	17,900	201	11/1/2022	Fremont Cut	463
24	60587	7/26/2021	253	2	20,535	205	11/3/2022	Webster Point	465
25	60588	7/26/2021	249	2	33,365	127	1/1/2022	Webster Point	159
26	60590	7/28/2021	262	2	11,804	97	2/9/2022	Webster Point	196
27	60591	7/28/2021	238	2	8,896	89	3/3/2022	Webster Point	218
28	60594	7/28/2021	221	2	14,990	136	3/17/2022	Lake Union	232

Table 2. Movements of yellow perch # 40359; an example of a fish we were able to track for 543 days that made extensive migrations between Lake Union (LU) and Lake Washington (LW) and was detected in multiple locations in Lake Washington. This fish was tagged and released on August 14, 2020, and was 259 mm total length on the day of tagging. Data are from stationary receivers except one mobile tracking data point on January 22, 2022. Locations are shown in Figure 1.

Start date	End date	Number of days	Lake	Location
August 14, 2020	October 4, 2020	51.1	LU	North Lake Union
October 4, 2020	October 8, 2020	3.8	LW	Webster Point
October 9, 2020	October 10, 2020	0.6	LW	Sand Point
October 10, 2020	October 12, 2020	1.3	LW	St. Edwards Park
October 12, 2020	October 12, 2020	0.4	LW	Sand Point
October 13, 2020	October 13, 2020	0.7	LW	Webster Point
October 14, 2020	October 18, 2020	4.3	LU	North Lake Union
October 19, 2020	November 2, 2020	14.8	LW	Webster Point
November 4, 2020	November 11, 2020	7.7	LW	Sand Point
November 14, 2020	January 3, 2021	50.3	LW	St. Edwards Park
January 4, 2021	May 25, 2021	141.6[a]	LW	Sand Point
May 25, 2021	May 26, 2021	0.5	LW	Webster Point
May 26, 2021	October 28, 2021	155.4	LU	North Lake Union
October 29, 2021	November 7, 2021	9.6	LW	Webster Point
January 20, 2022	January 20, 2022	0.1	LW	Webster Point
January 22, 2022[b]			LW	Sand Point
February 8, 2022	February 8, 2022	0.1	LW	Webster Point

a - period included several breaks in detection; tag was detected 57 of the 141 days
b - from mobile tracking