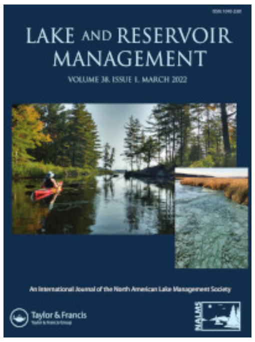

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Effectiveness monitoring of juvenile Chinook salmon restoration projects in south Lake Washington, Washington State

Roger A. Tabor[a], Martin C. Liermann[b], Howard A. Gearns[a], Zachary J. Moore[a, †], Katherine D. Lynch[c], Keith Kurko[c, ‡], Julie Crittenden[c] and Monica E. Shoemaker[d]

[a]Western Washington Fish and Wildlife Conservation Office, U. S. Fish and Wildlife Service, Lacey, WA, USA; [b]Northwest Fisheries Science Center, NOAA Fisheries, Seattle, WA, USA; [c]Seattle Public Utilities, Seattle, WA, USA; [d]Washington Department of Natural Resources, Enumclaw, WA, USA

ABSTRACT

Tabor RA, Liermann MC, Gearns HA, Moore ZJ, Lynch KD, Kurko K, Crittenden J, Shoemaker ME. 2022. Effectiveness monitoring of juvenile Chinook salmon restoration projects in south Lake Washington, Washington State. Lake Reserv Manage. XX:XX–XX.

We evaluated 4 large restoration projects in south Lake Washington that were designed to improve nearshore habitat for lake-rearing juvenile Chinook salmon (*Oncorhynchus tshawytscha*). Restoration projects included shoreline modification, substrate enhancement, addition of engineered log jams (ELJs), and nonnatal tributary improvements. For most projects, we used a BACI (before-after-control-impact) study design. Projects were evaluated by determining the nighttime abundance of juvenile Chinook salmon through visual observations (primarily snorkeling with some surface observations in small nonnatal tributaries). Juvenile Chinook salmon are typically concentrated in the south end of the lake near their natal stream, and the project that was the farthest away from the natal stream did not appear to be beneficial, likely because few Chinook salmon were present. The highest observed abundance of juvenile Chinook salmon was associated with ELJs, where the abundance in February to April was typically 2 to 5 times higher than along adjacent, open shorelines. From January to April, juvenile Chinook salmon were usually more abundant in a daylighted nonnatal tributary (i.e., reconfigured from an unusable underground culvert to a more natural stream channel at the surface) than in 2 reference sites. Overall, all 4 project types improved juvenile use of the restored area, with substrate enhancement generally having the weakest response and ELJs the strongest response. Although most restoration projects for salmonids in the Pacific Northwest have focused on lotic systems, our results suggest projects in lentic systems may also be beneficial and should be considered by land-use managers.

KEYWORDS
BACI study design; juvenile Chinook salmon; Lake Washington; lentic nearshore habitat restoration; night snorkeling; nonnatal tributary

An integral component in recovery of salmonid populations is often habitat restoration. Widely varied techniques have been employed, and many have often been effective for improving habitat and increasing salmonid abundance (Roni et al. 2008). The most common technique is instream habitat improvement such as the addition of logs, wood, or rock structures. Instream habitat improvement projects have generally benefited salmonid population beyond simple redistribution of individuals (Hunt 1988, Binns 1999, Whiteway et al. 2010, Roni 2019, Polivka and Claeson 2020). Salmonids also make extensive use of lakes for spawning and rearing (Arostegui and Quinn 2019); however, salmonid habitat restoration projects have typically focused on improving lotic systems from small streams to large rivers, while relatively little attention has been given to lacustrine habitats.

In lakes, urban and residential development alter both the shoreline and the littoral zone by the addition of armored shorelines, by removing woody debris, and by reducing riparian vegetation and shoreline complexity (Christensen et al. 1996, Francis and Schindler 2006, Wehrly et al. 2012). The nearshore habitats of lakes are

CONTACT Roger A. Tabor roger_tabor@fws.gov
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†Present address: King County, 201 South Jackson Street, Suite 600, Seattle, WA, USA.
‡Retired.

important rearing habitats for juvenile salmonids by providing refugia from predation and a diversity of foraging opportunities (Tabor and Wurtsbaugh 1991, Koehler et al. 2006). In some lakes, such as Lake Washington in Washington State, the nearshore areas are important rearing habitats for juvenile Chinook salmon (Tabor et al. 2011a). Additionally, lake-rearing juvenile Chinook salmon may use small nonnatal lake tributaries, which have often been altered by culverts, loss of riparian vegetation, armored banks, and an altered hydrologic regime (Tabor et al. 2011b).

Within their native distribution, Chinook salmon (*Oncorhynchus tshawytscha*) occasionally inhabit lake systems, with adults typically spawning in lake tributaries and juveniles moving downstream to rear in lakes prior to marine migrations (Russell et al. 1980, Tabor et al. 2006, Tabor et al. 2011a). The use of lakes by Chinook salmon has also greatly increased with introductions both within (Higley and Bond 1973, Hard 1986) and outside the Pacific Northwest (e.g., Great Lakes and New Zealand lakes; McDowall 1990, Fuller et al. 1999, Johnson et al. 2010). Additionally, changes to freshwater habitats resulting from damming of rivers have forced some Chinook salmon populations to use lacustrine-type habitats (e.g., Columbia River mainstem reservoirs). In native habitats, as well as for introduced populations that use lakes, nearshore areas are critically important for juvenile Chinook salmon (Curet 1993, Graynoth 1999, Tiffan et al. 2006, Johnson et al. 2007, Tabor et al. 2011a).

Presently, there is little information on the effectiveness of various habitat restoration projects to improve conditions for juvenile Chinook salmon in lakes. As lakes in the Pacific Northwest and lakes with introduced Chinook salmon become increasingly developed and urbanized, there is a need to understand what types of restoration projects are effective in improving habitat for rearing juveniles. A key element of these projects is effectiveness monitoring; however, this element is often lacking due to budget constraints and/or the need to sample over multiple years including both pre- and posttreatment years (Roni et al. 2003). The objectives of our study were to evaluate 4 types of restoration projects in south Lake Washington that were designed to improve juvenile Chinook salmon rearing habitat.

Study area

Lake Washington is a monomictic lake with a total surface area of 87.6 km^2, a mean depth of 32.9 m, and 128 km of shoreline (Arhonditsis et al. 2003). Surface water temperatures range from 6 to 7 C in winter to higher than 20 C in summer, and the lake typically stratifies from June through October. Lake level is controlled by the Hiram Chittenden Locks, located at the downstream end of the Lake Washington Ship Canal (Figure 1). During winter (Dec to Feb), the lake level is kept at an elevation of 6.1 m, and starting in late February the level is slowly raised to 6.7 m by 1 June.

Land use along the lake is mostly residential. The shoreline of Lake Washington is extensively developed, with only 17% of the shoreline naturally vegetated (Toft 2001). In the south end of Lake Washington, <8% of the shoreline has natural vegetation, which is in a few small patches. Roughly 70% of the shorelines are armored with riprap or bulkheads, resulting in steep sloping shorelines and little shallow water area (<1 m deep). Overwater structures, such as piers, docks, and floats, that shade nearshore areas are also common.

The 4 study sites were located in south Lake Washington (Table 1, Figure 1) near the mouth of the Cedar River, the primary spawning area of Chinook salmon in this watershed. Because of the proximity to the Cedar River, juvenile Chinook salmon abundance is substantially higher in this area than in other areas of the lake (Tabor et al. 2006). Sites closer to the Cedar River would be expected to have higher abundance of juvenile Chinook salmon than sites farther away if they had similar habitat conditions. The number of Chinook salmon fry entering the lake annually from the Cedar River has ranged from 11,000 to 1,427,000 over the last 20 yr; this corresponds to an annual redd count of 53 to 899 (Lisi 2019). Other minor sources of naturally produced juvenile Chinook salmon in the Lake Washington system are primarily Bear Creek and Issaquah Creek. Hatchery-produced juvenile Chinook

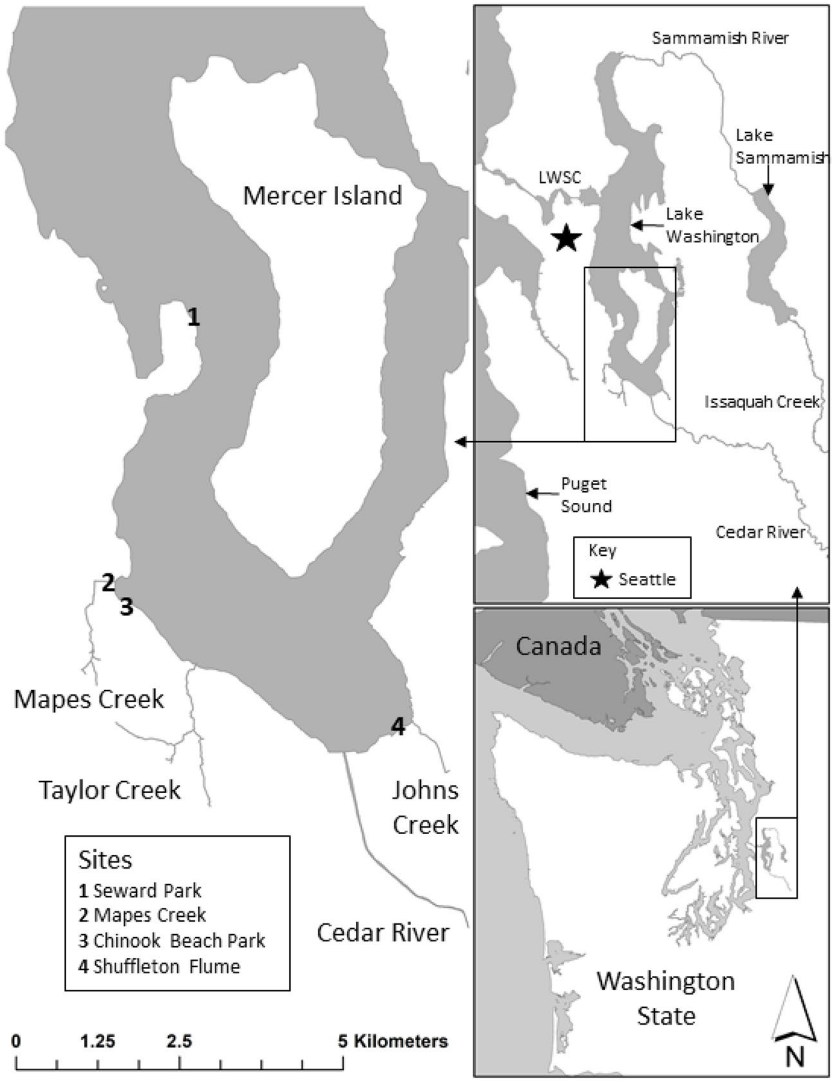

Figure 1. Map of the south end of Lake Washington displaying the locations of 4 restoration projects that were evaluated. Each restoration project is designated with a number. Johns, Mapes, and Taylor creeks are nonnatal Chinook salmon streams. Cedar River is the primary spawning site for Chinook salmon in the Lake Washington basin. LWSC = Lake Washington Ship Canal.

Table 1. Sites, construction year, and monitoring information of 4 types of south Lake Washington restoration projects implemented to improve juvenile Chinook salmon habitat conditions.

Project type	Site (number)	Construction year	Preproject year(s)	Postproject years	Length (m)	Reference site length (m)	Distance to Cedar River (m)
Engineered log jams	Shuffleton Flume (4)	2014	2011–2013	2016–2017	50–80	57	453, 596
Nonnatal tributary enhancement	Mapes Creek (2)	2014	None	2015–2017	135	97—Taylor Creek 22—Shoreline	4,662
Shoreline modification	Chinook Beach Park (3)	2005	2003–2005	2006–2008	84	126	4,041
	Shuffleton Flume (4)	2014	2011–2013	2015–2017	100	57	666
Substrate enhancement	Seward Park (1)	2001	2001	2002–2004	300	500	9,877
	Shuffleton Flume (4)	2014	2011–2013	2015–2017	79	57	549

The length and reference site length are the shoreline lengths used to enumerate juvenile Chinook salmon. For the Shuffleton Flume, the total and log jam lengths varied with lake level as the amount of the log jams was inundated. Two reference sites were used to evaluate Mapes Creek and both lengths are given. Distance to Cedar River is the distance from the mouth of the Cedar River to the midpoint of the restoration project. Site number corresponds to Figure 1.

salmon are released annually in May or June from Issaquah Creek (about 2 million fish/yr; Figure 1).

The Puget Sound Chinook salmon population in Washington was listed as threatened in 1999 under the Endangered Species Act (US Office of the Federal Register 1999). Following the federal listing of Puget Sound Chinook salmon, resource managers in the Seattle metropolitan area have looked for opportunities to improve nearshore habitat conditions in Lake Washington for juvenile Chinook salmon use. Projects have included shoreline modification, substrate enhancement, large woody debris enhancement, and nonnatal tributary improvements.

Puget Sound Chinook salmon are primarily ocean-type, which typically emigrate to the marine environment as subyearlings. During their 3 to 5 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 2 groups of emigrants: an early migrant group that moves downstream as fry and rears in estuaries, coastal ocean habitats, or lakes, and another later migrant group that rears in the natal river system and emigrates as parr or smolts (Healey 1991). In the Lake Washington system, fry have represented an average of 82% of the Chinook salmon migrants from the Cedar River from 1999 to 2018 (Lisi 2019), and thus this strategy represents an important component of the population, although the overall survival to adulthood of the 2 groups is not known.

Compared to other similar-sized basins in the Pacific Northwest, the Lake Washington basin is inhabited by a relatively large number of fish species, including 25 native species (primarily salmonids, cottids [*Cottus* spp.], and cyprinids) and at least 20 introduced species. Other salmonids in the Lake Washington basin include coastal cutthroat trout (*O. clarkii clarkii*), coho salmon (*O. kisutch*), rainbow trout (including steelhead; *O. mykiss*), and sockeye salmon (including kokanee; *O. nerka*).

Chinook Beach Park—shoreline modification

Chinook Beach Park is a small City of Seattle park that consists of a narrow beach area along Lake Washington (approximately 230 m long and 0.4 ha in size; Figure 1). The northern 84 m shoreline section of the park was originally a riprap and bulkhead shoreline that was replaced with a more gradual sloping shoreline with gravel substrate (0.5–3.0 cm diameter gravel). We used a 126 m long shoreline transect in the park that was immediately to the south of the treated shoreline as our reference site.

Mapes Creek—nonnatal tributary restoration

Mapes Creek is a small tributary (stream length, 2.0 km) to the southwest part of Lake Washington. The stream's drainage basin is roughly 37 ha and is in a highly urbanized area. The entire lower 900 m of the stream was located in a culvert and the outlet of the stream entered the lake approximately 2.5 m below the water surface. Because of poor light conditions in the deep culvert and the culvert being below their preferred depth, we assumed that juvenile Chinook salmon did not use Mapes Creek. Electrofishing surveys of upper Mapes Creek in 2006 found the only fish species upstream of the culvert (1.0 stream km) was threespine stickleback (*Gasterosteus aculeatus;* Tabor et al. 2010). The lowest 135 m of Mapes Creek was daylighted (reconfigured from an underground culvert to a more natural stream channel at the surface) in late 2014. Besides daylighting the stream, the restoration project included substrate and rootwad enhancement, and riparian planting. The new stream channel has a gradient of approximately 1% and the mean wetted width during January through June base flows is 2.2 m. To evaluate the daylighting of Mapes Creek, we used 2 reference sites. The first reference site was a shoreline site (Be'er Sheva Park boat ramps, City of Seattle) 85 m to the southwest of the mouth of Mapes Creek. Earlier surveys of this reference site indicated juvenile Chinook salmon were usually present (Tabor et al. 2006). The second reference site was Taylor Creek, another small nonnatal stream of Chinook salmon (Tabor et al. 2011b, Figure 1). Similar to Mapes Creek, Taylor Creek is a small independent tributary to the southwest part of Lake Washington (Figure 1). However, Taylor Creek is a larger stream, roughly 2 km closer to the Cedar River than Mapes Creek, and the gradient is approximately 3%. We only surveyed the lowest 97 m of Taylor Creek because a small barrier limited small-bodied fish from moving farther upstream (Tabor et al. 2020).

Seward Park—substrate enhancement

Seward Park is a 120 ha City of Seattle park that occupies all of Bailey Peninsula (Figure 1). The City of Seattle and the Army Corps of Engineers (ACOE) deposited 1100 m^3 of gravel along a 300 m shoreline section in the northeast part of the park in December 2001. The substrate composition was modified from angular quarry spalls (i.e., small boulders) to a smaller substrate. The north 150 m long section received fine substrate (0.5 to 5.0 cm), while the south 150 m section received coarse substrate (2.5 to 15 cm). The new substrate extended out approximately 5 m from shore. We used five 100 m long shoreline transects spread around the peninsula as the reference site.

Figure 2. Photos of the Shuffleton Flume site. The top 2 photos display before and after the flume structure was removed (photos were taken at the same approximate location). The bottom photo is of one of the engineered log jams (ELJ; photo was taken on 15 Jan 2015, shortly after construction). From January to June, the lake level rises approximately 0.6 m to inundate much of the ELJ shown.

Shuffleton Flume—shoreline modification, addition of engineered log jams (ELJs), substrate enhancement

The Shuffleton Flume site is a 360 m long shoreline section on the south end of Lake Washington managed by the Washington Department of Natural Resources (Figure 1). Much of this shoreline consisted of a flume (Figure 2) that was no longer being used. The flume structure consisted of 2 parallel, vertical steel walls. Water inside the flume was only connected to the lake at the west end (old flume outlet), had limited circulation, and was usually extremely turbid. In the summer of 2014, a 168 m long section of the flume structure was removed and replaced with a gradually sloping gravel beach. Gravel consisted of 0.48–3.8 cm diameter gravel that was placed at a minimum thickness of 0.6 m with a 15 cm layer of course sand (0.03–0.48 cm diameter) on top. In addition, 3 engineered log jams (ELJs) were placed along the shoreline. Each ELJ consisted of several overlapping pieces (approximately 9–13 pieces) of large natural wood with rootwads that were anchored together and attached to vertical pieces of coniferous wood that were driven into the substrate (Figure 2). Small pieces of native woody debris (5–15 cm diameter) were placed within the structure to create complexity. In other areas of this site, the substrate was modified with the addition of 6900 m^3 of gravel; this included altering a 45 m long sandy shoreline section and a 34 m long cobble shoreline section. A 57 m long armored shoreline transect (~350 m east of the treated shoreline) in Gene Coulon Park (City of Renton) was used as a reference site for the Shuffleton Flume site. We did not know the exact location of where the ELJs would be placed, so we used the abundance estimate for the entire shoreline (flume and substrate enhancement transects) as the pretreatment estimate.

Methods

Field surveys

We primarily used night snorkeling to monitor the relative abundance of juvenile Chinook salmon. Snorkeling allowed us to effectively survey a variety of habitat types and no handling of fish was required (Roni and Fayram 2000). Night surveys minimize the effect the snorkeler has on the behavior of juvenile Chinook salmon. At night, juvenile Chinook salmon typically are inactive, rest near the bottom, are not closely associated with each other, can be easily approached by snorkelers, and can be accurately counted (Tabor et al. 2011a). During the day, juvenile Chinook salmon are often in schools that move away from snorkelers and can easily be missed. One disadvantage of night snorkeling is that juvenile Chinook salmon may move away from complex structures (Tabor et al. 2011a) and thus their overall use of these habitats may be underestimated. However, in January through March, they appear to only move a few meters away from the structures and their use of these structures can be estimated. In April through June determining their use of complex structures may be more problematic because they may move farther away, and thus our estimates are likely conservative.

For lakeshore transects at all 4 study areas, one snorkeler swam parallel to the shore such that juvenile Chinook salmon could easily be observed to the shoreline on one side and to at least 0.7 m depth on the other side. Earlier observations indicated that most juvenile Chinook salmon will be in this depth range (Tabor et al. 2011a). At all transects, the bank slope was steep enough to allow this criterion to be met. Our ability to observe juvenile Chinook salmon between 0 and 0.7 m depth appeared to be the same between transects, and thus our snorkel counts provided a shoreline relative abundance estimate that could be used to compare between restoration and reference sites. The transect width was generally 2.5 to 3 m, and within this narrow area, we assumed our viewer efficiency was high because Chinook salmon were inactive and light from the dive light reflects well off them, making counting relatively straightforward. All transects were done in a consistent manner for both pretreatment and posttreatment surveys. Within the monitoring efforts of each project, we used the same core group of experienced snorkelers to reduce observation error. Also, we limited sampling to nights with calm water and good water visibility. Increased turbidity levels from high wind events or from high streamflow events (Cedar River discharge) occasionally limited our ability to survey.

Snorkeling began shortly after sunset (45 min to 1 h after posted sunset time). Snorkelers used an underwater flashlight to observe the fish. Surveys were conducted from late January to early June to coincide with when juvenile Chinook salmon were expected to be present. For Seward Park, Shuffleton Flume, and Mapes Creek sites, surveys were conducted twice a month (once during the first 2 weeks and once during the last 2 weeks), while at the Chinook Beach Park site, surveys were conducted once a month.

Snorkel surveys of log jams (i.e., large woody debris piles) were conducted in 2016 and 2017. Two of the log jams were ELJs with 9–13 large overlapping pieces, while the third log jam was a small natural log jam consisting only of a few pieces of wood. The surveys consisted of a single transect around the outside perimeter of 3 log jams. We observed fish from the shoreline on one side of the log jam to the outside edge of the log jam and then back to the shoreline on the opposite side of the log jam. Maximum depth on the outside edge of the log jam varied from 0.75 to 0.8 m in February and March, to 1.2 to 1.4 m in May and June. The complexity of the log jams prevented observation of the inner parts of each log jam and we assume our fish counts are an underestimate.

In Mapes (restored site) and Taylor creeks (reference site), we used a combination of snorkeling and surface observations to determine the abundance of juvenile Chinook salmon. Because shallow areas were difficult to snorkel effectively, we conducted surface observations in these habitats. Observers slowly walked upstream and counted fish with the aid of high-powered lights. The use of surface observations has been effective for studying juvenile salmonid habitat use in lotic systems where there is little surface turbulence (Heggenes et al. 1990). Because juvenile Chinook salmon are not typically present in riffles (i.e., areas with surface turbulence; Tabor et al. 2011b), we felt we were able to count the vast majority of Chinook salmon present.

Study design and data analysis

For the ELJ, shoreline modification, and substrate enhancement projects, we used a BACI (before-after-control-impact) study design (Stewart-Oaten et al. 1986). The fish count data included many zeros, with variability in counts tending to increase with larger means. Therefore, we used a negative binomial linear model, standardizing with an offset for survey length. The log mean for treatment, t, period, p, year, y, and date, d, is defined as

$$\mu + \alpha_t + \beta_p + \alpha\beta_{t,p} + \gamma_{y(p)} + \alpha\gamma_{t,y(p)} + \delta_{d(y(p))} + log\left(l_{t,p,y,d}\right) \quad (1)$$

Here, μ is the intercept, α is the treatment effect, β is the period effect (before/after treatment), $\alpha\beta$ is the interaction between treatment and period (i.e., effect size), γ is the year effect nested within period, $\alpha\gamma$ is the interaction between year and treatment, δ is the effect for day nested within year and period, and l is the survey length in meters (included as an offset; i.e., no coefficient). The year, year by treatment, and day effects (γ, $\alpha\gamma$ and δ) were modeled as random variables. For the posttreatment design used to compare the 2 ELJs to the natural log jam, treatment included 3 categories and all parameters related to period were excluded from the model (α, $\alpha\beta$). See Supplement for details.

The model was fitted using a Bayesian framework. Therefore, uncertainty in the estimates was expressed using credible intervals, which are roughly equivalent to confidence intervals (e.g., Albers et al. 2018). We limited the analysis to periods within the year that had relatively consistent densities to reduce within-year temporal patterns resulting from fish movement. We also removed dates with data missing for one of the 2 sites (see Supplement). Because there were relatively few years before and after treatment, estimates of before vs. after treatment effects will tend to be uncertain. For the Seward Park substrate study, with only one before year, any before–after comparison is confounded by annual variability. We avoided P values and use of the word “significant” when describing results, instead reporting estimates and 95% credible intervals where appropriate (e.g., McShane et al. 2019). We did not adjust for multiple comparisons, but avoided drawing conclusions based on isolated differences.

Results

Engineered log jams

The highest abundances observed for all our sites in this study were from the Shuffleton Flume log jams, with a peak Chinook salmon abundance of 10.3/m for 2016 and 4.9/m for 2017. The ratio of Chinook salmon abundance between the log jams and reference sites was estimated to be more than 3 times higher in 2016 than in all of the 3 preproject years (Figure 3). However, these estimates were uncertain, with lower credible interval bounds extending to just below 1 (no effect), and differences between pretreatment years and 2017 were negligible. The estimated overall before–after effect was 1.9 but was very uncertain (95% CI = 0.3 – 12.5). The highest densities of juvenile Chinook salmon observed in log jams were from February to April, and during this period, densities were substantially higher than in the nearby standard open shoreline transects (Figure 4). Chinook salmon were concentrated in the shallow waters (typically in water that was less than 0.5 m deep) on the perimeter of each log jam. In May and June, densities of juvenile Chinook salmon in the log jams decreased sharply and were typically less than the densities in the nearby standard open shoreline transects (Figure 4). Both of the ELJs had higher densities of juvenile Chinook salmon than the small natural log jam for the 2 study years (Figure 5), averaging more than 2 and 5 times higher densities for ELJ A and ELJ B, respectively.

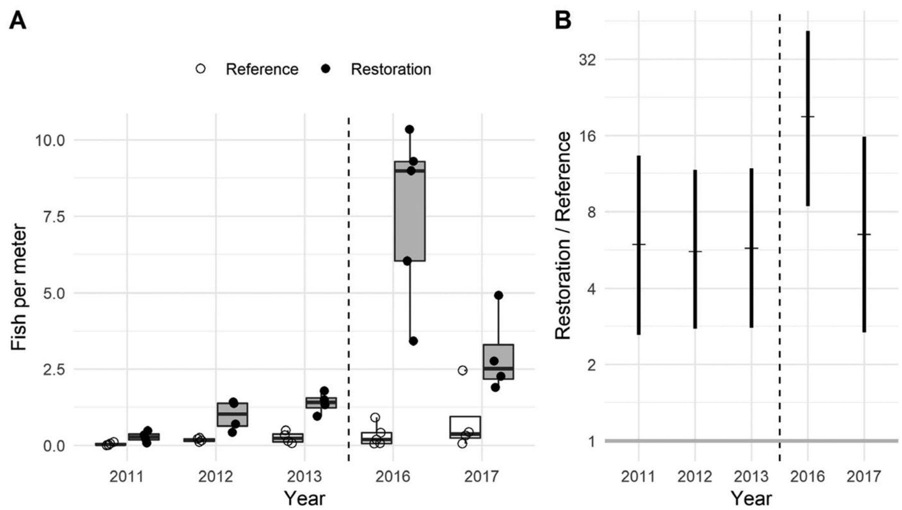

Figure 3. Juvenile Chinook salmon nearshore densities (Chinook/m) for Shuffleton Flume log jams (Restoration) and reference site. Pretreatment monitoring was conducted in 2011–2013 and posttreatment monitoring in 2016–2017. Panel A includes the raw densities for sampling dates between 15 Feb and 15 Apr. Points are jittered slightly along the horizontal axis and boxplots are overlaid to show the median and quartiles. Panel B is the estimated ratio of restoration to reference site densities for each year, along with 90% credible intervals.

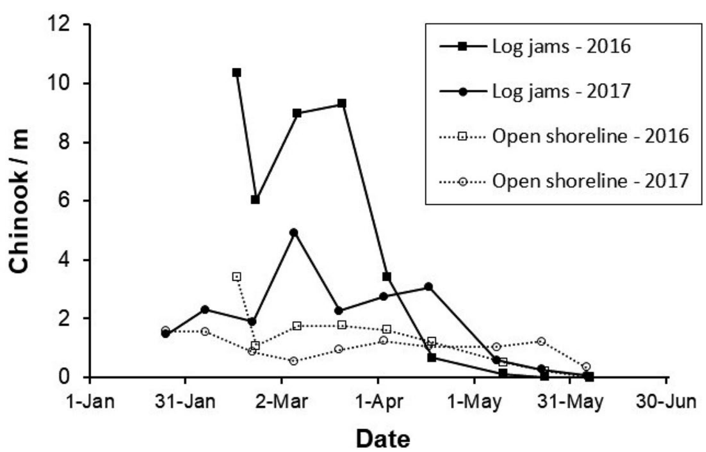

Figure 4. Juvenile Chinook salmon nearshore densities (Chinook/m) along log jams (3 log jams combined) and nearby open shoreline, Jan–Jun 2016 and 2017.

Nonnatal tributary improvement

The abundance of juvenile Chinook salmon in Mapes Creek generally increased sharply from January through February with a peak in early March and then declined sharply in April and May (Figure 6). Peak abundance along the shoreline reference site had a much later peak in April or May. Juvenile Chinook salmon in Mapes Creek (1% gradient) tended to be well distributed along the entire daylighted reach of the stream channel (Figure 7). In contrast, juvenile Chinook salmon in Taylor Creek (2.6% gradient) were usually concentrated near the stream mouth.

Shoreline modification

For both shoreline modification projects, the estimated ratio of restoration to reference densities was higher in the post years than in the pre years, averaging 5.8 (95% CI = 0.9 – 30) and 4.8 (95% CI = 0.9 – 54) times higher for the Shuffleton Flume and Chinook Beach Park sites, respectively (Figure 8). During Chinook Beach Park pretreatment surveys (2003–2005), the density of Chinook salmon was higher in the reference site than in the treated site on 12 of 13 surveys, while during posttreatment surveys, the reference site was only higher in 4 of 14 surveys (Figure 8). The mean

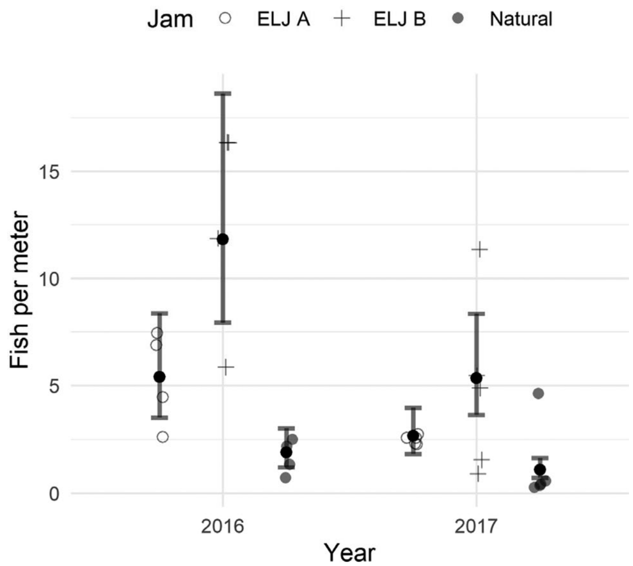

Figure 5. Juvenile Chinook salmon nearshore densities (Chinook/m) for the Shuffleton Flume engineered log jams (ELJ A and ELJ B) and a natural log jam (Natural) for 2 postproject years. Points are jittered slightly along the horizontal axis and the estimated median densities along with 90% credible intervals are included.

Chinook salmon density at the Shuffleton Flume site was only 1.07 times higher than the reference site during pretreatment surveys but was 4.79 times higher during posttreatment surveys.

Substrate enhancement

Of the substrate enhancement sites that reduced the substrate size, differences in Chinook salmon abundance (treated vs. reference sites) at the 2 Seward Park sites showed little change between pre and post project (Figure 9). In comparison to the other restoration sites, few Chinook salmon were observed at the Seward Park sites. On only 3 of 26 surveys was the Chinook salmon density >0.02 fish/m for the restoration sites. Peak Chinook salmon counts were only 0.18/m for the reference sites, 0.05/m for the small gravel site, and 0.04/m for the large gravel site. For the Shuffleton Flume sites, the cobble to gravel treatment tended to show higher densities post

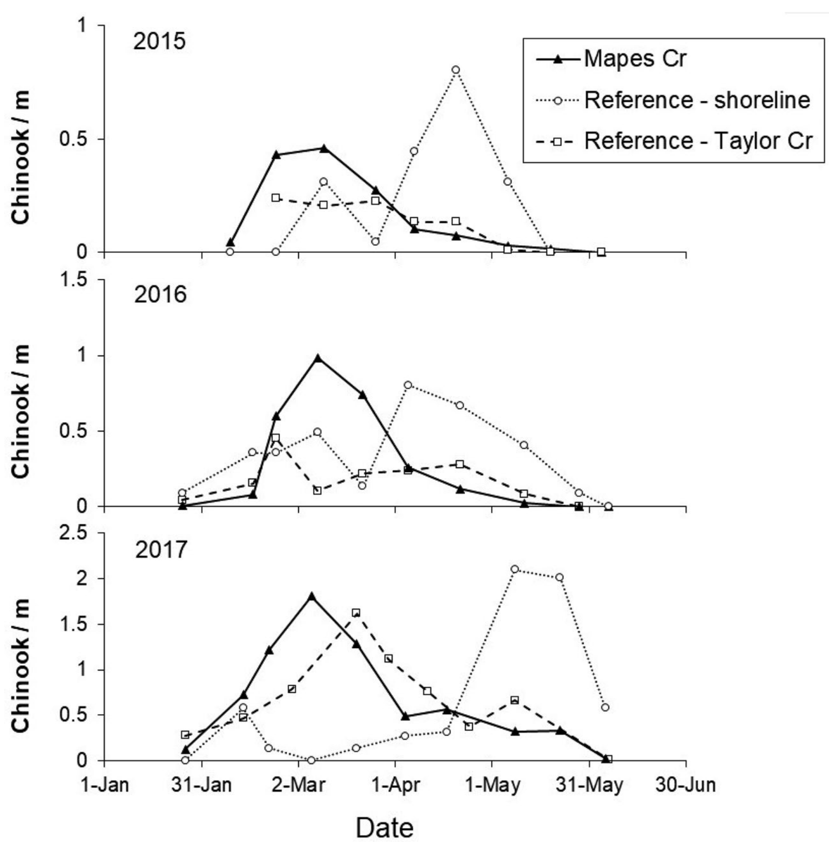

Figure 6. Juvenile Chinook salmon densities (Chinook/m) in lower Mapes Creek, lower Taylor Creek, and along a lakeshore reference (Be'er Sheva Park boat ramps), Jan–Jun 2015–2017. For the lakeshore transect, surveys were all snorkeling surveys; for the streams, surveys were a combination of surface (riffles and glides) and snorkeling (pools) observations.

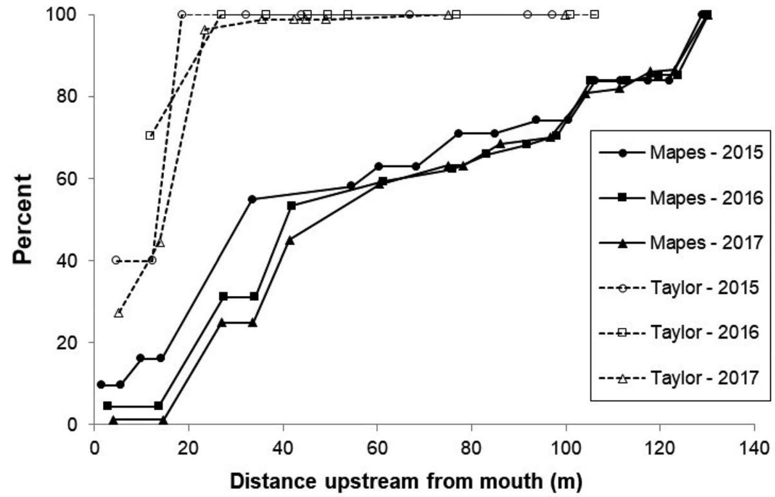

Figure 7. Cumulative percent of the number of juvenile Chinook salmon in lower Mapes Creek (solid lines and solid symbols) and lower Taylor Creek (dashed lines and open symbols) from the stream mouth to the upstream end of their distribution. Each data point represents the midpoint of a habitat unit (i.e., pool, glide, or riffle). For each year, data are from the survey date with the highest abundance in the stream (Mapes Creek—10 Mar 2015, 8 Mar 2016, and 6 Mar 2017; Taylor Creek—10 Mar 2015, 23 Feb 2016, and 20 Mar 2017).

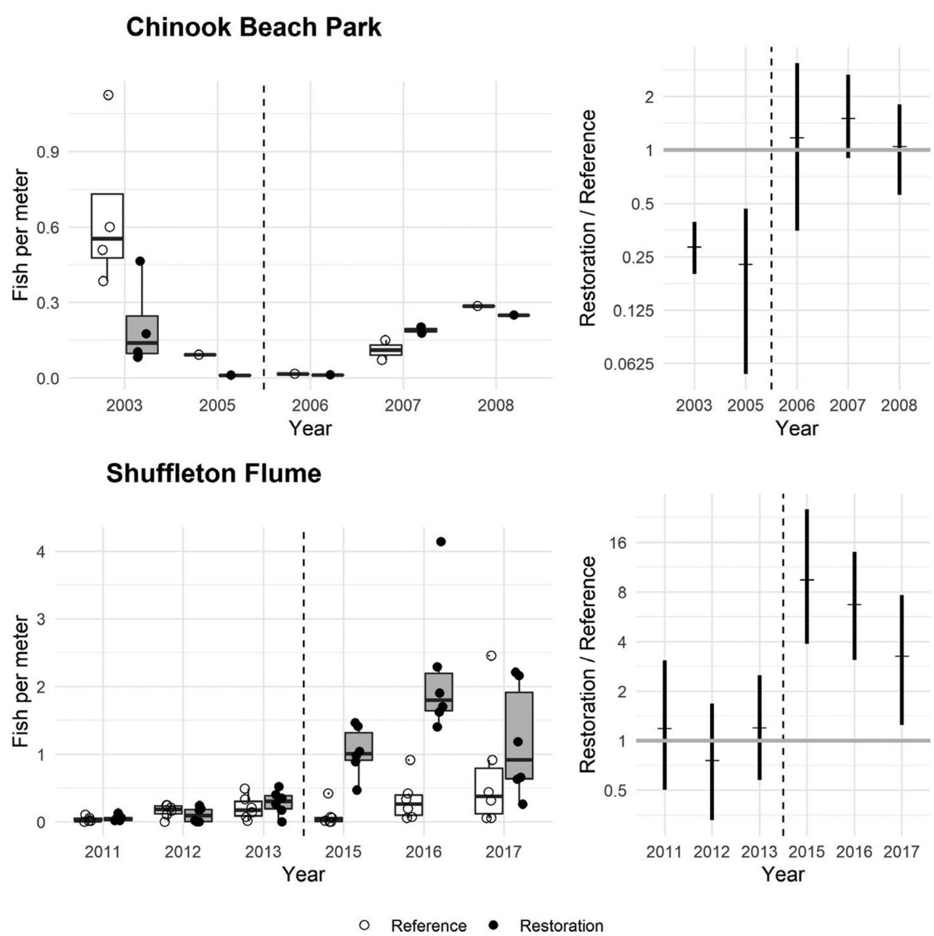

Figure 8. Juvenile Chinook salmon nearshore densities (Chinook/m along nighttime snorkel transects) between treatment and references sites at 2 shoreline modification projects (Chinook Beach Park and Shuffleton Flume), Jan–Jun. Densities were truncated to dates between 1 Jan and 14 Apr for Shuffleton Flume and between 15 Mar and 10 May for Chinook Beach Park. Plots to the left include the raw densities with points jittered slightly along the horizontal axis and boxplots overlaid to show the median and quartiles. Plots to the left show the estimated ratio of restoration to reference site densities for each year, along with 90% credible intervals.

treatment and the sand to gravel tended to have lower densities post treatment (Figure 9). However, credible intervals for both effect sizes included 1.

Discussion

A key component of habitat restoration projects is biological monitoring to establish the effectiveness of the project for target species. This is particularly important for recovery efforts of federally listed species such as Puget Sound Chinook salmon. Through night snorkeling, we were able to evaluate 4 restoration projects in south Lake Washington. Our evaluations may guide planning of future restoration projects for lake-rearing juvenile Chinook salmon. All 4 project types we evaluated appeared to have some positive benefit for juvenile Chinook salmon; however, substrate enhancement generally had a weaker response than the other 3 types. Conversely, ELJs at the Shuffleton Flume site appeared to be particularly valuable habitat for juvenile Chinook salmon.

Evaluation of log jams

Nighttime surveys of log jams indicated large numbers of Chinook salmon were often closely associated with these structures. Based on Shuffleton Flume 2016–2017 nighttime surveys and a few daytime surveys in 2015, as well as other observations in Lake Washington, Lake Sammamish, and Lake Quinault (Tabor and Piaskowski 2002, Tabor et al. 2006, Tabor et al. 2011a), it appears juvenile Chinook salmon are primarily in small schools in the middle of a complex structure such as a log jam during the day and then move to the outside perimeter of the structure at night to rest on the bottom of the lake. The degree to which juvenile Chinook salmon

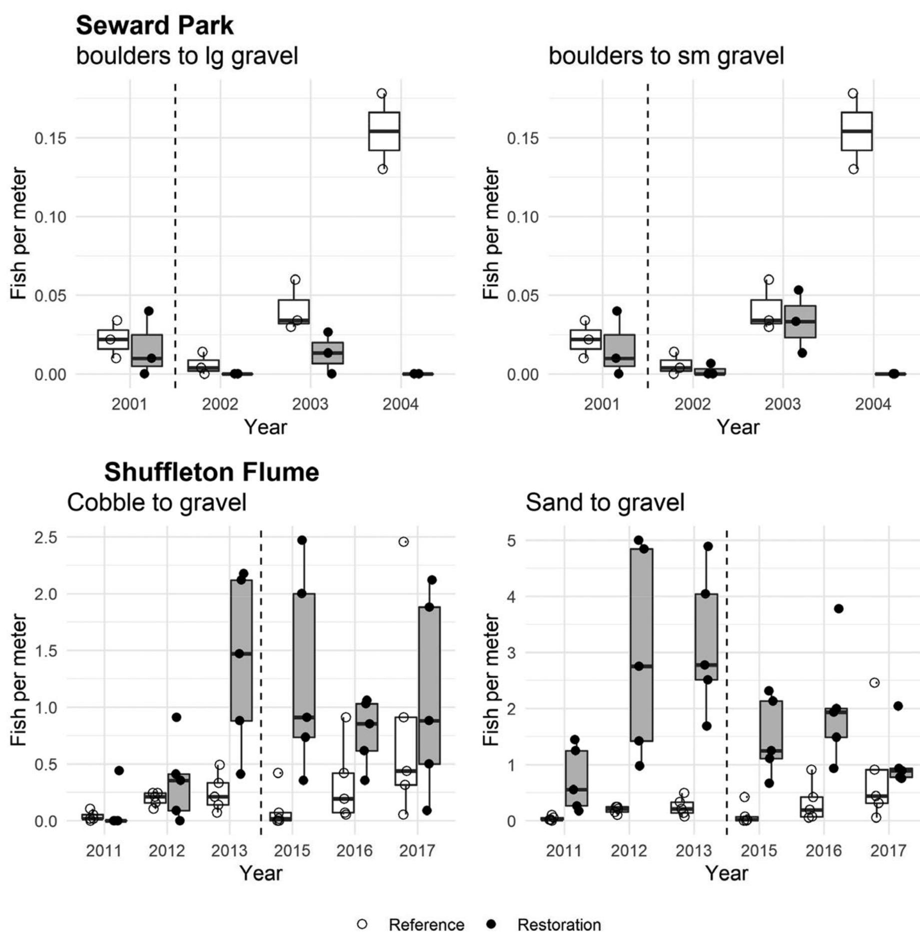

Figure 9. Juvenile Chinook salmon nearshore densities (Chinook/m along nighttime snorkel transects) between treatment and references sites at 2 substrate enhancement projects (Seward Park and Shuffleton Flume projects). Points are jittered slightly along the horizontal axis, and boxplots are overlaid to show the median and quartiles.

may forage inside the log jam is unknown. Koehler (2002) found that among various Lake Washington shoreline types, natural forested shorelines with overhanging vegetation often had the lowest densities of chironomids (the main forage item of juvenile Chinook salmon); therefore, log jams may not have as high or higher levels of prey abundance than other areas of the lake. There are likely times (e.g., dawn and dusk) when some juvenile Chinook salmon move away from log jams to forage. Likely, the most important function of log jams is to provide juvenile Chinook salmon refuge from predators. In laboratory experiments, Sergeant and Beauchamp (2006) found cover (overhead cover and woody debris) had a weak effect on juvenile Chinook salmon habitat use when predators were present. However, field experiments and observations have suggested juvenile Chinook salmon often use cover and it is likely important to reduce predation risk (Brusven et al. 1986, Meehan et al. 1987, Tabor et al. 2011a). While juvenile Chinook salmon appear to be more risk-prone than other juvenile salmonids (Abrahams and Healey 1993), cover is still an important habitat element and should be considered when designing restoration projects.

Log jams appear to provide valuable habitat for juvenile Chinook salmon; however, how much large woody debris is needed is not well known. At the Shuffleton Flume site there were 3 ELJs and one small natural log jam spread out over a roughly 300 m long shoreline section, representing about 15% of the shoreline. South Lake Sammamish (a smaller lake connected to Lake Washington) has a natural 300 m long structurally complex shoreline section with large and small woody debris and emergent vegetation, and juvenile Chinook salmon primarily used the 2 opposite ends of this complex shoreline that are adjacent to open beaches (Tabor and Piaskowski 2002). This may indicate the influence of an edge effect where juvenile Chinook salmon primarily use the periphery of the log jam, which enables them to easily retreat to cover when needed but also allows them to move into open shorelines to forage and rest at night. The ELJs at the Shuffleton Flume were 10 to 15 m wide which may be closer to an ideal size that provides a balance of cover and forage opportunities while larger ELJs than these may not provide much additional benefit and thus may be less cost-effective. The ELJs at the Shuffleton Flume were spaced 100 to 130 m apart. Placing ELJs closer together may be beneficial, but the ideal distance between ELJs is not known.

The large ELJs consistently had Chinook salmon densities that were 2 to 10 times higher than for the smaller natural log jam. The use of large overlapping pieces of woody debris in ELJs appears to provide ample structural complexity and overhead cover (Figure 2). The use of ELJs has also been shown to improve habitat conditions for juvenile Chinook salmon in riverine environments (Pess et al. 2012, Polivka and Claeson 2020). In Lake Quinault (western Washington), the highest concentrations of juvenile Chinook salmon during the day were directly under large pieces of woody debris (Tabor et al. 2006). Conversely, rootwads (similar to the natural log jam at Shuffleton Flume) used at the Chinook Beach Park site were not used extensively by juvenile Chinook salmon (Tabor R, pers. obs.), likely because of how they were placed. Each of these rootwads was laid flat on the bottom and provided little overhead cover.

The log jams appeared to provide valuable habitat for juvenile Chinook salmon, but there is a risk that they may also provide habitat for smallmouth bass (*Micropterus dolomieu*) and other nonnative fishes that could prey on juvenile Chinook salmon. However, nonnative fishes we observed were mostly juveniles and were too small to predate on juvenile Chinook salmon (Tabor R, unpubl. data). The log jams did not extend out into deep water (i.e., >1.5 m depth) which probably minimizes their 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 log jams. Therefore, the new ELJs likely do not directly affect juvenile Chinook salmon through predation but could indirectly affect them by enhancing nonnative fish populations.

Evaluation of nonnatal tributary restoration

Surveys of lower Mapes Creek demonstrated that juvenile Chinook salmon were commonly using the recently daylighted stream channel. Results were consistent with surveys of other nonnatal tributaries of Lake Washington and Lake Sammamish (Tabor et al. 2011b). Also, densities of juvenile Chinook salmon in Mapes Creek compare favorably with densities observed in nonnatal tributaries from other systems (Murray and Rosenau 1989, Scrivener et al. 1994, Scarnecchia and Roper 2000, Bradford et al. 2001). Small, low-gradient streams that are close to the mouth of a natal stream (e.g., Cedar River) appear to be particularly valuable habitat for rearing juvenile Chinook salmon. Restoring Mapes Creek appears to have successfully added this valuable rearing habitat. There are additional small, nonnatal tributaries in Lake Washington and Lake Sammamish that likely served as juvenile Chinook salmon rearing habitat historically. Some of these streams (e.g., Taylor Creek) are targeted for future restoration projects, and others may represent additional restoration opportunities.

Mapes Creek is 1.7 times farther away from the mouth of the Cedar River than Taylor Creek (4662 m vs. 2700 m; Figure 1), yet Mapes Creek often had more juvenile Chinook salmon than Taylor Creek (a reference site for Mapes Creek). In Mapes Creek, juvenile Chinook salmon were distributed throughout the restored reach, while in lower Taylor Creek they were concentrated in the lower section of our study reach and were rarely found farther upstream. Differences in distribution and abundance were likely in large part because the gradient in Mapes Creek was about 1% while it was about 3% in Taylor Creek. Tabor et al. (2011b) also found that the nonnatal tributaries used extensively by juvenile Chinook salmon in the Lake Washington system had a gradient less than 1%. Studies from other systems have also found the nonnatal tributaries used extensively by juvenile Chinook salmon have a low gradient, ranging from <0.25% to 2% (Murray and Rosenau 1989, Scrivener et al. 1994, Bradford et al. 2001). Additionally, Taylor Creek is a large stream with more pool habitat and has a larger population of cutthroat trout, including individuals >150 mm fork length (FL). Perhaps the presence of large cutthroat trout may affect the distribution of juvenile Chinook salmon through predation risk. In some situations, cutthroat trout can be a predator of juvenile Chinook salmon (Nowak et al. 2004). It is unclear to what extent interactions with other species affects their use of nonnatal tributaries.

In comparison to a lakeshore reference site, juvenile Chinook salmon were generally more abundant in Mapes Creek in January through March but less abundant in April and May. In Mapes Creek, some of this is likely because the requirements of juvenile Chinook salmon for space and food increase as they grow (Chapman 1966) and there should be some level of self-thinning due to intense competition (Elliot 1993, Dunham and Vinyard 1997). Additionally, habitat conditions in Mapes Creek may not support larger juvenile Chinook salmon because there are few pools. In Johns Creek (another nonnatal tributary in Lake Washington) in late March and April, juvenile Chinook salmon shifted from inhabiting shallow-water habitat (glides) to using deeper water habitats (pools; Tabor et al. 2011b). In contrast to Mapes Creek, juvenile Chinook salmon at the lakeshore reference site (Be'er Sheva Park boat ramps) were able to progressively move to deeper waters as they grew (Tabor et al. 2011a).

Evaluation of shoreline modification

The surveys at Chinook Beach Park and the Shuffleton Flume sites indicated that the removal of armored shorelines and the replacement with a gradual sloping shoreline had a positive effect on juvenile Chinook salmon abundance. This positive benefit was predicted, as the removal of these armored shorelines resulted in gradual sloping shallow shorelines that are generally preferred by Chinook salmon (Tiffan et al. 2002, Sergeant and Beauchamp 2006, Tabor et al. 2011a). Shallow water depths may be preferred by Chinook salmon as a predator avoidance strategy (DeVries 1990). Additionally, armored banks may also have a higher abundance of potential predators (e.g., smallmouth bass and large cottids; Sammons and Bettoli 1999, Knaepkens et al. 2002) than other shoreline types and thus present a higher predation risk.

At the Shuffleton Flume site, 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 noticeably different than in the lake. The water inside the flume was only connected to the lake at the west end and thus there was limited water circulation. There was more structural complexity inside the flume than outside it, 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 the flume was 2 to 3 times what we observed outside the wall, the restoration project would still have a positive effect because there were roughly 9 times as many Chinook salmon observed along the Flume transect after the restoration project as before the project. In addition, the overall posttreatment estimate would be substantially higher if the large numbers of Chinook salmon present in the ELJs were added to the total.

Evaluation of substrate enhancement

Overall, substrate enhancement projects did not appear to be as beneficial as other types of restoration projects. At the Seward Park site, the project effect may have been difficult to document because few Chinook salmon were present in both pre- and posttreatment surveys.

We also examined changes in juvenile Chinook salmon abundance due to substrate enhancement at a section of the Shuffleton Flume site where cobbles were removed and replaced with small gravel. Although we observed an increase in juvenile Chinook salmon at the Shuffleton Flume site, the effect was much weaker than for other types of projects at the Shuffleton Flume site, including shoreline modification and the addition of ELJs. In laboratory experiments, Sergeant and Beauchamp (2006) found substrate type had a weak effect on juvenile Chinook salmon habitat use. Therefore, the substrate enhancement project at Seward Park may have had a small positive benefit on juvenile Chinook salmon but it would be difficult to determine because few juvenile Chinook salmon were present, and the effect may be weak because of the project type.

All south Lake Washington restoration projects except the Seward Park substrate enhancement project appeared to noticeably improve habitat conditions for juvenile Chinook salmon as measured by density of fish present. The distance from the natal stream, type of project, and project year may all have been factors in the lack of performance success at this project site. The Seward Park project site was more than 5 km farther away from the mouth of the Cedar River than any of the other projects. Juvenile Chinook salmon are typically concentrated in the south end of the lake near the mouth of the Cedar River and locations that were more than 9 km from the mouth, such as Seward Park, typically have few juvenile Chinook salmon (Tabor et al. 2006). Similarly in Lake Coleridge, New Zealand (Graynoth 1999), and in Lake Huron (Johnson et al. 2007), juvenile Chinook salmon were more abundant close to the natal tributary than a few kilometers away. Therefore, shoreline restoration projects closer to the mouth of the natal stream will likely have a higher concentration of juvenile Chinook salmon than projects located farther away. Distance from the natal stream should be considered in planning lakeshore habitat restoration for juvenile Chinook salmon. Additionally, the annual number of juvenile Chinook salmon entering Lake Washington in 2001 through 2004 during our Seward Park assessment was generally much lower than the annual number entering the lake after 2011 (Lisi 2019). Therefore, the abundance of juvenile Chinook salmon in Seward Park may have been higher after 2011 and we may have been better able to assess whether the restoration project improved their habitat.

Conclusion

The restoration projects we examined demonstrated that nearshore habitat can be improved for juvenile Chinook salmon. These projects were relatively large and expensive, and effectiveness monitoring provided valuable evaluations of their success. An important question for these projects is whether they increase the survival of juvenile Chinook salmon and ultimately increase the number of emigrating smolts or whether they just concentrate fish (Roni 2019). Because juvenile Chinook salmon appear to grow well in Lake Washington (Koehler et al. 2006), the effects of lakeshore development are believed to cause decreased survival rates due to increased predation risk (Tabor et al. 2011a). Shoreline restoration projects in Lake Washington were primarily designed to provide refuge from predators by adding structural complexity (Tabor and Wurtsbaugh 1991) and shallow water habitats (DeVries 1990). Additionally, small nonnatal tributaries, such as Mapes Creek, tend to support higher numbers of juvenile Chinook salmon than large nonnatal tributaries, likely because of the amount of shallow water refuge and reduced predation risk (Tabor et al. 2011b). Our projects represented only a small fraction of the shoreline of south Lake Washington, and it may be difficult to detect any change in the survival of juvenile Chinook salmon and the number of emigrating smolts because there is large annual variability in juvenile Chinook abundance and a significant portion also rear in the Cedar River. However, as other restoration projects are completed in Lake Washington, the change in survival may be more pronounced and easier to detect. On public shorelines in Lake Washington, some sections with armoring have been removed and additional ELJs have been installed. Additionally, local municipalities have been working with residential shoreline owners to improve nearshore habitat for juvenile Chinook salmon (e.g., Green Shorelines Project; City of Seattle 2011). Therefore, a long-term program of monitoring the Chinook salmon population would be needed to fully evaluate the cumulative effect of all restoration efforts in south Lake Washington.

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