Squamish River Estuary Culvert Monitoring

Implementation Year 1 (2018):

Reference: SQUAMISH ESTUARY

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Executive Summary

The objective of this study was to determine whether culverts in the Squamish River training dike allow for the passage of juvenile Chinook Salmon into the Squamish River estuary during their migration into Howe Sound. The training dike is a potential barrier to juvenile fish migration from the Squamish River into the estuary rearing environment. The Squamish River Watershed Society in Partnership with the Department of Fisheries and Oceans and Squamish First Nation have received funding to upgrade fish passage structures in the dike. Prior to culvert upgrades, monitoring of fish passage through culverts was required. Radio-frequency identification (RFID) telemetry was used to monitor the passage of juvenile salmon (minimum fork length 60 mm) through the culverts. Fish were implanted with passive integrated transponder (PIT) tags. Beach seining was used to capture juvenile salmon at mid-channel and bank-edge sand bars. Chinook Salmon were the most abundant species encountered at fishing sites, but a small number of Coho Salmon juveniles were also captured and tagged. A total of 454 PIT tagged salmon were released at their point of capture, none of which were detected on the antenna in the two culverts. An additional 49 fish were released proximate to the culvert mouths, 22 of which were detected moving through one of the Culverts. The results of this study indicate Chinook Salmon are not using Culverts 3 and 4 to access the estuary. These results, as well as the patterns of habitat usage of Chinook Salmon in the estuary (Lingard 2018), indicate upgrading culverts in the Squamish River training dike is a valuable and necessary step towards recovery of salmon in the Squamish River system.

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1.0 INTRODUCTION

The Squamish River is a glacial, salmon bearing watershed in the South Coast of British Columbia located within the traditional territory of the Squamish First Nation. Multiple species of salmonids are harvested from the Squamish River and its tributaries by the Squamish First Nation for food, ceremonial and social purposes. In addition to traditional use, the Squamish River watershed also supports multiple stakeholder groups such as commercial angling and raft guiding companies, as well as recreational user groups (i.e., anglers, campers, hunters, and various water sports).

Chinook Salmon, the largest of the Pacific salmon, are an important species in the Squamish River. In general, Chinook Salmon populations have been in decline along the coast of British Columbia, Washington and Oregon since the 1980's (Slaney et al. 1996; Heard *et al.* 2007; 2011), largely due to poor ocean survival, overharvest and habitat losses (Slaney et al. 1996; Walters and Martel 2004; Beamish et al. 2012). Salmon populations in the Squamish River may have been impacted by many of these regional stressors as well as local stressors including loss in estuarine habitat (Anon 2005), a major flood in 2003, and a caustic soda spill in the Cheakamus River in 2005 (McCubbing et al. 2005). Although data are sparse for Chinook Salmon in the Squamish River, recent data suggest the population is in decline. Monitoring of juvenile Chinook Salmon abundance on the Cheakamus River (a tributary of the Squamish River) for BC Hydro, as part of a water use planning (WUP) process, was conducted between 2000 and 2018 (Lingard et al. 2018). Estimates of Chinook Salmon fry abundance in the Cheakamus River between 2000 and 2013 ranged from 137,000 to 800,000; however, between 2014 and 2018 estimates were lower (between 16,000 and 114,000).

Limited access to the estuary is a potential local stressor for Chinook Salmon in the Squamish River. Estuarine habitats are important transition zones for Pacific salmon in both the juvenile and adult stages of their life history. Previous work, in the Pacific Northwest, suggests juvenile Chinook Salmon use estuaries to a greater extent than other species of salmon (Sibert 1975; Levy and Northcote 1982; Levings et al. 1991; Korman et al. 1997; Bottom et al. 2005; Hering et al. 2010; Moore et al. 2016). Estuarine habitat of the Squamish River was significantly reduced by both industrial and urban development. Specifically, a dike that separates the Squamish River from its estuary was built along the eastern bank of the Squamish River in the 1970's in preparation for a coal port development. To enable the passage of river water and fish into the estuary, ten culverts were installed in the training dike in the early 2000's; however, a three-year (2013-2016) survey of juvenile salmonid habitat usage in the Squamish River estuary indicated salmon may not have adequate access to estuarine habitat through the training dike culverts (Lingard et al. 2018). In 2018, the Squamish River Watershed Society was awarded a grant, by the Government of Canada's Coastal Restoration Fund, to assess the effectiveness of culverts for fish passage and inform future decisions for upgrading fish passage structures in the training dike.

1.2 Project Objectives

This project had two objectives:

i) To determine the feasibility of using RFID technology to monitor Chinook Salmon passage into the Squamish River estuary.

ii) To determine if Chinook Salmon juveniles use the culverts in the Squamish River training dike to access the estuary.

2.0 METHODS

2.1 Study Area

The Squamish River watershed covers an area of 3650 km^2 in the Coastal Mountain range of southern British Columbia. The Squamish River is the largest tributary of Howe Sound and forms the northern terminus of the glacial fjord (Figure 1). There are four main tributaries in the Squamish River watershed (Mamquam, Cheakamus, Ashlu and Elaho Rivers) (Figure 2) that are home to nine species of Pacific salmon (Chinook, Coho, Chum, Sockeye, and Pink salmon) and trout (Dolly Varden, Cutthroat, Rainbow/ steelhead and Bull trout). The Squamish River typically experiences low discharge periods in both winter and late summer/early fall, and high discharge periods in spring (April to July) and late fall. High discharge events in the spring result from a combination of snow melt and storm events, while high discharge events in fall generally result from storm events.

The Squamish River channel is bound by a training dike on its eastern bank beginning at the confluence of Howe Sound (river kilometer [rk] 0) that separates the river from the historical estuarine flood plain of the river between rk 0 and rk 4. The width of the river channel along the dike varies between 200 and 500 m. Ten culverts in the dike connect the river to the estuary which are numbered in ascending numerical order from north to south. At culverts 1, 2 and 5, side channels lead to and from the training dike on both the river and estuary sides of the road. At Culverts 3 and 4 the central estuary channel butts directly against the training dike. At culverts 6 through 10 the structures connect the deep Squamish River channel to a short channel on the estuary side of the dike; however, this channel is not well connected to the central estuary and the majority of the estuarine habitat (Figure 3).

Culverts 3 and 4 were selected as the top candidates for upgrades (and were the focus of this study) due to their location in the northern section of the training dike and their relatively low importance as flood protection for the community of Squamish. Culvert 3 has two twinned 4-foot diameter culverts, but one was fully blocked by debris during this survey. Culvert 4 has one 4-foot diameter culvert.

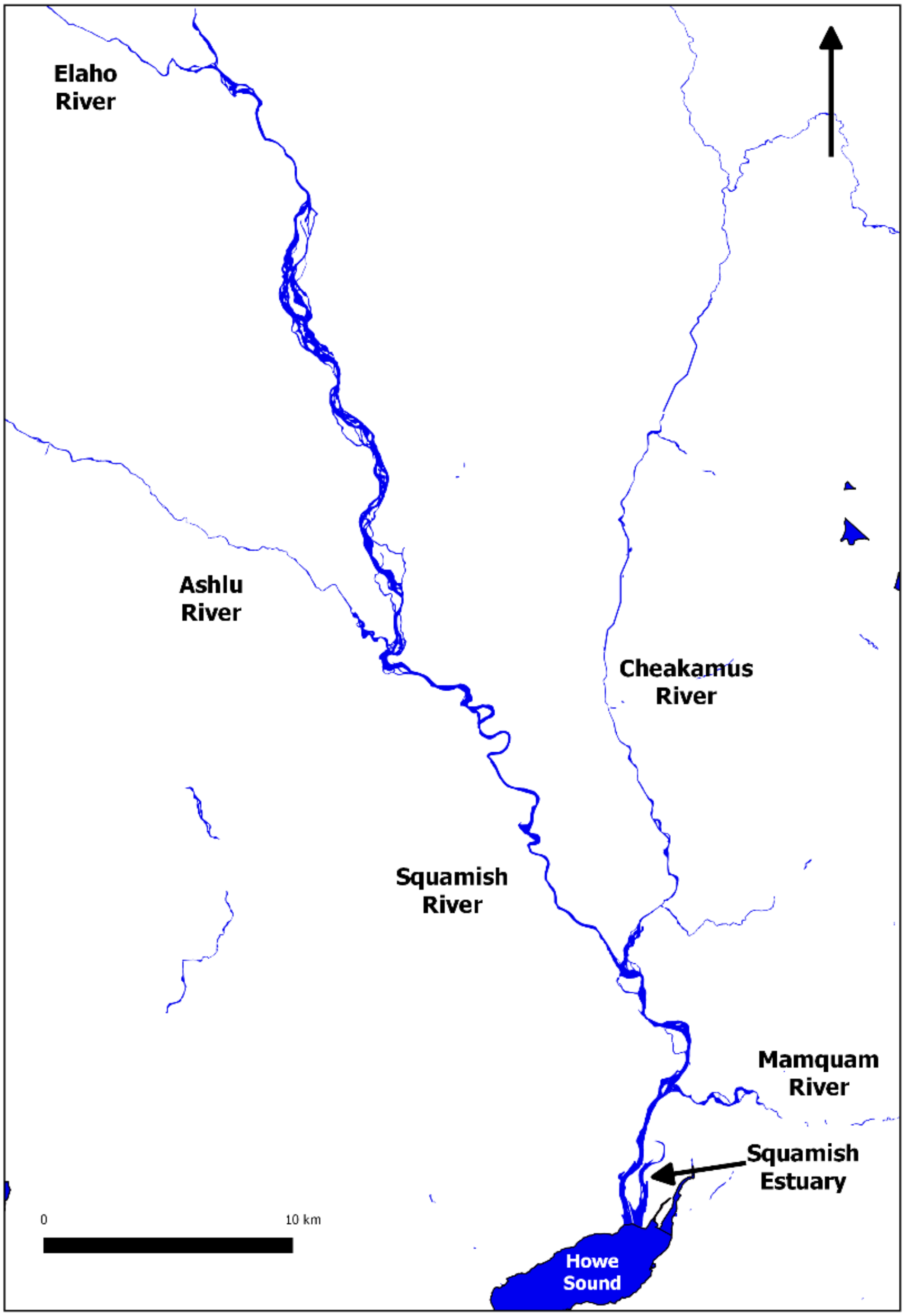

Figure 1. Map of Squamish River watershed including major tributaries.

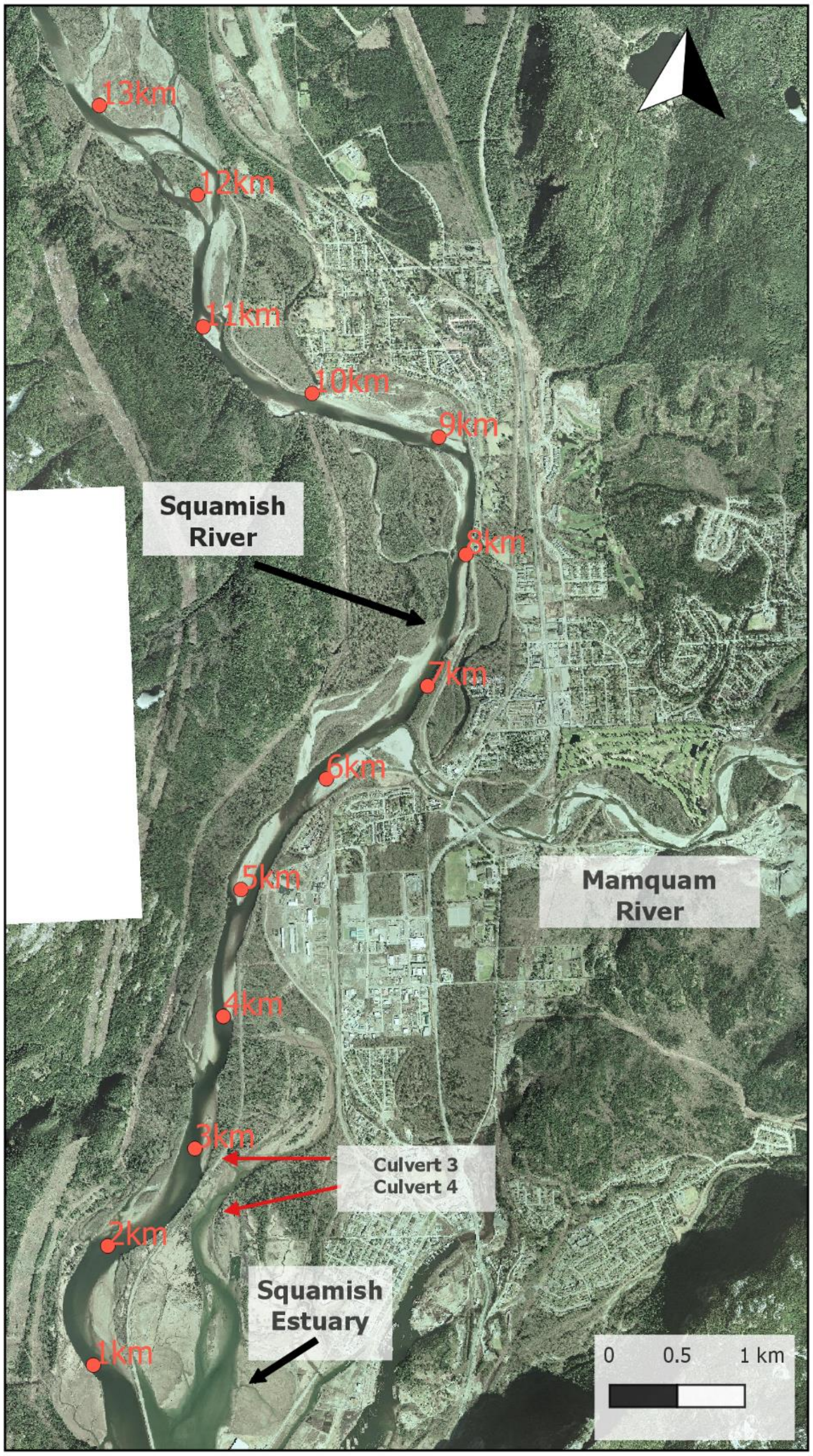

Figure 2. Map of study area in Squamish River and estuary. Culverts 3 and 4 where PIT antennae were placed are indicated with red arrows.

2.2 PIT telemetry

Multiple 'pass through' Passive Integrated Telemetry (PIT) antennae were installed in Culverts 3 and 4 from May 10th until July 31st. Multiple antennae were installed in each culvert to determine direction of travel through the culvert. Antennae were connected to a remote tuner box and multi reader (Oregon RFID) via twin-axial cable and powered using three deep cycle 6-volt batters in series. Batteries were changed twice per week. Downloading of the multi readers occurred once per week. Efficiency testing of each antenna was conducted three times per week by passing a test tag through the center of each antenna (perpendicular to the antenna) and ensuring 100% efficiency throughout the culvert area.

Three antennas were installed on Culvert 3. Two antennas were installed on the river end of the culvert approximately 0.4 m apart. The first antenna was installed inside the culvert and the second was attached to a wood frame outside the culvert. The third antenna was installed on the estuary end of the culvert (Figure 3). Two antennas were installed on the estuary side of Culvert 4 (Figure 4), but it was not possible to install antennae on the river side due to high discharge. During this survey, Squamish River discharge ranged from 150 to 800 m^3s^{-1} and the river end of Culvert 4 was fully submerged.

Figure 3. Antenna attached to estuary (right) and river (left) ends of Culvert 3.

Figure 4. Antenna configuration attached to estuary end of Culvert 4.

2.3 Fish Capture

Beach seining (1/4-inch mesh size) was used to capture fish in the Squamish River two to three times per week between May 15 and July 7, 2018. Juvenile Chinook Salmon were the primary target species and capture sites were selected based on documented habitat preferences for this species (Garland et al. 2002, Holecek et al. 2009). A total of 10 sites were fished over the course of this project. All seining sites were bar edges in the main channel of the Squamish River between rk 2.4 and rk 12 that were dominated by sand or small gravel substrates (Table 1, Figure 5). Seining occurred between Squamish River discharges of 150 and 850 m^3s^{-1}.

Figure 5. Photo of fishing site.

2.4 Biological Sampling

All salmonids captured during beach seining were sampled for length and weight. For non-salmonids, 20% of the total catch up to a maximum of 25 individuals were randomly measured and weighed. Fork length was taken to the nearest millimetre and weight to a tenth of a gram. To ensure accuracy of measurements and reduce handling stress, fish were anesthetised in a water bath of clove oil and ethanol mixed at a ratio of 1:10 prior to sampling.

All Chinook and Coho Salmon with a fork length greater than 60 mm were ventrally tagged with a passive integrated transponder (PIT tag). Half duplex (HDX) PIT tags (Oregon RFID;12 X 2.12 mm) were used for this study. All fish were recovered in aerated buckets until being released at their original capture location. A sub-sample of 49 fish, captured at river kilometer 4.5, were moved downstream in aerated buckets and released at the entrance to Culvert 3 to test whether fish near the culvert would choose to pass through the culvert. as well as to allow calculation of detection efficiency for the antennae.

2.6 Age Structure Analysis

Scale samples were collected from Chinook Salmon juveniles captured in the Squamish River during beach seining. Scales were collected from the area above the lateral line and posterior to the dorsal fin and dried and stored in labelled envelopes. Scales were mounted directly on glass slides and aged under a microscope using methods outlined in Ward and Slaney (1988). Two analysts independently determined age without knowing the size, date and location of capture.

2.5 PIT telemetry Analysis

Analysis of PIT telemetry data was completed in R Project Software (reference) using the PITR package developed by InStream Fisheries Research (Harding et al. 2018). PITR was used to collate telemetry data and summarize the movement of PIT tagged fish passing through the two culverts. The date and duration of movement through the culverts was determined for each detected fish. We also determined the detection efficiency for each culvert array (i.e., three antennas) for fish moving from the Squamish River into the estuary. Detection efficiency is a measure of accuracy for a PIT antenna based on the number of tags detected by subsequent downstream antennas.

3.0 RESULTS

3.2 Catch Composition and Catch Per Unit Effort

A total of 73 beach seine sets were completed between May 17th and July 7th, 2018 at 10 sites between rk 2.5 and rk 12. We captured 1,042 juvenile Chinook Salmon, with Chinook Salmon fry (> 60 mm) and parr (60-89 mm) being the most abundant size classes (521 and 453, respectively) (Table 1). Chum Salmon fry (*O. keta*) and *O. mykiss* juveniles (Rainbow or steelhead trout) were the next most abundant salmonids. We also captured 27 Coho Salmon juveniles (*O. kisutch*, 15 Bull Trout (*S. confluentus*) and 8 Cutthroat trout (*O. clarkii*) (Figure 5). Several non-salmonid species such as Starry Flounder (*Platichthys stellatus*), Coast Range Sculpin (*Cottus aleuticus*) and Three-spined Stickleback (*Gasterosteus aculeatus*) were also present at fishing sites in small numbers.

A total of 19.5 hours of seining was completed in the Squamish River. Catch per unit effort (CPUE; measured as catch-per-hour) of Chinook Salmon juveniles was highly variable both spatially and temporally. The highest CPUE for Chinook Salmon fry was 94 fish/hour at rk 11.75 on June 11th (Figure 6). The highest CPUE for Chinook Salmon parr was 532 fish/hour at rk 11 on June 13th, while the highest CPUE of Chinook Salmon smolts was 20 fish per hour at rk 10 on May 20th (Figure 6).

Table 1. Total catch by species (or age class) of fish captured by beach seine in the Squamish River in spring 2018. Minimum and Maximum fork length for each species is also reported.

Species	**Total Catch**	**Min Fork Length (mm)**	**Max Fork Length (mm)**
Bull Trout	15	153	545
Coast Range Sculpin	52	2	93
Chinook fry	522	35	59
Chinook par	454	57	105
Chinook smolt	70	91	135
Chum fry	84	36	46
Coho fry (<70 mm)	20	37	85
Coho smolt (>70 mm)	21	62	121
Cutthroat Trout	8	135	320
Lamprey	5		
Rainbow/ steelhead Trout	75	63	223
Starry flounder	75	82	82
Three-spined Stickleback	3	33	38

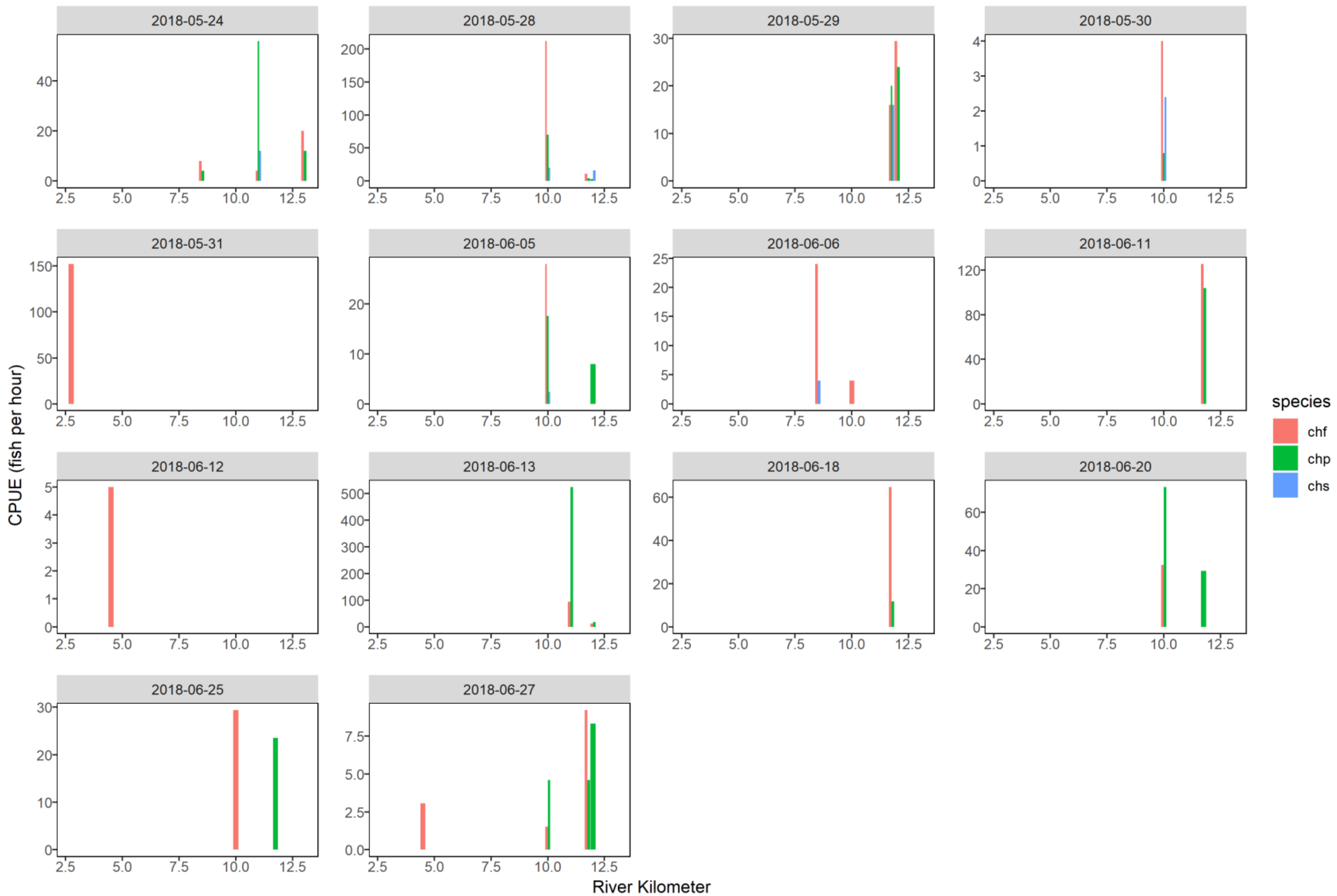

Figure 6. CPUE of juvenile Chinook Salmon size classes (chf=<60 mm, chp= 60-89 mm, chs= >89 mm) across capture sites in the Squamish River in spring 2018.

3.4 Chinook Salmon Age Classes

A total of 34 Chinook Salmon scale samples were collected and aged during this project. Chinook Salmon captured during this study ranged from age 0 to age 2. Age 0 fish ranged from 58 to 86 mm, Age 1 fish range from 70 to 99 mm, and Age 2 fish ranged from 74 to 179 mm (Figure 7).

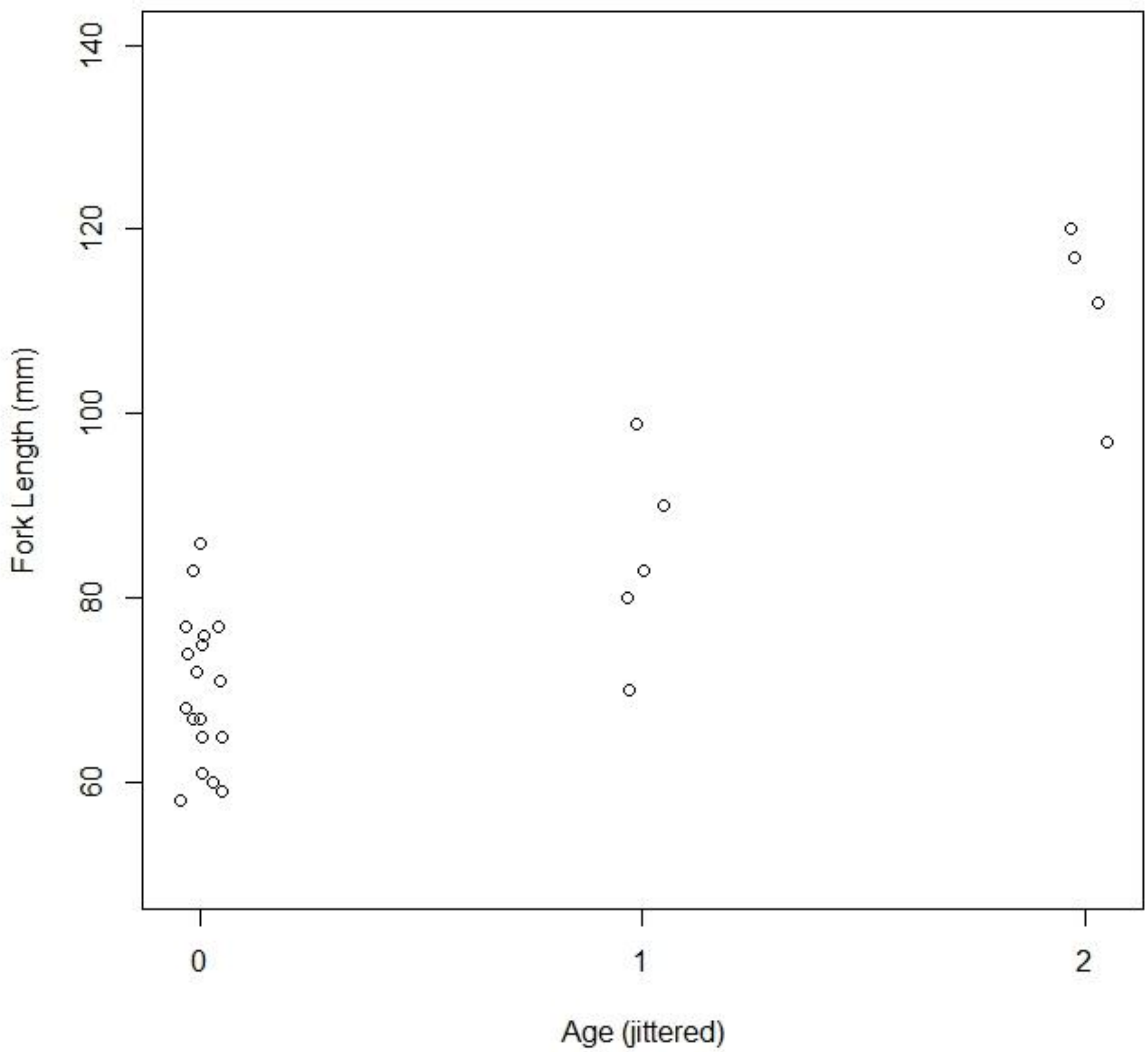

Figure 7. Age-length plot of Chinook Salmon juveniles captured in the Squamish River between river kilometer 2.5 and 12 in spring 2018.

3.5 Pit Telemetry Analysis and Salmon Culvert Usage

Efficiency testing determined that the detection range for all antennae consistently covered the entire area inside each antenna. The multi readers functioned from May 15th to July 31st, 2018 with no outages.

A total of 454 PIT tags were applied to Chinook Salmon and 9 tags were applied to Coho Salmon. Forty-nine tagged fish were released near the entrance of Culverts 3 and 4, while the remaining 405 fish were released at their point of capture. None of the fish released at their point of capture were detected on the multi-readers monitoring antennas in Culverts 3 and 4.

Of the 48 fish released near the river side entrance to Culvert 3, 22 were detected passing through the antennas in Culvert 3. Six of the fish detected were only detected on one antenna. Only 1 fish was released near Culvert 4 and it was not detected by the antennas in Culvert 4. Detection efficiencies of antennas 1 and 2 in Culvert 3 were below 50% (Table 2; detection efficiency cannot be calculated for the most downstream antenna, antenna 3). No detections occurred on the antennas on Culvert 4 and detection efficiency could not be calculated.

Fish passing through the antennas in Culvert 3 demonstrated variable movement behaviour. Fish were released near Culvert 3 on June 20th and 25th at approximately 2 pm on each day. On the 20th fish were released on a falling tide while on the 25th fish were released on a rising tide. Nearly all the fish (21 out of 22) moved on a rising tide. After release, fish waited between 4 and 73 hours to move into the culvert (Table 3, Figure 8). One fish moved into the culvert, retreated, then passed through the culvert at a later time (Figure 8).

Table 2. Detection Efficiency for the two river side antennae (antennas 1 and 2) on Culvert 3 in the Squamish River training dike.

Antenna	Detection Efficiency
1	0.46
2	0.36

Table 3. Summary of tide conditions at time fish were released and detected at Culvert 3 in the Squamish River training dike.

Date-Time detection	Tide height (m)	Tide direction	Date-time released	release tide height (m)	release tide direction	Detection - Release (hr)
2018-06-20 20:35	2.5	rise	2018-06-20 14:00	3.00	falling	6.6
2018-06-20 20:40	2.5	rise	2018-06-20 14:00	3.00	falling	6.7
2018-06-20 20:45	2.5	rise	2018-06-20 14:00	3.00	falling	6.8
2018-06-20 20:54	3.1	rise	2018-06-20 14:00	3.00	falling	6.9
2018-06-20 20:55	3.1	rise	2018-06-20 14:00	3.00	falling	6.9
2018-06-21 00:00	4.6	rise	2018-06-20 14:00	3.00	falling	10.0
2018-06-23 13:45	2.8	rise	2018-06-20 14:00	3.00	falling	71.7
2018-06-23 15:00	3.7	rise	2018-06-20 14:00	3.00	falling	73.0
2018-06-23 15:00	3.7	rise	2018-06-20 14:00	3.00	falling	73.0
2018-06-25 18:25	4.3	high/slack	2018-06-25 14:00	2.40	rise	4.4
2018-06-25 23:55	3.4	rise	2018-06-25 14:00	2.40	rise	9.9
2018-06-26 00:15	3.4	rise	2018-06-25 14:00	2.40	rise	10.2
2018-06-26 06:14	3.8	falling	2018-06-25 14:00	2.40	rise	16.2
2018-06-26 15:00	2.7	rise	2018-06-25 14:00	2.40	rise	25.0
2018-06-26 15:00	2.7	rise	2018-06-25 14:00	2.40	rise	25.0
2018-06-26 15:20	2.7	rise	2018-06-25 14:00	2.40	rise	25.3

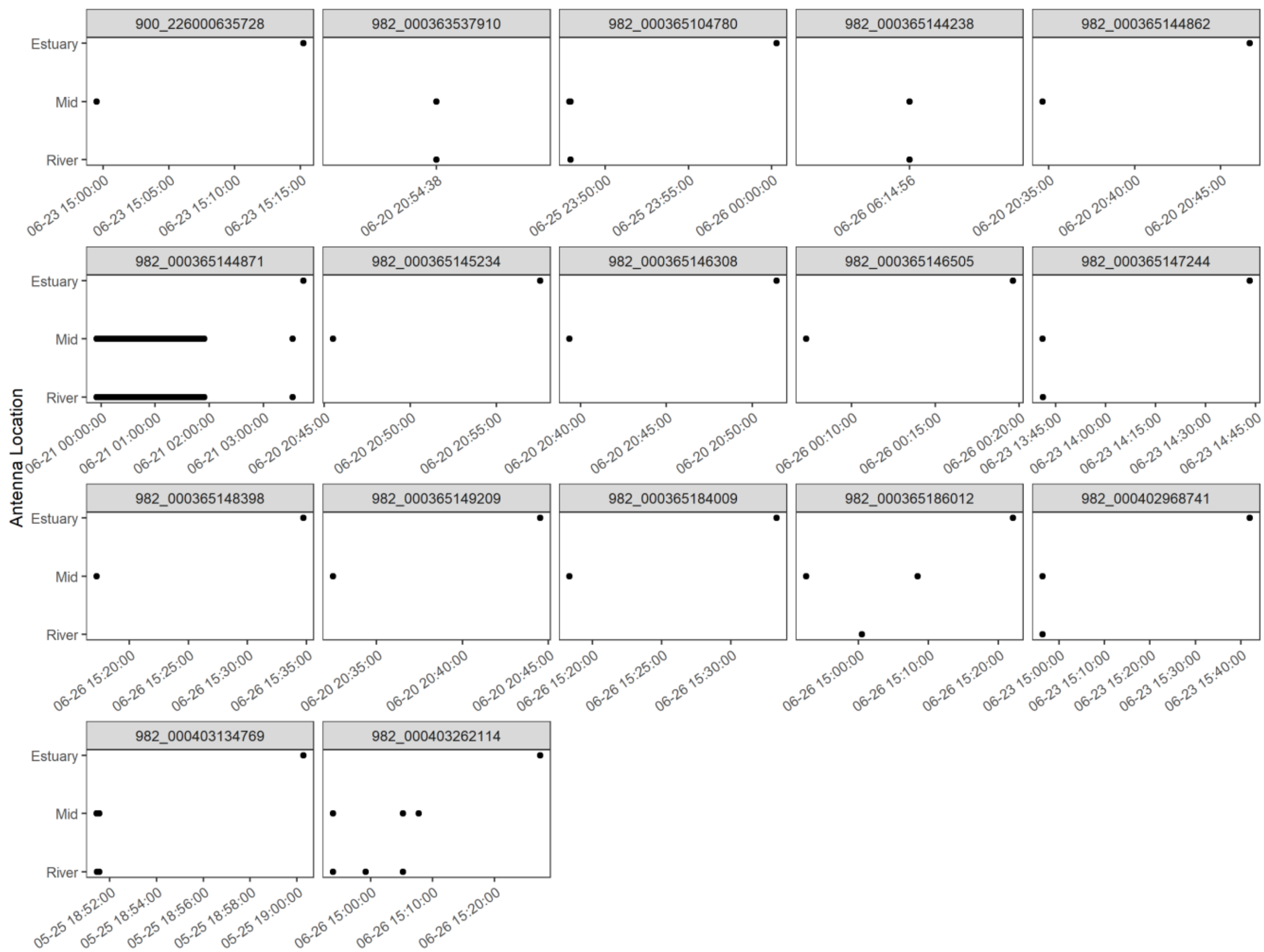

Figure 8. Fish detections on the PIT antennae in Culvert 3 between June 20th and June 26th. Only fish detected on more than one antenna are shown.

3.5 Recapture of Tagged Fish

Forty-two Chinook Salmon were recaptured over the six-week fishing period (Figure 7). All of the fish recaptured were tagged between rk 10 and rk 12. The majority (39) of Chinook Salmon were recaptured only once within two weeks of the original capture. Seventeen of the Chinook Salmon recaptured were recaptured in the same location they were released, while 6 fish were captured upstream of the location they were tagged and released (Figure 9).

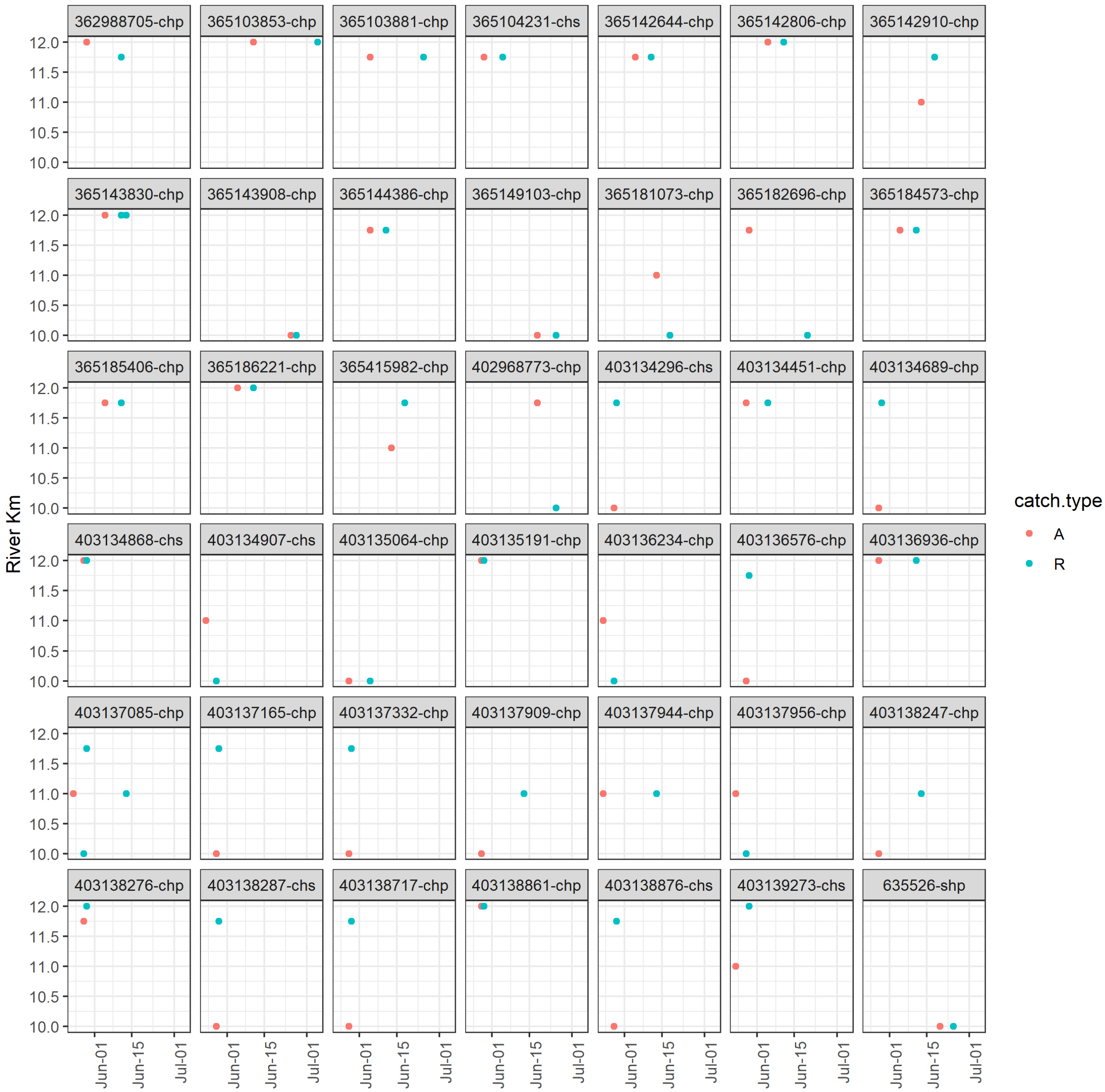

Figure 9. Capture profiles of individual juvenile Chinook Salmon PIT tagged in the Squamish River, spring 2018. A = tag applied, R = tag recaptured.

4.0 DISCUSSION

The objective of this study was to determine whether culverts in the Squamish River training dike allow for the passage of juvenile Chinook Salmon into the Squamish River estuary during their migration to

Howe Sound. We successfully tagged and released Chinook Salmon in the Squamish River using beach seining and monitored their passage through 2 culverts using PIT antennas.

Chinook Salmon do not appear to be using Culverts 3 and 4 to access the estuary during their migration from the Squamish River into Howe Sound. No Chinook Salmon released at the point of capture were detected on the RFID readers in Culverts 3 and 4. Of the fish released near the entrance to Culvert 3 (n = 48), less than 50% were detected moving through the culvert. These results may not be surprising given that the culverts are not optimal for fish passage. For example, the entrance to Culvert 3 is a ~100 m long channel which hides its presence from fish in the mainstem. The channel also dewaters at most low tide periods except during neap tides (which only occur twice a month). Culvert 4 is also challenging for fish to access due to a siphon that forms at the river side of the culvert when it is fully wetted. The whirlpool and velocity of water in the culvert are likely detrimental for fish survival. The culvert is surrounded by a rip rap bank on the Squamish River side (as opposed to a natural bank), which may further deter fish from approaching the culvert.

Despite efficiency testing suggesting that the antennas had 100% read range throughout the study period, detection efficiencies for the two antennae on the river side of Culvert 3 were less than 50%. Low detection efficiencies reduce certainty in the timing and direction of fish movement through the culverts; however, this does not affect our conclusion regarding the use of the culverts by juvenile fish as it is unlikely fish moved undetected through three antennae.

Low detection efficiencies in Culvert 3 may be related to the design of the antenna structures or the orientation of fish as they pass through the culvert. Antenna 1 was attached to a wood frame outside the culvert with hollow sides that allowed water to pass, potentially allowing fish to swim between the frame and culvert without being detected. During efficiency testing, PIT tags were passed through the culvert perpendicular to the antenna, simulating a fish swimming in a controlled manner through the culvert. When the tide is falling, the water velocity through the culverts increases drastically (observed through time lapse photos) and it is conceivable fish were propelled past the antennae too quickly to be detected. Additionally, the siphon formed through the culvert during the dropping tide could also orient fish parallel to the antenna and reduce the detection efficiency of the tag. Finally, the saline nature of tidal water may also have affected the efficiency of the antennas. In future, installing more paired antenna and releasing multiple groups of tagged fish near the culvert will improve estimates of detection efficiency and certainty in the patterns of fish movements.

Experimentally released, Chinook Salmon juveniles almost exclusively moved into Culvert 3 on a rising tide. The fish release on June 20th occurred during a falling tide, and all fish detected from this group waited until a subsequent rising tide before entering the culvert. Some fish spent three days rearing in the channel around the culvert before passing through. The fish release on June 25th occurred on a rising tide and again nearly all (6 of 7) waited until a subsequent rising tide prior to entering the culvert. Fish preference for moving through Culvert 3 on a rising tide suggests fish may avoid, or have trouble locating the structure at some phases of the tide cycle.

Water velocity in the training dike culverts may be a deterrent to fish. Water velocity in the culverts was not measured as part of this study. However, the presence of siphons at both culverts 3 and 4 suggest velocities are high during some phases of the tide cycle. Chinook Salmon are documented to display avoidance behaviour when areas of accelerating flow are encountered (Enders et al. 2009). Furthermore, the presence of light when juvenile fish encounter a velocity gradient increases the likelihood of avoidance behaviour (Vowels et al. 2014). Juvenile salmon are also documented to migrate in greater abundance at night than during the day (Furey et al. 2016). The culverts in the training dike are not consistently wetted at night due to the variable nature of tide cycles and river discharge; therefore, the daily window of time the culverts are passable by juvenile fish is likely quite limited. Future upgrades to this fish passage structure should consider water velocity, as well the range of conditions the structure will be wetted.

The recapture profiles of individual fish indicate juvenile Chinook Salmon are rearing the Squamish River between rk 10 and 12 for weeks prior to moving towards Howe Sound. Fish captured below rk 10 do not appear to be moving among sites or holding at individual sites. The holding behaviour of fish in the Squamish River is interesting in both furthering understanding of critical habitat for Chinook Salmon in the watershed, as well as informing on potential designs of future monitoring projects. Indeed, it may be possible to use beach seine and PIT telemetry and mark recapture methodology above rk 10 to estimate Chinook Salmon smolt abundance (> 60 mm) in the future.

Through beach seine and PIT telemetry, we were able to determine Chinook Salmon juveniles do not use Culverts 3 and 4 in the Squamish River training dike to access the estuary. However, experimental releases of fish near the entrance of Culvert 3 indicate it is possible for fish to pass through the culvert. Water velocity and detection of culvert entrances are likely factors influencing usage of culverts in the training dike. There are 8 additional culverts in the training dike that were not monitored as part of this study. Given that these culverts are either hidden by channels or are near the terminus of the training dike where the river is over 300 m in width, it is unlikely fish are using these culverts in any great abundance.

Loss of estuarine habitat access as a result of diking is a widespread issue in the Pacific Northwest (Hood 2004; Simenstad and Thom 1992). Removal of dikes in the Salmon River in Washington resulted in wider distribution of Chinook Salmon throughout estuarine habitat as well as an increased expression of juvenile life history types (Bottom et al. 2005). The results of this study, as well as previously documented patterns of Chinook Salmon estuary habitat usage (Lingard 2018), indicate that upgrading of fish passage structures in the Squamish River training dike is warranted. Appropriate water velocities, the range of conditions structures are adequately wetted, and the detectability of structures should be considerations in future structure upgrades.

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