InStream FISHERIES RESEARCH INC.

Squamish River Central Estuary Restoration Effectiveness Monitoring

Implementation Year 1 (2019)

Reference: SQUAMISH ESTUARY

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Executive Summary

A new box culvert was installed in a training berm that divides the Squamish River and its estuary in May 2019 as part of the Central Estuary Restoration Project (CERP). To evaluate success of the box culvert in terms of fish passage and gather baseline data for future CERP activities, movement of juvenile Chinook Salmon in the Squamish River and the Squamish River Estuary was monitored using both Passive Integrated Transponder (PIT) and acoustic telemetry. The research aimed to understand if CERP restoration activities improve habitat access for juvenile Chinook Salmon and how they may impact species richness of specific habitats of interest.

Fish collected from the Tenderfoot Creek Hatchery were implanted with acoustic tags (n = 100) and released at river kilometer 3 of the Squamish River to determine if and how fish access the estuary, or if they go directly to Howe Sound (i.e., do not use the estuary). A total of 982 PIT tags were also implanted into both wild and hatchery origin Chinook Salmon juveniles captured in-river. Acoustic receivers were installed in both the Squamish River and at various locations within the estuary. PIT antennas were installed in the new box culvert and in a channel connecting two northern culverts to the Central Estuary.

Telemetry data shows that seven juvenile Chinook Salmon passed through the box culvert. Another 13 of the 100 fish implanted with acoustic tags and two PIT-tagged fish (one wild and one hatchery) accessed the estuary, presumably by migrating around the spit and into the estuary from Howe Sound. Tagged hatchery fish accessing the estuary were detected using estuarine habitat for up to several weeks, emphasizing the importance of estuaries even for larger hatchery fish. The remaining 86% of hatchery Chinook implanted with acoustic tags were never detected on receivers in the estuary and are assumed to have migrated directly into Howe Sound and not used any estuarine habitat.

Use of estuarine habitat was also assessed through a capture program in the estuary using seine nets and traps. The goal was to recapture tagged fish, and to provide a coarse assessment of distributions of salmonids. Chinook Salmon were primarily captured in southern portions of the estuary and no PIT tagged fish were recaptured. Additionally, specific areas of interest for future restoration activities (i.e., Pretty Slough, Bridge Pond and Cattermole Slough) were fished to collect baseline species assemblage data; salmonids were only encountered in Cattermole Slough. These results, combined with previous years of capture data from the estuary, suggest that improvements to estuarine habitat access are still needed. However, less fishing effort was allotted to the estuary in this initial year of research relative to that dedicated to the Squamish River. We propose to increase and strategically structure estuary fishing efforts in future years to improve recapture probability and knowledge of fish distributions.

Results from this first year of research are inherently biased due to delays in culvert construction and because hatchery fish were used for most tagging. Hatchery fish may be more motivated to migrate directly to marine environments than wild fish, and fish may also be less attracted to estuarine habitat later in the Spring. To increase relevancy of results to wild Chinook populations, we propose to tag wild fish starting at the beginning of the migration period in 2020.

Overall the 2019 monitoring program indicated the installation of the box culvert was a successful step in restoration activities to improving fish passage in the Squamish River Estuary, but most fish still migrated directly to Howe Sound and were not able to access estuarine habitat. Additional restoration efforts are still needed to improve fish passage between the Squamish River and its estuary.

Introduction

The Squamish River is a glacial, salmon bearing watershed on the south coast of British Columbia, located within the traditional territory of the Squamish First Nation. The Squamish Nation harvests salmon in the Squamish River and its tributaries for food, social and ceremonial purposes and the watershed also provides opportunities for commercial anglers, raft guiding outfitters and recreation.

Chinook Salmon (*Oncorhynchus tshawytscha*) populations have been in decline along the Pacific coast since the 1980's (Slaney et al. 1996; Heard et al. 2007). Although data are sparse for Squamish River Chinook Salmon, recent research suggests the population is also in decline. Monitoring of juvenile Chinook Salmon abundance on the Cheakamus River for BC Hydro was conducted between 2000 and 2018 as part of a water use planning process. Fry abundance estimates resulting from that research ranged from 137,000 to 800,000 between 2000 and 2013 and from 16,000 to 114,000 between 2014 and 2018 (Lingard et al. 2018). Coast-wide declines in Chinook Salmon abundance have been attributed to poor ocean survival, overharvest and habitat losses (Slaney et al. 1996; Walters and Martel 2004; Heard et al. 2007; Beamish et al. 2012). In the Squamish River, salmon populations may also be impacted by these regional stressors as well as local stressors including loss in estuarine habitat, a major flood in 2003, and a caustic soda spill in 2005 in the Cheakamus River, a tributary of the Squamish River (McCubbing et al. 2005).

Estuarine habitats are important transition zones for both the juvenile and adult stages of their life history and 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 access and the quality and quantity of estuarine habitat in the Squamish River has been significantly reduced by both industrial and urban development. Of specific concern is a training berm that separates the Squamish River from its estuary. Installed in the 1970s to accommodate a coal port that was never realized, the training berm restricts the river to the west bank. Beginning in the mid-1990's, restoration work began on the estuary through the Squamish River Watershed Society (SRWS) in partnership with Squamish Nation, Fisheries and Oceans Canada (DFO) and the Province of British Columbia. Restoration projects in the estuary have included removing dredge spoils and contaminated soils, re-grading and vegetating areas to form tidal marshes and natural flood-plain habitats, and construction of tidal channels and culverts in the training berm. The construction of ten culverts began in the early 2000's to enable the passage of river water and fish into the estuary. However, monitoring of these culverts in 2018 revealed that they do not provide adequate fish access to the Squamish River estuary (Lingard et al. 2018).

In response to these findings, SRWS started the Central Estuary Restoration Project (CERP) in partnership with Squamish Nation and DFO. CERP is focused on reconnecting and restoring habitat to support the outmigration of Pacific salmon, particularly rearing juvenile Chinook Salmon. The goal of CERP is to improve rearing conditions for juvenile salmonids in the Squamish estuary by: 1) upgrading existing culverts in the training berm to improve fish access; 2) modifying the lower section of the training berm to reconnect the lower estuary; and 3) installing a flow control device under the CN rail spur to re-water historical channels.

These actions align with three distinct phases of CERP. Phase 1 was implemented in 2019 with the replacement of twinned 3-foot culverts with a three-meter box culvert. Phases 2 & 3 are currently in the planning phase. InStream Fisheries Research (IFR) was contracted by SRWS to assess the effectiveness of Phase 1 by monitoring passage of juvenile Chinook Salmon through the new box culvert. This report summarizes these results and further provides an assessment of movements patterns and presence of juvenile Chinook Salmon in the Squamish River and its estuary. Two management questions guided the monitoring program:

1. Are CERP restoration activities improving habitat access for juvenile Chinook Salmon?
2. Does improving water quality in Pretty Slough and Bridge Pond through CERP restoration activities alter species richness of these habitats?

Methods

To monitor movements of juvenile Chinook Salmon between the Squamish River and the estuary, tagging and tracking technologies (i.e., telemetry) were used in addition to surveys for fish presence in specific estuary habitats.

Study Site

The Squamish River watershed, located in the Coastal Mountain range of southern British Columbia, covers an area of 3650 km^2. The Squamish River is the largest tributary of Howe Sound and forms the northern terminus of the glacial fjord. The Squamish River watershed has four main tributaries (Mamquam, Cheakamus, Ashlu and Elaho Rivers) and is 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 is bound by a training berm on its eastern bank beginning at the confluence of Howe Sound (river kilometer [rk] 0) that separates the river from its historical estuarine flood plain between rk 0 and rk 4. The width of the river channel along the training berm varies between 200 and 500 m. Ten culverts of approximately 1.2-meter diameter in the berm 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 berm on both the river and estuary sides of the road. At culverts 3 and 4 the central estuary channel butts directly against the training berm. At culverts 6 through 10 the structures connect the deep Squamish River channel to a short channel on the estuary side of the berm, but it is not well connected to the central estuary and most estuarine habitat. Culvert 3 was selected for upgrade to a larger box culvert.

Monitoring activities covered a large area and encompassed all areas of interest identified by SRWS (Figure 1). For the telemetry component, fish implanted with PIT and acoustic tags were detected at key locations by PIT arrays and acoustic receivers, respectively. All hatchery fish were released upstream of the box culvert in the Squamish River, while wild-caught fish were released at their capture location. Fish presence in the estuary was also determined by seine netting and various types of trapping throughout the Central Estuary.
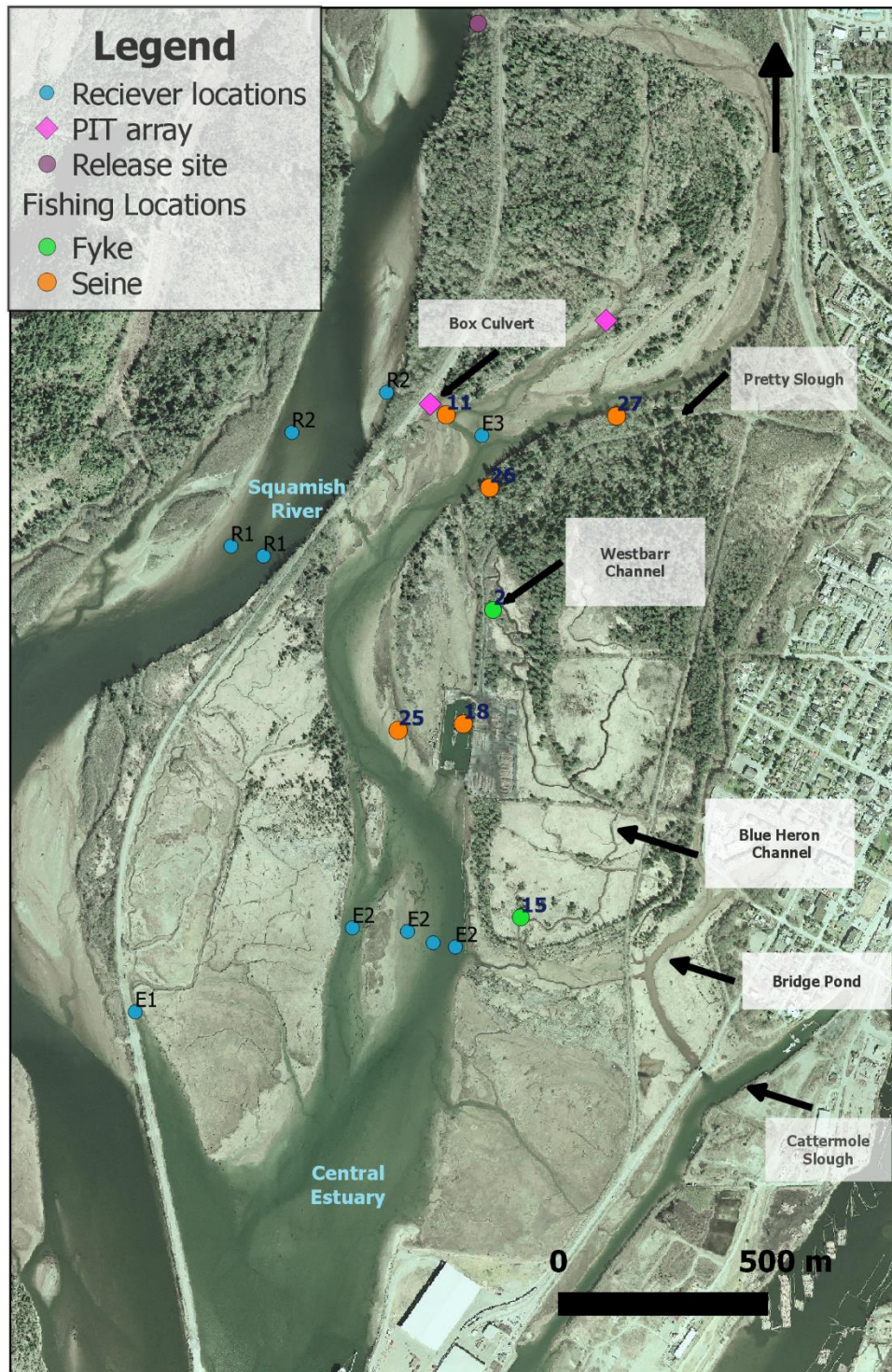
Figure 1. Map of CERP monitoring project locations including: acoustic receiver locations, PIT arrays, fishing sites within the Squamish River restuary and the release location for tagged hatchery fish.

Hydrological conditions within the Squamish River and Estuary are highly dependent on river discharge and tidal cycles. The Squamish River typically experiences low discharge periods in both winter and late summer/early fall, and high discharge periods in spring 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 are generally due to storm events. Squamish River discharge values were obtained from the Environment Canada gauge at Brackendale (08GA022) and tidal times and heights from location #7811 (Howe Sound, Squamish) from DFO. The study period ranged from May 15, when the first fish were tagged, to June 20, when the last tagged fish was detected. Discharge showed regular diurnal cycles and ranged from 183 to 644 m^3/s. Water levels dropped with a hot dry spell in early June but increased again after a rain event (Figure 2). Tide heights ranged from 0.3 to 4.9 m; large tidal cycles were observed in late May and early June (Figure 2). Other environmental and water quality variables such as temperature and water levels within the estuary were monitored by Laketrail Environmental and are not included in this report.
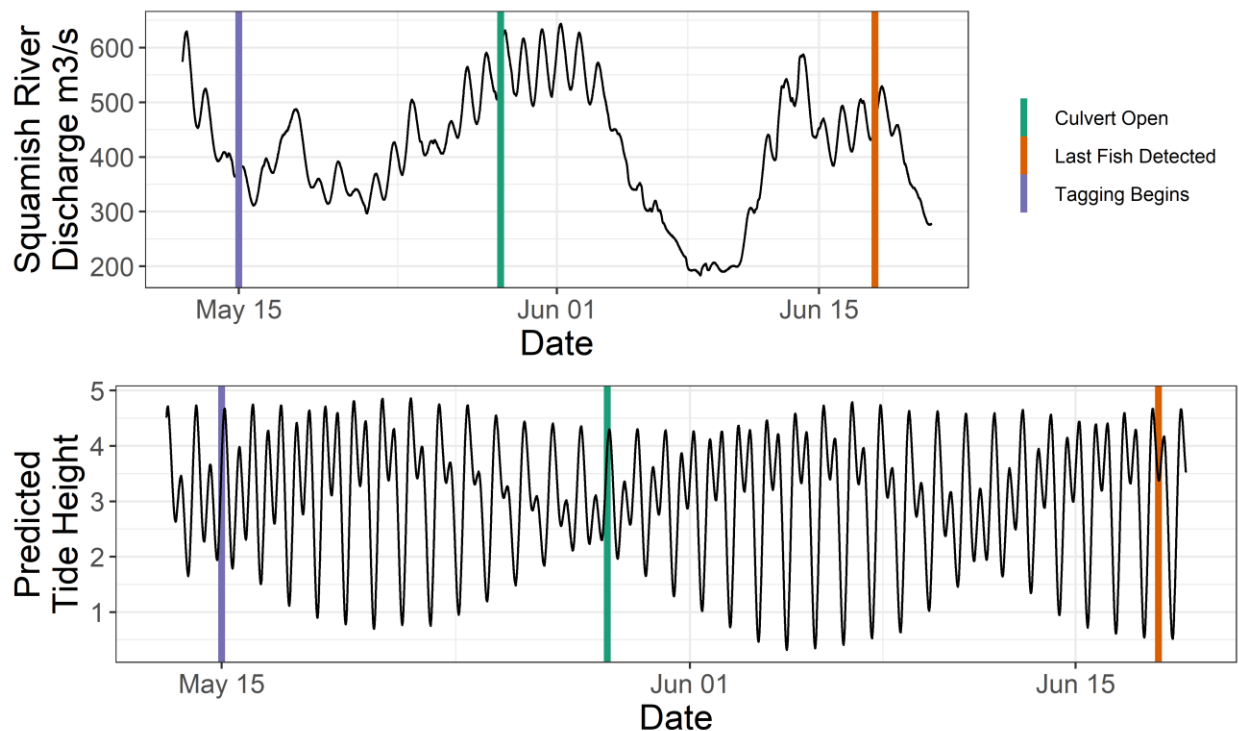

Figure 2: Discharge in Squamish River and predicted tide heights in Howe Sound throughout the study period. Coloured vertical bars represent the study period dates (between pink and blue) and when the box culvert opened (green).

Fish Capture

Fish were captured in the Squamish River and estuary for tag application and recapture monitoring. Additional capture efforts were focused in specific areas of the Central Estuary to determine presence of salmonids. All fish were identified to species and enumerated. Very abundant and non-target species (e.g., sculpins) were not enumerated and numbers were estimated when caught in large numbers (e.g., >20 chum in one set).

Squamish River

Juvenile Chinook Salmon were the target species and capture sites were selected according to documented habitat preferences for this species (Garland et al. 2002, Holecek et al. 2009). Fish were captured in the Squamish River using a 1/4-inch mesh beach seine deployed from a raft. Fishing occurred two to three times per week between May 17th and June 13th, 2019. Two additional trips were made after dark on May 24th and June 13th. There were five seining sites on bar edges in the main channel of the Squamish River between rk 2.4 and rk 12, all dominated by sand or small gravel substrates (Figure 3). Seining occurred between discharges of 200 and 650 m^3s^{-1}.
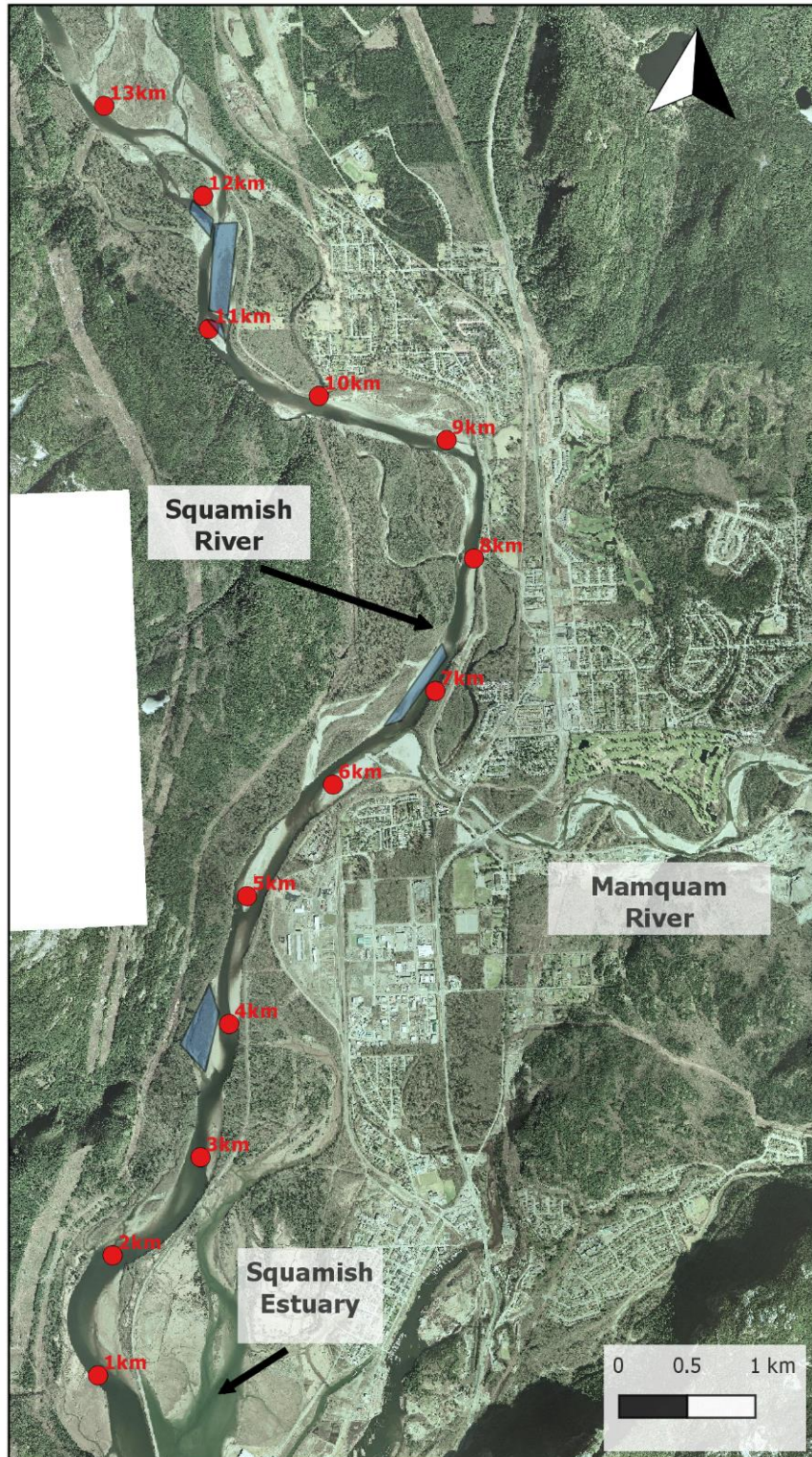
Figure 3. The Squamish River with river kilometers marked and fish capture locations identified by shaded blue.

Central Estuary

Monitoring of juvenile Chinook Salmon from 2013-2016 identified six sites suitable for capturing Chinook juveniles (Lingard 2018), five of which were sampled in 2019. Two sites were in tidal channels and fished with fyke net traps and three within the main Central Estuary fished by seining (Figure 1). A fishing site at the terminus of the Squamish River was not sampled due to lack of access during culvert construction.

To capture fish by seine in the Central Estuary, a crew of three technicians set the seine net (100 ft long x 4 ft deep with ¼ inch mesh) either by hand or boat. Conditions are only appropriate for seining at tides > 1.5 m, and boat access is only possible at high tide. The goal was to seine sites twice a week between May 17 and June 13.

To capture fish in the two constructed tidal-channels, referred to as Blue Heron and Westbarr Channels (Figure 1), custom constructed Gee-trap style fyke nets (Redden Nets, Langley, BC) were fished two nights per week between May 17 and June 7. The rectangular nets had ¼ inch mesh and measured 1 m x 1 m x 2 m. A directional codend at each end prevented fish from escaping the main chamber.

Additional specific sites of interest were fished to collect baseline fish species assemblage data. Several activities form the basis of CERP; Activity 3 aims to improve water quality and flow from the upper estuary through Bridge Pond towards Cattermole Slough. Activity 3 proposes to install culverts under the rail line between Pretty Slough and Bridge Pond, allowing water to flow from Pretty Slough in the upper estuary to Bridge Pond. Prior to construction, baseline assessment of species assemblages in Pretty Slough and Bridge Pond was requested by SRWS. Using methods appropriate to each area (Table 1), sites in Pretty Slough, Bridge Pond (between the tide gate and flap gate) and Cattermole Slough were each fished once for this component of the work (Figure 4). Sampling at these sites will be continued as restoration activities in the Bridge Pond Complex progress.

Table 1. Area and types of traps selected for evaluating baseline species assemblages in Site A and Cattermole Slough of the Squamish River Estuary

Area	Selected Trapping Modality
Pretty Slough	Electrofishing and minnow trapping
Bridge Pond	Minnow trapping
Cattermole Slough	Beach Seine

Figure 4. Fishing locations in the Pretty Slough, Bridge Pond, and Cattermole Slough to collect baseline fish species assemblage data.

Biological Sampling

Fork length (FL) was recorded to the nearest millimeter for all salmonids, and weight to a tenth of a gram for a subset of Chinook Salmon. Scale samples were also obtained from a subset of Chinook Salmon to archive and determine age if there is future interest. Scales were collected from above the lateral line posterior to the dorsal fin using a scalpel blade. To ensure accuracy of measurements and reduce handling stress, fish were anesthetized in a water bath of clove oil and ethanol mixed at a ratio of 1:10 prior to sampling.

Tagging Procedures

PIT and acoustic telemetry were used, both of which provide fish with an individual ID that can be detected remotely. Combining the two technologies maximizes data quality while minimizing costs. PIT telemetry is best suited to confined waterways and has limitations in saline environments, whereas acoustic telemetry is best for tracking in open, dynamic and saline environments (Thorstad et al. 2013). Conversely, acoustic tags are expensive, require surgical implantation, and are larger than PIT tags (~0.1g for PIT and 0.43 g for acoustic), typically leading to higher mortality relative to PIT-tagged fish (Brown et al. 2013, Hockersmith et al. 2003).

PIT tags were implanted in both wild-captured fish and fish collected from the Tenderfoot Creek Hatchery. Because culvert construction timelines were uncertain in this initial year of study, we limited the acoustic telemetry component to hatchery fish that could be held on site if culvert construction extended beyond the peak juvenile outmigration period.

Hatchery releases were spread throughout the field season to encompass a variety environmental conditions (e.g., river discharge, tide magnitude) from May 15 to June 7. Our experimental design adapted to delayed culvert construction timelines; half of the hatchery releases occurred prior to culvert construction completion, and half after.

Implanting PIT Tags

Wild-caught and hatchery fish were tagged according to the same protocols, following the recommendations of a size threshold of 65 mm FL (Columbia Basin Fish and Wildlife Authority PIT Tag Steering Committee, 1999). Prior to tagging, fish were anesthetized in a water bath of clove oil and ethanol mixed at a ratio of 1:10 until loss of consciousness (Stage 2; Summerfelt and Smith 1990). For tagging, fish were held ventral-side up and a 12 x 2.12 mm half duplex (HDX) PIT tag (Oregon RFID) loaded within a tagging needle was implanted into the ventral cavity. Fish were recovered in aerated buckets. Wild-caught fish were released at their capture location once recovered and all fishing at that site was complete. Recovery buckets were covered to provide shade, water quality was monitored, and water changed as necessary. In the hatchery, once tagging was complete fish were relocated to hatchery holding facilities until release with fish implanted with acoustic tags (see 'Surgery Recovery and Release').

Surgical Implantation of Acoustic Tags

Hatchery fish for study were held in 8' diameter 3220 L circular tanks with continuously recirculating water. Untagged fish were all held in one tank and fed weekly according to standard hatchery protocols. Qualified and experienced IFR staff conducted the surgeries and practiced suturing techniques on the study population prior to tagging. For surgery, fish were brought to stage 3 anesthesia (Summerfelt and

Smith 1990) using clove oil emulsified in alcohol (1:10 ratio). After obtaining FL and weight, fish were placed ventral side up on a surgical board lined with padding. A 4-5 mm incision was made on the linea alba anterior to the pelvic girdle with a surgical scalpel for tag insertion (V4-180kHz, InnovaSea Marine Systems Canada Inc; weigh 4.2 g). Monocryl absorbable 5–0 monofilament sutures (Monocryl; Ethicon, Somerville, NJ, USA) were used to close incisions with one simple interrupted suture using square knots with two wraps on the first row and a single wrap on the second row. Gills were continuously irrigated throughout the procedure, first with the prepared clove oil mixture and then with water once suturing began. Individual fish were monitored in buckets until recovered from anesthesia (i.e., swimming and responding to stimuli).

Surgery Recovery and Release

Tagged fish were provided with ample recovery and river acclimatization time, and release procedures aimed to optimize survival probability (Table 2). Following surgery and initial recovery from anesthesia, all tagged fish were placed in a segregated holding pen within a recovery tank for > 48 hours. If fish did not recover during this time (e.g., were pale or showing erratic swimming behavior) they were euthanized by cerebral percussion. The goal was to tag 10 fish with acoustic tags and 50 fish with PIT tags per tagging day, but final daily numbers varied slightly (e.g., due to mortalities). We had concerns of low survival among fish with acoustic transmitters (see Melnychuk 2009), especially when released later in the season as a small group. Research has shown Bull Trout predation on juvenile Chinook is lower when fish migrate in large groups (Furey et al. 2016). Therefore, to improve survival probability of tagged fish, additional untagged hatchery fish were released concurrently.

Table 2: Timeline of the process of starvation to release for hatchery fish implanted with PIT and acoustic tags.

Timeline of Surgeries and Release	
Starvation	Fish fed 1x per week as per hatchery protocols
Surgery	>48 hours post-feeding
Recovery	>48 hours post-surgery in segregated holding pens in hatchery
Acclimation	6-12 hours in a submerged and closed in-river tank
Release	Released at civic Twilight on day of transport to river

Following recovery, fish were transported in a transport tank equipped with a continuous supply of dissolved oxygen to the release site in the lower Squamish River (*rk 2.5*; ~25-minute drive). Fish were then netted out of the tank into buckets and carried to a closed holding tank submerged in the river to acclimate to river conditions. Fish were released that same day at civic twilight in a single group to best

align with migration patterns of wild fish thought to reduce predation (Furey et al., 2016). The release site was located on river left (same side as box culvert), approximately 1 km upstream of the box culvert (Figure 1).

Telemetry Arrays

PIT and acoustic technologies each require their own arrays to detect tagged fish. Arrays underwent extensive testing under varying environmental conditions prior to and during deployment to ensure appropriate read range (maximum distance that a receiver or antenna can effective decode a transmitter) and efficiency (the probability of detecting a passing tagged individual), not all of which is detailed here.

PIT Array

The PIT array consisted of 'pass through' rectangular antennas that detect tags as fish pass through or over antennas. Two antennas were installed within the box culvert and another two within a channel just downstream of the confluence of channels leading from culverts 1 and 2 (Figure 1). The dual antenna design at each location allowed for determination of efficiency and directionality of movements. Antenna construction and configuration differed slightly between the two locations. In the box culvert, antennas were built within a (1.06 x 4.3 m) rectangular PVC housing installed approximately 1.5 m apart. Antennas were both connected to a remote Oregon RFID tuner box and multi-reader via twin-axial cable and powered by two deep cycle 6V batteries in series that were changed twice per week. In the Central Estuary, flexible antenna approximately 2 m apart were suspended over the channel by rope and secured in position with sandbags such that they conformed to channel geometry. At this location, each antenna was connected to an Oregon RFID remote tuning box and single reader via twin-axial cable. The 12V system was powered by four 6V deep cycle batteries (two each in a series) continuously charged by a solar panel (no battery changes required).

At both locations, antenna function was tested weekly by manually passing a test tag through each antenna. If the test tag was not detected by both antennas, they were tuned accordingly; this procedure ensured optimal performance throughout the deployment period.

Efficiency Testing

The goal of array testing was to identify the probability of detecting a passing fish. With each array having two antennas, detection efficiency for upstream antennas is a ratio of detections shared on both relative to upstream detections. Because detection efficiency of upstream detection sites is determined using downstream data, arrays must be directional, and the reliability of estimates will increase with the number of detection points. Performance was also assessed by comparing numbers of fish detected by antenna and overall fish numbers relative to the number released during controlled releases, whereby a

known number of PIT-tagged fish were released within the vicinity of the PIT antennas. In the Central Estuary, fish were released at the exits of culvert 1 and culvert 2 and in the immediate vicinity of the antennas (Table 3). At the box culvert, three releases were conducted at various distances from the culvert to additionally provide insight into culvert attraction.

Detection efficiency is measured at the first antenna encountered based on detections at the second (i.e., the proportion of fish detected on both antennas). As an additional efficiency test, fish were individually forced through the box culvert antennas using a release tube. With this release we know that fish passed through both antennas and can calculate a true efficiency for each antenna.

Fish collected from the Tenderfoot Creek hatchery were used for all controlled released and tagging was conducted as detailed above.

Table 3: Details of controlled releases of PIT-tagged hatchery Chinook Salmon to test efficiency of the Central Extuary and Box Culvetr PIT antennas.

Location	Date	Release Location
Central Estuary	June 4	Culvert 1
	June 4	Culvert 2
	June 18	1 m from antennas
Box culvert	June 16	0 m from culvert
	June 5	10 m from culvert
	June 5	50 m from culvert
	June 16	Forced through both antennas

Acoustic Array

The acoustic array consisted of nine 180 kHz receivers that made up four 'gates'. An acoustic gate is a checkpoint, designed such that tagged fish are unlikely to pass that point without being detected. Tags emitted two types of ID transmissions: High Residence (HR; 8-12 s burst rate) and Pulse Position Modulation (PPM; 15-25 s burst rate). The array contained both HR2 (n = 3) and VR2W (n = 7) receivers (InnovaSea Marine Systems Canada Inc). HR2s provide measures of acoustic noise and position (which both affect detection efficiency), can decode both tag ID transmissions, and emit PPM and HR self-transmissions, providing a continuous test of array performance. The VR2W only detects PPM transmissions and provides no other data. HR2s were split between the river and the estuary. Gate locations were established to determine whether fish enter Howe Sound prior to entering the estuary, if they access the estuary through the box culvert, or if they use the estuary at all. The 30-day tag life

additionally allowed gathering of some information regarding residence time in the estuary and lower Squamish River.

In the river gate, two receivers were deployed on either side of the river near the box culvert (R2) and two downstream of the box culvert (R1; Figure 1). Fish detected on the downstream river receivers (R1) failed to find and pass the box culvert. Estuary receivers were deployed away from Squamish terminals to reduce potential boat traffic noise and within natural constrictions not dewatered at low tide. There were three estuary gates: Spit Estuary-side (E1), Central Estuary (E2), and Culvert Exit (E3; Figure 1). Fish first detected on river receivers but then detected on either the Spit Estuary-side or Central Estuary gates (E1 or E2) likely entered the estuary from Howe Sound. Fish detected on the Culvert Exit gate (E3) but not previously detected on other estuary gates can be categorized as having entered the estuary through the box culvert. Fish only detected on the River Gate are assumed to have not accessed the estuary.

Deployment method varied with receiver location. In the river where high flows and debris were a concern, an anchor was built by pouring a 50 cm^2 slab of concrete over a rebar frame. Two pieces of rebar extended 50 cm from each side of the slab, preventing the anchor from rolling in high flows. A PVC housing was attached to the anchor to hold receivers. In the estuary some deployment sites were dewatered at low tide and others up to 4 m deep at high tide. The top of acoustic receivers emits a 'listening cone' that detects tagged fish as they pass through. If the top of the receiver became exposed at low tide, fish would go undetected. To ensure fish were still detected at low tide, estuary receivers were buried at a very low tide. Receivers were held within a PVC housing with just the top exposed. A rebar frame was built around the top of the housing and it was buried to the level of the frame so that it remain level with the substrate. The unit was attached to an anchor located ~1 m away to prevent interference with detections.

The first receivers were deployed on May 13 and the last retrieved on July 17. Three river receivers were presumably lost in a high-water event, one of which was downloaded prior (Table 4).

Table 4:Details of deployed acoustiuc receivers. Individual or multiple receivers made up several acoustic gates, or a checkpoint at which tagged fish are unlikiely to undetected upon passing.

	Receiver Position	Gate	Receiver Number	Date Deployed	Date Removed
River	River left, upstream	R2	461372	May 13	June 10
	River right, upstream	R2	302547		Not retrieved
	River left, downstream	R1	461370		May 23 (download only)
	River right, downstream	R1	302546		Not retrieved
Estuary	Culvert exit	E3	302549	May 27	July 17
	Central estuary, east	E2	461374	May 10	
	Central estuary, center-east	E2	302552		
	Central estuary, center-west	E2	302551		
	Central estuary, west	E2	302548		
	Spit Estuary-side	E1	302550	May 21	

Testing Receiver Range and Array Performance

A range testing tag affixed with an end cap attachment was used for all array testing. Considerable range testing was conducted prior to array deployment to select optimal locations and determine detection range under various environmental conditions. For initial testing, a line of six receivers (three each of VR2Ws and HR2s) was deployed in both the estuary and river for at least 24 hours with a range testing tag affixed to a receiver on the farthest end of the line. Receiver range at both high and low tides was determined by assessing the maximum distance the range testing tag was detected, and the maximum distance HR2 self-transmissions were detected. Working with scientists at InnovaSea Marine Systems, receiver range was estimated to be approximately 80 m. Therefore, receivers in a line were deployed at a conservative maximum distance of 60 m apart.

To test array performance in the final deployment configuration, a series of passes were conducted with the range testing tag. The test tag was affixed to a weighted line extending from a float with an attached GPS unit. The float was deployed from an upstream point expected to be outside of the detection range of the gate and left to float to a downstream point expected to be outside of the detection range. Having an independent float ensured no interference with acoustic signals (e.g., from a vessel).

Several passes were conducted at each gate. The goal over the study period is to conduct 3 passes per receiver location at each tidal condition (i.e., ebb, high and low tide). In 2019 considerable testing was conducted (Table 5), and results will be expanded on in 2020. In the Squamish River we only conducted

testing at an ebb tide. This is the most important time as preliminary testing revealed it to be very noisy; results therefore represent a worst-case scenario. For the estuary gates, our concern was water levels rather than noise and they were tested at high and low tides to have full representation of all water levels.

Table 5: Summary of efficiency testing passes conducted with the range testing tag over the four acoustic gates.

Gate	# of Receivers	Number of passes		
		Ebb tide	High tide	Low tide
Squamish River	4	6	NA	NA
Central Estuary	4	NA	6	7
Spit – Estuary Side	1	NA	3	4
Culvert Exit	1	NA	5	5

Analyses

Analysis of telemetry data was completed in R Project Software. For PIT data, the PITR package developed by InStream Fisheries Research (Harding et al. 2018) was used to collate data and summarize fish movements. 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. Calculating the efficiency of each receiver requires a full spatial analysis whereby the proportion of tag transmissions detected relative to those expected to be detected is calculated at various distances. This analysis will be conducted to inform deployment of receivers in 2020. For 2019, we use three parameters to determine performance of the acoustic array: 1) results from test tag passes (i.e., detected or not), 2) detections of HR2 receivers on neighboring receivers, and 3) levels of acoustic noise.

Results

Fish Characteristics and Distributions

Wild-caught Salmonids

In the Squamish River, 95 beach seine sets were completed between May 15 and June 13 at 5 sites between rk 2.5 and rk 12. Of the 517 Chinook Salmon captured (Mean FL ± SD = 73.6 ± 15.5), 332 were tagged. It is apparent from size distributions over time that Chinook are larger earlier in the season; every fishing week the number of fish > 80 mm declined from the previous week (Figure 5).
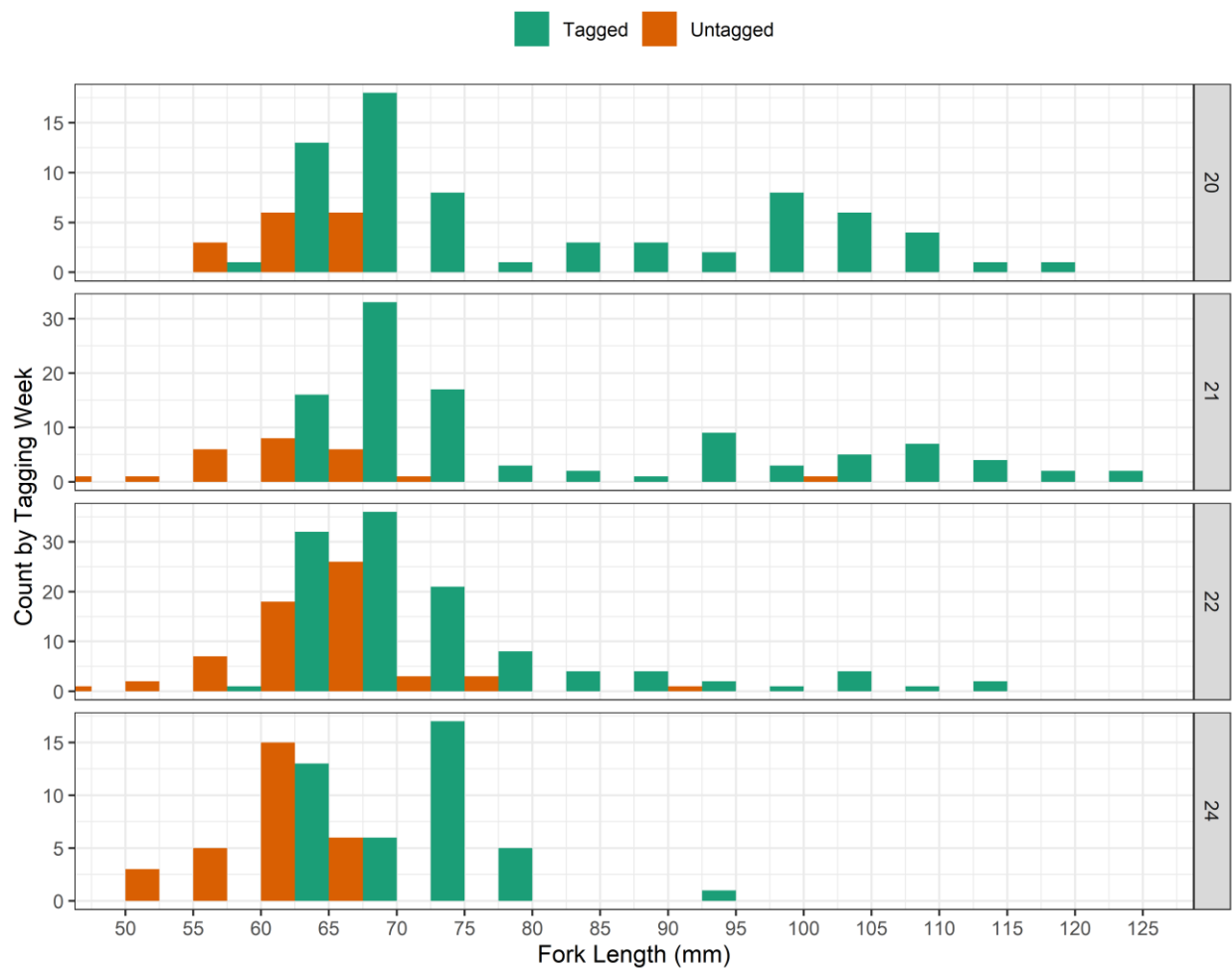

Figure 5. Size distribution of Chinook Salmon juveniles captured in the Squamish River by beach seine in spring 2019. Week 20 = May 13; 21 = May 20; 22 = May 27; 24 = Jun 10

In the estuary, 30 capture attempts were completed by trap (n = 14, 24-hour periods) and beach seine (n = 16 sets) between May 17 and June 13. Across all fishing events, 97 juvenile Chinook Salmon were captured of which 47 were tagged. No Chinook Salmon were captured in the tidal channels, and no PIT tagged fish were recaptured in the estuary. Chinook Salmon were captured by beach seine in the southern portions of estuary (i.e., between Westbarr and the box culvert) while Coho Salmon fry (*O. kisutch*; < 50 mm) dominated catches north of the box culvert (Figure 6).
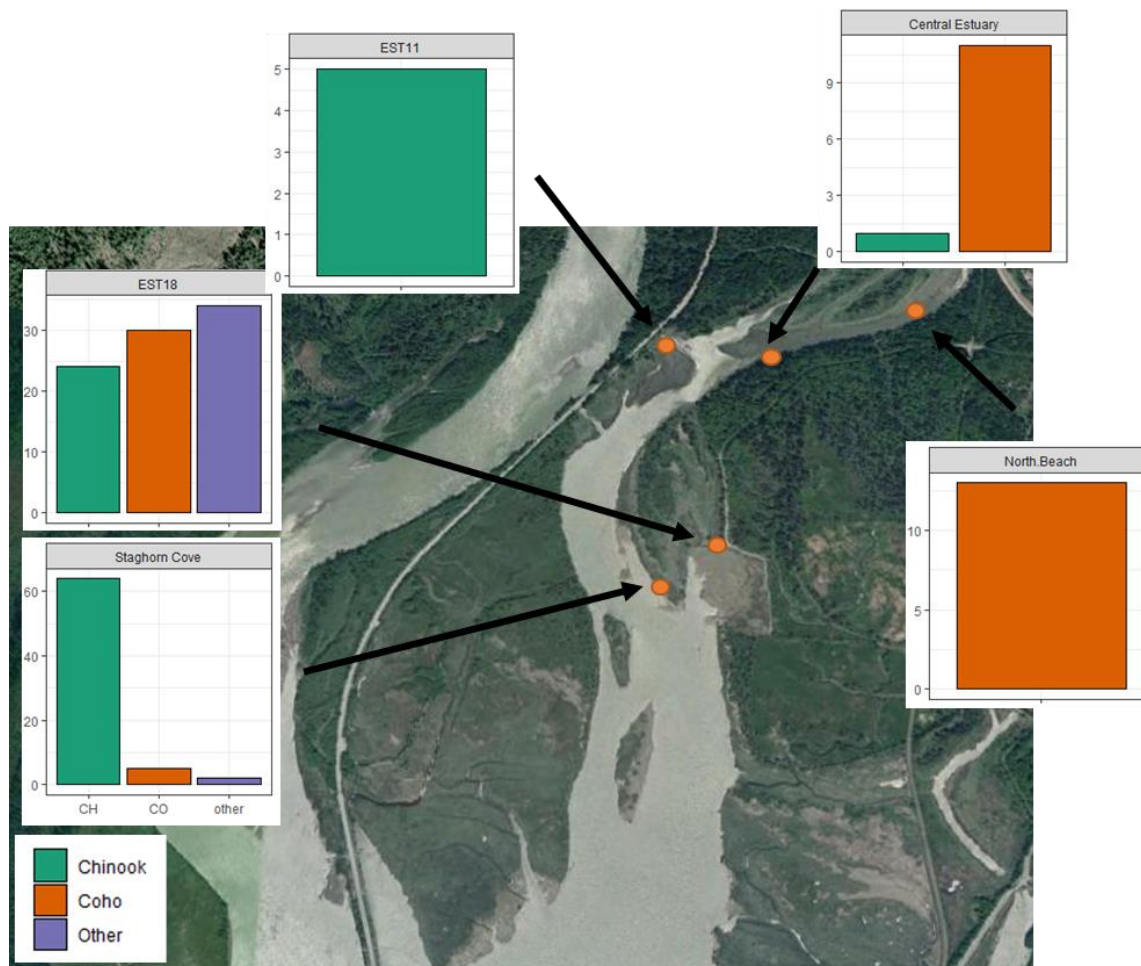

Figure 6: Total number of Chinook, coho, and other salmonids captured by sine at the five capture sites within the Squamish River Estuary

Several other species were captured during fishing. Notably, Bull Trout (*Salvelinus confluentus*) and Steelhead Trout (*O. mykiss*) were often captured in the Squamish River. and Chum Salmon (*O. keta*) fry and Coho Salmon fry and smolts were commonly captured in the estuary (Table 6). Species composition and fish size cannot be directly compared between the two locations as different methods and nets were used (e.g., mesh size of ½" in river versus ¼" in estuary).

Table 6. Catch composition and size of fish captured in the Squamish River and Estuary by beach seine in Spring 2019.

Species	River Seining		Estuary Seining	
	n	FL (mm) ± SD	n	FL (mm) ± SD
Bull Trout	13	217.3 ± 89.5	NA	
Chinook Salmon	473	73.6 ± 15.5	96	70.3 ± 11.9
Chum Salmon fry	2	NA	26	54.7 ± 5.6
Coho Salmon fry	3	62 ± 6.1	31	43.7 ± 8.9
Coho Salmon smolts	3	77 ± 9.5	57	86.8 ± 9.5
Cutthroat Trout	3	211 ± 29.4	1	157
Starry Flounder	1	NA	2	72
Gunnel Fish	NA		1	NA
Lamprey	1	64	2	83
SFL	1	NA	1	NA
Steelhead Trout	67	117.1 ± 29.7	7	77.5 ± 36.1
Staghorn sculpin	NA		2	NA
Three-spine stickleback	NA		6	NA

Sizes cannot be compared between the Squamish River and estuary given differences in mesh sizes of nets used within each location.

Hatchery Chinook Salmon

Chinook Salmon collected from the hatchery were implanted with either PIT or acoustic tags and released at the release site above the box culvert (Figure 1). Hatchery fish were larger than wild-caught Chinook; mean (± SD) FL was 121.9 mm ± 11.1. Mean tag burden of for fish implanted with acoustic tags was 2.2 % (SD = 0.6 %).

Chinook Salmon Movement in Squamish River and Estuary

Movement results primarily focus on acoustic telemetry data, as this is more robust than PIT data and had various detection sites throughout the Squamish River and Estuary. However, the larger sample size of PIT-tagged fish further informs if juvenile Chinook Salmon used the box culvert or upper culverts (i.e., culvert 1 or 2), and information regarding movement and residency times can be derived from the recapture of tagged individuals.

Fish of both tag types were released before and after the culvert opening. All fish tagged at the hatchery were released at the release site above the box culvert and wild-caught Chinook implanted with PIT tags were released at location of capture (Table 7).

Table 7. Table of location, number and timing (before= before culvert open, after=after culvert open) of fish releases in the Squamish River in spring, 2019.

Release Site	PIT		Acoustic	
	Before	After	Before	After
At site of Capture (wild-caught Chinook)	206	126	NA	
~1 rkm above box culvert (hatchery Chinook)	250	401	48	52

Of the 100 fish implanted with acoustic tags, 69 were detected. Undetected fish (n = 31) likely migrated to Howe Sound but were missed by the river receivers.

In-River Movement

River residency times for hatchery fish were low, as determined by acoustic detections; the mean time between release to last detection on river receivers approximately 1 rkm downstream was 7.3 hours (SD = 21.7). Most fish detected on river receivers travelled that distance in < 9 hours, but five fish remained at the release site for an extended period (i.e., ~ 1.9 to 5.5 days; Figure 7). Of the 30 PIT tagged fish recaptured, the time between tagging and recapture was up to 17 days (mean ± SD = 6.6 ± 4.7 days; Figure 7). Chinook captured in the Squamish River were of both wild and hatchery origin, and the three hatchery fish recaptured in-river had longer residency times than fish released from the hatchery.
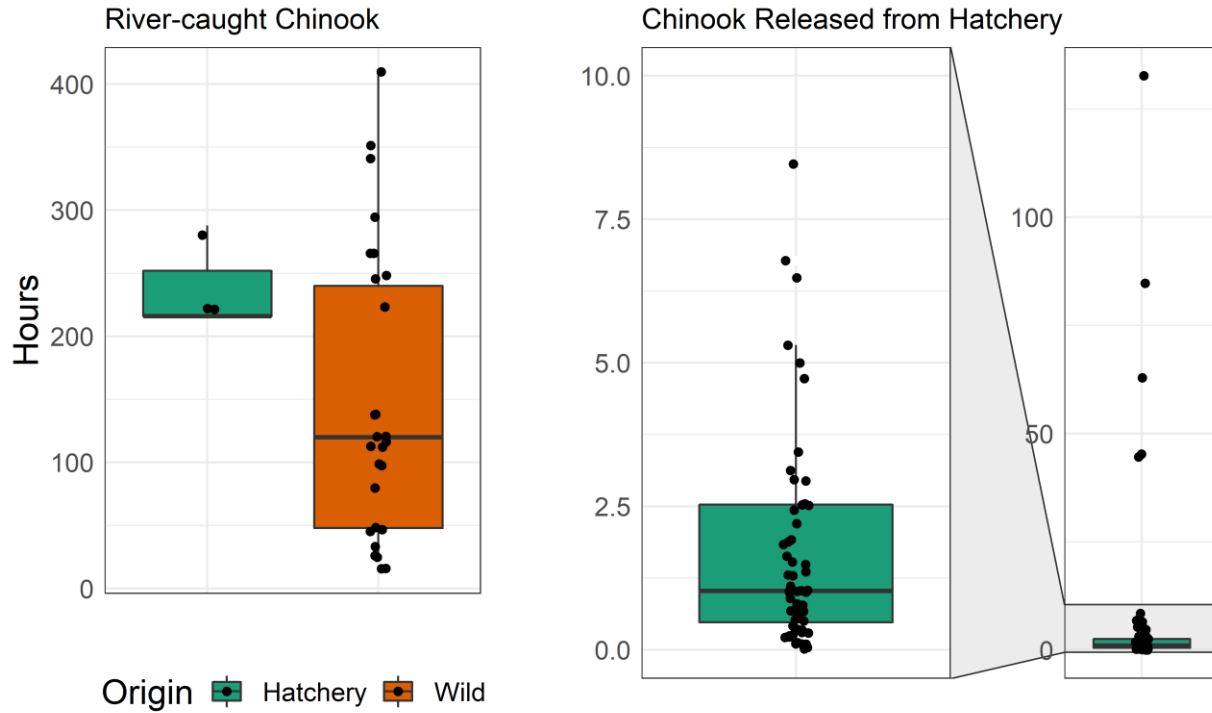
Figure 7: Minimum river residency times as determined by recapture data (for wild-caught Chinook; left panel) or detection data (for Chinook released from the hatchery; right panel. Each point represents an individual fish. Whiskers of boxplots represent the interquartile range, outside of the box the 25th and 75th percentiles, and the line in the middle the median.

Tagging began on May 15, but the box culvert wasn't flowing until May 29. Most wild-caught fish were tagged prior to the culvert opening (67%), but if they remain in-river for several days, as this limited data suggests, the culvert would have been available for a greater proportion of tagged fish than reflected by tagging dates.

The apparent differences in mean minimum river residency times from the tagged hatchery population (~160 vs. 6.8 hours) highlight how the observed behavior of the hatchery fish may not represent that of wild-caught fish. However, any wild fish not residing in-river for long durations are unlikely to be recaptured and therefore estimates of river residency for wild-captured fish are undoubtedly biased high.

Accessing the Squamish River Estuary

Of the tagged study population (n = 957), 22 individuals accessed the estuary from the Squamish River (14 with acoustic and 8 with PIT tags), all but one were collected from the hatchery (and thus released above the box culvert). More of these fish accessed the estuary prior to the culvert opening (9 of 48; 18.8%) than after (5 of 52; 9.6%; Figure 8). The most successful release group in terms of estuary access was on May 24, from which 50% of fish navigated into the estuary prior to the box culvert opening

(Figure 8). This release occurred on an incoming tide and the river had increased 100 m^3/s over the previous 24 hours to ~500 m^3/s. Of the five fish detected in the estuary after completion of the box culvert, one was detected passing through it.
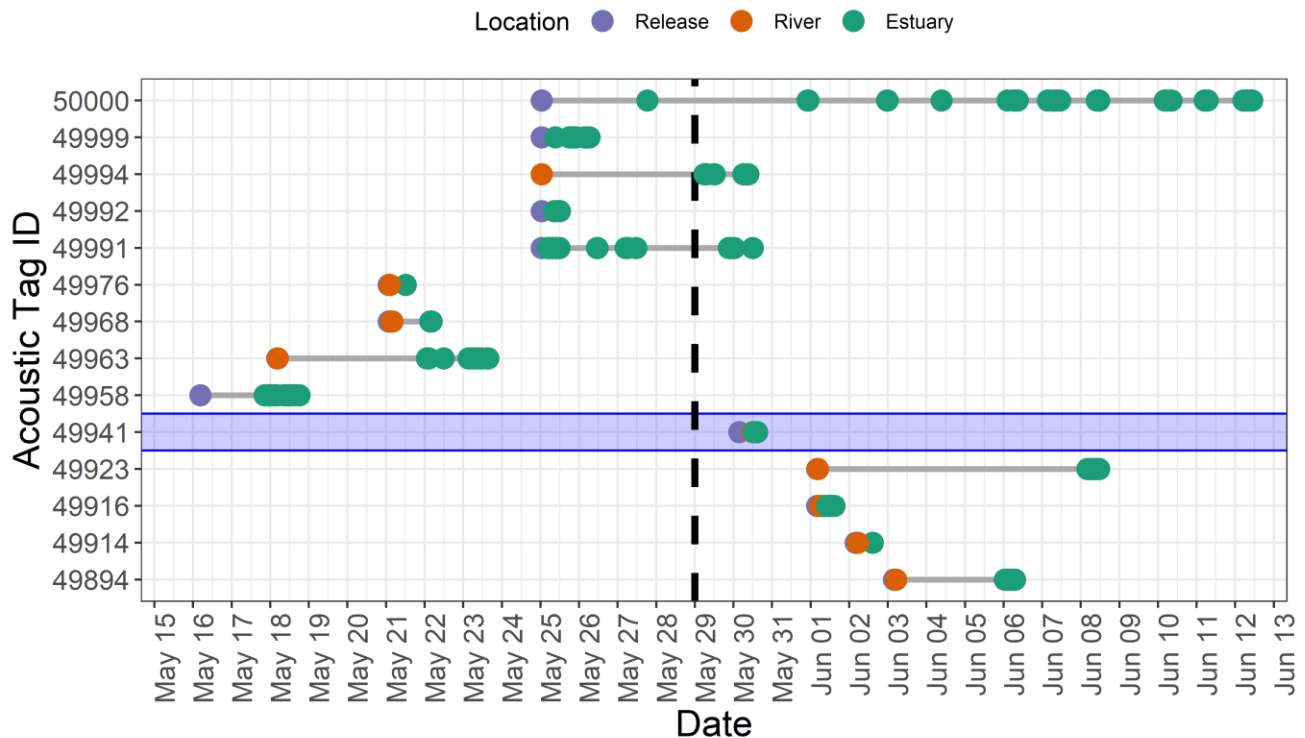

Figure 8: Timeline of movement from the Squamish River to the estuary for hatchery Chinook Salmon implanted with acoustic tags. Each point represents and individual tagged fish, with the colour representing the location of detection. The vertical dotted line indicates when the culvert opened, and the individual highlighted in blue is the only fish to have used the culvert.

There was considerable variation in travel times from the river to estuary (Figure 8). Among hatchery fish implanted with acoustic tags, two travelled from release to first detection in under four hours (Fish 49994 and 49916) whereas one fish took over a week (Fish 49923; median = 18.3 hours). Two fish (49976 and 49914) were only detected once on one estuary receiver.

No wild-caught fish implanted with PIT tags were recaptured in the estuary, but one was detected on the Central Estuary array.

Box Culvert Passage

The box culvert was opened on May 29. Seven hatchery fish (one with an acoustic tag and six with PIT tags) from three release groups entered the culvert between tide heights of 2.5 and 3.4 m and river discharges of 514 and 594 m^3/s (Table 8; Figure 9). Five fish were detected on both antennas and are thus confirmed to have entered the estuary via the culvert and another two fish with PIT tags were only detected on the first antenna. We can confirm these fish entered the culvert but cannot confirm they passed through it, though it is likely. All fish detected on the culvert antennas were released at the release site above the culvert on river-left. No wild-caught fish, released at site of capture, used culverts.

Table 8: Details of fish passage events at the box culvert

Release Date	Passage at Box Culvert			Fish ID	Tag Type	Tide		Discharge (m³/s)
	Date	Time	Confirmed			Height (m)	Direction†	
May 29	May 30	12:09	Yes	49941	Acoustic	2.487	↑	542
May 31	May 31	23:04	Yes	461929	PIT	3.083	↑	583
		23:14	Yes	461966		3.139	↑	586
		22:31	Yes	461877		2.931	↑	574
		23:50	No*	461755		3.346	↑	594
Jun 2	June 2	21:42	Yes	461965		3.453	↓	514
		22:30	No*	461818		3.269	↓	523

* Only detected on river-side culvert antenna and not estuary-side antenna

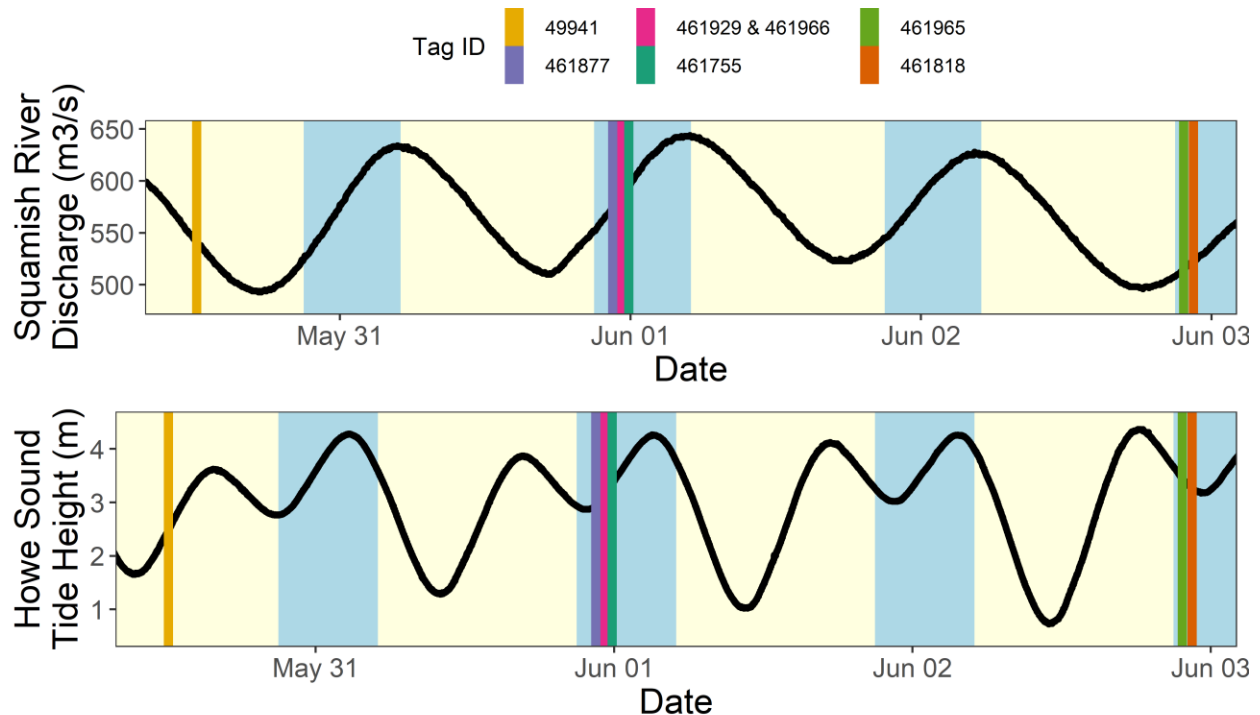*† Up arrow represents flooding and down ebbing tides*

Figure 9: Squamish River discharge (top) and tide heights for Howe Sound (bottom) during the period of box culvert passage. Vertical lines are displayed at times of culvert passage events. The pink line represents two fish that passed the culvert within 10 minutes of each other. Shading indicates approximate daylight hours (dark = blue; 6PM-5AM; light = yellow; 5AM-9PM). All fish were released at civic twilight and detected the evening of release, except for 49941 which passed the day after.

Accessing the Estuary by Other Means

Tagged fish detected in the estuary but not by antennas and receivers in the box culvert (n = 15) are assumed to have entered from Howe Sound. Acoustic receivers deployed in-river downstream of the culverts were lost in a high-water event. One of these receivers was downloaded on May 23, after which in-river fish presence downstream of culverts cannot be confirmed. Use of the old culverts (i.e., culverts 1, 2, 4-9) is unlikely, as previous research has found them to be ineffective for fish passage (Lingard 2018; Lingard et al. 2018). Although entrance from Howe Sound cannot be confirmed without downstream river receiver data, we have strong evidence for four individuals prior to culvert completion:

- Two fish (acoustic tags 49968 and 49976) detected on river receiver downstream of the culverts.
- Two fish (acoustic tags 49991 and 49999) first detected on the Spit – Estuary Side receiver and then detected on the central estuary receivers. It is most likely that these fish contoured around The Spit prior to continuing into the estuary. Fish 49991 later returned to The Spit.

Two PIT tagged fish were detected on the Central Estuary antennas. One hatchery fish from the June 1st release group was detected on the on the morning of June 2nd and the direction of travel for this fish is unclear. One wild fish released on June 3rd was detected numerous times on the downstream Central Estuary antenna on the evening of June 19th and morning of June 20th, suggesting it moved into the area from the South.

Estuary Residency

Estuary residency and habitat use was limited by battery life of acoustic tags (~30 days), however, the area alongside The Spit was used more often than expected, with fish often moving between here and the Central Estuary gate. Detection histories reveal small movements among the deployed estuary receivers over the course of days and weeks (Figure 10). Minimum estuary residency times, the time elapsed between first and last detection on estuary receivers, ranged from less than 1 hour to nearly 16 days for the 11 fish with multiple detections within the estuary (mean = 1.9 days; Figure 10). These estimates are considered minimums because fish may move beyond acoustic gates (i.e., into the northern portion of Central Estuary) or reside in the estuary longer than the battery life of the tag.
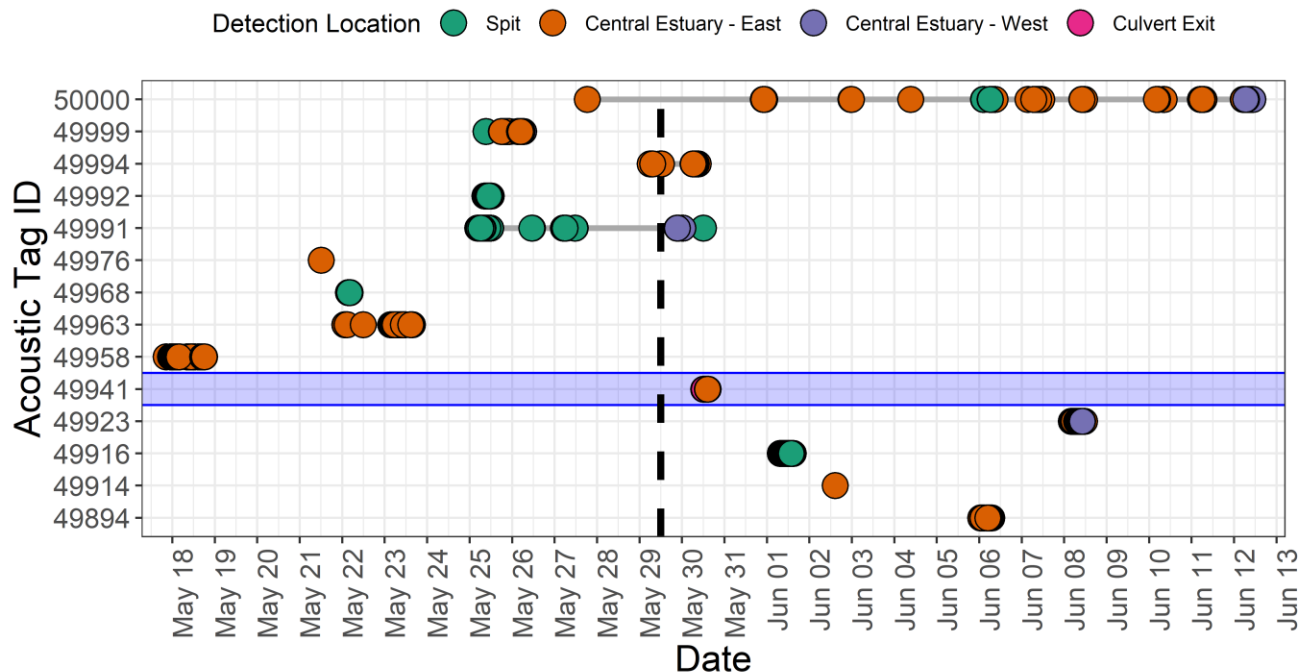

Figure 10: Positional data for tagged hatchery Chinook Salmon fish detected on acoustic receivers in the Squamish River Estuary. Each point represents a detection event at a given receiver location, as identified by colour. The vertical dotted line indicates when the culvert opened, and the individual highlighted in blue is the only fish to have used the culvert. Some fish resided in the estuary for several weeks (e.g., Fish 50000) and most were detected at multiple receiver locations.

Performance of Telemetry Arrays

PIT Array

Performance was measured through detection efficiency of upstream antennas (i.e., the ratio of detections shared on both antennas relative to upstream detections) and by comparing numbers of fish detected by each antenna and overall, relative to the number released during controlled releases.

Box Culvert Antenna

Detection efficiency for study fish (i.e., excluding controlled releases) was 67%. Six study fish were detected, four of which were detected by both antennas. The other two fish were only detected by the upstream (river side) antenna and were either missed by the downstream antenna, as the measure of detection efficiency assumes, or entered but not passed through the culvert. Likewise with controlled releases, where measures of detection efficiency among groups released in front of the culvert ranged from 0.29 to 0.72 (Table 9), fish may have milled around the entrance of the culvert (detected only on upstream) and not passed through, inaccurately reducing detection efficiency.

Assessing the percentage of fish detected relative to the number released during controlled releases were variable, ranging from 28% to 70% (Table 9). When fish were forced through the culvert antennas in a release pipe detection probability was 69.4 % for the downstream antennas, 95.9% for the upstream antennas and 98% for both combined (Table 9). In future years, efficiency should be determined through forced passage events at various environmental conditions.

Table 9: Performance testing results from for PIT antennas in the box culvert for study fish (i.e., excluding controlled releases) and by each controlled release trial. Detection efficiency is provided for the upstream antenna given detections shared among both antennas.

Release Group		n	Upstream Antenna Detection Efficiency	Individuals Detected (%)		
				Up Ant.	Down Ant.	Combined
All study fish			0.67	NA	NA	NA
Controlled Releases	At culvert entrance	50	0.29	12.0	28.0	32.0
	10 m from culvert	50	0.72	36.0	36.0	46.0
	50 m from culvert	41	0.53	51.2	41.4	70.7
Forced through antennas		49	NA	95.9	69.4	98.0

The central estuary antennas were not tested as extensively as the box culvert; fish were not forced through antennas to test efficiency. With only two study fish detected, antenna efficiency cannot be reliably estimated. Controlled releases do provide some information and suggest good performance. Detection efficiency from the releases at the exit of Culvert #2 and at 1 m upstream of the antennas was 0.65 and 0.46, respectively (Table 10). None of the fish released at the exit of Culvert #1 were detected.

Table 10: Performance testing results from PIT antennas in the Central Estuary for study fish (i.e., excluding controlled releases) and by each controlled release trial. Detection efficiency is provided for the upstream antenna given detections shared among both antennas.

Release Group		n	Upstream Antenna Detection Efficiency	Individuals Detected (%)		
				Up Ant.	Down Ant.	Combined
Controlled Releases	Culvert 1 exit	49	NA	0	0	0
	Culvert 2 exit	49	0.65	30.6	34.7	42.9
	1 m from antennas	101	0.46	41.6	80.1	85.1

Acoustic Array

Performance at each receiver location was determined with: 1) results from passes of a testing tag, 2) detections of HR2 receivers on neighboring receivers, and 3) levels of acoustic noise. Note that the range testing tag has a higher burst rate than study tags and is therefore more likely to be detected than a tagged fish. Test tag data is best used to create a distance matrix of efficiency whereby efficiency is calculated for varying distances from each receiver. The spatial analysis required to calculate true efficiency of the array will be conducted prior to deployment of receivers in 2020. Results are discussed by area.

Performance of estuary receivers was excellent. Test tag passes were 100% successful; the test tag was detected on all test passes of individual estuary receivers and by all three receivers at the eastern Central Estuary site during each of the three passes.

Examining the proportion of HR2 PPM self-transmissions detected by the two neighboring VR2 receivers at the Central Estuary site also suggests good performance. Although there was some daily variation, HR2 self-transmissions were consistently detected by the closer VR2 (60 m away; 50-95% of self-transmissions emitted were detected per day) and were also detected by the VR2 130m away on most days (up to 27% of self-transmissions emitted were detected per day; Figure 11). These values are higher

than expected because both VR2s were dewatered and unable to detect any signals at low tide. Dewatering of receivers wasn't monitored, but the farthest VR2 was deployed in a shallow tidal flat and was likely out of water 50% of the deployment time.
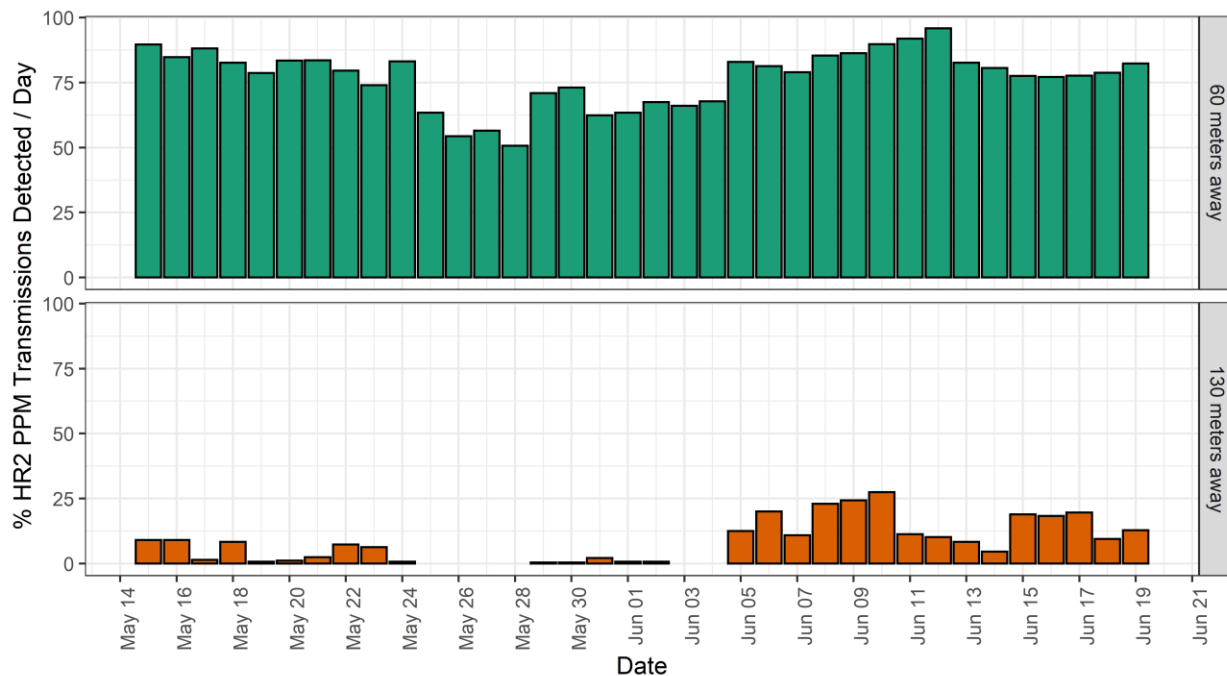

Figure 11: The proportion of PPM transmissions emitted by the HR2 detected by the two neighboring VR2 receivers at the Central Estuary site

Together, the test tag passes and detections of HR2 PPM self-detections indicate overlapping coverage between receivers. It is therefore unlikely that a fish passing within 60 m of estuary receivers would go undetected, and detection range of receivers may have exceeded 130 m under some conditions. Ultimately detection range is dependent on environmental condition. Performance of the array did appear to drop between May 24 and Jun 4 (i.e., the percentage of HR2 transmission detected dropped; Figure 11). Reasons for this drop are unknown, and it is not associated with tides, discharge, or noise levels.

Squamish River Receiver Gates

River receivers did not perform as well as estuary receivers. The Squamish River is a difficult environment for deployment and testing, and thus testing was not as extensive as in the estuary. A fast river environment produces high levels of acoustic noise, especially during freshet. We have diagnostic data from the two river receivers deployed on river left, one until May 23 and the other for the entire deployment period. Acoustic noise, as measured by HR2 receivers, mimicked tidal cycles and was highest on an outgoing tide (Figure 12). Above noise levels of 30 dB performance will markedly decrease

(InnovaSea, personal communication). At the upstream receiver, noise levels were rarely above this 30dB threshold but at the downstream receiver, acoustic noise approached 60 dB on an outgoing tide daily (Figure 12). Conversely, acoustic noise never exceeded 16 dB on the HR2 receiver in the estuary.
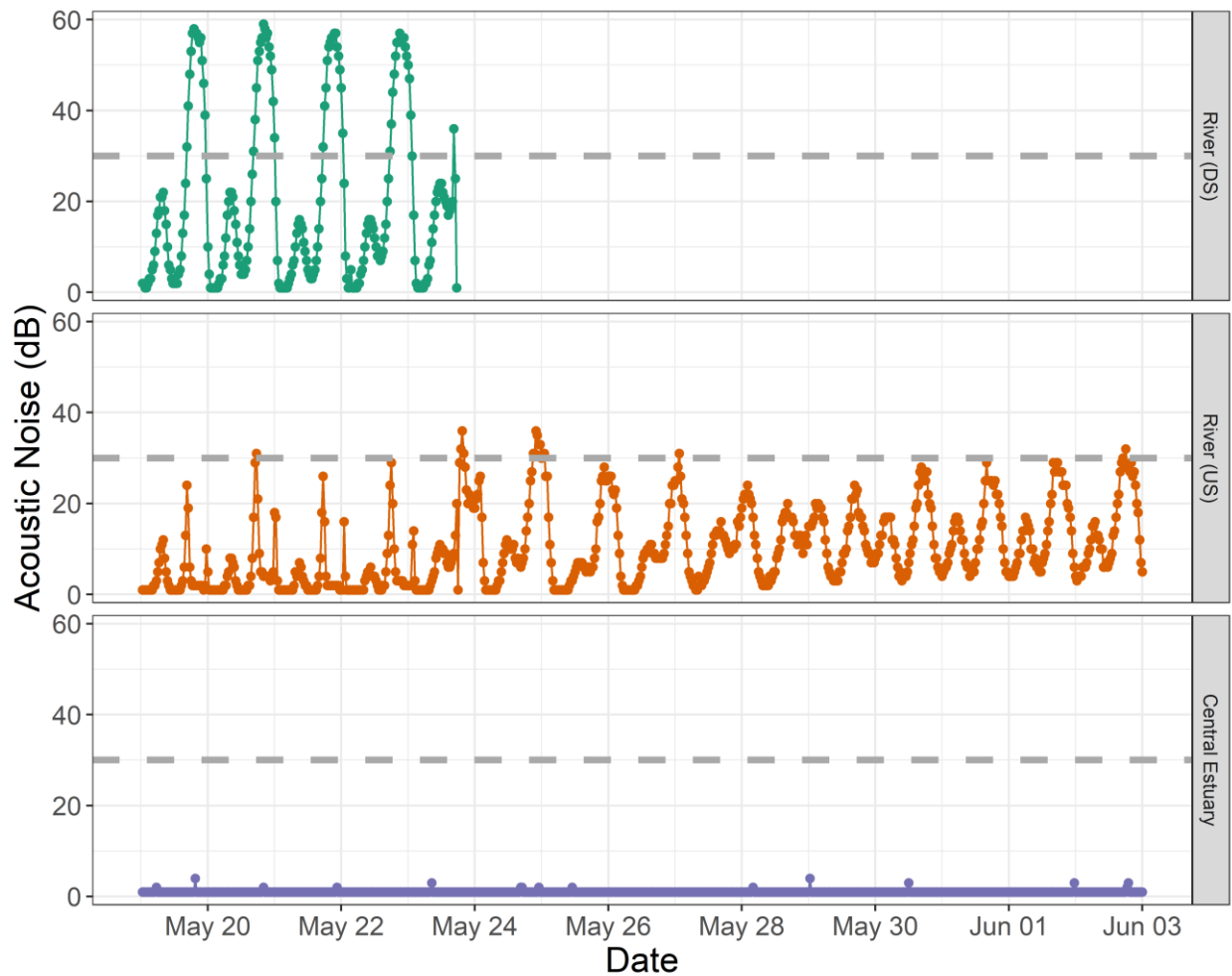

Figure 12:Levels of acoustic noise recorded by HR2 receivers deployed near the East bank of the Squamish River [Downstream (DS) and at (Upstream; US) the box culvert; two top plots) and in the Central Estuary (bottom plot). Noise levels in the Squamish River mimic tidal cycles, being noisiest during an ebbing tide. When noise levels exceed 30 dB, as indicated by the grey dashed line, receiver performance (i.e., ability to detect passing tagged fish) decreases.

The test tag was detected on two of the three passes conducted over river left receivers. The two VR2s on river right were never found or downloaded after deployment. Preliminary testing suggested that range of river receivers was approximately 50 meters. That river receivers detected 69% of tagged fish after release indicates functionality despite some poor performance measures.

Fish Capture in Pretty Slough, Bridge Pond, Cattermole Slough

Three different methods of fish capture were used to sample Bridge Pond, Pretty Slough and Cattermole Slough in 2019. Bridge Pond was sampled near the tide gate with 10 minnow traps set over night. The catch in bridge pond was dominated by stickleback and both Staghorn and Coast Range Sculpin (Table 11).

Juvenile Chinook, Coho and Chum Salmon and Staghorn Sculpin were captured by seine in Cattermole Slough. Pretty Slough was sampled using minnow traps and electrofishing. Neither method successfully captured fish, but fish were observed (Table 11).

Table 11. Results from fishing efforts in Bridge Pond, Pretty Slough and Cattermole Slough in the eastern portion of the Squamish River estuary in spring 2019. CAL= Cottus alueticus, STAG= Leptocottus armatus, CH=O. tshawytscha, CO= O. kisutch, CM= O. keta, Gunnel= Pholis laeta.

Site	Method	# Sets	Species	Catch
Bridge Pond	Minnow Trap	1	CAL	11
Bridge Pond	Minnow Trap	1	GUNNEL	1
Bridge Pond	Minnow Trap	1	STAG	24
Bridge Pond	Minnow Trap	1	STB	503
Cattermole Slough	Seine	3	CH	6
Cattermole Slough	Seine	3	CMF	1
Cattermole Slough	Seine	3	CO	5
Cattermole Slough	Seine	3	STAG	5
Pretty Slough	EF & Minnow	1 each	NA	0

Discussion

During this first year of research, over 1000 Chinook Salmon were tagged to monitor movement between the Squamish River and its estuary. Tagged juvenile Chinook Salmon were detected using the newly constructed box culvert, but more Chinook accessed the estuary by other means. However, the overall proportion of fish detected in the estuary was small; most study fish migrated to Howe Sound from the Squamish River without entering the estuary.

Fish Passage at the Box Culvert

It is promising that juvenile Chinook Salmon were detected using the culvert to access the estuary. Seven hatchery fish passed the culvert from the Squamish River to the estuary, whereas in 2018 when the twinned 3-foot culverts were in the same location, no fish other than those released at the entrance for testing were detected using the culvert (Lingard et al. 2018). However, the passage effectiveness detailed herein should be interpreted as a maximum or best-case scenario. All fish detected using the culvert were released ~1 km upstream of the culvert on the same side of the river as the culvert, a contrived situation created to improve survival of tagged fish that substantially improved probability of locating the culvert. No tagged wild-caught fish, released at the location of capture, were able to locate the culvert, suggesting that culvert attraction for fish traveling in the center or right side of the river channel may be limited.

Throughout the monitoring period anecdotal observations of water and flow conditions within the culvert were made and a time-lapse camera was installed. It is evident from these observations and the photos that the culvert is not wetted at all discharges and tide elevations. The seven fish that did pass the culvert did so in three groups and conditions were similar for each passage event. All fish passage through the culvert occurred at higher tides (>2.5 m) and high river discharge (500-600 m^3/s). Therefore, it appears locating the culvert may be difficult and the correct river elevation conditions need to occur at the time fish are passing the culvert approach channel for the culvert to be effective.

Use of the Squamish River Estuary

Despite limited potential for fish passage through culverts, our results confirm that the Squamish River Estuary is an important rearing area for juvenile Chinook Salmon. Both young of the year and yearling wild Chinook Salmon were captured in the Squamish River estuary, the majority (97%) of which were wild fish. Capture data from the estuary indicates a decrease in captures of Chinook Salmon juveniles from south to north in the central estuary, a pattern also documented by a previous trapping study in the estuary (Lingard 2018). Reasons for this distribution are unknown. If most fish enter the estuary from Howe Sound, as our data suggests, it may be difficult to locate and access these protected Northern

portions of the estuary. Alternatively, lack of flow from the Squamish River into the Northern estuary could cause conditions not suitable for rearing and feeding (e.g., elevated temperatures, low dissolved oxygen). Continued monitoring in these areas as restoration activities progress will inform these uncertainties.

Although none of the over 1000 Chinook implanted with PIT tags were recaptured during estuary fishing efforts, acoustic data shows that 14% of hatchery fish implanted with acoustic tags used the estuary (one of which used the box culvert). Fish detected on the estuary receivers spent up to two weeks in the estuary before their tags either went silent or they migrated to Howe Sound. In the Skeena River watershed, juvenile Chinook Salmon have been demonstrated to spend weeks to months in the estuary prior to marine residence (Moore et al. 2016). It is well established that estuaries are important for sub-yearling Chinook, but our results add to the evidence that larger yearling (i.e., >100mm) Chinook Salmon may rear for extended periods of time in estuaries (Bottom et al. 2005; Moore et al. 2016). Potential survival benefits of estuarine access for this population is unknown. However, a study comparing juvenile to adult survival for Chinook Salmon between altered and natural estuaries found that decreases in the availability of natural estuarine habitat negatively influenced survival (Magnusson and Hilborn 2003).

Among hatchery fish implanted with acoustic tags, 86% did not access the estuary and it is suspected these fish migrated directly to Howe Sound. Although it is possible some study fish died prior to having the opportunity to access the estuary, particularly the 31 undetected fish. However, the short distance between release and river receivers was travelled quickly making it conceivable for fish to have been missed by river receivers, especially during ebb tide. Fish move quickly downstream; there may only be seconds for a receiver to detect the tag. Out-migrating fish will move even faster during ebb tides, when levels of acoustic noise are high (and probability of detection low). Conversely, performance of estuary receivers was very high and it's unlikely a tagged fish entering the estuary would have gone undetected.

Few (14%) individuals were able to successfully navigate to the estuary. All study fish were released close to the estuary, increasing their chances of surviving to the estuary over wild fish migrating greater distances from upstream tributaries. Given limitations of using hatchery fish and the one release location, this percentage cannot be extrapolated to the wild Chinook population. Therefore, the proportion of wild Chinook able to access the Squamish River estuary is unknown, but if it is as low as our research suggests for hatchery fish, negative impacts to juvenile survival given lack of estuarine access is likely.

Results from this year and previous years of monitoring clearly show that estuary access could be improved for juvenile Chinook Salmon. Further breaches in the Spit are required to improve fish access. Aerial photographs of the estuary show several locations where the Squamish River would naturally braid

into the estuary. For example at culvert 4, just downstream of the box culvert, the river and central estuary both abut the training berm. Given that the box culvert is not wetted at all tide and river elevations, designs for future breaches or fish passage structures in the spit should strive to expand windows of passage to a wider range of environmental conditions (i.e., tide and discharge).

Limitations and Future Directions

This study was successful in determining proportion of hatchery reared Chinook Salmon entering the Squamish River estuary via the new box culvert and from Howe Sound (i.e., around The Spit). Behavioural differences between wild and hatchery fish are well established (see Melnychuk et al. 2009 for an example from the Squamish River), and thus we do not suggest our results provide an accurate representation of wild fish behavior. For example, river residence times differed substantially between wild-caught and hatchery and suggest wild fish will reside in the river for several days or weeks, whereas most of our study population consisting of hatchery fish migrated downstream within hours of release. However, estimates of river residence time are highly uncertain and inferences have been derived from a small sample of fish. Residence times for wild-caught fish are based on recaptures of few individuals (e.g., ~5% of tagged population), and recapture probability is inevitably higher for fish with higher residence times (i.e., fish migrating downstream shortly after tagging won't be recaptured).

The timing of the study (mid-May to mid-June) was relatively late in the known Chinook Salmon migration period, which begins in April for larger fish (> 65 mm; Lingard & Melville 2017). Examining fish size by date also indicates large fish (> 100 mm) tend to migrate earlier than smaller fish (60-80 mm). All hatchery fish tagged in 2019 were over 100 mm; the delayed study period may have added additional bias as the hatchery fish may have been motivated to leave the river to a greater extent than smaller wild fish.

There are several methodology changes that could be made to reduce biases in study design. The primary limitations from 2019 is the use of hatchery fish, and the late start, both of which were required with the delayed construction timelines of the box culvert. For the 2020 study year, wild fish will be implanted with acoustic tags. Beginning the study in early April and extending through June will allow for evaluation of estuary access and residence across a wider range of environmental conditions.

More strategic effort should also be spent in the estuary to improve chances of recapture in future monitoring years. Recapture effort in the estuary was roughly 60% less than the effort expended to capture fish in the Squamish River. The reduced fishing effort is likely a considerable factor in the lack of recaptures in the estuary. Fishing conditions are very specific in the estuary as much of the habitat is only accessible by boat, and it was not feasible to move the seine net around by hand. In future years, a

concentrated and systematic period of recapture (e.g., fishing every day for 7-10 days) could be implemented to evaluate whether greater effort results in re-capture of fish.

The estuary was a low risk location for the acoustic receivers compared to the Squamish River and their performance was greater than expected. Additional effort and distribution of acoustic arrays in the estuary could be used to improve knowledge of fish passage and habitat usage. The resulting data could potentially be used to identify key areas that juvenile Chinook Salmon use for rearing. Conversely, the river acoustic telemetry gate was challenging to deploy and maintain, and several receivers were lost in high flows; research goals can be achieved in future years without receivers in the Squamish River.

Conclusions

Chinook Salmon exhibit a continuum of juvenile life history types (Miller et al. 2010; Volk et al. 2010; Bourret et al. 2016). Estuaries are important transition habitats for all life history types of Chinook Salmon, with both young of the year and larger yearling known to rear for extended periods of time in estuaries of other watersheds of British Columbia and Washington state (Bottom et al. 2005; Moore et al. 2016). In this study, findings are restricted fish meeting the tagging threshold of 65 mm. However, given the importance of estuaries to all Chinook Salmon juveniles and the low catches of Chinook Salmon in 2019 and previous years of trapping (Lingard 2018), an assumption can be made that smaller fish likely have an equally difficult time accessing the estuary as the larger wild fish monitored in this study. Continued seining in the estuary and an acoustic tagging program targeted at wild Chinook Salmon (size threshold of 85 mm) in 2020, will provide a much more accurate representation of the population.

Despite potential biases associated with using hatchery fish and the timing of the 2019 monitoring program, results indicate that additional fish passage improvements are required between the Squamish River and its estuary. The installation of the box culvert appears to be an improvement from the previous 1.2 m culvert installed at the same location, but fish access to the structure is limited to a select range of tidal and river discharge conditions. Future restoration efforts should strive to provide more options for fish access to estuarine habitat across a wider range of river discharge and tidal elevations. Additional years of monitoring wild fish will enhance our knowledge of the system and restoration needs.

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