U.S. Fish and Wildlife Service

Restoration monitoring of the Shuffleton Power Plant flume site in south Lake Washington

Final Report, 2011—2017

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Before - Jan. 2013


After - Jan. 2015

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Summary

To determine if a Washington State Department of Natural Resources restoration project in south Lake Washington improved juvenile Chinook salmon (*Oncorhynchus tshawytscha*) habitat conditions, we monitored fish abundance three years before the project (2011-2013) and three years after the project (2015-2017). The restoration project involved removing 168 m of an old metal flume structure and replacing it with open gravel/sand beaches and three engineered logjams (ELJs). Twice a month from January to June we conducted nighttime snorkeling transects in shallow water to estimate the abundance of Chinook salmon and other fishes. A BACI (before-after-control-impact) study design was used to assess changes in fish abundance. The restoration project appeared to have a strong positive effect on juvenile Chinook salmon abundance. There were roughly nine times as many Chinook salmon observed along the flume transect (open gravel/sand beach post-project) after the restoration project than before the project, while there was little difference in the control sites pre- and post-project. In addition, Chinook salmon were commonly abundant at the ELJs and their densities from January to April were substantially higher than a small natural logjam and along the open gravel/sand shorelines. Warmwater fishes (nonnative centrarchids and percids) were also common at the ELJs but they were only abundant in May and June, when Chinook salmon numbers at these sites were low. In conclusion, removal of the flume structure and replacing it with a more natural shoreline appeared to have improved juvenile Chinook salmon habitat conditions in south Lake Washington. The restored nearshore area now has a large area of preferred habitat for juvenile Chinook salmon (shallow water < 1 m deep, primarily sand and gravel substrate, a gentle slope, and some nearby logjams for refuge).

Introduction

A key component of habitat restoration projects is biological monitoring to establish the effectiveness of the project to target species. Puget Sound Chinook salmon (*Oncorhynchus tshawytscha*) are currently listed as threatened under the Endangered Species Act and many restoration projects have been designed to improve their habitat conditions in lotic and lentic environments. The Washington Department of Natural Resources (WDNR) completed a large restoration project in the south end of Lake Washington to benefit Chinook salmon. Both pre- and post-project monitoring of this project were needed to determine if shoreline conditions have been improved for juvenile Chinook salmon. This report presents data from six years of monitoring (three years of pre-project monitoring and three years of post-project monitoring).

Puget Sound Chinook salmon are primarily “ocean-type” which typically emigrate to the marine environment as subyearlings. During their three to five month juvenile freshwater phase they can inhabit a wide range of habitat types including large rivers, small streams, lakes, and estuaries (Healey 1991). Ocean-type Chinook salmon commonly have two groups of emigrants; a group that moves downstream as fry and rears in estuaries, coastal ocean habitats, or lakes and another group that rears in the natal river system and emigrates as parr or smolts (Healey 1991).

In the Lake Washington system, the major Chinook salmon spawning tributary is the Cedar River and large numbers of fry emigrate from January to April to rear in the south end of Lake Washington. These fish prefer shallow, non-armored (no bulkheads or rip rap) shorelines with sand and gravel substrates that have both open beaches and areas with riparian vegetation that provide woody debris and overhanging vegetation (Tabor et al. 2011a). However, the Lake Washington shoreline has been extensively developed and resource managers have looked for opportunities to improve shoreline habitat conditions. The abundance of juvenile Chinook salmon is substantially higher at sites close to the mouth of the Cedar River (Tabor et al. 2006). Therefore, restoration projects close to the Cedar River are likely to have a stronger effect on the Chinook salmon population than projects located further away.

One good location for a restoration project was the Shuffleton Power Plant flume structure because it had poor habitat conditions, was relatively large, and was only about a half of a kilometer from the mouth of the Cedar River. The flume was built to help cool water from the adjacent power plant that began operation in 1929. The power plant has been torn down and replaced with apartments and a hotel and thus the flume structure was no longer used. This restoration site is relatively large in comparison to other potential restoration sites in Lake Washington. The flume structure was part of a 360-m long shoreline section owned by WDNR. The flume structure consisted of two parallel, vertical steel walls that resulted in poor habitat conditions (i.e., little shallow water, no sand or gravel substrates, and little structural complexity) for juvenile Chinook salmon. Also, the steep walls were likely habitat for predators of juvenile Chinook salmon such as smallmouth bass (*Micropterus dolomieu*). The area between the two walls was usually extremely turbid and likely had poor water quality for juvenile Chinook salmon. In the summer of 2014, a 168-m long section of the flume structure was removed and replaced with a gentle-sloping gravel/sand beach (see cover photos) and engineered logjams (ELJs).

The overall objective of this study was to monitor the abundance of juvenile Chinook salmon and other fishes at the Shuffleton Power Plant flume structure site before and after the restoration project, which was completed during the summer of 2014.

Methods

Standard Snorkel Transects

Night snorkeling was used to monitor the Shuffleton Power Plant flume structure site and control sites for six years; three pre-project monitoring years (2011-2013) and three post-project monitoring years (2015-2017). Snorkeling allowed us to effectively survey a variety of habitat types and no handling of fish was required. Night surveys were undertaken to minimize the effect the snorkeler had on the behavior of juvenile Chinook salmon. At night, juvenile Chinook salmon typically are inactive, rest near the bottom, can be easily approached by snorkelers, and can be accurately counted.

Five standard snorkel transects were established in the south end of Lake Washington (Table 1; Figure 1); one along the outside edge of the flume wall (see cover photos) and four other transects that represented a wide-range of habitat conditions in the south end of Lake Washington. Two of the other transects are also part of the WDNR shoreline and were part of the restoration project (Figures 1 & 2). The last two transects were in Gene Coulon Park (City of Renton) and were used as control sites. Length of transects was based on easily recognizable landmarks (e.g., edge of piers) and obvious changes in habitat type (e.g., edges of logjams and abrupt changes in substrate size).

Transects were snorkeled twice a month from late January to early June for a total of ten surveys. Snorkelers swam parallel to the shore along the 0.4-m depth contour for shallow, non-armored transects. Because the armored transects had a vertical wall, the snorkeler swam parallel to the vertical wall and approximately 1 m from it so that fish close to the wall could be easily observed. Because juvenile Chinook salmon typically inhabit water less than 1-m deep and close to shore (Tabor et al. 2011a), we felt that surveys of both non-armored and armored shorelines provided a good estimate of the abundance of juvenile Chinook salmon in that general area. Transect widths were standardized at 2.5 m for shallow, non-armored transects (0.4 m) and 2.0 m for armored, deep transects. Snorkelers visually estimated the transect width and calibrated their estimation at the beginning of each survey night by viewing a pre-measured staff underwater.

Snorkeling began shortly after sunset (45 min to 1 h after posted sunset time). Snorkelers used an underwater flashlight to observe the fish. All fish were counted and identified to species or lowest taxonomic category that could be determined accurately through snorkeling (e.g., cutthroat trout [*O. clarkii*] and rainbow trout [*O. mykiss*] were grouped together as trout). We also recorded separate counts for different life stages (juvenile, subadult, adult). Sculpin (*Cottus* spp.) were divided into those less than and greater than 75 mm total length (TL). Sculpin in Lake Washington consist of two species, coastrange sculpin (*C. aleuticus*) and prickly sculpin (*C. asper*) (Tabor et al. 2007); however, we made no attempt to distinguish the two species.

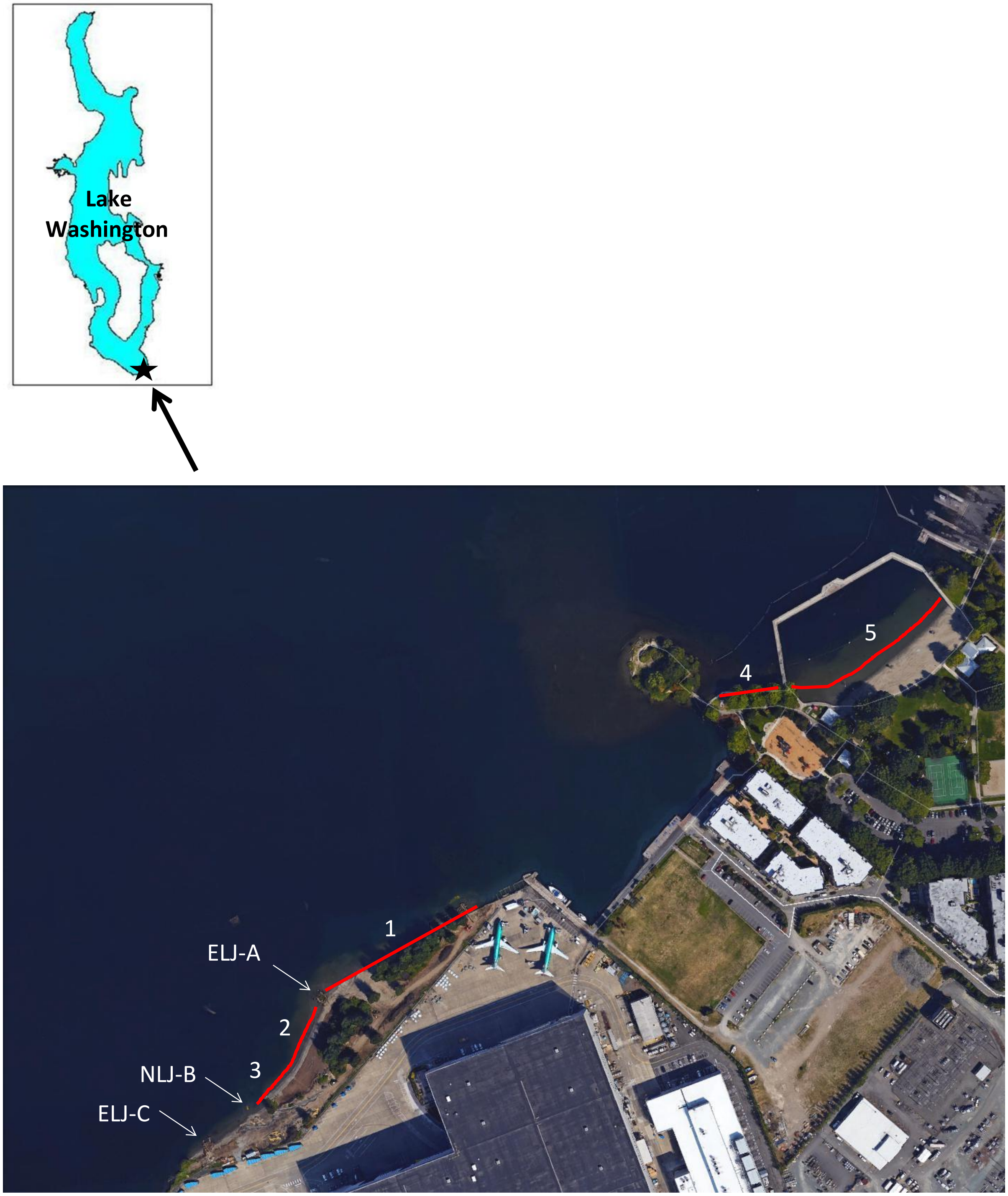

FIGURE 1.— Location of five transects (#'s 1-5) and three logjams (A-C) used to monitor abundance of juvenile Chinook salmon in the south end of Lake Washington, January-June 2011-2017. Transect numbers correspond to numbers in Table 1. The land adjacent to transect #'s 1-3 and logjam A-C is WDNR property. The developed property to the southeast of WDNR property is The Boeing Company property. Transects #'s 4 and 5 are in City of Renton's Gene Coulon Park. ELJ = engineered logjam; NLJ = natural logjam.

FIGURE 2.— Before and after photos of the cove snorkel transects. In the upper photo, part of the cove-cobble transect is in the foreground, the cove-sand transect is in the upper right, and the flume structure can be seen in the background. In the lower photo, part of the old cove-sand transect is in the foreground and an engineered logjam (ELJ-A) can be seen in the background.

On each survey night, we also took a water temperature (^{o}C) and a Secchi depth (m) measurement at the boardwalk between transects #'s 4 and 5. Water temperatures were taken at 0.5 m depth near the shoreline. A dive light was used to observe the Secchi disc (0.2-m diameter disc with alternating black and white quadrants). Preliminary measurements indicated taking Secchi depth measurements at night with a dive light gave similar results as taking them during the day.

TABLE 1.— Names and habitat characteristics of five snorkel transects in the south end of Lake Washington, January-June 2011-2013 and 2015-2017. Transect measurements were taken in 2011 and 2015. Highlighted cells in yellow indicate changes in 2015-2017 from 2011-2013. GC = Gene Coulon Park (City of Renton). The depth was taken along the midpoint of each transect. The distance offshore is the distance from the shoreline to the midpoint of each transect.

Pre-project 2011-2013

Transect #	Transect name	Armored shore?	Length (m)	Width (m)	Depth (m)	Distance offshore (m)	Substrate
1	Flume	Yes	100	2.0	2.5 - 4.7	1	100% steel wall
2	Cove-sand	No	45	2.5	0.4	2 - 5	100% sand
3	Cove-cobble	No	34	2.5	0.4	4 - 6	88% cobble, 12% gravel
4	GC bulkhead	Yes	57	2.0	0.4 - 0.9	1 - 2	10% sand, 26% gravel, 48% cobble, 16% cement wall
5	GC swim beach	No	140	2.5	0.4	8 - 12	100% sand

Post-project - 2015-2017

Transect #	Transect name	Armored shore?	Length (m)	Width (m)	Depth (m)	Distance offshore (m)	Substrate
1	Old flume site	No	100	2.5	0.4	2 - 3	30% sand, 70% gravel
2	Old cove-sand site	No	45	2.5	0.4	2 - 4	30% sand, 70% gravel
3	Old cove-cobble site	No	34	2.5	0.4	2 - 3	30% sand, 70% gravel
4	GC bulkhead	Yes	57	2	0.4 - 0.9	1 - 2	10% sand, 26% gravel, 48% cobble, 16% cement wall
5	GC swim beach	No	140	2.5	0.4	8 - 12	100% sand

Initial habitat information (substrate and slope) was collected in 2011 to help characterize each transect (Table 1). Habitat conditions did not appear to have changed from 2011 to 2013 and no additional habitat information was collected. In 2015, we measured the flume and cove transects again to determine how the habitat had changed as a result of the restoration project. For each transect, we established three to five equal-spaced measurement lines that ran perpendicular from shore. At each measurement line, water depth was measured every 2 m from shore until the water depth was 1 m. Also at 0.5 m depth of each measurement line, we estimated the substrate composition within a 1-m-diameter circle around that point.

Logjam Surveys

Snorkel surveys of logjams (i.e., large woody debris piles) were also conducted in 2016 and 2017. The surveys consisted of a single transect around the outside perimeter of three logjams. Two of the logjams were engineered logjams (ELJ-A and ELJ-C) with several large overlapping pieces (Figure 3) while the third logjam was a small natural logjam (NLJ-B) consisting only of a few pieces of wood. The restoration project also included one additional ELJ located at the east end of the restoration area but we did not survey this ELJ because water visibility was consistently poor due to a nearby outflow pipe. Logjam surveys were conducted at night on the same dates as our standard snorkel transects. We observed fish from the shoreline on one side of the logjam to the outside edge of the logjam and then back to the shoreline on the opposite side of the logjam. Maximum depth on the outside edge of the logjam varied from 0.75 to 0.8 m in February and March to 1.2 to 1.4 m in May and June. For each transect, we were able to effectively observe fish throughout the water column. The length of the logjam transects varied with lake level: ELJ-A 15 to 26 m, NLJ-B 7 to 14 m, and ELJ-C 32 to 40 m. Transect width was 2 m. Because of the complexity of the logjams, we were not able to observe the inner parts of each logjam and we assume our fish counts are an underestimate of the actual number present.

FIGURE 3.— Photo of a newly constructed engineered logjam (ELJ-A, January 15, 2015). From January to June, the lake level rises approximately 0.6 m to inundate much of the logjam shown.

Data Analysis

Our basic study design was a BACI (before-after-control-impact) design (Stewart-Oaten et al. 1986). The difference in Chinook salmon density between a restoration (i.e., impact) transect and a control transect was determined for each sample night (Stewart-Oaten et al. 1986; Smith et al. 1993). Mann-Whitney *U* tests were used to compare Chinook salmon density at each set of restoration and control transects (Smith et al. 1993). Additionally we calculated a combined Chinook salmon density for restoration transects (all three restoration transects pooled together) and compared it to each control transect as well as a combined control transect. Nights that had zeros in both the restoration and control transects were not included in the analysis (Smith et al. 1993).

To compare Chinook salmon abundance between logjams, we used a Friedman two-way analysis of variance test (a nonparametric repeated measure ANOVA) (Systat 2009). Data from 2016 and 2017 were pooled together to provide an adequate sample size.

Results

Ten nighttime standard snorkel surveys were completed each year except in 2011 and 2013 when only nine surveys were completed (Appendices A-1 to A-5). Poor visibility conditions in late January 2011 and early May 2013 forced us to skip two surveys. Water visibility and weather conditions were adequate for conducting snorkel surveys on all other survey nights; however, we were not only able to do some surveys at the Gene Coulon swim beach in May or June due to poor visibility conditions (presumably due to human swimming activity during the day). During 2016 and 2017 surveys, logjam surveys were also conducted (Appendices B-1 and B-2).

Water temperatures and Secchi depth reading were often variable between years but there did not appear to be any strong overall difference between pre- and post-project monitoring years (Figure 4). For water temperature, an ANCOVA (analysis of covariance) and Tukey's multiple comparison tests indicated the only comparison that was marginally statistically different was between two post-project years: 2015 and 2017 ($P = 0.06$). Secchi readings among years were not statistically different (one-way ANOVA, $P = 0.915$).

Juvenile Chinook salmon.— In comparison to the pre-project monitoring years (2011-2013), substantially more juvenile Chinook salmon were observed along the old flume transect in the post-project monitoring years 2015-2017 (Figure 5). A total of 791, 1,533, and 1,093 juvenile Chinook salmon were observed along the old flume transect in 2015, 2016 and 2017, respectively. In comparison, at the same site, only 39 were observed in 2011, 98 in 2012, and 227 in 2013. A peak number of 414 juvenile Chinook salmon (1.66 fish/m^2) were observed along the old flume transect on February 16, 2016. The mean number of juvenile Chinook salmon observed along the flume transect (January to May) was significantly higher for the years after the restoration than before (*t*-test assuming unequal variances, $P = 0.048$). For the other four standard snorkel transects, there was no significant difference in the mean number of juvenile Chinook salmon observed (January to May) among the years before and after the restoration project.

Differences in the density of Chinook salmon between the flume transect and each of the control transects as well as the combined control transect were significantly greater after the restoration project than before (Table 2; Figures 6, 7 & 8), thus indicating a positive effect of the restoration project. The cove-cobble and the combined restoration transect also showed a positive effect of the restoration project when compared to the Gene Coulon bulkhead control but not to the Gene Coulon swim beach control. In contrast, the cove-sand showed a negative effect of the restoration project when compared to the Gene Coulon swim beach control but not to the Gene Coulon bulkhead control.

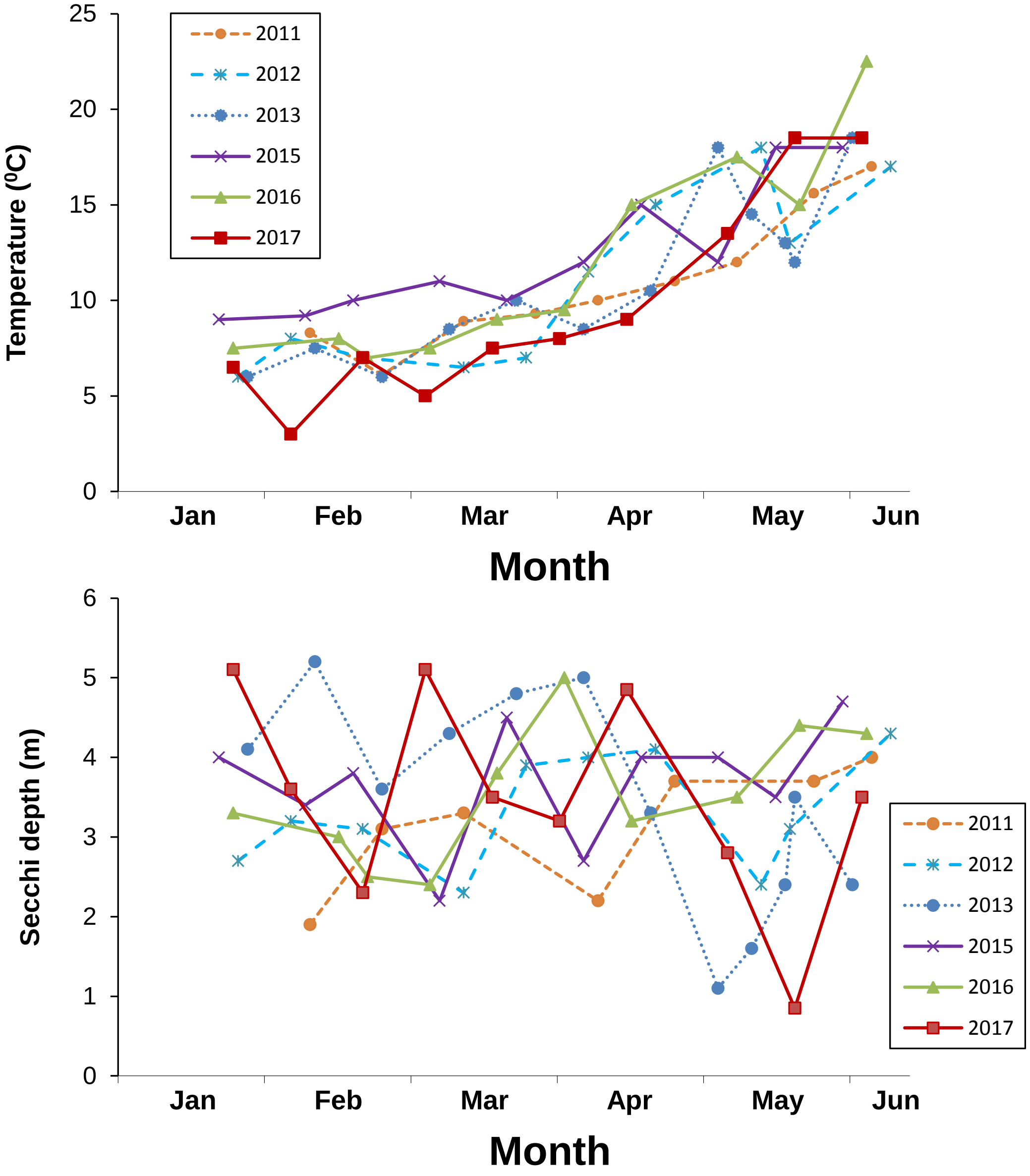

FIGURE 4.— Temperature (^{o}C) and Secchi depth (m) measurements at Gene Coulon Park, January to June 2011-2013 (dashed lines - pre-project monitoring) and 2015-2017 (solid lines - post-project monitoring). Measurements were taken on the boardwalk between transects #'s 4 and 5.

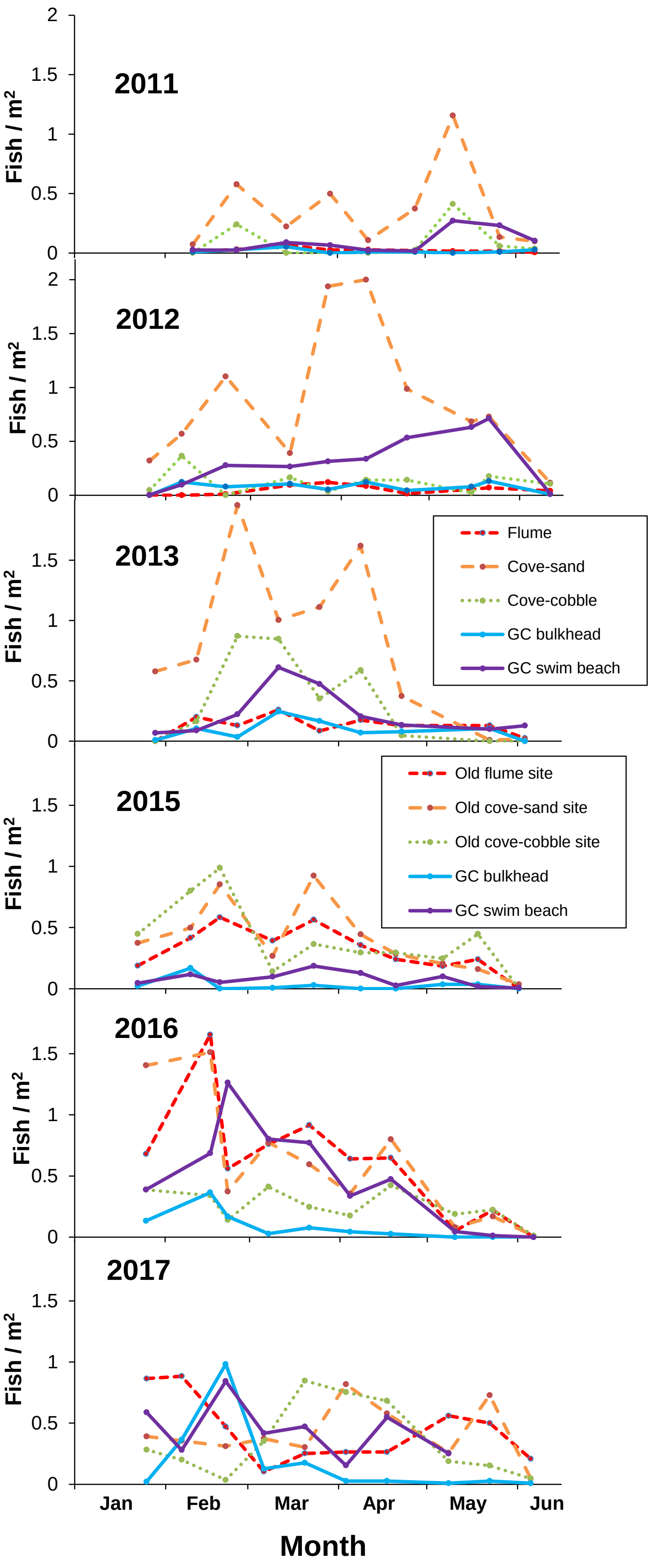

FIGURE 5.— Density (fish/m^2) of juvenile Chinook salmon at five transects in the south end of Lake Washington, January-June 2011-2013 and 2015-2017. Restoration transects are dashed lines while control transects are solid lines. Pre-project monitoring was conducted in 2011-2013 and post-project monitoring in 2015-2017. GC = Gene Coulon Park.

During the 2017 surveys, there was a notable outlier when 140 (0.98 fish/m^2) juvenile Chinook salmon were observed along the Gene Coulon bulkhead control transect on February 21 (Figures 5 & 6). This density was roughly 3 to 100 times higher than what was observed at this transect on other surveys. Why so many juvenile Chinook salmon were present on February 21, 2017 is unclear; however, many were near an outflow pipe from the park and recent heavy rain events may have attracted them to this area (Tabor et al. 2011b).

TABLE 2.— Results of statistical tests (Mann-Whitney *U* tests) to compare the differences in Chinook salmon densities between restoration and control transects, south Lake Washington, January-June 2011-2013 (pre-project) and 2015-2017 (post-project). Significant *P*-values ($P < 0.05$) are in bold. The combined restoration transect is based on pooled data from the three restoration sites and the combined control transect is based on pooled data from the two control transects.

Comparison		Sample size		Rank sums			
Control transect	Restoration transect	Pre-project	Post-project	Pre-project	Post-project	*U*-statistic	*P*-value
Gene Coulon bulkhead	Flume	28	30	502	1,209	744	**< 0.001**
Gene Coulon bulkhead	Cove-cobble	26	29	581	959	524	**0.013**
Gene Coulon bulkhead	Cove-sand	28	30	925.5	785.5	320.5	0.122
Gene Coulon bulkhead	Combined	28	30	668	1,043	578	**0.014**
Gene Coulon swim beach	Flume	28	27	546	994	616	**< 0.001**
Gene Coulon swim beach	Cove-cobble	28	27	701	839	461	0.162
Gene Coulon swim beach	Cove-sand	28	27	907	633	255	**0.038**
Gene Coulon swim beach	Combined	28	27	695	845	467	0.134
Combined	Flume	28	27	531	1,009	631	**< 0.001**
Combined	Cove-cobble	28	27	698	842	464	0.148
Combined	Cove-sand	28	27	903	637	259	**0.045**
Combined	Combined	28	27	634	906	528	**0.012**

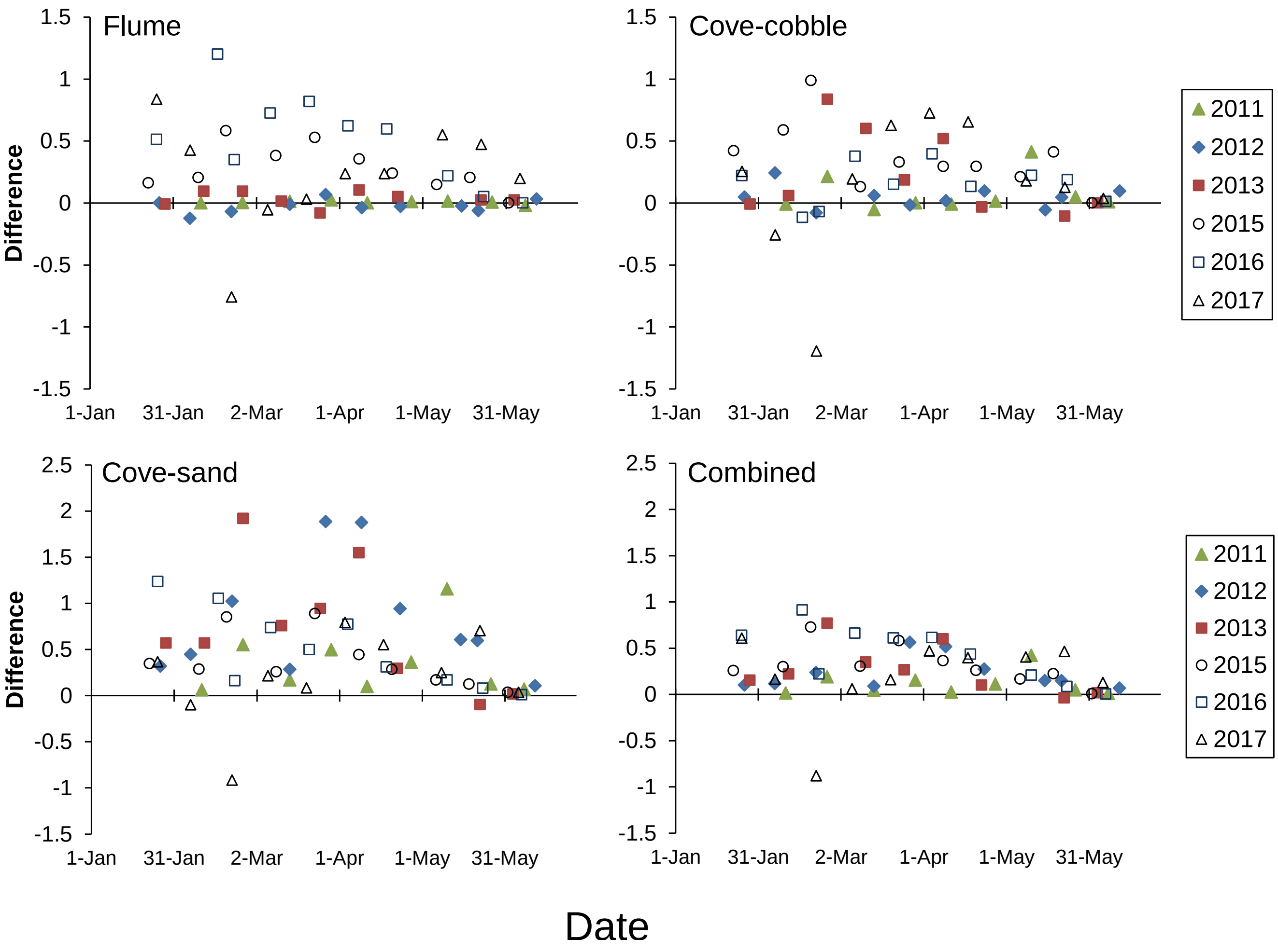

FIGURE 6.— Differences in juvenile Chinook salmon densities between restoration transects (including a combined restoration transect value) and the Gene Coulon bulkhead control transect, January-June 2011-2013 and 2015-2017. Pre-project monitoring was conducted in 2011-2013 (solid symbols) and post-project monitoring in 2015-2017 (open symbols). The combined values are pooled values from the three restoration sites.

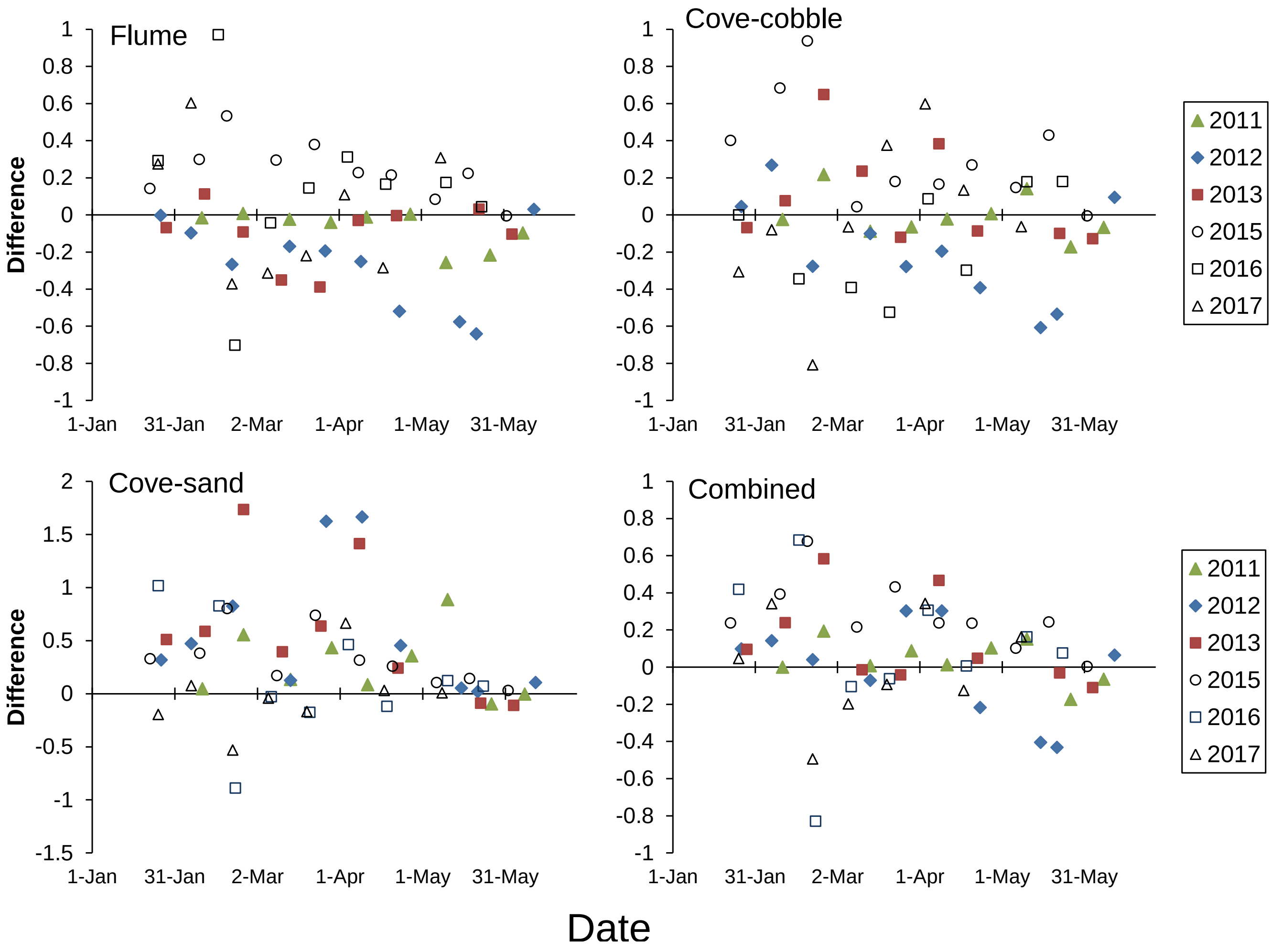

FIGURE 7.— Differences in juvenile Chinook salmon densities between restoration transects (including a combined restoration transect value) and the Gene Coulon swim beach control transect, January-June 2011-2013 and 2015-2017. Pre-project monitoring was conducted in 2011-2013 (solid symbols) and post-project monitoring in 2015-2017 (open symbols). The combined restoration transect values are pooled values from the three restoration sites.

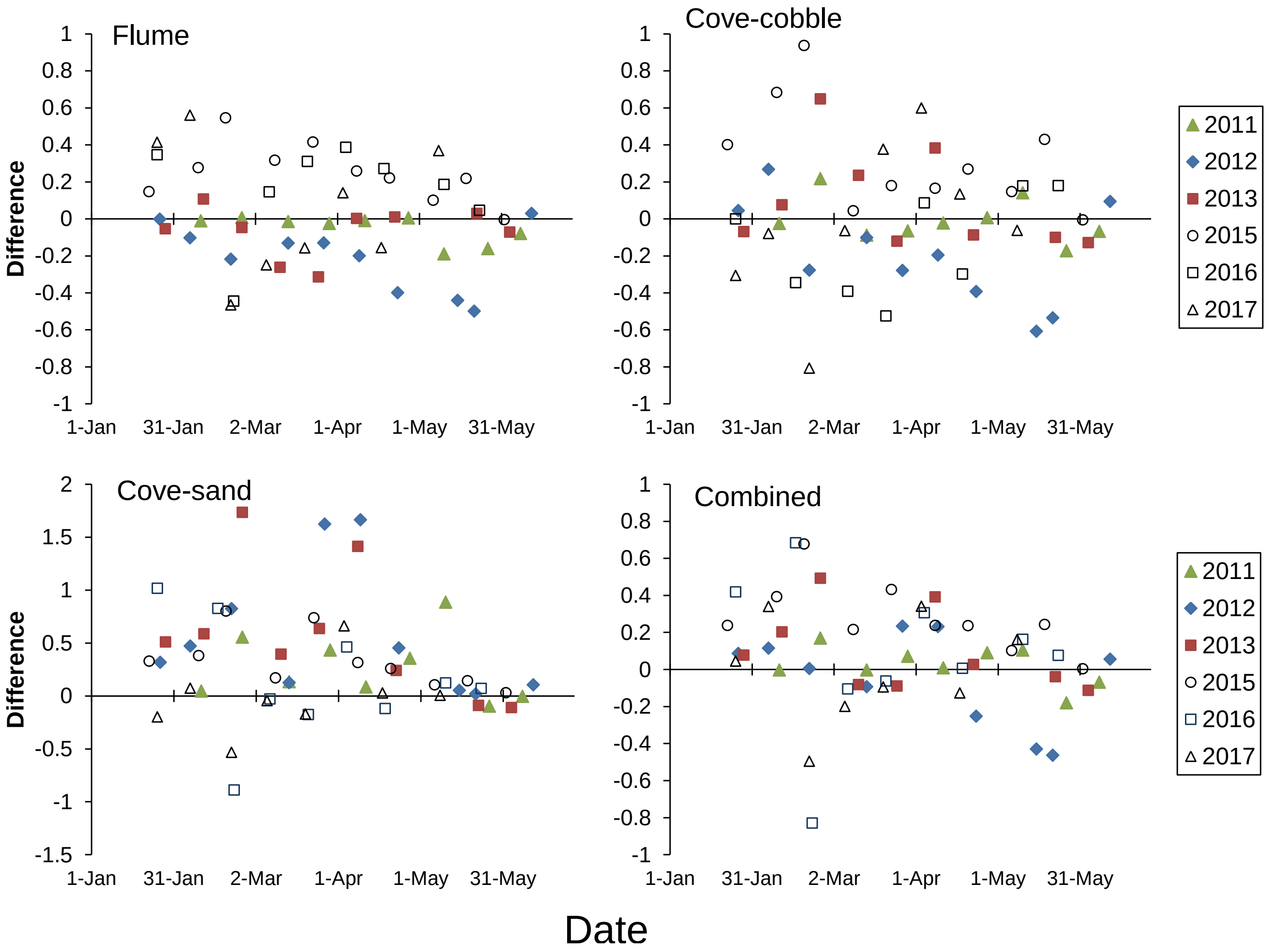

FIGURE 8.— Differences in juvenile Chinook salmon densities between restoration transects (including a combined restoration transect value) and the combined control transect (Gene Coulon swim beach and bulkhead transects combined), January-June 2011-2013 and 2015-2017. Pre-project monitoring was conducted in 2011-2013 (solid symbols) and post-project monitoring in 2015-2017 (open symbols).

Surveys of logjams indicated the highest densities of juvenile Chinook salmon were from February to April (Figure 9) and during this period, densities were substantially higher than in the nearby standard open shoreline transects (Figure 10). Chinook salmon appeared to be concentrated in the shallow waters (typically in water that was less than 0.5 m deep) on the perimeter of each logjam (Figure 11). The larger logjams (ELJs A and C) usually had significantly higher densities of juvenile Chinook salmon than the small logjam NLJ-B (Figure 10; Friedman test, *P* = 0.005; Freidman multiple comparisons test table: ELJ-A=ELJ-C, ELJ-A and ELJ-C > NLJ-B). In May and June, densities of juvenile Chinook salmon in the logjams decreased sharply and were typically less than the densities in the nearby standard open shoreline transects (Figure 10).

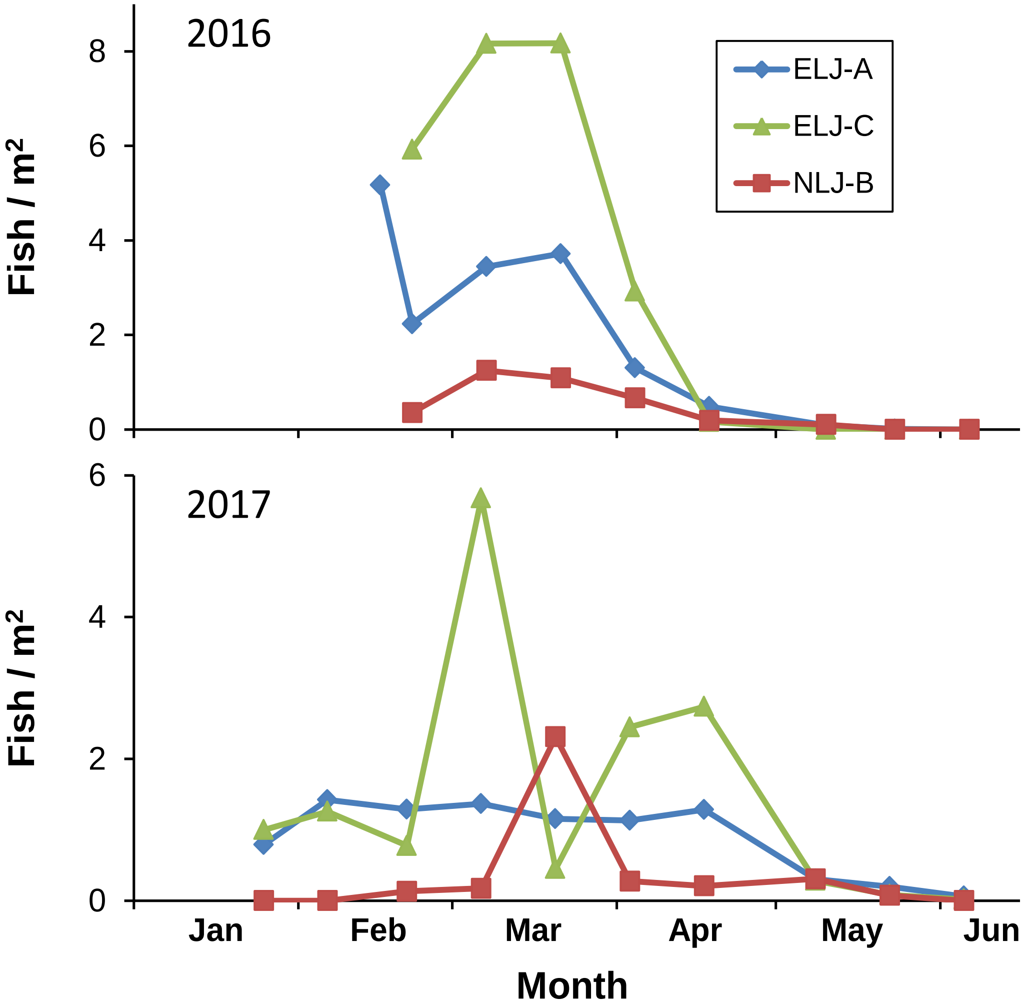

FIGURE 9.— Density (fish/m^2) of juvenile Chinook salmon at three logjams, January-June 2016 and 2017.

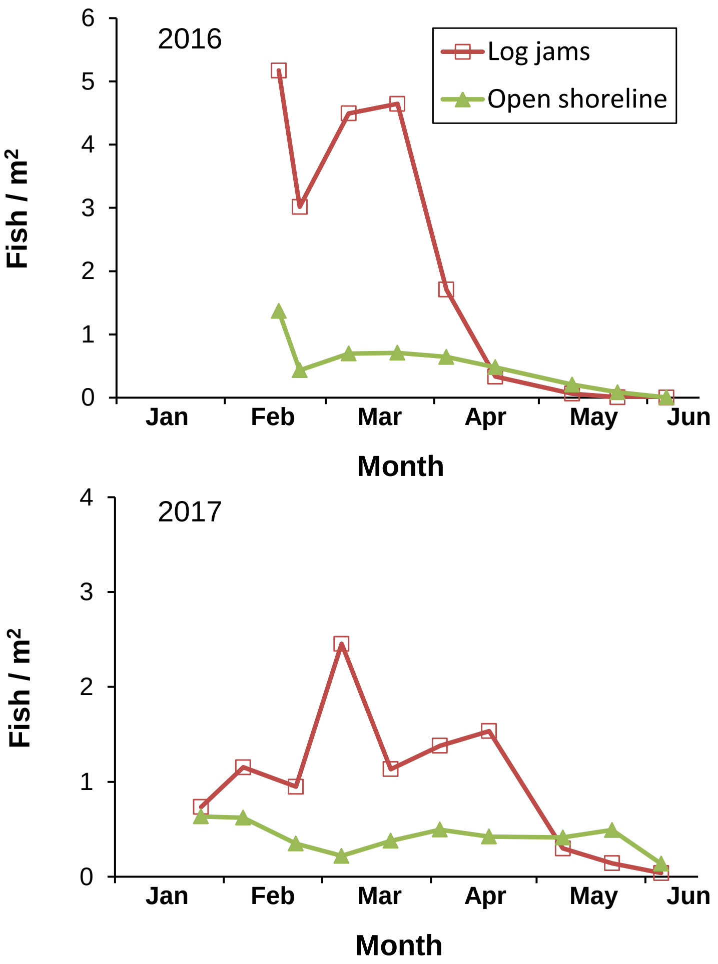

FIGURE 10.— Comparison of the density (fish/m^2) of juvenile Chinook salmon along WDNR open beach transects (old cove-cobble, old cove-sand, and old flume transects combined) and three logjams combined, January-June 2016 and 2017.

FIGURE 11.— Photo of a group of juvenile Chinook salmon at ELJ-C (March 6, 2017). Although the photo was taken at night, their behavior resembles more of daytime behavior: active, not closely associated with the substrate, and displaying some schooling behavior. Artificial lighting from the adjacent Boeing facility was likely affecting their behavior. See discussion section of this report for more information.

Threespine stickleback.— For all standard snorkel transects combined, a total of 7,053 threespine stickleback (*Gasterosteus aculeatus*) were observed during pre-project years; however, only 251 were observed during post-project years (83 in 2015, 167 in 2016, and 1 in 2017; Figure 12). The peak yearly threespine stickleback count was 4,952 in 2013 whereas only one was observed in 2017. Because all standard transects displayed the same sharp decline between pre- and post-restoration years, it would be difficult to detect any restoration effect on the abundance of threespine stickleback. Few threespine stickleback were usually observed in January through March; however, in 2013, they were commonly observed in all months. An additional 61 threespine stickleback were observed while surveying the three logjams in 2016 but none were observed in 2017.

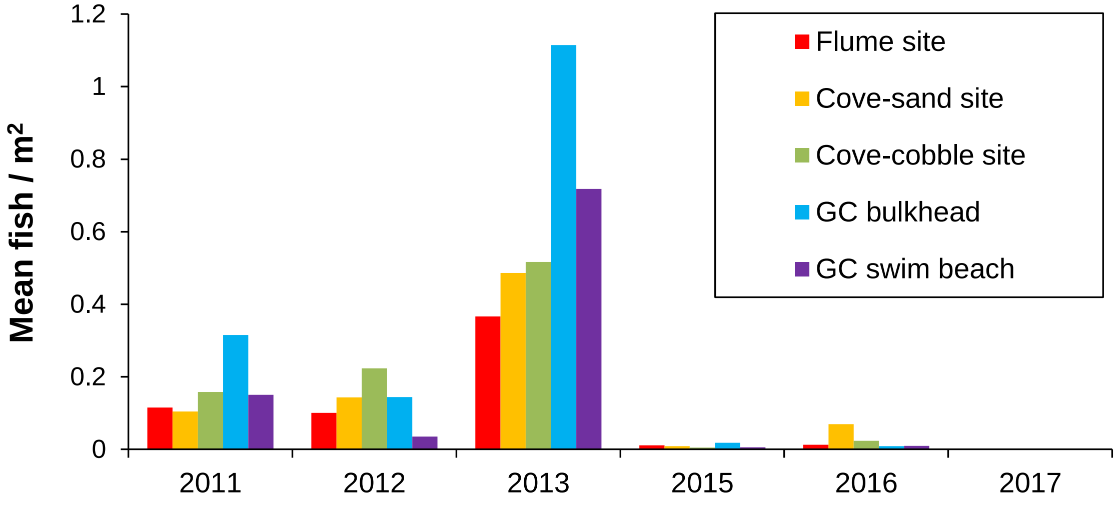

FIGURE 12.— Mean density (fish/m^2) of threespine stickleback along five standard snorkel transects in the south end of Lake Washington, January-June 2011-2013 and 2015-2017. GC = Gene Coulon Park.

Sculpin.- The density of sculpin was generally low in January and February and then increased in later months as water temperatures rose. Peak abundance usually occurred in May. Substantially more sculpin were observed along the old flume transect in 2015 through 2017 than in earlier survey years (Figure 13); however, we likely severely underestimated their abundance in the earlier surveys because the transect water depth was much deeper and we were usually unable to observe the bottom.

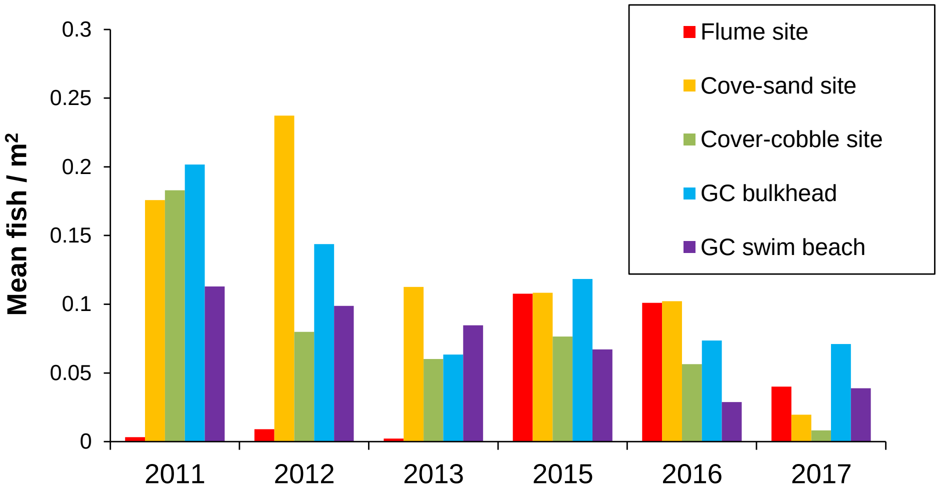

FIGURE 13.— Mean density (fish/m^2) of sculpin (prickly sculpin and coastrange sculpin combined) along five standard snorkel transects in the south end of Lake Washington, January-June 2011-2013 and 2015-2017. GC = Gene Coulon Park.

Other Fishes.— The total number of sockeye salmon (*O. nerka*, fry and juveniles) varied widely among years from 23 in 2016 to 3,487 in 2013. The number of sockeye salmon along the cove-cobble transect decreased from a total of 1,418 (range, 77-1,131) for pre-project years to a total of only 12 (range, 2-6) for post-project years; however, the Gene Coulon swim beach transect showed the same trend albeit not as pronounced (range: pre-project 92-1,777; post-project 21-71). Small numbers of trout were also observed. Based on other nearshore sampling in Gene Coulon Park, we assumed trout were most likely cutthroat trout. Most trout were observed during the May and June surveys and almost half of the observed trout were observed along the Gene Coulon swim beach transect.

The combined abundance of nonnative centrarchid fishes (pumpkinseed [*Lepomis gibbosus*], bluegill [*L. macrochirus*], rock bass [*Ambloplites rupestris*], smallmouth bass, largemouth bass [*M. salmoides*], and black crappie (*Pomoxis nigromaculatus*]) in all five transects was higher in 2015 and 2016 than in other survey years (Figure 14). Most of the centrarchid fishes were juveniles. The higher abundances in 2015 and 2016 may have been due in part to higher than average water temperatures (Figure 4). The other nonnative fish species that was often encountered was yellow perch (*Perca flavescens*; n = 354).

Abundance of nonnative warmwater fishes (centrarchids and yellow perch) along the standard and logjam snorkel transects was generally low in February and March but increased in April through June (Figures 15 and 16) as water temperatures increased. The larger, more structurally complex ELJs (A and C; Figure 17) had larger populations of nonnative fish when compared to the smaller and shallower NLJ-B. Most of the subadult and adult warmwater fish were often observed where the water column depths were > 0.5 m. Additionally, yellow perch egg masses were occasionally observed on the ELJs in May.

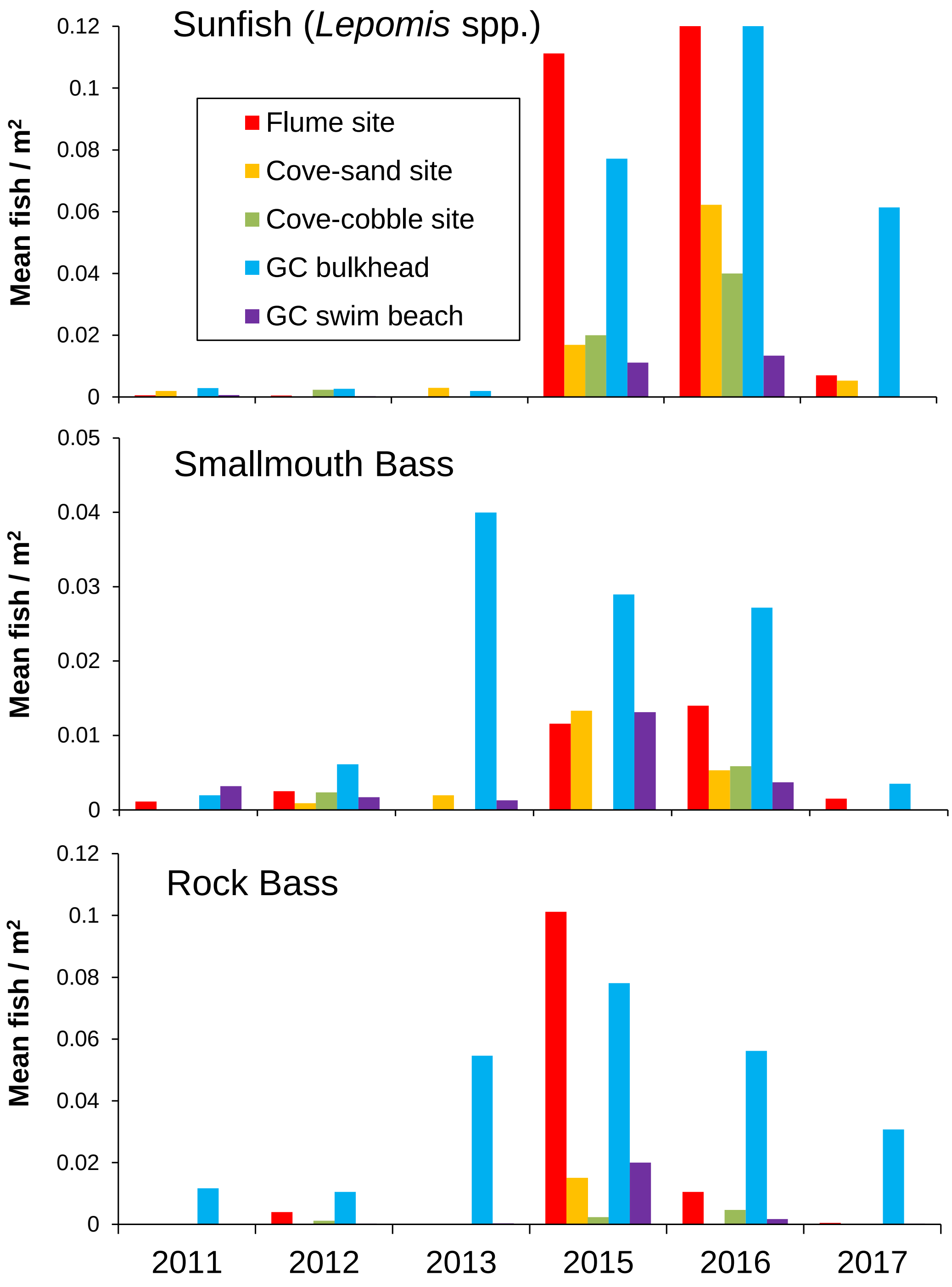

FIGURE 14.— Mean density (fish/m^2) of three types of nonnative centrarchids at five transects in the south end of Lake Washington, January-June 2011-2013 and 2015-2017. Sunfish (*Lepomis* spp.) includes pumpkinseed, bluegill, and unidentified juvenile sunfish. GC = Gene Coulon Park.

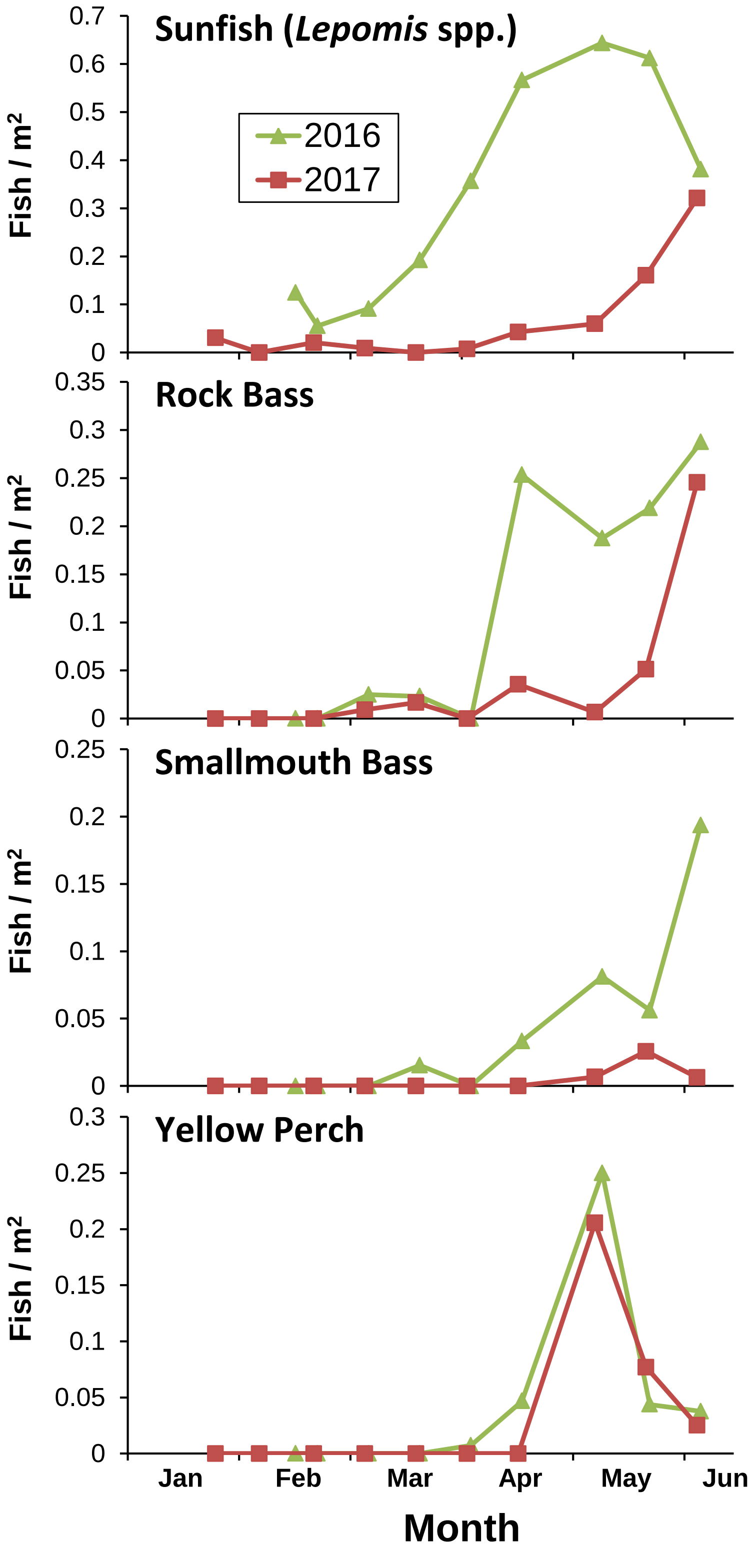

FIGURE 15.— Density (fish/m^2) of three types of nonnative centrarchids and yellow perch along three logjam transects (ELJs A and C and NLJ-B), January-June 2016 and 2017. Sunfish (*Lepomis* spp.) includes pumpkinseed, bluegill, and unidentified juvenile sunfish.

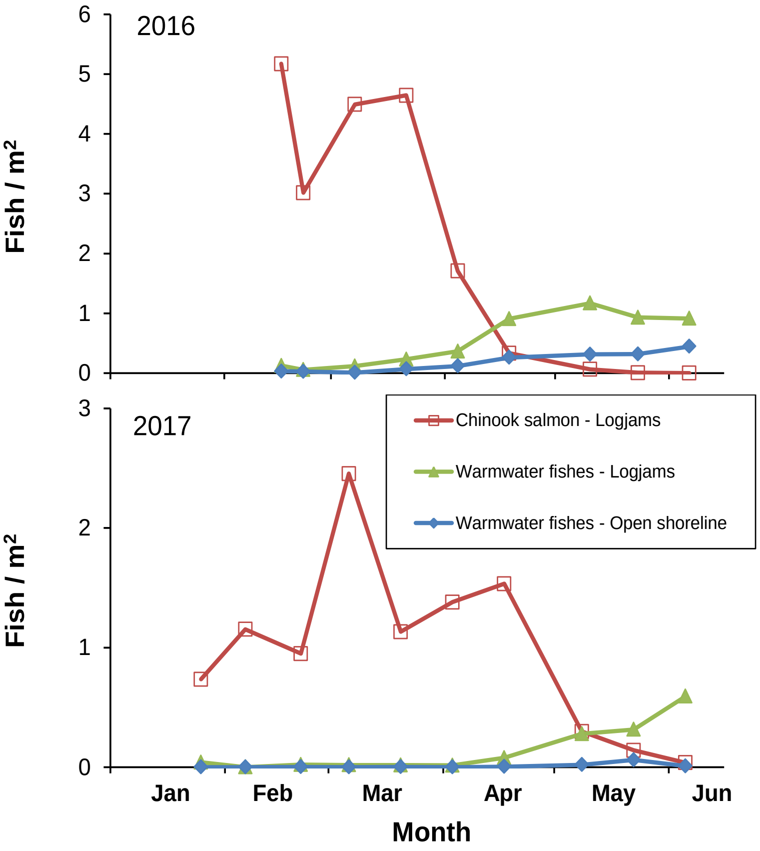

FIGURE 16.— Comparison of the density (fish/m^2) of juvenile Chinook salmon along logjam transects and warmwater fishes along logjam and open shoreline transects (old cove-cobble, old cove-sand, and old flume transects combined), January-June 2016 and 2017.

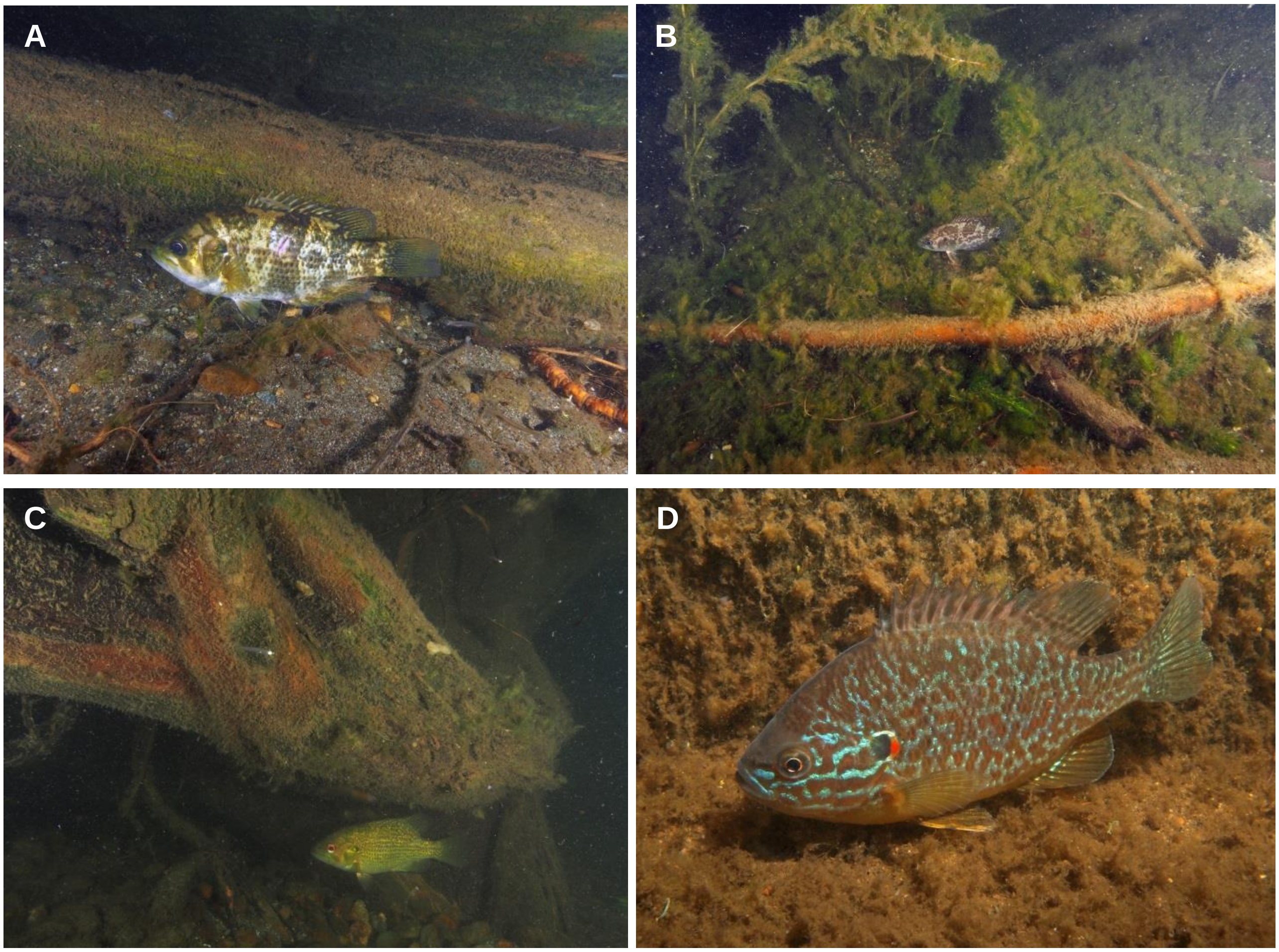

FIGURE 17.— Examples of warmwater fishes observed at logjams (photos A-C; June 2017) and Gene Coulon bulkhead transect (photo D; June 2012). Photos A and B are of rock bass, photo C is of a smallmouth bass, and photo D is of a pumpkinseed. All photos were taken at night along snorkel transects.

Discussion

Because good numbers of juvenile Chinook salmon (i.e., > 40 fish on each survey night from January to mid-May in 2015-2017) were observed along the flume transect and their density was similar or higher than control sites, removal of the flume structure and replacing it with a gravel/sand beach appeared to create valuable habitat for juvenile Chinook salmon. This site should be particularly valuable for juvenile Chinook salmon because it is close to the mouth of the Cedar River, the source from which large numbers of Chinook salmon fry emigrate in the winter and early spring. The old flume wall structure was a good example of a suboptimal habitat: little shallow water with no sand and gravel substrates (Tabor et al. 2011a).

The abundance of Chinook salmon along the flume transect (outside wall) before the restoration project was consistently low; however, we were unable to survey the entire flume structure because of high turbidity and potentially hazardous water quality conditions inside the structure. We assumed few juvenile Chinook salmon were using this area based on the poor habitat and water quality conditions. Inside the flume, water was always turbid with a rust color and looked quite different than surrounding areas. There was more structural complexity inside the flume than outside but the vertical walls limited the amount of available shallow water habitat. During our snorkel surveys in this study and other studies (Tabor et al. 2011a), we generally observed that when juvenile Chinook salmon are present along vertical walls, they are usually present near the water surface and next to the wall. We commonly conducted surface observations to look for juvenile Chinook salmon inside the flume and rarely saw any. Even if we assume the total number of Chinook salmon inside and outside of the flume was two to three times what we observed outside the wall, the restoration project would still have a positive effect because there was roughly nine times as many Chinook salmon observed along the flume transect after the restoration project than before the project. In addition, the overall post-project estimate would be substantially higher if the large numbers of Chinook salmon present in the ELJs were added to the total.

Another potential complicating factor in our assessment was artificial nighttime lighting. Removal of some trees appears to have increased the amount of artificial lighting reaching the nearshore area from a large, nearby Boeing building. Our initial measurements indicated that light intensity levels were elevated above ambient conditions at the restoration site; however, the exact amount of increase from pre-project conditions is unknown because no light measurements were taken during pre-project monitoring. In addition, Boeing replaced the upper lights (high-pressure sodium lights to LED lights) on their large, nearby building prior to our 2017 surveys and the light intensity was increased (Table 3). How much the increased light is affecting the abundance of juvenile Chinook salmon is also unknown; however, recent light experiments in Lake Washington and Lake Sammamish have indicated that juvenile Chinook salmon are attracted to artificial nighttime lighting (Tabor et al. 2017). We did not notice any obvious difference in Chinook salmon abundance in 2017 from 2016 or 2015 but we did notice a noticeable change in their behavior. Instead of being inactive, close to the substrate, and not associated with other fish (Figure 18), their behavior resembled more of daytime behavior: active, not closely associated with the substrate, and displaying some schooling behavior (Figure 11). On one occasion in 2017, we also noticed large numbers of sockeye salmon fry a little further offshore (where the water depth was 1 to 1.5 m deep) from the flume transect. Sockeye salmon fry display a strong attraction to artificial nighttime lighting (Tabor et al. 2004; Tabor et al. 2017).

FIGURE 18.— Photos of juvenile Chinook salmon at night. These fish are displaying typical nighttime behavior: inactive, close to the substrate, and not associated with other fish. The top left photo was taken in February 2012, top right in March 2017, and the bottom photo in June 2017. The top two photos were taken at the Gene Coulon swim beach while the bottom photo was taken at ELJ-A.

The major concern of artificial nighttime lighting for Chinook salmon and other subyearling salmonids is the potential to increase predation risk (Tabor et al. 2004; Tabor et al. 2017). Of particular concern in Lake Washington is predation by great blue herons (*Ardea herodias*). During the 2017 surveys, a great blue heron was often observed near the ELJ at the east end of the restoration site where large numbers of juvenile Chinook salmon were likely present. This shoreline-oriented predator has often been seen feeding in other artificially lit areas in Lake Washington and Lake Sammamish (Tabor et al. 2017). They are a large predator with a high energetic demand and are capable of consuming large numbers of fish. Any reduction to light intensity levels will likely be beneficial. As the recently planted trees grow, the effect of artificial nighttime lighting should also be reduced.

TABLE 3.— Light intensity readings taken in 2015, 2016, and 2017. All readings were taken at the water edge. Transects and locations are listed from west to east. Readings taken in 2015 were taken with an International Light photometer (model IL 1440A), while those in 2016 and 2017 were taken with an Extech Instrument light meter (model 104036).

		Date			
Transect	Location	8-Apr-15	23-May-16	6-Feb-17	6-Mar-17
ELJ-C	West side		0.6	2.1	1.42
ELJ-C	East side		1.6	3.4	2.25
NLJ-B	Middle		1.6	3.6	2.85
3	Middle of transect		2.9	4.1	
3	W 1/3 of transect	2.636			4.03
3	E 1/3 of transect	0.84			3.44
2	W 1/3 of transect	0.537	2.4	2.8	2.4
2	E 1/3 of transect	0.118	0.4	1	1.35
ELJ-A	West side				1.42
ELJ-A	East side		0.4	1.1	0.95
1	W 1/3 of transect	0.204	0.3	1.4	1.27
1	E 1/3 of transect	0.07	0.1	1.4	1.38
5	Middle of transect			0.1	0.15

Besides having a strong effect on the number of Chinook salmon using the flume site, the restoration project also had a moderate effect on the other two transects (cove-cobble and cove-sand). The restoration project had a positive effect on the cove-cobble transect while a negative effect on the cove-sand transect. Changes in Chinook salmon use were most likely due to changes in substrate size. The cove-cobble had a reduction in substrate size (cobble/gravel to gravel/sand) while the cove-sand site had an increase in substrate size (sand to gravel/sand; Table 1). Previous studies have also found that juvenile Chinook salmon in Lake Washington and other lentic systems primarily use small substrates (Curet 1993; Johnson et al. 2007; Tabor et al. 2011a).

The strong association of Chinook salmon with sand and gravel may also be related to slope preference, at least in part, because slope and substrate are usually correlated. Both Tiffan et al. (2002) and Sergeant and Beauchamp (2006) found juvenile Chinook salmon often select gentle slopes. The change in substrate size at the cove-cobble and cove-sand sites provided a good test of the importance of substrate size for juvenile Chinook salmon because it is difficult to determine if Chinook salmon abundance is related to substrate size and not just due to the slope. The cove-cobble and the cove-sand sites had the substrate altered while the slope remained about the same. Results indicated that changing the substrate size to gravel/sand from cobble (cove-cobble transect) increased the abundance of juvenile Chinook salmon while changing the substrate from sand to gravel/sand (cove-sand transect) decreased the abundance of juvenile Chinook salmon. While this was not a comprehensive test of this hypothesis, it does provide additional evidence that substrate size is an important variable in their habitat selection.

Our first assessment of the logjams was completed in 2016. In 2015, we attempted to assess logjams through daytime snorkeling observations but juvenile Chinook salmon were often difficult to observe because of poor visibility and it was difficult to see fish inside of the logjam. In 2016, we switched to nighttime snorkeling observations. Based on previous snorkeling efforts (Tabor et al. 2011a), we expected juvenile Chinook salmon would move away from the logjams at night and it would be difficult to determine Chinook salmon use of these structures. However, it appeared they only moved a short distance away (< 2 m) from the structure and were concentrated on the outside perimeter.

Nighttime surveys of logjams indicated large numbers of Chinook salmon are often closely associated with these structures. Based on nighttime surveys in 2016 and 2017, a few daytime surveys in 2015, and other observations (Tabor et al. 2011a), it appears juvenile Chinook salmon are primarily in small schools in the middle of the logjam during the day and then move to the outside perimeter of the logjam at night to rest on the bottom. The degree that juvenile Chinook salmon forage in the logjam is unknown. Koehler (2002) found that, among various Lake Washington shoreline types, natural forested shorelines with overhanging vegetation had the lowest densities of chironomids (the main forage item of juvenile Chinook salmon); therefore, logjams may not have higher levels of prey abundance than other sites. There are likely times (e.g., dawn and dusk) when some juvenile Chinook salmon move away from logjams to forage. Likely, the most important function of logjams is to provide juvenile Chinook salmon refuge from predators.

Among the logjams, the large ELJs consistently had Chinook salmon densities that were 2 to 10 times higher than the small NLJ-B. The use of large overlapping pieces of woody debris appears to provide ample structural complexity and overhead cover (Figure 3). Although we only surveyed one NLJ, our results are consistent with other surveys. In Lake Quinault, the highest concentrations of juvenile Chinook salmon during the day were directly under large pieces of woody debris (Tabor et al. 2006). Also, rootwads (similar to NLJ-B in this study) used at the Chinook Beach Park (City of Seattle park at Rainier Beach) restoration project were not used extensively by juvenile Chinook salmon (R. Tabor, personal observation). Each of these rootwads was laid flat on the bottom and there was little overhead cover.

The logjams appeared to provide valuable habitat for juvenile Chinook salmon but may also provide habitat for nonnative centrarchids including smallmouth bass. However, centrarchids we observed were mostly juveniles and too small to predate on juvenile Chinook salmon. The logjams do not extend out into deep water (i.e., > 1.5 m depth) which probably minimizes the use by subadult and adult smallmouth bass. Also, the abundance of juvenile Chinook salmon is usually low in May and June when smallmouth bass are common in the logjams. Therefore, the new ELJs likely do not directly affect juvenile Chinook salmon through predation but could indirectly affect them by enhancing centrarchid populations.

The number of introduced centrarchid fishes (pumpkinseed, bluegill, rock bass, smallmouth bass, and largemouth bass) observed in shoreline transects appeared to be higher in 2015 and 2016 than in the previous survey years. Several factors could account for this change. First, the flume structure was removed and shallow water habitat is now available for juvenile centrarchids; however, this would only account for an increase in abundance in one of the five transects. Secondly, water temperatures were higher in 2015 and 2016 than in other survey years and our observed centrarchid abundance in May and early June may be typical of their abundance in late June through August in other years. Many of the centrarchids observed in 2015 were observed during our last survey on June 1. Lastly, observed increases in their abundance may be an indication of an increase in their population size in south Lake Washington. This may be particularly true for rock bass and bluegill which were not observed during snorkel and electrofishing surveys of south Lake Washington in the late 1990's (R. Tabor, unpublished data) and may have recently colonized south Lake Washington. There has also been some evidence of an increase of overall lake temperatures (Arhonditsis et al. 2004), which may favor warmwater fishes such as centrarchids over cool-water fishes.

In conclusion, removal of the flume structure and replacing it with a more natural shoreline appeared to have improved juvenile Chinook salmon habitat in Lake Washington. The restored nearshore habitat now has a large area of shallow water < 1 m deep, primarily sand and gravel substrate, a gentle slope, and some nearby logjams for refuge.

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Appendix A-1. Number of fish observed in 2011 along five shoreline transects in the south end of Lake Washington. GC = Gene Coulon (City of Renton park). Length and area surveyed for each transect is given in Table 1.

			Date									
Transect	**Fish group**	**Species**	10-Feb	25-Feb	14-Mar	29-Mar	11-Apr	27-Apr	10-May	26-May	7-Jun	**Total**
Flume	Salmonids	Chinook salmon	2	6	13	5	2	4	3	3	1	39
		Sockeye salmon		42	1	3						46
		Trout							1			1
	Other native	Sucker (juveniles)							1			1
		Threespine stickleback		2		9		104	53	7	33	208
		Sculpin	3		2			1				6
	Nonnative	Smallmouth bass						1		1		2
		Black crappie							1	2	4	7
		Sunfish (juveniles)								1		1
Cove - sand	Salmonids	Chinook salmon	8	65	25	56	12	42	130	15	11	364
		Sockeye salmon		42	4	23	7			1		77
		Trout						1				1
	Other native	Longfin smelt				4						4
		Peamouth									1	1
		Sucker (juveniles)							1		5	6
		Threespine stickleback					8	2	42	22	32	106
		Sculpin	14	4	31	37	4	3	30	21	34	178
	Nonnative	Sunfish (juveniles)							1			1
		Pumpkinseed								1		1
		Yellow perch							5	10	6	21
Cove - cobble	Salmonids	Chinook salmon		15				2	35	5	3	60
		Sockeye salmon	1	21								22
		Trout									1	1
	Other native	Threespine stickleback					2	4	40	15	60	121
		Sculpin	10	2	37	44	1	2	25	15	4	140
	Nonnative	Yellow perch							5	6	5	16
GC bulkhead	Salmonids	Chinook salmon	1	3	6		1	1		1	3	16
		Trout					1					1
	Other native	Threespine stickleback					23	52	65	88	95	323
		Sculpin	8	2	5	24	17	27	38	42	44	207
	Nonnative	Smallmouth bass				1	1					2
		Sunfish (juveniles)								1	2	3
		Rock bass				1		4	2	2	3	12
		Yellow perch							1	1	3	5
GC swim beach	Salmonids	Chinook salmon	9	8	31	23	8	6	95	81	36	297
		Sockeye salmon	11	9	9	19	4	1	3	35	1	92
		Trout		2		1	1				2	6
	Other native	Longfin smelt	2		8		1					11
		Peamouth									4	4
		Sucker (juveniles)							2			2
		Threespine stickleback			2	2	41	134	90	125	80	474
		Sculpin	25		24	19	15	14	124	111	24	356
	Nonnative	Smallmouth bass								9	1	10
		Sunfish (juveniles)							1			1
		Pumpkinseed							1			1
		Yellow perch							2	21	3	26

Appendix A-2. Number of fish observed in 2012 along five shoreline transects in the south end of Lake Washington. GC = Gene Coulon (City of Renton park). Length and area surveyed for each transect is given in Table 1.

			Date										
Transect	**Fish group**	**Species**	26-Jan	6-Feb	21-Feb	14-Mar	27-Mar	9-Apr	23-Apr	15-May	21-May	11-Jun	**Total**
Flume	Salmonids	Chinook salmon			2	19	24	17	3	11	14	8	98
		Sockeye salmon					2	1					3
	Other native	Longfin smelt			1								1
		Peamouth									1	5	6
		Threespine stickleback			1			1	180	11	4	4	201
		Sculpin	1	6	3		6	1	1				18
	Nonnative	Smallmouth bass								2	1	2	5
		Black crappie										2	2
		Sunfish (juveniles)										1	1
		Rock bass										8	8
		Yellow perch									1		1
Cove - sand	Salmonids	Chinook salmon	36	64	124	44	218	225	111	77	82	13	994
		Coho salmon							2			1	3
		Sockeye salmon	10	10	143	4	19	20		4			210
		Trout								2	1	1	4
	Other native	Sucker (juveniles)										3	3
		Threespine stickleback							3	3	115	40	161
		Sculpin	6	3	6	32	3	17	12	30	53	105	267
	Nonnative	Smallmouth bass										1	1
		Yellow perch										11	11
Cove - cobble	Salmonids	Chinook salmon	4	31		14	3	12	12	2	15	9	102
		Sockeye salmon	1	5			1	2					9
		Trout									3		3
	Other native	Threespine stickleback								23	92	75	190
		Sculpin	2	11		7	3	10		1	25	9	68
	Nonnative	Smallmouth bass					1					1	2
		Sunfish (juveniles)										2	2
		Rock bass									1		1
		Yellow perch										3	3
GC bulkhead	Salmonids	Chinook salmon		14	9	12	6	14	5	9	15	1	85
		Sockeye salmon					4						4
		Trout					1						1
	Other native	Peamouth									3		3
		Threespine stickleback					1	9	31	25	48	50	164
		Sculpin	9	4	9	6	22	12	17	1	32	52	164
	Nonnative	Largemouth bass			1					1			2
		Smallmouth bass	1	1			1	1	1		1	1	7
		Sunfish (juveniles)										2	2
		Pumpkinseed										1	1
		Rock bass							2	1	5	4	12
GC swim beach	Salmonids	Chinook salmon	1	34	97	93	110	118	187	221	249	4	1,114
		Coho salmon							1				1
		Sockeye salmon	4	9	50	34	22	4	27		1		151
		Trout							6	1	2		9
	Other native	Threespine stickleback		1		1		2	72	5	29	13	123
		Sculpin	16	41	40	28	36	17	44	4	96	24	346
	Nonnative	Smallmouth bass	1	1					2		1	1	6
		Sunfish (juveniles)										1	1
		Rock bass										1	1
		Yellow perch										2	2

Appendix A-3. Number of fish observed in 2013 along five shoreline transects in the south end of Lake Washington. GC = Gene Coulon (City of Renton park). Length and area surveyed for each transect is given in Table 1.

			Date									
Transect	**Fish group**	**Species**	28-Jan	11-Feb	25-Feb	11-Mar	25-Mar	8-Apr	22-Apr	22-May	3-Jun	**Total**
Flume	Salmonids	Chinook salmon		40	26	52	17	35	26	26	5	227
		Coho salmon							9			9
		Sockeye salmon		50	20	270	47	6	2			395
	Other native	Threespine stickleback	48	120	15	35	52	16	36	187	150	659
		Sculpin	3						1			4
Cove - sand	Salmonids	Chinook salmon	65	76	220	113	125	182	42	1	2	826
		Coho salmon							106			106
		Sockeye salmon	38	3	76	160	800	30	24			1,131
	Other native	Longfin smelt			1							1
		Peamouth								30	6	36
		Sucker								6	4	10
		Threespine stickleback	2	29	25	52	42	72	10	110	150	492
		Sculpin	4	8	17	4	6	44		12	19	114
	Nonnative	Smallmouth bass								1	1	2
		Sunfish (juveniles)								3		3
		Yellow perch			1	2		1	2	10	15	31
Cove - cobble	Salmonids	Chinook salmon	0	14	74	72	30	50	4			244
		Sockeye salmon			28	57	15	15	2			117
	Other native	Threespine stickleback	2	27	33	59	67	39	20	73	75	395
		Sculpin			10	8	5	18	3	2		46
	Nonnative	Black crappie								1		1
		Yellow perch				4						4
GC bulkhead	Salmonids	Chinook salmon	1	12	4	28	19	8	9	12		93
		Sockeye salmon	1	12	3	20	27	3	1			67
	Other native	Threespine stickleback	80	108	42	55	157	107	57	238	300	1,144
		Sculpin	2	11	3	4	1	11	7	11	15	65
	Nonnative	Smallmouth bass	7	4	2	8	9	4	5	2		41
		Sunfish (juveniles)								2		2
		Rock bass	2	5	4	3	11	9	8	8	6	56
		Yellow perch						3				3
GC swim beach	Salmonids	Chinook salmon	24	31	78	214	166	72	47	35	45	712
		Coho salmon		1					4			5
		Sockeye salmon	6	73	25	741	870	27	13	10	12	1,777
		Trout	1						4			5
	Other native	Longfin smelt						1	3			4
		Peamouth					1					1
		Sucker									2	2
		Threespine stickleback	215	172		602	740	167	56	235	75	2,262
		Sculpin	35	5	27	40	40	55	32	16	17	267
	Nonnative	Smallmouth bass								2	2	4
		Rock bass									1	1
		Yellow perch				3		5	2	8	9	27

Appendix A-4. Number of fish observed in 2015 along five shoreline transects in the south end of Lake Washington. Length and area surveyed for each transect is given in Table 1.

			Date										
Transect	**Fish group**	**Species**	22-Jan	9-Feb	19-Feb	9-Mar	23-Mar	8-Apr	20-Apr	6-May	18-May	1-Jun	**Total**
Old flume	Salmonids	Chinook salmon	47	104	146	98	141	89	60	46	60		791
		Coho salmon							3	4	2		9
		Sockeye salmon				1				2			3
		Trout								2	2		4
	Other native	Peamouth	1										1
		Threespine stickleback				1	1	7	11	2	2	4	28
		Sculpin	3	6	8	1	24	44	39	38	40	66	269
	Nonnative	Largemouth bass	3		1								4
		Smallmouth bass					1	2	1	3	1	21	29
		Rock bass	1	1				2	21	25	83	120	253
		Sunfish (juveniles)	54	7	16	2	5	1	5	6	59	120	275
		Pumpkinseed										3	3
		Yellow perch				1			1	2	4	4	12
Old cove-sand	Salmonids	Chinook salmon	42	56	96	30	104	50	32	23	18	4	455
		Coho salmon							6	1			7
		Sockeye salmon				2	1	2		1			6
		Trout		1					2				3
	Other native	Threespine stickleback				2			6		2		10
		Sculpin	2		5		5	3	6	33	42	26	122
	Nonnative	Largemouth bass									2		2
		Smallmouth bass					1	1	2	2		9	15
		Rock bass								1		16	17
		Sunfish (juveniles)	1						1			14	16
		Bluegill									1	1	2
		Pumpkinseed										1	1
		Yellow perch		1						2	2		5
Old cove-cobble	Salmonids	Chinook salmon	38	68	84	12	31	25	25	21	38		342
		Coho salmon							5				5
		Sockeye salmon	1				1			2			4
		Trout										1	1
	Other native	Threespine stickleback						1		2	1		4
		Sculpin			4			2	9	10	30	10	65
	Nonnative	Rock bass								1	1		2
		Sunfish (juveniles)										13	13
		Pumpkinseed										4	4
		Black crappie										3	3
		Yellow perch								1	1	4	6
GC bulkhead	Salmonids	Chinook salmon	3	24		1	4			4	4		40
		Trout								3	2	1	6
	Other native	Threespine stickleback				4	1	9	6			1	21
		Sucker						1					1
		Sculpin	1	3	5	14	29	30	17	9	7	20	135
	Nonnative	Largemouth bass					2	2			2	1	7
		Smallmouth bass	8	4	3	7	3			1	1	6	33
		Rock bass	3	3	13	1	9	12	9	8	6	25	89
		Sunfish (juveniles)		1		1	4	5			1	40	52
		Bluegill							4	3	12		19
		Pumpkinseed								1	6	10	17
		Yellow perch			1					2	3	1	7
GC swim beach	Salmonids	Chinook salmon	16	41	18	34	65	45	9	35	6	2	271
		Coho salmon							2				2
		Sockeye salmon	3	2		2	7	6	3	11	1		35
		Trout				6	1	1		4	1	1	14
	Other native	Peamouth								2	2		4
		Threespine stickleback				2	2	12	1	2		1	20
		Sculpin	16	7	26	13	25	25	22	32	38	31	235
	Nonnative	Bullhead									1		1
		Largemouth bass				1				2			3
		Smallmouth bass	2		1	4		2	2	11	8	16	46
		Rock bass						1	3	12	9	45	70
		Sunfish (juveniles)			1							26	27
		Bluegill									1		1
		Pumpkinseed									5	6	11
		Yellow perch				1			2	2	10	9	24

Appendix A-5. Number of fish observed in 2016 along five shoreline transects in the south end of Lake Washington. Length and area surveyed for each transect is given in Table 1. ND = no data (i.e., too turbid to survey).

			Date										
Transect	**Fish group**	**Species**	25-Jan	16-Feb	22-Feb	7-Mar	21-Mar	4-Apr	18-Apr	10-May	23-May	6-Jun	**Total**
Old flume	Salmonids	Chinook salmon	170	414	140	190	229	162	160	55	13		1,533
		Trout							1	2	5	2	10
	Other native	Threespine stickleback						5	12	4	2	2	25
		Sculpin			6	2	5	16	36	34	73	30	202
	Nonnative	Largemouth bass					1		2				3
		Smallmouth bass		1	1		4	1	3	4	5	9	28
		Rock bass							1	6	4	10	21
		Sunfish (juveniles)	75	12	11	1	19	48	61	82	86	113	508
		Yellow perch				1		1	4	14	4		24
Old cove-sand	Salmonids	Chinook salmon	158	170	42	87	67	90	40	19	9	1	683
		Sockeye salmon	2										2
	Other native	Threespine stickleback						55	22	1			78
		Sculpin						3	5	37	40	30	115
	Nonnative	Smallmouth bass							3	2		1	6
		Sunfish (juveniles)	1				2	1	29	6	20	11	70
		Yellow perch						1	1	10	2	9	23
Old cove-cobble	Salmonids	Chinook salmon	33	29	12	35	21	36	15	19	16	1	217
		Coho salmon								1			1
		Trout									1		1
	Other native	Threespine stickleback							10	8	2		20
		Sculpin						2	2	23	15	6	48
	Nonnative	Largemouth bass							1				1
		Smallmouth bass					2					3	5
		Rock bass								3		1	4
		Sunfish (juveniles)							10	8	13	3	34
		Yellow perch				2	2	1	1	5	8	39	58
GC bulkhead	Salmonids	Chinook salmon	19	52	24	4	11	3	5				118
		Trout								1			1
	Other native	Threespine stickleback						4	5		1		10
		Sculpin	2	1	4	21	10	14	11	7	8	6	84
	Nonnative	Bullhead				1	1						2
		Largemouth bass		1		1	2		3				7
		Smallmouth bass	8	4	6	1	7	2	1	1	1		31
		Rock bass						2	19	22	6	15	64
		Sunfish (juveniles)	2	8	2	1	7	26	76	34	51	43	250
		Yellow perch							2	2	5	2	11
GC swim beach	Salmonids	Chinook salmon	136	240	442	281	270	118	166	16	3	ND	1,672
		Trout						7	2	3	2	ND	14
		Sockeye salmon	3	3	2		3	9			1	ND	21
	Other native	Peamouth								1		ND	1
		Threespine stickleback		1			3	28	1		1	ND	34
		Sculpin	7	5	3	8	8	19	5	6	27	ND	88
		Yellow perch				1						ND	1
	Nonnative	Largemouth bass							1			ND	1
		Smallmouth bass						4	3	3	3	ND	13
		Rock bass						1	1	2	2	ND	6
		Sunfish (juveniles)		3				4	6	3	21	ND	37
		Pumpkinseed					1					ND	1
		Yellow perch					2	1	3	1		ND	7

Appendix A-6. Number of fish observed in 2017 along five shoreline transects in the south end of Lake Washington. Length and area surveyed for each transect is given in Table 1. ND = no data (i.e., too turbid to survey).

			Date										
Transect	**Fish group**	**Species**	25-Jan	6-Feb	21-Feb	6-Mar	20-Mar	3-Apr	17-Apr	8-May	22-May	5-Jun	**Total**
Old flume	Salmonids	Chinook salmon	216	221	118	26	63	66	66	140	125	52	1,093
		Coho salmon								1			1
		Trout									2	7	9
		Sockeye salmon			15		34						49
	Other native	Sculpin		3	1	1	3		11	15	26	20	80
	Nonnative	Smallmouth bass									1	2	3
		Rock bass								1			1
		Sunfish (juveniles)			1		1		2		10		14
		Yellow perch								8	4		12
Old cove-sand	Salmonids	Chinook salmon	44	40	35	42	34	92	65	29	82	5	468
		Trout								1		4	5
		Sockeye salmon			3	1							4
	Other native	Sculpin			1				2	10	6	3	22
		Sucker	1										1
	Nonnative	Sunfish (juveniles)									6		6
		Yellow perch									4	2	6
Old cove-cobble	Salmonids	Chinook salmon	24	17	3	30	72	64	58	16	13	4	301
		Trout								1		1	2
		Sockeye salmon			1		3						4
	Other native	Threespine stickleback			1								1
		Sculpin				1				1	2	3	7
	Nonnative	Yellow perch									2		2
GC bulkhead	Salmonids	Chinook salmon	3	52	140	18	25	3	3	1	3	1	249
		Trout					1			1		1	3
		Sockeye salmon			4			1					5
	Other native	Sculpin	3	3	3	4	9	7	33	13	3	3	81
	Nonnative	Brown bullhead										2	2
		Largemouth bass	4	2									6
		Smallmouth bass								1	3		4
		Rock bass							1	8	9	17	35
		Sunfish (juveniles)	4	1		2	1		2	5	21	27	63
		Pumpkinseed										4	4
		Bluegill								1			1
GC swim beach	Salmonids	Chinook salmon	206	98	295	146	165	54	192	88	ND	ND	1,244
		Trout				1					ND	ND	1
		Sockeye salmon			8	8	17	17	17	4	ND	ND	71
	Other native	Sculpin	2	2	3	3	19	8	17	53	ND	ND	107
	Nonnative	Rock bass								1	ND	ND	1
		Yellow perch							3	1	ND	ND	4

Appendix B-1. Number of fish observed in 2016 along the outside perimeter of three logjams in the south end of Lake Washington. ND = no data.

			Date									
Logjam	**Fish group**	**Species**	16-Feb	22-Feb	7-Mar	21-Mar	4-Apr	18-Apr	10-May	23-May	6-Jun	**Total**
ELJ-A	Salmonids	Chinook salmon	331	144	222	253	94	37	7	1		1,089
		Trout								1		1
	Other native	Threespine stickleback					4	7	5	5	1	22
		Sculpin	1	1	2	7	17	5	12	41	11	97
	Nonnative	Largemouth bass							1		1	2
		Smallmouth bass				1		4	7	7	24	43
		Rock bass			3	3		35	30	25	33	129
		Sunfish (juveniles)	8	6	10	22	48	81	89	64	36	364
		Pumpkinseed			1							1
		Crappie						1				1
		Yellow perch					1	2	14	3	1	21
NLJ-B	Salmonids	Chinook salmon	ND	5	25	24	16	5	3			78
		Trout	ND						1	2		3
	Other native	Threespine stickleback	ND			9	1	5		4	1	20
		Sculpin	ND	1		1		4	3	8	4	21
	Nonnative	Largemouth bass	ND								1	1
		Smallmouth bass	ND			1			1	2	3	7
		Rock bass	ND							1	5	6
		Sunfish (juveniles)	ND					3	3	4	8	18
		Bluegill	ND			1						1
		Yellow perch	ND					1	10	3	2	16
ELJ-C	Salmonids	Chinook salmon	ND	178	294	327	129	8				936
	Other native	Threespine stickleback	ND				4	5	6	4		19
		Sculpin	ND			2	5	2	10	17	11	47
	Nonnative	Smallmouth bass	ND					1	5		4	10
		Rock bass	ND					3		9	8	20
		Sunfish (juveniles)	ND			2	2	1	11	30	17	63
		Yellow perch	ND					4	16	1	3	24

Appendix B-2. Number of fish observed in 2017 along the outside perimeter of three logjams in the south end of Lake Washington.

			Date										
Logjam	**Fish group**	**Species**	25-Jan	6-Feb	21-Feb	6-Mar	20-Mar	3-Apr	17-Apr	8-May	22-May	5-Jun	**Total**
ELJ-A	Salmonids	Chinook salmon	41	74	67	82	75	79	96	24	16	5	559
		Coho salmon								1	16	6	23
		Sockeye salmon			3								3
	Other native	Sculpin			5	2	3		25	8	13	7	63
	Nonnative	Oriental weatherfish						1					1
		Largemouth bass	1										1
		Smallmouth bass								1	2		3
		Rock bass				1	2		5		6	26	40
		Sunfish (juveniles)	3		2	1		1	6	9	25	51	98
		Yellow perch								21	5		26
NLJ-B	Salmonids	Chinook salmon			2	3	45	6	5	8	2		71
	Other native	Sculpin					1		1	2		4	8
	Nonnative	Rock bass								1		3	4
		Yellow perch								7		4	11
ELJ-C	Salmonids	Chinook salmon	31	39	24	184	16	95	115	13	4		521
		Trout										1	1
	Other native	Sculpin		1			1	1	8	1	5	8	25
	Nonnative	Smallmouth bass									2		2
		Rock bass									2	10	12
		Yellow perch								3	7		10