Mortality, Movements, and Migration Timing of Age-0 Cowichan Chinook Salmon Tagged in the Southern Gulf Islands in Fall 2017

Final Report to the Pacific Salmon Foundation and the Salish Sea Marine Survival Project

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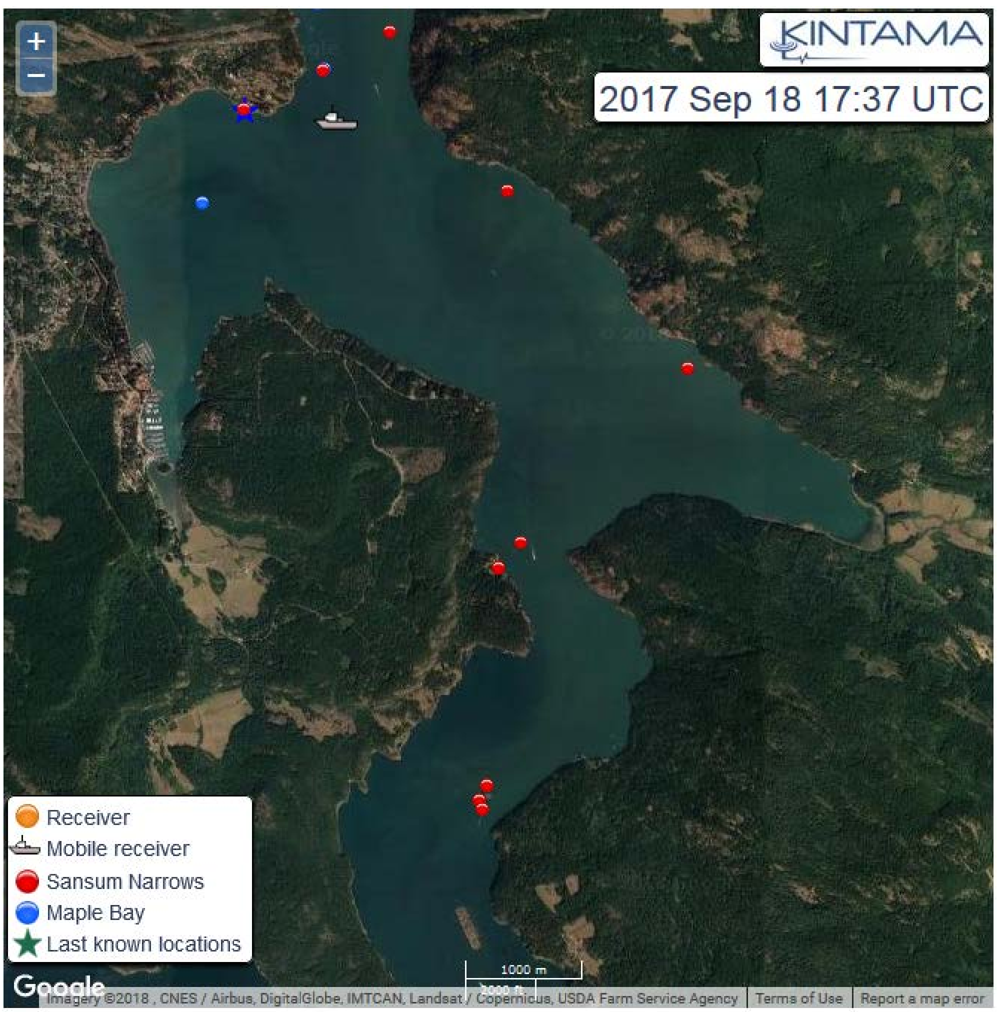

Screen capture from the animation of Cowichan River Chinook salmon movements in 2017-2018. The animation is available from Kintama's website: http://kintama.com/visualizations

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Salish Sea Marine Survival Project

marinesurvivalproject.com

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1. Introduction

The Cowichan River population of fall Chinook salmon is used as an indicator of the status of Lower Strait of Georgia Chinook salmon stocks and has been identified as “an important stock in need of rebuilding” by the Pacific Salmon Treaty Chinook Technical Committee. Marine survival for this population has declined precipitously since the 1990s from greater than 6% to less than 0.5% (Tompkins et al. 2005); however, the number of adults returning to the river has increased recently from an estimated low of 1,260 in 2009 to approximately 16,000 in 2018 for unclear reasons (preliminary estimate; K. Pellett, DFO Stock Assessment, pers. comm.). The wild population of Chinook salmon from the Cowichan River is supplemented by the Cowichan River Hatchery program which coded-wire tags or fin-clips a portion of the hatchery stock to estimate survival and exploitation rates for both wild and hatchery stocks. Hatchery contribution to the natural spawning population has averaged about 20% (K. Pellett, DFO Stock Assessment, pers. comm.).

The Pacific Salmon Foundation (PSF) and the SSMSP have supported research projects to examine the early life-history during downstream migration and early-marine residence in an effort to identify where and why the decline occurred. An extensive PIT tag study was initiated in the Cowichan River and adjacent marine environment by the British Columbia Conservation Foundation (BCCF) in 2014. Survival of PIT-tagged Cowichan River Chinook salmon during downstream migration was lower than expected (~25%) but similar for wild and hatchery fish; however, survival to adult return was lower for hatchery fish (Pellett 2017). Application of PIT tags to fish in spring in the estuary, early summer in Cowichan Bay, and late summer and fall in Sansum Narrows and Maple Bay (the site of the present study) revealed that survival rates to return remain low even for fish tagged in late summer and fall (<7% for wild fish and less than half of this for hatchery fish, K. Pellett, unpublished data; at time of writing, harvest by fisheries was unavailable). This difference in hatchery and wild return rate was less extreme than predicted by results of Beamish et al. (2012) who concluded that survival from ocean entry to mid-September was 1.3% for hatchery and 7.8% to 32.5% for wild Cowichan Chinook salmon. A key finding of the BCCF PIT tagging study is that considerable mortality occurs after the first marine summer, highlighting the need to investigate mortality during the first fall and winter at sea.

From 2014 to 2016, University of Victoria was funded to investigate fine scale spatiotemporal patterns in distribution, diet and growth of Cowichan Chinook salmon during the latter part of their first summer at sea. This work demonstrated that hook and line sampling (microtrolling; Duguid and Juanes 2017) was an effective method to sample Chinook salmon in later summer and fall when they had reached fork lengths of 140-240 mm. In the southern Gulf Islands, first ocean year Chinook salmon catch per unit effort by microtrolling increased from August through early October. Limited reconnaissance efforts suggested that it then declined precipitously later in October as fish died or emigrated (W. Duguid unpublished 2016 data). The microtrolling studies in 2015 and 2016 also suggested that habitat use by juvenile Chinook salmon varied at fine spatial scales. Cowichan Chinook salmon captured at Sansum Narrows were consistently larger than those captured at Maple Bay throughout the late summer and fall. In addition, Chinook at Sansum Narrows had more fish in their diet (age-0 Pacific Herring) and were growing faster based on scale circulus spacing (W. Duguid unpublished data). The current study expands the scope of knowledge on Cowichan Chinook salmon to the broader Salish Sea area.

Prior studies have suggested that juvenile Cowichan Chinook salmon survival in the Salish Sea may be low (Neville et al. 2015). Neville et al. (2015) captured and acoustic-tagged 70 juvenile Chinook salmon in the Southern Gulf Islands in July of 2008, most of which were Cowichan stock. These authors used 69 kHz tags with an approximate battery life of 120 days. These fish could have potentially been detected on Pacific Ocean Shelf Tracking array (POST; now maintained by the Ocean Tracking Network) in Juan de Fuca Strait (JDF), the northern Strait of Georgia (NSOG), and Queen Charlotte Strait (QCS) if they migrated from the Salish Sea within that time; however, only one was detected on JDF prior to battery expiry (this fish was identified by genetics to belong to the Big Qualicum River population rather than the Cowichan River population). The authors concluded that very high apparent mortality occurred within the Salish Sea, but they could not exclude the possibility that some juvenile Chinook salmon may have remained resident.

Similar results were found in the Puget Sound area: of 58 yearling Chinook salmon smolts tagged in Hood Canal in May 2008, none were detected leaving the Salish Sea for the duration of the study (i.e., until the tag batteries died, approximately 150 days post-tagging (Chamberlin et al. 2011)). Because the fish were tracked on a finer scale in Hood Canal, they concluded that fish may remain resident. Thirty-one percent were detected for up to ~100 days indicating residence in Hood Canal for several months. These fish may have also resided or died between Hood Canal and JDF. Further, DFO's High Sea Salmon Program has captured very few juvenile Cowichan Chinook salmon beyond the Salish

Sea (S. Tucker, DFO, personal communication). Some CWT-tagged Cowichan Chinook salmon have been caught outside the Salish Sea in sport and commercial fisheries (Regional Mark Information System (http://www.rmpc.org/); however, the fishery focuses on older age classes. This suggests that a significant proportion of Cowichan Chinook salmon may remain resident in the Salish Sea for at least their first winter at sea and at some point in the life history at least a portion of the population moves out of the Salish Sea. Consistent with this, Arostegui et al. (2017) reported complex long-term patterns of residence in southern Salish Sea populations of Chinook salmon. Collectively, these results indicate that it is important to more carefully assess migration, residency, and survival during the first winter for Chinook salmon populations in the Salish Sea.

In this pilot study, we captured and acoustic-tagged 80 age-0, wild and hatchery Chinook salmon (>140 mm FL) in Maple Bay and Sansum Narrows (north of Cowichan Bay) in late summer and tracked their movements and fate until the transmitter batteries died in late February. Genetic stock identification (GSI) was used to determine stock, and molecular techniques were used to reveal whether select infectious agents were present in tagged fish using a small biopsy sample taken at the time of tagging. A receiver array was deployed between Vancouver Island and Saltspring Island to estimate survival and residency in the Cowichan Bay area (Figure 1). Receivers were also deployed to monitor two seal haul-out islets in or adjacent to the study area to estimate a lower limit of seal predation, and mobile acoustic tracking was used to investigate fine-scale habitat occupancy and to help quantify time and location of death for individual tagged fish. The existing POST array at JDF and NSOG, and several individual receivers maintained by Ocean Networks Canada were used to determine residency in the Salish Sea. During tagging, fish were double-tagged with a PIT tag so that we may ultimately estimate adult survival back to the Cowichan River which will be complete in 2021 (for fish identified as Cowichan). Thus, this study forms one of the most comprehensive salmon studies within the SSMSP. It builds on previous SSMSP-funded studies, brings together novel techniques (microtrolling, acoustic telemetry, and genomic disease profiling), and relies on cooperation and collaboration with numerous organizations (UVic, DFO, OTN, ONC, BCCF, and Kintama).

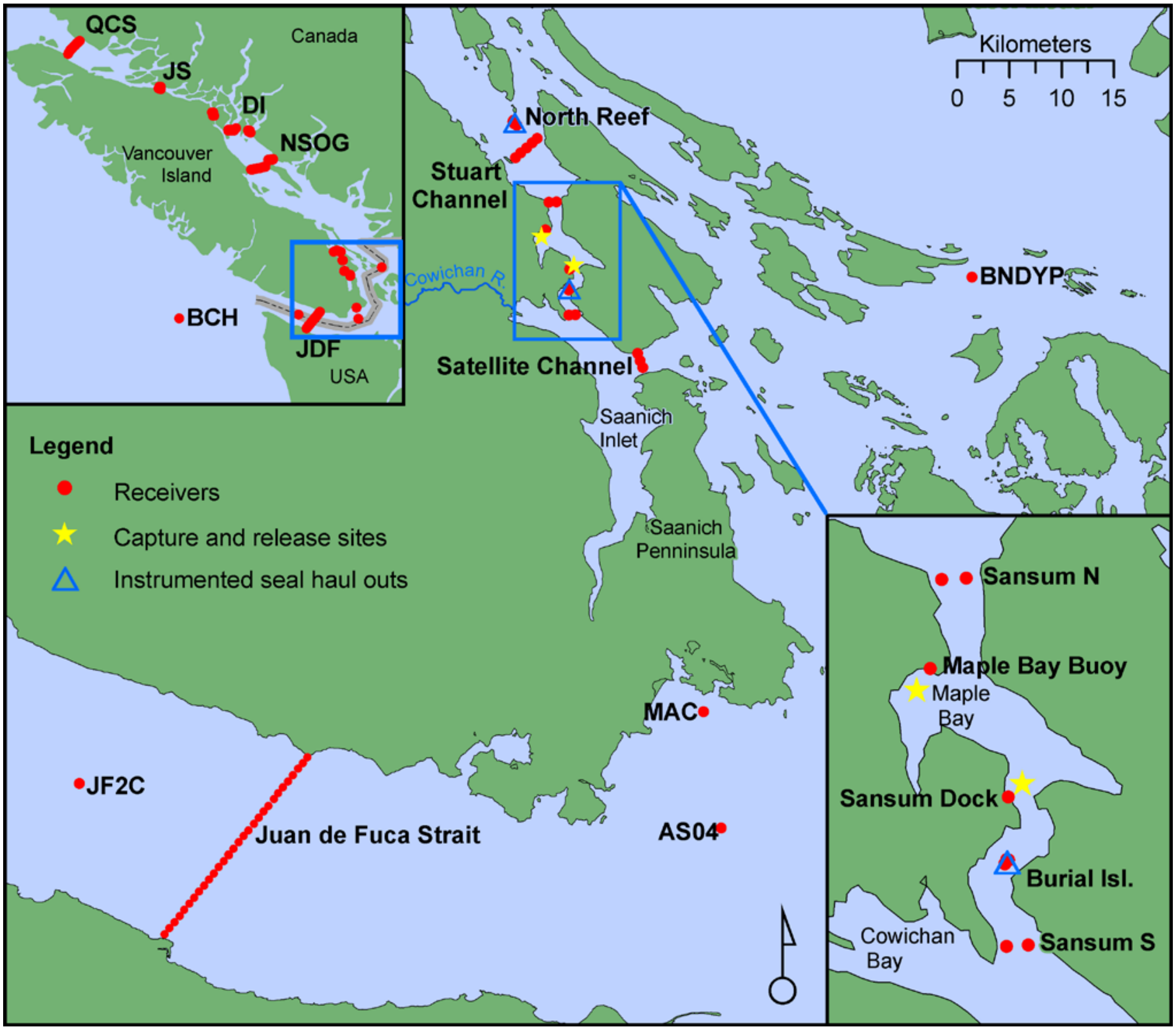

Figure 1. Map of the acoustic array and release locations of juvenile Chinook salmon captured in the southern Gulf Islands (SGI; Maple Bay and Sansum Narrows B.C.) in September 2017. Microtrolling occurred near the yellow stars. BNDYP, MAC, AS04, JF2C, and BCH are receivers maintained by Ocean Networks Canada; OTN manages Juan de Fuca (JDF), Northern Strait of Georgia (NSOG) and Queen Charlotte Strait (QCS); Kintama and the Pacific Salmon Foundation maintain the Discovery Islands (DI) and Johnstone Strait (JS) arrays. The SGI array was short-term and was recovered after tag batteries died.

2. Methods

2.1. Tagging

A small vessel and modified recreational fishing gear (microtrolling; (Duguid and Juanes 2017)) were used to non-lethally capture juvenile Chinook salmon in Maple Bay on Sept 12 and 13th 2017, and in Sansum Narrows on Sept 14th and 15th (Figure 1). Microtrolling has proven effective for systematically sampling juvenile Chinook salmon across depths and habitats. The fork length of Chinook salmon captured via microtrolling appears to be broadly comparable to that of Chinook salmon caught in DFO purse seine and trawl surveys in the southern Gulf Islands (Duguid and Juanes 2017; 2016 data Duguid and Pellett).

Active fishing period for each microtrolling gear deployment was kept to four minutes in duration to reduce fish stress. Together with the time required to drop and raise gear, microtrolling gear deployments ranged from 6.3 to 9 minutes in length (mean = 7.4 minutes). Microtrolled fish were brought to the surface, placed in a dark, aerated, temperature-controlled bucket containing 0.5-1.0 ppm sedative (metomidate), and transported to the tagging sites. Fish were held in this bucket (with aeration) until surgery.

We implanted 80 fish with an acoustic transmitter and a PIT tag using standard surgical techniques (Table 1; Rechisky and Welch 2010). Forty-one were captured and tagged in Maple Bay and 39 in Sansum Narrows. Just prior to surgery, each fish was transferred to an anesthetic bath containing 40-70 ppm TMS (tricaine methanesulfonate). Once sedated, each fish was scanned for a coded wire tag (CWT), scales were collected for genetic stock identification, a gill tissue sample was taken for disease profiling, and tags were implanted. Fish were considered hatchery origin if they had a CWT or were missing an adipose fin. Fish were allowed to recover for ~one hour in a dark, aerated, temperature-controlled five gallon bucket of seawater, and then were transported away from shore near the capture location and released at depth (10-30 m).

Fish were implanted with VEMCO V9-6L acoustic tags (69 kHz, 9 x 20 mm, 2.9 g in air). The tags were programmed to transmit at random intervals every 30-60 seconds for the first 14 days after activation to accommodate a systematic mobile survey (see below), and transmission was then reduced to 30-90 second intervals to extend battery life. Tags were expected to begin expiry on Feb 24th 2018, 165 days after first activation. Each fish was also implanted with a 12 mm FDX-B PIT tag (Biomark.com) in order to identify mature fish returning to the Cowichan River using infrastructure installed for the survival study led by BCCF.

Fish ranged between 143-238 mm fork length at tagging. It was too windy to stabilize the scale at the Maple Bay tagging site, but the fish captured at the Sansum Narrows site weighed between 34.7-103.3 grams, which resulted in tag burdens ranging between 2.8-8.4% (in air; Figure 2).

Table 1. Southern Gulf Islands Chinook salmon tagging Sept 12-15, 2017. All fish were tagged with a V9-6L transmitter and a PIT tag. A gill tissue sample was taken for genetic analyses. Na = weight unavailable. The percent of fish missing an adipose fin is an estimate of the percent of hatchery fish. Median tag burden for the Sansum Narrows caught fish was 5.0% (range=2.8-8.4%).

Capture/release site	N	Fork length (mm; mean, range)	Weight (g; mean, range)	% missing an adipose fin
Maple Bay	41	171 (144-210)	na	24%
Sansum Narrows	39	178 (151-238)	63 (35-103)	23%

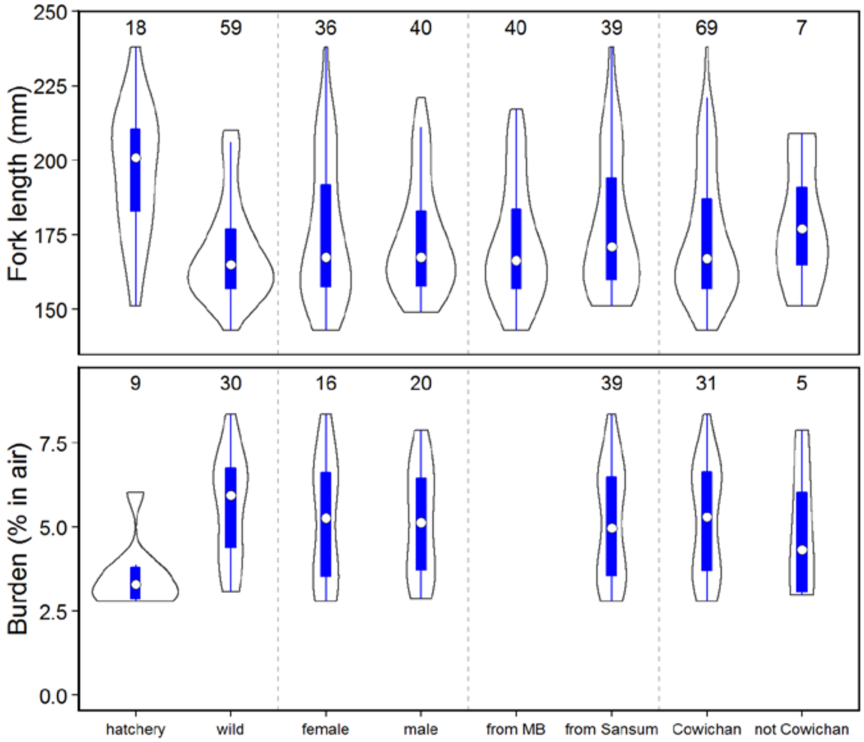

Figure 2. Fork length and tag burden distributions for juvenile Chinook salmon captured and acoustic-tagged Maple Bay and Sansum Narrows in 2017. The white dot in the middle is the median. The blue box presents the interquartile range with whiskers extending to the minimum and maximum values exclusive of outliers. The outer shape displays the probability density of the data at each value. Sample size is reported for each group; some fish were unknown so the combined sample size may be less than 80. We did not weigh fish at the Maple Bay tagging site. Sex was determined by success (male) or failure (female) to amplify the GH-Y locus.

2.2. Genetic Stock Identification

Scale samples on gummed scale cards were transferred to the Molecular Genetics Laboratory at the Pacific Biological Station, Fisheries and Oceans Canada (DFO) for genetic stock identification (GSI). Each fish was assigned probabilities of belonging to 296 North American Chinook salmon populations based on combinations of alleles at highly variable microsatellite loci (N = 15) following methods similar to Beacham et al. (2006). As part of the GSI process, GH-Y, a sex determination locus-linked pseudogene on the Y chromosome, was also amplified. Successful amplification of this pseudogene indicated individuals that were likely male (Devlin et al. 2005).

2.3. Disease Profiling

A small tissue sample (~2 mm) was cut from the gills of each tagged fish and placed into a 2 ml capped tube pre-filled with RNAlater. Each tube was pre-labelled with tissue type and a fish number. RNAlater is an aqueous, nontoxic, tissue storage reagent that rapidly permeates tissue to stabilize and protect the integrity of RNA in unfrozen tissue samples.

We used high-throughput genomic profiling to investigate select infectious agents and diseases present in salmon at the time of tagging as well as regulation of genes. We will relate these results to their subsequent migration success and survival. Procedures were performed at the lab of Dr. Kristi Miller at the Pacific Biological Station, Fisheries and Oceans Canada (DFO; detailed methods are available in Miller et al. 2017; Miller et al. 2014).

2.4. Passive Acoustic Array

On August 7-8th 2017, we deployed four subarrays of acoustic receivers in the southern Gulf Islands with two north of the release sites (Sansum North and Stuart Channel) and two south (Sansum South and Satellite Channel; Figure 1). In addition, on August 31st we deployed via scuba single receivers near each release location (Maple Bay Buoy and Sansum Dock), and sets of receivers around nearby seal haul-out islets to attempt to quantify a lower limit of seal predation (five units at North Reef and three units at Burial Island). Collectively, we refer to these deployments as the Southern Gulf Island (SGI) array. The four main subarrays were successfully recovered March 30-31st 2018 with the exception of one unit in Sansum South which was pulled up by crabbing activities on January 19th 2018 and returned to Kintama where it was offloaded (i.e. the unit was fully functional until January 19th). The Maple Bay buoy receiver, the Sansum dock receiver, and six of the seal haul-out receivers were recovered on March 8th; we were unable to locate one unit from each of the seal haul-out deployments.

Beyond the SGI array, the POST array (owned by the Ocean Tracking Network (OTN)) was operational during this study at Strait of Juan de Fuca (JDF), Northern Strait of Georgia (NSOG), and Queen Charlotte Strait (QCS). Ocean Networks Canada also had receivers deployed as part of OTN's Buoys of Opportunity program (BOOONC) at four locations within the southern Salish Sea area (BNDPY, MAC, AS04, JF2C) and a fifth unit west of Juan de Fuca Strait near the edge of the continental shelf (BCH). Finally, the Pacific Salmon Foundation funded Kintama Research Services to deploy and operate subarrays of receivers in the Discovery Islands (DI) and across Johnstone Strait (JS) during our study period.

Of the POST/OTN subarrays, 20 of 29 positions were successfully offloaded from NSOG in the spring of 2018. The remaining nine NSOG positions (positions 11-19) were pulled up by fishing activities in either late January (positions 13, 14, 17) or March 21st (remainder) with all units returned to OTN for data offload. All positions were successfully offloaded from QCS in spring 2018. The American side of JDF was offloaded in fall 2017, the Canadian side in spring 2018, and the full subarray November 14-15th 2018 with the exception of position 25 which was non-responsive. All but one non-responsive receiver were successfully offloaded from DI and JS in late September 2018. The units maintained by Ocean Networks Canada are recovered every six months to offload data, but the specific dates and outcome of these service events were not available by the time of this writing.

2.5. Mobile Tracking

Beginning immediately after tagging was completed, we conducted ten days (Sept 16, 18-24, 26-28) of systematic and high-resolution mobile tracking at 60 stations between the innermost subarrays (Sansum South to Sansum North; Figure 3). Alongshore stations (N = 51) were spaced approximately 600 m apart and 200 m offshore (mean = 189 m based on field validation with rangefinder); an additional 9 mid-channel stations were located approximately equidistant between shoreline stations within and adjacent to Maple Bay. The repeated complete coverage of this area over multiple days was intended to provide a detailed picture of movements of any fish which remained within the inner arrays and identify the location of any tagged animals that died. During this period, each station was surveyed once or twice per day. Surveys were conducted from a drifting vessel with motor and sonar switched off using a Vemco VHTx-69k omnidirectional hydrophone and a VR-100 deck box receiver. The hydrophone was deployed on 12 m of cable; however, actual hydrophone depth varied considerably due to wind and current induced drag. The initial listening interval for each survey was 135 seconds (the mean time required for a tag to transmit three times). Where a tag collision was heard, or where noise from passing vessels was deemed to have interfered with detections, additional time was added to the survey up to a maximum of 255 seconds. The order of stations surveyed was varied in response to weather conditions and vessel traffic with a goal of not repeating a similar order between sequential days.

The second phase of mobile tracking was conducted over four days (Nov 6, 7 and 10 and Dec 11) to monitor seal haul-outs to detect stationary transmitters that had been voided by predators. We classified seal haul-outs within the Southern Gulf Islands based on DFO seal census data (Olesiuk 2010); Majewski and Ellis, in review). Haul-outs with counts greater than or equal to 25 individuals during the 2014 census were considered high-use haul-outs. If the count was less than 25 in 2014, the mean count across all surveys conducted between 2003 to 2014 needed to be at least 25 (blue triangles in Figure 3). We surveyed all possible high-use haul-outs in a ring around the inner study area. Haul-out topography varied, and the location where seals were observed did not always correspond to DFO coordinates. The survey stations at each haul-out were therefore determined ad-hoc. In general 2-4 stations were surveyed around each haul-out approximately 100 m from shore. Stations were selected to detect tags on either side of abrupt topography which could mask transmission of tags on the bottom. In addition to surveys at seal haul-outs, a few additional surveys of opportunity were conducted at additional sites when practical. Listening duration during this phase of the survey was increased to 180 seconds, the mean duration for three tag transmissions for a 30-90 second transmission interval. Where tags were either decoded or audibly heard but not decoded, we alternated between directional and omnidirectional hydrophones to try to pinpoint tag location as closely as possible.

Finally, we conducted three days (Dec 12 and 14th, January 2nd) of broader mobile tracking surveys focused primarily on locating tagged fish mortalities. We occupied 152 stations on a 1 km by 1 km grid covering the entire region between the Stuart Channel and Satellite Channel subarrays (Figure 3). Stations were shifted directly away from shore and off the drop-off if water depth was <10 m. Stations very close to shore were shifted approximately 180 m offshore (as determined with a range finder). Where channel width was <360 m, stations were moved to the middle of the channel. At each station, we deployed the omnidirectional hydrophone for 120 seconds. Where a tag was either decoded or audibly detected but not decoded, we alternated between omnidirectional and directional hydrophones to pinpoint the tag location as closely as possible. Additional surveys were conducted on January 3rd, 28th, and 30th to revisit tag detection locations to determine if the tag had moved (live fish) or was still present (dead fish).

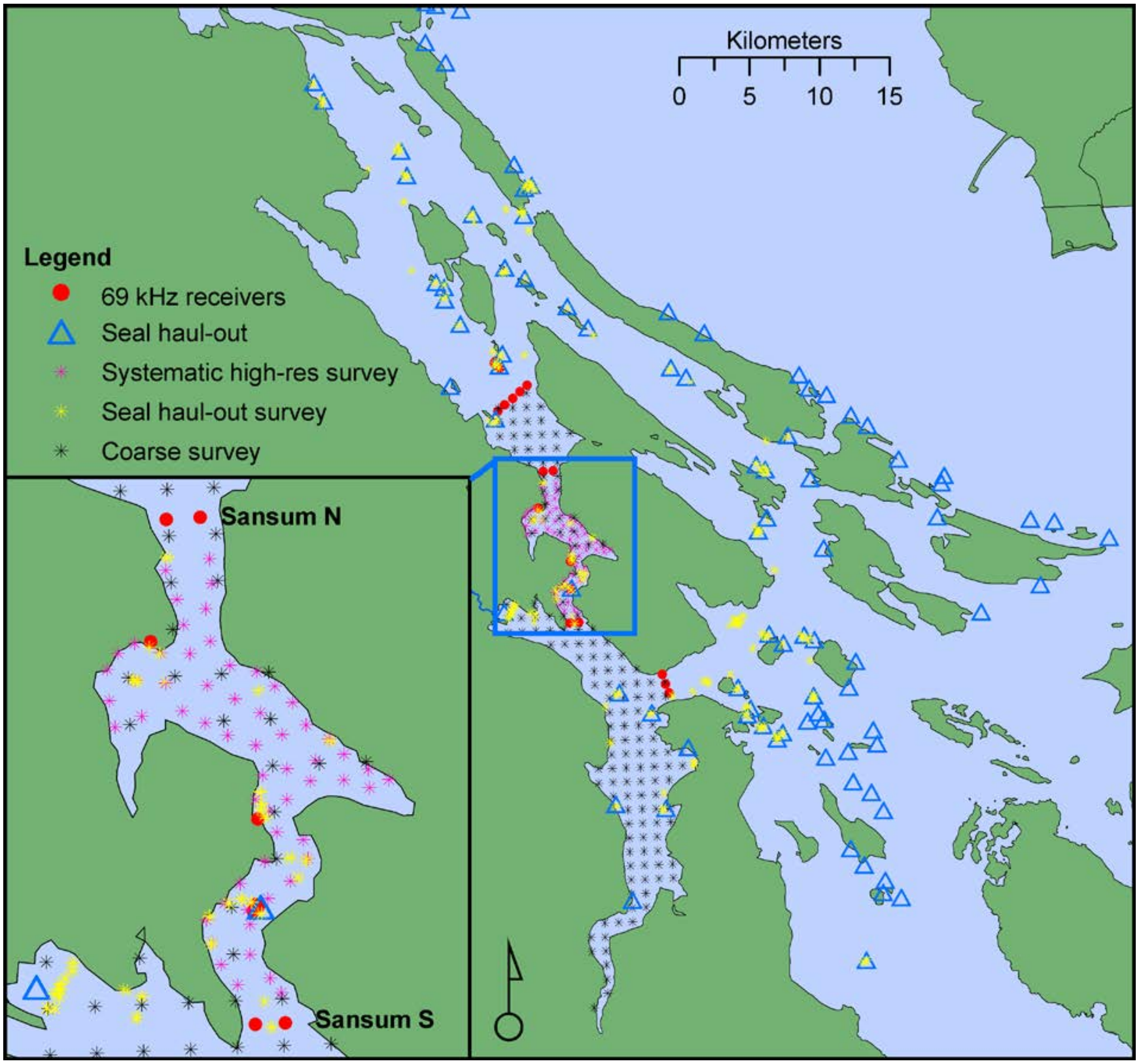

Figure 3. Location of mobile acoustic surveys conducted between September 2017 and January 2018 to detect juvenile Chinook salmon that were captured and acoustic-tagged in Maple Bay and Sansum Narrows in 2017. See Methods for definitions of survey types. Note that some “seal haul-out” surveys were actually opportunistic surveys to check for tag presence and are not overplotted on a seal-haul out. Seal haul-out data were provided by DFO.

2.6. Data Management

With the exception of the mobile tracking component, a copy of all project metadata and detections data were submitted to the Ocean Tracking Network data warehouse where they are publically available without an embargo period (https://members.oceantrack.org/project?ccode=NEP.CCSALMON). At Kintama, this information is stored in our PostgreSQL database for analysis.

Prior to analysis, we screened the data for false detections. False detections may occur as a result of environmental conditions creating transmissions similar to those used for telemetry, or from collisions between acoustic-tag transmissions that reach the receiver from direct or reflected paths (echoes). Tag codes with two or more detections within 0.5 hours and with more detections spaced with short intervals (<0.5 hour spacing) than with long intervals (>12 hours spacing) were passed. Detections that failed this first step were assessed individually and were passed if the migration sequence was reasonable and if the travel time for the preceding or subsequent segments were within the 10^{th}-90^{th} percentiles of travel times. Six of the 424,914 detections were classed as false.

2.7. Data Analyses

2.7.1. Survival and Residence in the Southern Gulf Islands

2.7.1.1. Classification of Final Status

We used a series of rules to classify fish in the SGI array area as 1) dead, 2) dead early, 3) alive until the end of the study, or 4) emigrants from the SGI array area.

- 'Dead' fish were last detected stationary, or disappeared without being detected exiting the SGI array (i.e. did not emigrate) at least two weeks before the start of tag expiry. We defined fish as stationary on the passive array if they were continually detected for over two weeks (and not detected afterward); in practice, these fish were stationary for 27 to 189 days. This two week interval is reasonable because fish were generally highly mobile: 95% of the travel time estimates in the SGI area were under two days, and the vast majority of individuals made multiple movements each week (see 3.9 Travel Times and Rates). Fish were also identified as stationary if they were repeatedly located in the same place by mobile tracking and not subsequently detected on a passive array (i.e. tags were in the same place on at least two visits, including the final one).

- ‘Dead early’ fish were classed as ‘dead’ as per the definition above, but their estimated mortality date (see next section) was <2.6 days after release. We created this class because the initial plots of survival with time showed that an unexpected number of fish died soon after release which may have been due to handling (microtrolling, transporting, tagging) or increased predation risk, which may have affected smaller fish (Figure 4). We used the R package “segmented” (Muggeo 2003; Muggeo 2008) to estimate the number of days after release when the mortality rate appeared to slow (Figure 5). We used the first 33 days after release for this analysis because the relationship between mortality and time became visibly non-linear after this date. Additionally, we excluded any fish that were last located in Saanich Inlet (by mobile tracking) because this large area was not monitored by the passive array and death dates were uncertain. There is some uncertainty in the death dates (see Outcomes), but examination of the individual fish indicates that this method provided a reasonable approximate date between the periods of elevated and reduced mortality rates.

- ‘Alive’ fish were last detected moving within the SGI area within two weeks of the start of tag expiry on Feb 24th 2018 or later.

- ‘SGI-emigrant’ fish were last detected on the outer subarrays (Stuart Channel, Satellite Channel, or North Reef) or outside the SGI array (on JDF or BOOONC) a minimum of two weeks before the start of tag expiry (Feb 24th, 2018).

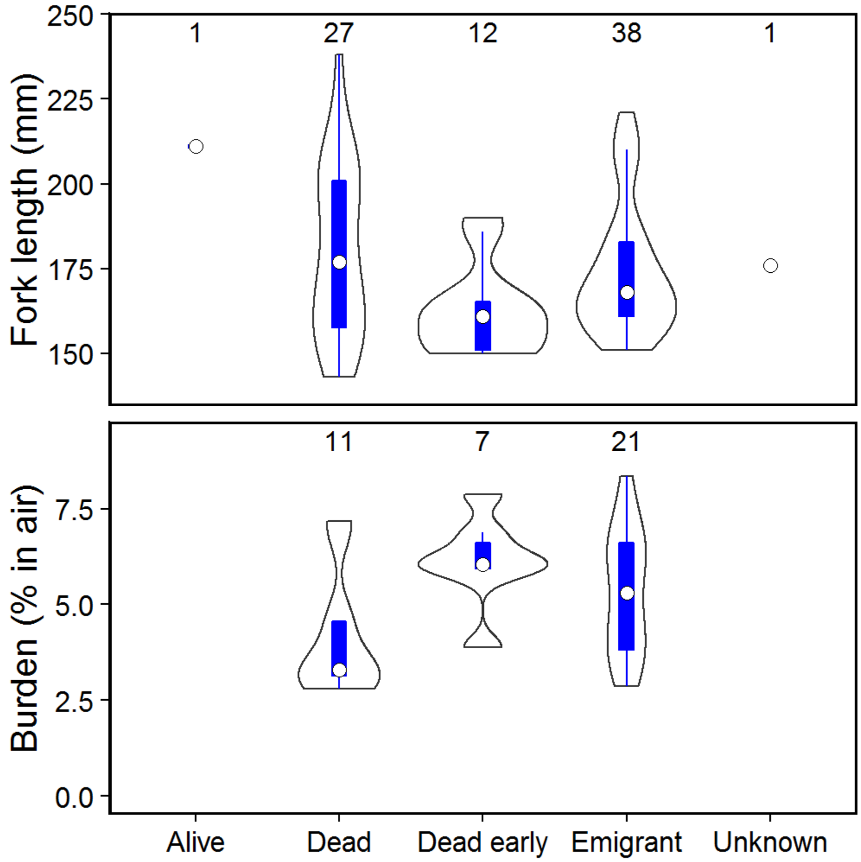

Figure 4. Comparison of the fork length and tag burden distributions of juvenile Chinook salmon that died within 2.6 days of release (Dead early), died after 2.6 days of release (Dead), emigrated, or survived within the SGI area until the end of the study in late February (Alive). The breakpoint of 2.6 days was estimated using linear regression models with a segmented relationship. Unknown: last detected alive in Saanich Inlet. We did not weigh fish at the Maple Bay tagging site; one fish was not measured for fork length.

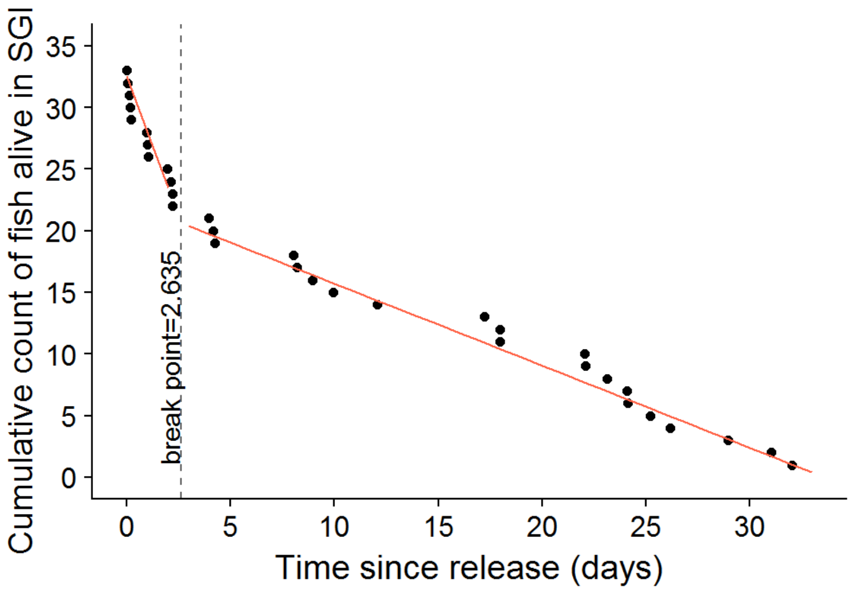

Figure 5. Count of fish alive in the Southern Gulf Island (SGI) study area over time. The break point indicates a change in mortality rate. Any fish that died within 2.6 days of release was classified as "dead early" due to handling and tagging effects.

2.7.1.2. Assignment of End Date

Once the final status of the fish was assigned, we used a second set of rules to define when they emigrated from the SGI area into the greater Salish Sea area or died in the SGI area.

- The date of emigration is simply the last date the fish was detected on the outer SGI subarrays (Stuart Channel, Satellite Channel, or North Reef) because detection rate was 100%.
- The death date was more challenging and was estimated in a number of ways:
    - If a fish was identified as dead by mobile tracking during the period of systematic daily mobile surveys (Sept 16th-27th), then we used the first date it was located at its final location during these surveys as the death date (code: first date stationary on mobile).
    - If a fish was identified as dead by mobile tracking, before or after the period of systematic daily mobile surveys (after Sept 16th - 27th), then we used the last date

the fish was detected on the passive array as the death date rounded up to the nearest day (code: last passive date). We used this approach because the fish were generally detected frequently on the passive array: all but six individuals were detected more than 100 times and 99.8% of detections were spaced by less than a day within the SGI area (~90% of the remainder when detections of <1 hr were removed; see 3.2 Number of Detections). However, the death date may be underestimated if individuals resided between subarrays; this is more likely for four individuals that were last located dead (by mobile tracking) in Saanich Inlet where there is no passive array (identified in Appendix A).

- For fish that were classified as dead because they disappeared without emigrating, we assigned the death date using their last detection on either the passive array or by mobile tracking (codes: last passive date; last mobile date).

- Finally, for fish that were identified as dead because they were continuously detected at one passive subarray, we assigned the death date as the first date of detection on that subarray (code: first date stationary on passive).

In addition to these classifications and dates, one fish was assigned as 'Unknown' because it was last detected presumably alive in Saanich Inlet during a mobile tracking survey on Jan 2nd 2018 having last been detected on a passive array 105 days prior on Sept 19th 2017. Because there were no passive deployments in Saanich Inlet, we cannot determine whether this fish died prior to battery expiration (and if so when it died) or remained alive within Saanich Inlet. We used the last date of detection for this fish (code: last mobile date) for the purposes of calculating residence time and survival.

2.7.1.3. Survival and Residence in the SGI

We calculated cumulative survival for non-emigrant tagged fish in the SGI area as the number alive each day divided by their total number. We did this calculation twice: once including all non-emigrants, and then again excluding the 12 fish that died early after release to avoid incorporating handling and tagging related mortality biases. Similarly, we calculated residence time for the SGI-emigrant fish as the number remaining in the SGI area each day divided by the total number of SGI-emigrants.

2.7.1.4. Detection Efficiency

In order to estimate detection efficiency, it is necessary to have an independent detection site further along the migratory path that can provide the number of fish not detected at the first site. We were able to estimate detection efficiency of the inner subarrays (Sansum S and Sansum N) for fish detected at their corresponding outer subarrays (Satellite Channel and Stuart Channel/North Reef), and of the outer subarrays (Satellite Channel and Stuart Channel) for subsequently fish detected at North Reef, JDF, or BOOONC. We estimated detection efficiency as the count of fish detected at each subarray divided by the count known to have crossed it because of one or more detections further along the migratory path.

2.7.2. Minimum Survival and Residence in the Salish Sea beyond the SGI area

We calculated survival to exit from the Salish Sea as the number of tagged fish detected at JDF divided by the number emigrating from the SGI area. Exit from the Salish Sea is also monitored to the north, but no fish were detected in this direction (NSOG, Discovery Islands, Johnstone Strait, Queen Charlotte Strait). The continental shelf beyond JDF is not monitored by acoustic receivers so it is not possible to confirm that fish detected here actually emigrated.

We estimated minimum residence time in the southern Salish Sea as the interval between departure from the SGI array, and the last detection on either the ONC buoys or JDF detection sites.

2.7.3. Travel Time and Rate

Segment travel time (hours) within the SGI area was calculated for each fish from release to arrival on the first subarray, and then from departure from each subarray until arrival at each subsequent subarray encountered, including return to subarrays on which it was previously detected. In the Salish Sea, we calculated travel times both from release and from exit from the SGI area until arrival at each of the receivers in the BOOONC array and arrival at JDF as a whole.

We converted the travel times into travel rates by dividing distance by time. Distance for each array segment was measured in two ways with the rate estimates then calculated using both methods. First, we measured the total segment length along the approximate shortest route in water between the central points of each subarray. Secondly, we attempted to take the detection range of the tags into account by subtracting the predicted maximum detection range of the tags from both ends of the total segment length. It is estimated that V9-6L tags are detected up to ~400 m (radius) from the receivers in good transmission conditions (Welch et al. 2003). Thus, we subtracted 800 m from the total segment length to account for the detection range of the tags. The detection range within the specific conditions of the SGI array are unknown so these distances bracket the likely values.

Within the SGI array, we calculated travel rates for all migration segments except between release in Maple Bay and detection at the Maple Bay Buoy, and release in Sansum Narrows and detection at Sansum Dock where distance was essentially zero.

In the Salish Sea, we calculated travel rates to either JDF or the furthest west ONC receiver. The MAC and AS04 ONC receivers were pooled as a single detection site because they are a similar distance from the SGI.

3. Results

A dynamic animation of the movements of the juvenile Chinook salmon captured in Maple Bay and Sansum Narrows in 2017 is available on our website (http://kintama.com/visualizations/). The animation can be panned and zoomed, and the display can be customized. Tags and receivers can also be queried to obtain summary statistics as well as full detection histories.

3.1. Genetic Stock Identification

Sixty-nine (86%) of the 80 juvenile Chinook salmon were identified as Cowichan stock; however, there was uncertainty in this assignment for some individuals (11 had <90% probability of being Cowichan; Appendix A). Two fish were identified as Puntledge fall-run Chinook salmon and one as Harrison. Four individuals were identified as either Puntledge (n=2) or Cheakamus (n=2) fall-run Chinook salmon, but these assignments had low probability. Four fish did not amplify; however, one of these subsequently returned as a jack to the Cowichan River (based on the time of river entry one year after release) so we assigned it as Cowichan origin. In this report, all stocks are pooled.

3.2. Number of Detections

Of the 80 juvenile Chinook salmon, 79 were recorded on the passive SGI array and 71 were recorded with mobile tracking, including the individual that was missed on the passive array (Table 2). On the passive array, most fish were detected many times (only seven individuals had under 100 total detections; Figure 6) and moved frequently between subarrays (Figure 7). Nearly all detections were spaced by under an hour (98.6%) even when detections of individuals who died within range of the passive receivers were removed. When we then removed detections spaced by under an hour to better reflect movement behaviours (i.e. reflects periods of absence from the detection range of each subarray as well as movement between subarrays), the majority of detections were still recorded within a day (89.1%; Figure 8).

Table 2. Counts of juvenile Chinook salmon detected in 2017 and 2018. Counts do not reflect repeated passes over the same acoustic subarray. 'Overall' counts exclude mobile tracking. BOOONC=Buoys of Opportunity Ocean Networks Canada.

	Maple Bay	Sansum Narrows	Total
Mobile tracking	**35**	**36**	**71**
Southern Gulf Islands Overall	**41**	**38**	**79**
Maple Bay Buoy	39	12	51
Sansum Dock	31	38	69
Sansum North	25	15	40
Stuart Channel	15	8	23
North Reef Haul-Out	8	3	11
Burial Island Haul-Out	29	36	65
Sansum South	25	33	58
Satellite Channel	19	18	37
Salish Sea Overall	**8**	**10**	**18**
BOOONC Overall	**6**	**8**	**14**
BNDYP	1	1	2
AS04	4	3	7
MAC	5	6	11
JDF	4	3	7

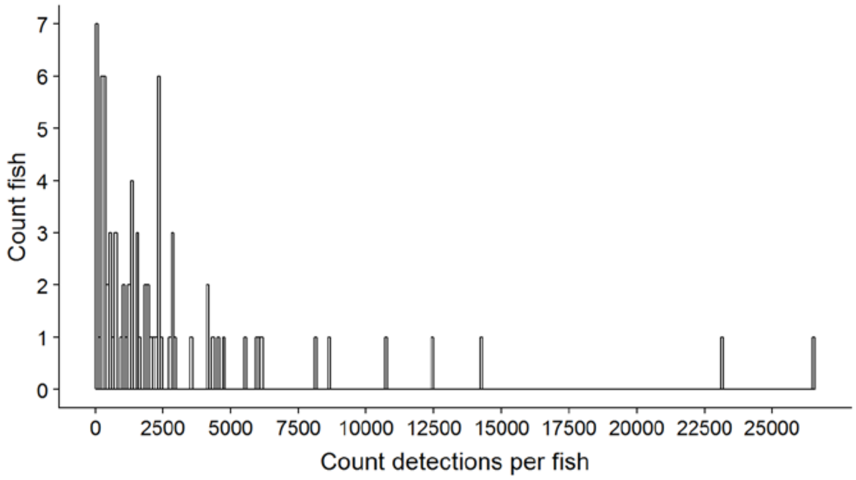

Figure 6. Histogram of the number of times individual juvenile Chinook salmon were detected on the Southern Gulf Islands passive acoustic array in 2017 and 2018. Detections of fish that died within detection range of the passive acoustic array were removed after the death date.

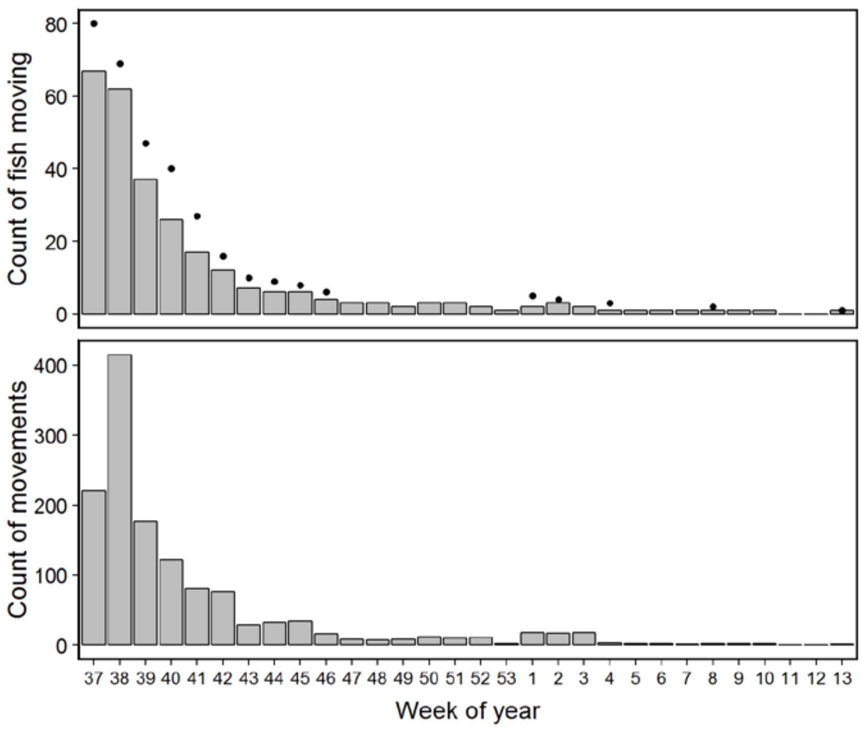

Figure 7. Histogram of the number individual juvenile Chinook salmon detected moving between subarrays in the Southern Gulf Islands array each week of the study (top), and of the number of movements they made (bottom). Dots indicate the number of fish in the SGI area at the start of each week.

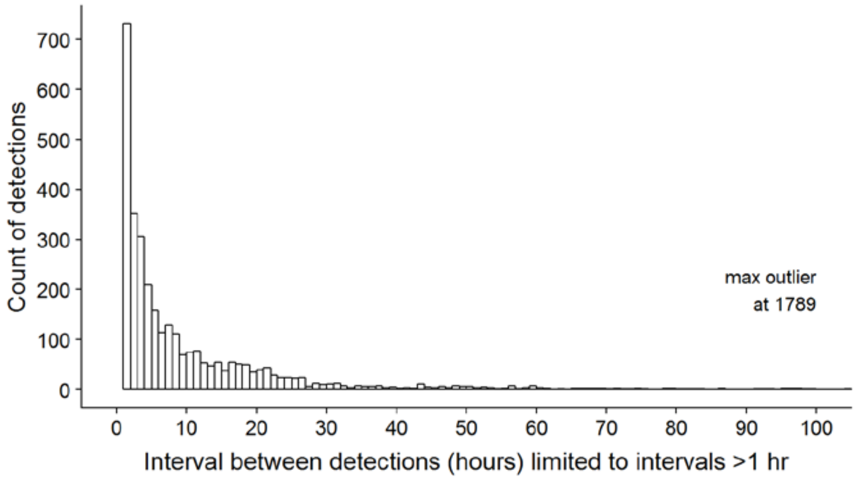

Figure 8. Histogram of the interval between individual detections of juvenile Chinook salmon on the Southern Gulf Islands array with intervals of <1 hour removed. Almost all detections were recorded within one hour (98.6%). Detections of fish that died within detection range of the passive acoustic array were removed after the death date.

3.3. Survival and Residence in the Southern Gulf Islands

By Feb 24th when tags began to expire, almost all of the tagged fish were classified as having either died or emigrated from the SGI area (Table 3; Figure 9). Fish emigrated or died in equal numbers (39 of each, with one unknown and 1 still alive in the SGI area), but the number dead may have been inflated in the first days after release as a result of the cumulative effects of handling (microtrolling, transporting, etc) and tagging. Once these fish were removed (n=12), emigration from the SGI array was 57% and was primarily towards the south (n=29 of 39; 74%). Emigration and mortality occurred at similar rates with the majority occurring by the end of October (medians of 19 and 18 days after release; Figure 9; Figure 10; Figure 11). Of the fish that were subsequently detected alive in the SGI area, one emigrated in November and the remaining five (one resident, three SGI-emigrants, and one unknown) resided within the SGI until 2018. Discounting the dead-early fish, cumulative survival in the SGI area of the non-emigrants declined from 62% at the end of September to 14% by the end of October and to 2.5% by late February (Figure 12).

Thirty percent of fish classified as dead were last detected at Sansum South (n=9; Figure 13). Four individuals were classed as dead in Saanich Inlet. The fish classified as alive near the end of March was last detected in Stuart Channel and may thus have emigrated from the SGI area; this fish was subsequently detected on October 2nd 2018 on the PIT tag array at the Cowichan River fence as a returning jack, but it was not detected elsewhere in the Salish Sea in the interim.

Table 3. Number of juvenile Chinook salmon captured and acoustic-tagged in Maple Bay and Sansum Narrows in 2017 classified as dying, emigrating from the SGI area, or still alive within the SGI area as of Feb 24, 2018. Results are specific to the SGI area. The unknown fish was last detected alive in Saanich Inlet in January.

Fate	Count	%
Alive in SGI	1	1%
Dead	27	34%
Dead early	12	15%
SGI-emigrant	39	49%
Unknown	1	1%

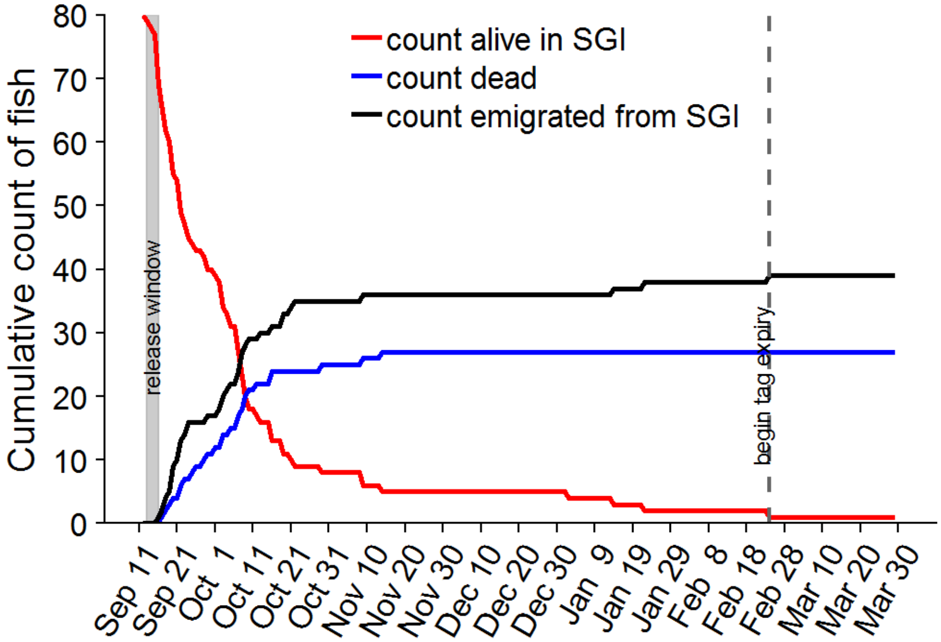

Figure 9. Attenuation in the number of acoustic-tagged juvenile Chinook salmon remaining alive and within the Southern Gulf Islands area after release in September 2017. The reduction in counts is due to both death and emigration to the Salish Sea. The "counts dead" do not include 12 mortalities that occurred soon after release presumably due to capture and tagging procedures.

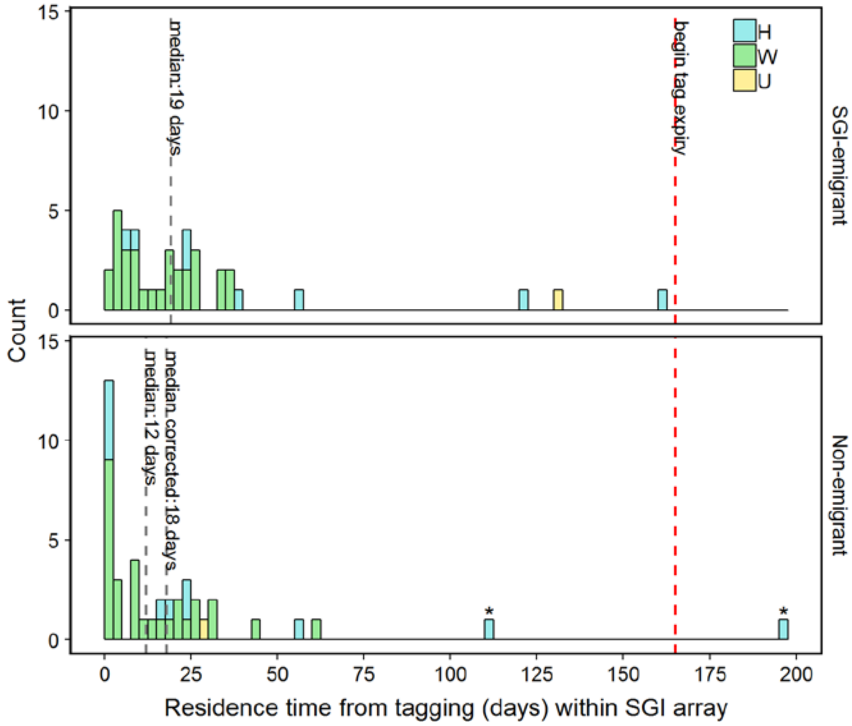

Figure 10. Distribution of residence times (days) within the Southern Gulf Islands area before emigration (Emigrants) or death or end of study (Non-emigrants) for juvenile Chinook salmon captured and tagged in Maple Bay or Sansum Narrows in 2017. Stars indicate fish last detected alive. The median contains all non-emigrant fish, while the corrected median excludes fish dying early presumably as a result of the tags or tagging process.

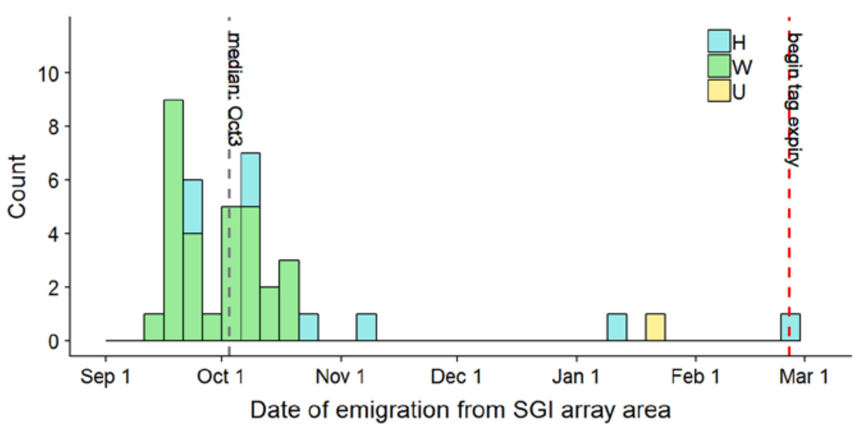

Figure 11. Distribution of the dates of emigration from the SGI area for juvenile Chinook salmon captured and tagged in Maple Bay and Sansum Narrows in 2017. H=hatchery; W=wild; U=unknown if hatchery/wild.

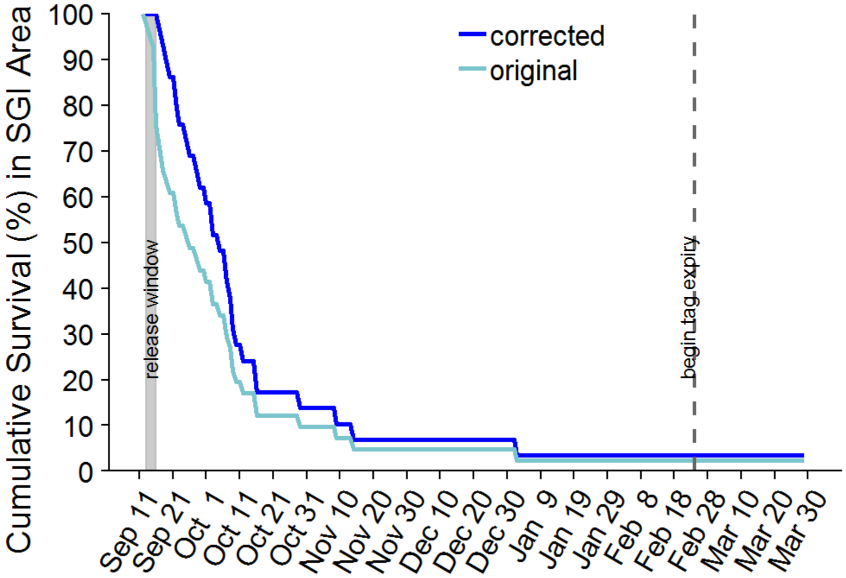

Figure 12. Cumulative survival of acoustic-tagged juvenile Chinook salmon not emigrating from the Southern Gulf Islands area between release in September 2017 and tag expiry in spring 2018. The original estimates contain all non-emigrant fish, while the corrected estimates exclude fish dying early, presumably as a result of the tags or tagging process.

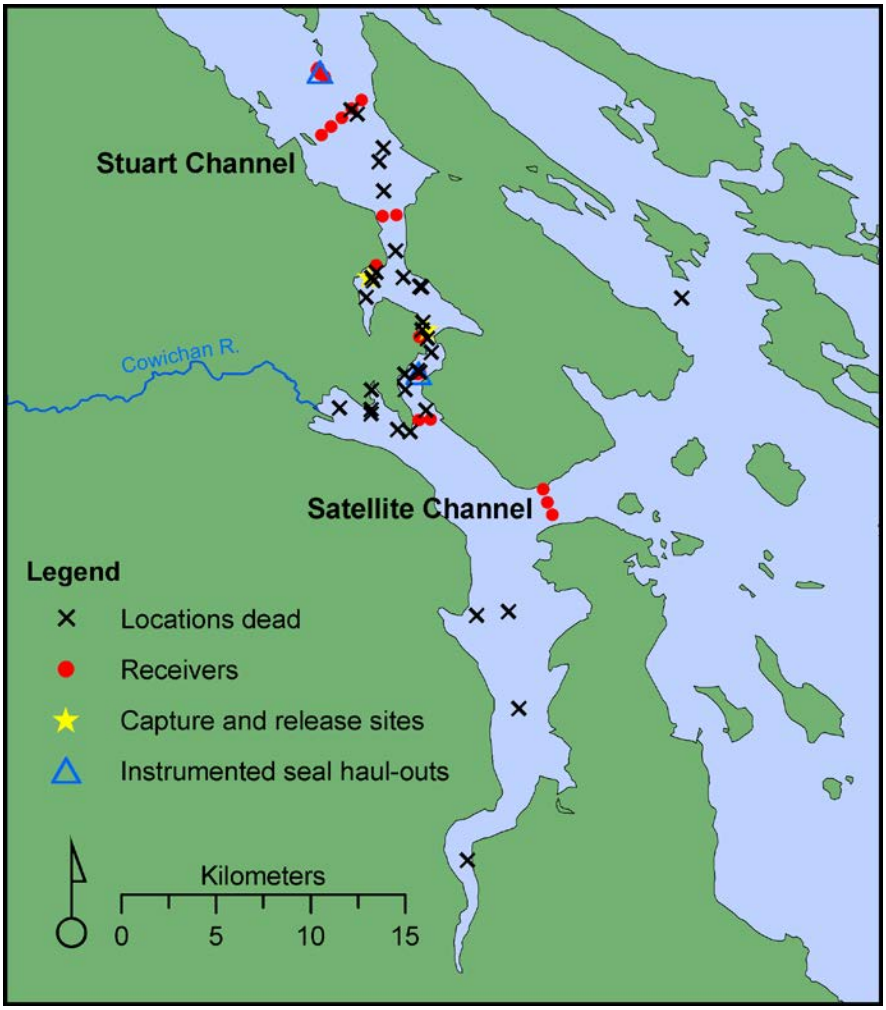

Figure 13. Locations where juvenile Chinook captured and tagged in Maple Bay and Sansum Narrows in 2017 were subsequently determined dead by the passive array or mobile tracking. Full acoustic subarray names are available in Figure 1.

3.4. Preliminary Disease Profile Results

Of 47 infectious agents screened, 13 agents were detected. The prevalence of these agents across the population sampled was generally very low except for *Candidatis Branchiomonas cysticola* (prevalence=45%), *Paranucleospora theridion* (31%), and a recently identified virus Arenavirus I MGL (22%). Arenavirus was more prevalent in fish that died; however, there were too few fish with Arenavirus (15 of 77 in the screening) to relate to fate. The 48 host gene assays have not yet been analyzed.

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3.5. Fine-Scale Habitat Use in the SGI Area

Mobile tracking and passive receivers indicated that fish captured, tagged, and released at Sansum Narrows and Maple Bay differed in their habitat use within the SGI array. Fish tagged in Maple Bay were detected frequently by mobile tracking in and immediately north of Maple Bay, while fish tagged in Sansum Narrows were detected more frequently immediately south and northeast of the narrows (Figure 14).

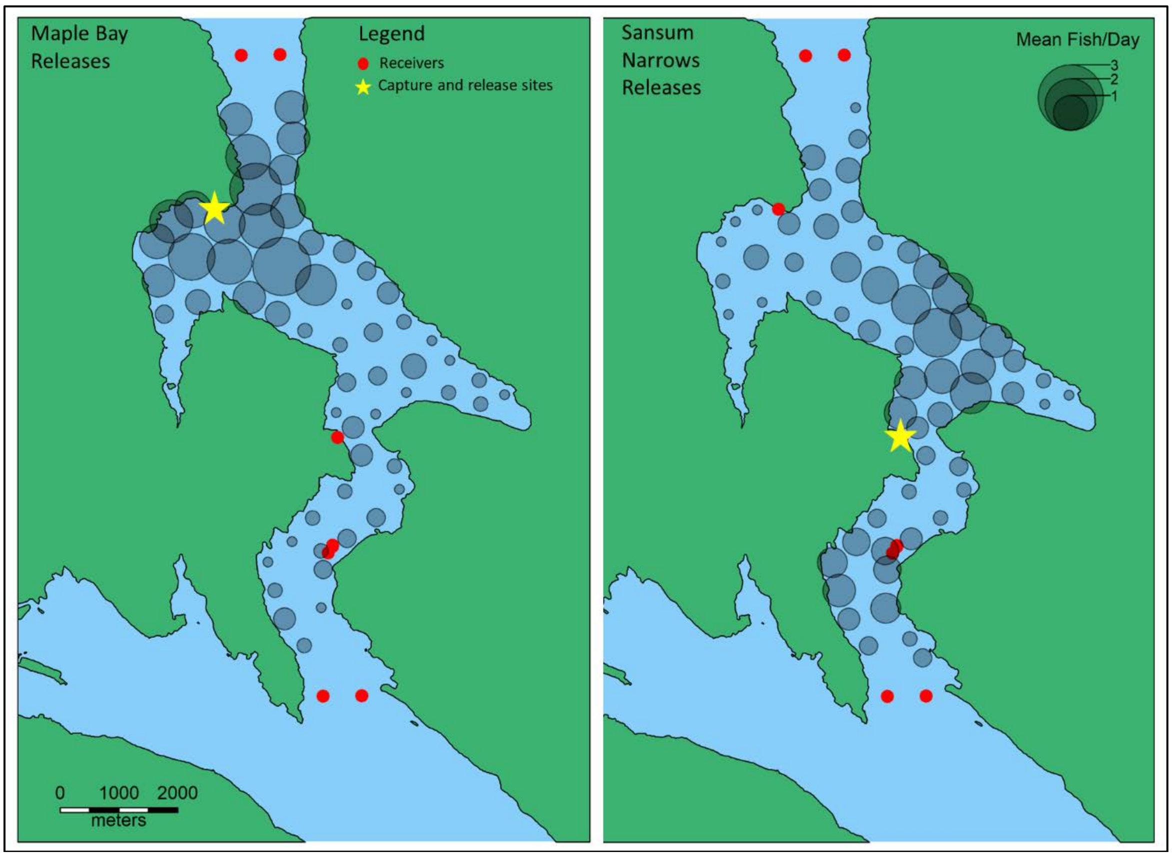

Figure 14. Mean number of tagged juvenile Chinook salmon released at Maple Bay (left) and Sansum Narrows (right) detected at 60 mobile tracking stations. Only data from 19 to 27 September are included to allow time for mixing following release. The figure therefore represents 4-5 to 12-13 days post tagging for Sansum Narrows fish and 6-7 to 14-15 days post tagging for Maple Bay fish. Fish detected but determined to be dead during this tracking period (N=11) are excluded.

Receivers deployed from a dock at the Sansum Narrows tagging site (Sansum Dock) and from a buoy adjacent to the Maple Bay tagging site (Maple Bay Buoy; Figure 1) provided another indication that juvenile Chinook salmon utilized habitats near where they had originally been captured, i.e., more Sansum Narrows tagged fish were detected at Sansum Dock and more Maple Bay tagged fish were detected at Maple Bay Buoy (Table 2). This pattern was present even well after tagging and release. In Maple Bay, presence of tags of Maple Bay origin was consistently more frequent than that of Sansum Narrows origin tags for the first five weeks post tagging, and total detections of Maple Bay tags were higher for the first eight weeks post-tagging (Figure 15). A similar, though less pronounced pattern occurred at Sansum Narrows with consistently more Sansum Narrows tags present and more total detections of Sansum Narrows tags in the first three weeks post-tagging.

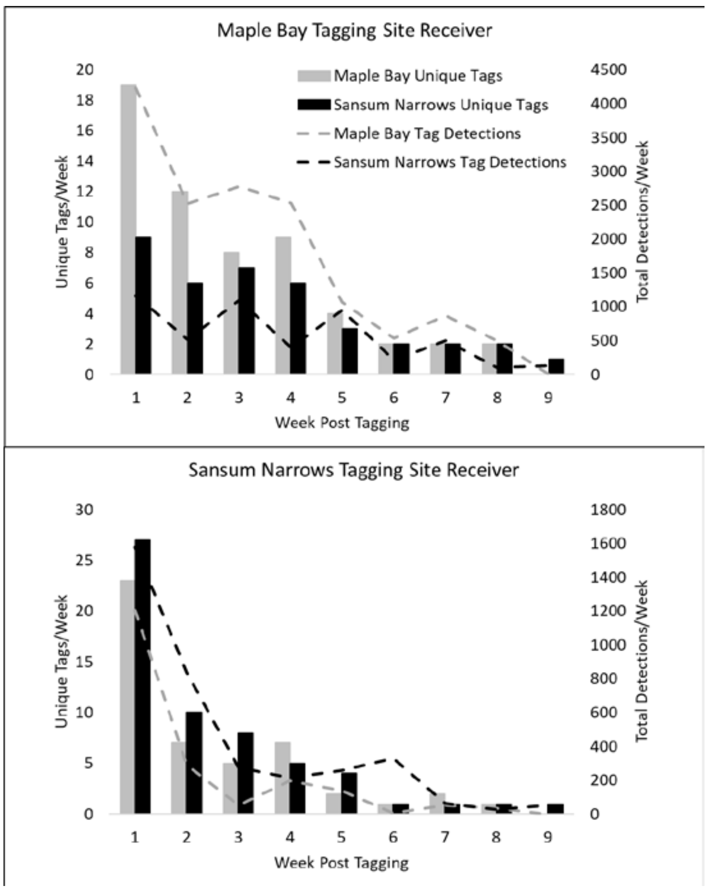

Figure 15. Total unique tags and total tag detections each week after the end of the tagging period (beginning 16 September 2017; 1-2 days post tagging for Sansum Narrows fish and 3-4 days post tagging for Maple Bay fish) at Maple Bay Buoy (top) and Sansum Dock (bottom) receivers. Individuals which were stationary within range of the receivers are excluded.

3.6. Minimum Survival and Residence in the Salish Sea beyond the SGI Area

Of the 39 tagged juvenile Chinook salmon emigrating from the SGI array, 18 (46%) were subsequently detected alive in the southern Salish Sea beyond the SGI (Figure 1; Table 2). Twelve of these fish were detected on two ONC buoys near Victoria and one was detected on an ONC buoy near Saturna Island. Seven emigrants (18%) reached JDF near the exit from the Salish Sea (one of which turned back east and was subsequently detected at a buoy near Victoria). None of the tagged juveniles were detected north of the SGI area. One dead individual was located by mobile tracking approximately 650 m from a seal haul-out (Channel Islets) on the east coast of Saltspring Island. The fate of the remaining 20 is unknown. Given the extremely sparse receiver coverage within the region of the Salish Sea proximal to the Southern Gulf Islands (Figure 1), there are many areas where the SGI emigrants which were not detected departing through Juan de Fuca (n=32 excluding 1 found dead) could have resided without detection for the duration of tag battery life.

Minimum residence time in the southern Salish Sea outside the SGI area ranged between 1 and 145 days (Figure 16). When restricted to the seven individuals reaching JDF, residence time between the SGI and JDF arrays was between 6 and 78 days with the last individual detected on May 12th, about two months beyond the start of tag expiry (this fish left the SGI area on Feb 24th). It is unclear whether fish detected on JDF continued migrating. After detection on JDF, one individual turned around and was subsequently detected at AS04 south of Victoria, BC. Although this return is based on a single detection, it is probably real (fish is known to have been in the area, no other tags present to cause signal collisions with over 1.5 days of silence on either side of the detection, no checksum errors recorded on the receiver that day, and the observed false positive rate was 0.001% for the array). Additionally, the Chinook salmon in this study were detected for significantly longer periods of time on JDF than other salmon species that migrate directly out of the Salish Sea (median of 6 days for Chinook salmon, 18 mins for sockeye, and 17 mins for steelhead; Figure 17) indicating that Chinook salmon are not actively migrating.

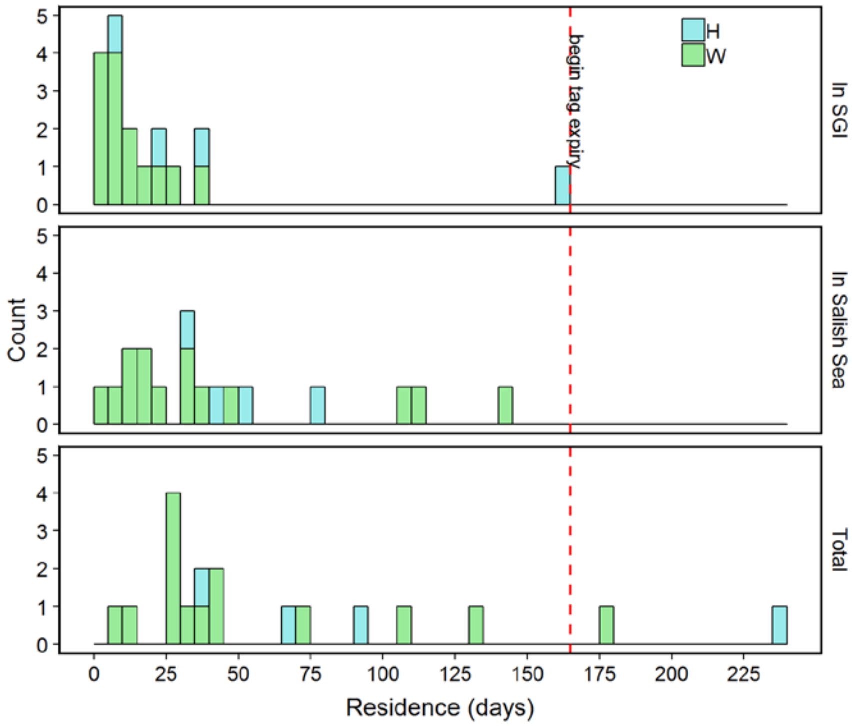

Figure 16. Distribution of the post-tagging residence time (days) for the 18 juvenile Chinook salmon captured and tagged in Maple Bay or Sansum Narrows in 2017 and subsequently detected in the Salish Sea outside the Southern Gulf Islands area. Top panel shows residence time for the area within the Southern Gulf Islands Area (SGI); middle panel shows the minimum residence time within the Salish Sea beyond the SGI; and bottom panel shows the totals of the top and middle panels.

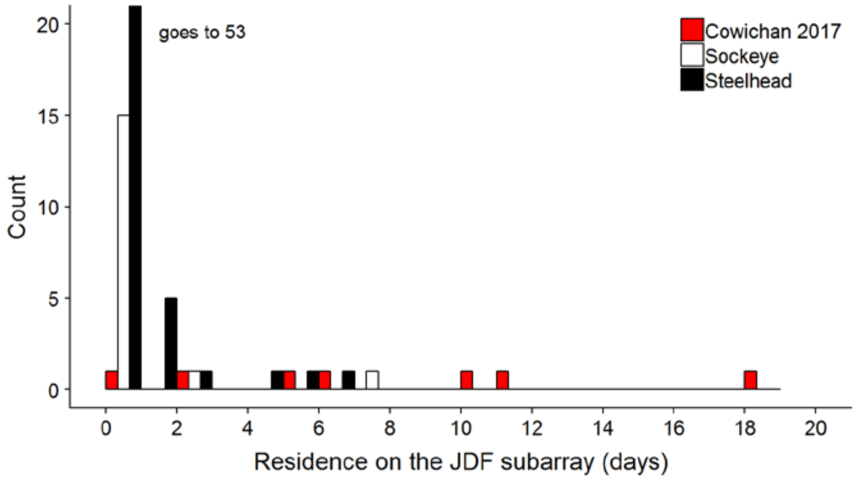

Figure 17. Residence time on the Juan de Fuca subarray for the juvenile Chinook salmon captured in Maple Bay and Sansum Narrows in 2017 (primarily from the Cowichan River) relative to stocks of outmigrating juvenile sockeye and steelhead from southern British Columbia (Fraser, Cheakamus, Sakinaw, and Seymour rivers). Residence time is the period between the first and last acoustic detection and includes time spent beyond detection range.

3.7. Estimated Minimum Seal Predation

There is evidence that at least five tagged Chinook salmon (18.5% of mortalities excluding early dead) may have been eaten by seals: two had anomalously high swim speeds and synchronous tracks indicating they were in the same predator, one tag was detected stationary under a log boom used as a haul-out by seals, and one was last detected near the North Reef haul-out and exhibited peculiar behavior (see the animation: ID codes 2560, 2535, 2525, 2530). A final tag was located stationary by mobile tracking approximately 650 m from the Channel Islets haul-out on the east coast of Saltspring Island.

3.8. Detection Estimates

The detection probability was 100% at all passive acoustic subarrays where it could be estimated: Sansum North, Sansum South, Satellite Channel, and Stuart Channel.

3.9. Travel Times and Rates

The travel times between segments in the SGI array were generally short, with half taking under 3.5 hours, almost 90% under a day, and 95% under two days (Figure 18). The majority of individuals remaining alive in the study area were included in these calculations with a median of four movements between subarrays per fish in each week of the study (Figure 7).

Travel rate estimates within the SGI array are uncertain because the actual distance moved is not known. Minimum travel rate estimates calculated using the straight line distances in water between detection sites had medians of 26.2 km/day (1.62 BL/sec) using the full distance between sites, and 18.9 km/day (1.2 BL/sec) using the distance reduced by the probable detection range of the tags.

Travel times between exit from the SGI and arrival at JDF took between 3-77 days (Figure 19). These times resulted in movement rates between 29 km/day (1.9 BL/sec) and 1.5 km/day (0.09 BL/sec).

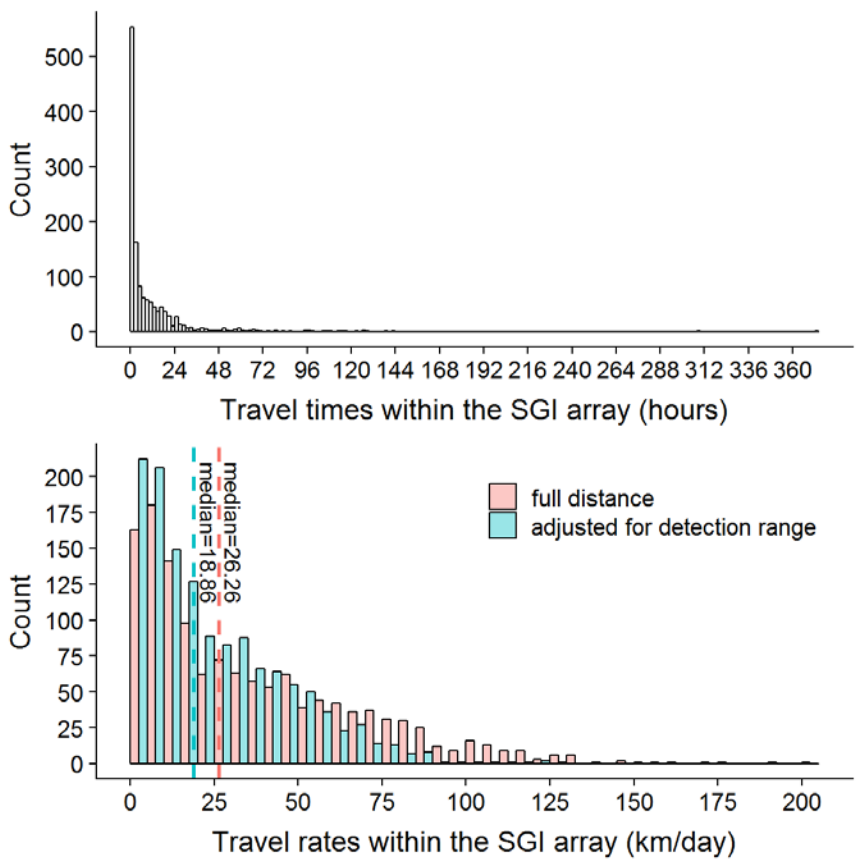

Figure 18. Distribution of travel times and rates of acoustic-tagged juvenile Chinook salmon between all segments of the acoustic array deployed in the Southern Gulf Islands (SGI) in 2017 and 2018. For the travel rates, the full distance is the estimated shortest in-water route between acoustic subarrays. The distance adjusted for detection range is the full distance minus a 400 meter detection radius for V9-6L tags on each end of the segment. Together, these distances bracket the most likely values for minimum travel rate.

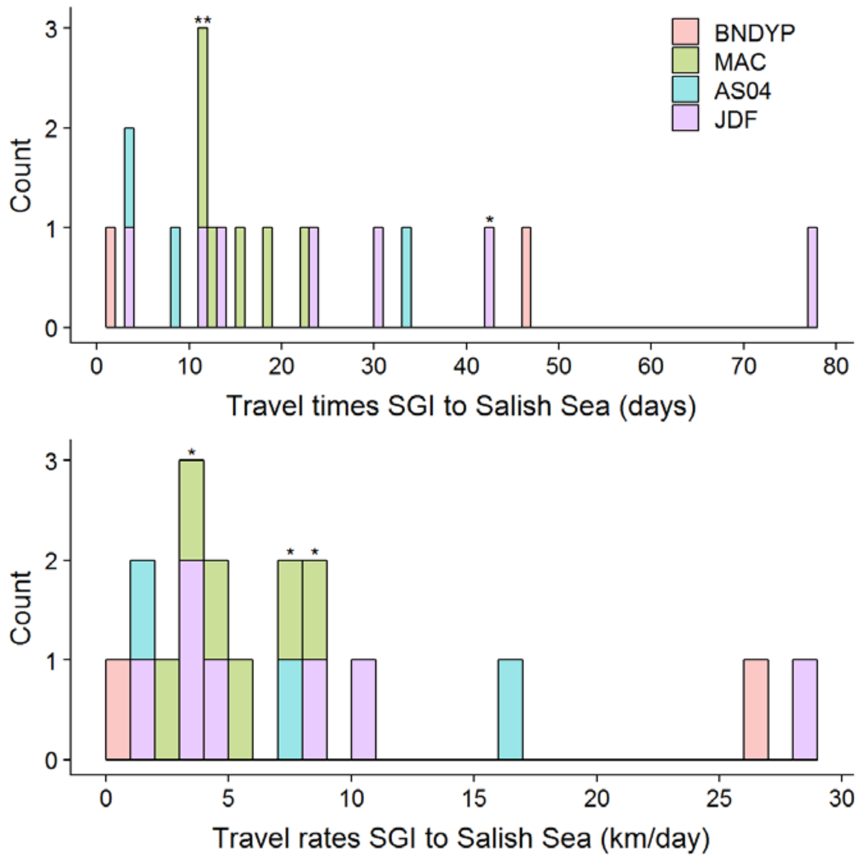

Figure 19. Distribution of travel times and rates of acoustic-tagged juvenile Chinook salmon between exit from the Southern Gulf Islands (SGI) and arrival at their furthest west detection site in the Salish Sea (JDF or the ONC buoys BNDYP, MAC, AS04). Stars indicate fish exiting the SGI array to the north (3 individuals total). All other fish exited SGI to the south.

4. Discussion and Conclusions

Our data indicate that some lower Strait of Georgia Chinook salmon reside in the Southern Gulf Islands and/or greater Salish Sea at least into the spring of their second ocean year (Figure 20). Eight of the 80 tagged fish (10%; or 12% after dead early fish are removed) were detected alive in the new year (2018) in the SGI or Salish Sea. The last detection was in mid-May, on JDF 2.5 months after the predicted date of tag expiry and a year after ocean entry (fish was detected 35 times in ½ hour confirming it was a real detection; see Data Management).

Since fish were tagged in mid-September, this means that the minimum survival of Chinook salmon (primarily from the Cowichan River) in the SGI/Salish Sea was 12% during the fall and early winter, although the true value is probably higher. If we include the fish that likely emigrated from the Salish Sea as survivors, then the minimum estimate increases to 19%. Additionally, the passive acoustic arrays monitor only a small fraction of the overall Salish Sea which could be occupied by resident Chinook salmon. By January 1st, eight fish were alive in the Salish Sea, five had presumably left via JDF; and 27[1] were unaccounted for (the balance were found dead). Parsimony suggests some of the unaccounted fish were alive which means that over-winter residence was probably more common in our sample than departure.

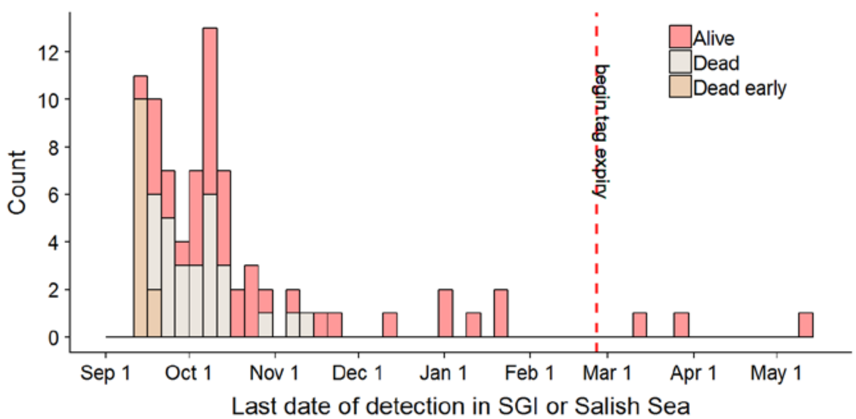

Figure 20. Last date of detection of juvenile Chinook salmon in the Southern Gulf Islands (SGI) or in the Salish Sea (JDF or ONC receivers) in 2017-2018.

By the end of the study, six individuals (7.5%; or 9% if we account for early dead fish) presumably migrated out of the Salish Sea to the south through the Strait of Juan de Fuca; however, it is unclear if fish continued migrating or moved out of detection range. A seventh individual that was detected on JDF subsequently turned around and re-entered the Salish Sea. Given predicted battery expiry, others may have taken this path out or back in undetected later in the spring. Notably, Chinook salmon took far longer to cross over JDF than did sockeye and steelhead that migrate actively from the

[1] 80 originals, 39 dead, 1 emigrant dead at haul-out, 5 JDF emigrants before Jan 1, 8 alive after Jan 1

Salish Sea (median of 6 days vs. ~17 mins). No individuals were located on the receiver deployed by Ocean Networks Canada (JF2C) 15 kms west of JDF or on the offshore receiver beyond Juan de Fuca Strait (BCH).

Our results differ from a previous telemetry study (Neville et al. 2015), where only 1 of 70 Chinook from the southern Gulf Islands was detected after release (this fish was from the Big Qualicum stock and arrived at JDF in mid-August). Neville et al's conclusion that their tagged Chinook must have died was supported by trawl surveys which caught very few Chinook salmon during winter surveys suggesting that Chinook die or migrate from the area prior to the first winter. In contrast, our results demonstrate that some fish remain in the Salish Sea for 8-12 months after ocean entry. Our study used a finer scale array, mobile tracking, and longer-lived transmitters, but another reason for the different result might be time of capture: in the Neville et al study, fish were captured in July while our fish were captured in the same area, but in September. South Thompson Chinook salmon captured in September had higher survival to emigration from the Salish Sea and were detected until late December (Neville et al 2015). The South Thompson stock has unique characteristics and higher marine survival than other Salish Sea stocks (Beamish et al. 2010) so might not be directly comparable to Cowichan; however, their improved survival in September may indicate better conditions in the Salish Sea for juveniles that survive their first summer.

By the end of October, the majority of tagged Chinook salmon either died in the SGI area (25 of 27 dead excluding early mortalities) or emigrated from the SGI array area to the southern Salish Sea (35 of 39 emigrants); the rest remained in the SGI study area beyond October. Both processes occurred at similar rates. The timing of this compressed emigration was consistent with an abrupt decline in CPUE observed in 2016 microtrolling data (W. Duguid unpublished data). With the exception of one emigrant which departed in November, all other fish which were subsequently detected alive within the SGI array (one resident, three late emigrants, and one fish of unknown fate) were last detected alive in the SGI in the new year (Jan 2 - March 31). The migratory life-history strategy of these fish (residence near the natal river for part or all of the first marine winter) was distinct from that of the balance of the emigrant fish.

The different patterns of habitat occupation within the SGI array observed for juvenile Chinook salmon captured, tagged, and released at two closely adjacent (water distance ~ 4.5 km) sites is consistent with previous microtrolling results which indicated that size, diet, and growth of juvenile Cowichan chinook salmon varied predictably between these sites (W. Duguid unpublished 2015 and 2016 data). While some difference in distribution between fish released at Maple Bay and Sansum Narrows would be expected due to time required to disperse for release sites, the time required to swim between these sites at the observed median estimate of travel speed in the SGI (1.2 BL/sec) is only six hours for a 170 mm Chinook salmon. Differences in distribution continued to be observed for several weeks post-tagging. It is likely that variation in fine-scale distribution of juvenile Chinook salmon has implications for survival. For example, fish which spent more time in Sansum Narrows were closer to several harbour seal haul-outs (Figure 3) than those spending more time in Maple Bay, and may therefore have been more exposed to predation. Conversely, previous work has shown that juvenile Chinook salmon in Maple Bay are smaller, have less fish in their diet, and are growing more slowly than those at Sansum Narrows (W. Duguid unpublished 2015 and 2016 data). If survival is linked to size (Beamish and Mahnken 2001; Duffy and Beauchamp 2011) this strategy could reflect a trade-off between growth and predation risk (Werner et al. 1983) .

Handling (capture and tagging) and seal predation were two causes of mortality that we attempted to quantify. Fifteen percent (12 of 80) of fish died within days after tagging (Figure 5). The cause of these mortalities is unknown, but the fish that died were smaller than those that died later or emigrated which is consistent with tag burden related mortality or increased predation risk. The median tag burden for the early mortalities was 6% (range 3.8-7.9%) which is comparable to the recommended limits for salmon smolts (~6-8%; Collins et al 2013, Brown et al 2010). Although no mortalities were observed during or after surgery, there may been cumulative effects from the microtrolling, tagging, and limited recovery period which made fish susceptible to predation following release. Neville et al (2015) reported 13% mortality in a captive tag-effects study in which there were no predators; therefore, the handling-related mortality we report here could be potentially worse. Following the initial period of high mortality, there is evidence that five tagged Chinook salmon may have been eaten by seals. Expressed in terms of known dead fish, at least 5 of 40[2] fish (12.5% or 18% after the 12 early dead fish are removed) exhibited seal-like behavior or the tag was detected stationary near a seal haul-out. This is the minimum seal predation that could be estimated from this study thus far. Further analysis of movement rates and detections near seal haul-outs may reveal additional seal-like behavior.

[2] Includes 39 located dead in the SGI area plus one located dead at a seal-haul out beyond the SGI area on the east coast of Saltspring Island.

To date, one tagged Chinook salmon has returned to the Cowichan River as a jack. This fish remained within the SGI array until the array was recovered in late March 2018 and suggests that Cowichan Chinook salmon that will return early as jacks may reside within the Salish Sea until maturity. Although the sex of this fish was not determined, it was almost certainly a male given the early return age. The sample size is too limited to assess if residents are more likely to be males; however the sex ratio was even for those that remained alive and resident in the Salish Sea until November (6 females; 5 males).

Our results apply to acoustic-tagged Chinook salmon of mostly Cowichan origin that were captured and tagged in September. It is unknown how well they will apply to the general population entering the SGI area in spring, but PIT tag studies are ongoing to address this period of the life history. Early-marine survival has been linked to timing of ocean entry so survival and timing of emigration from the SGI may differ for summer arrivals versus those who had already survived until fall.

5. Outcomes

Please describe specifically how this activity made progress toward achieving the objectives of the Salish Sea Marine Survival Project. Describe how this work addressed hypotheses identified in the research planning process of the Salish Sea Marine Survival Project.

Our study addresses several of the SSMSP hypotheses including critical period, residency, predation, and disease.

5.1. Critical period

The minimum survival of Chinook salmon (primarily from the Cowichan River) in the SGI/Salish Sea was 12% during the fall and early winter although the true value is likely higher. If we include the fish that likely emigrated from the Salish Sea as survivors, then the minimum estimate increases to 19%. Additionally, the passive acoustic arrays monitor only a small fraction of the overall Salish Sea which could be occupied by resident Chinook salmon. By January 1st, eight fish were alive in the Salish Sea, five had presumably left via JDF; and 27 were unaccounted for (the balance were found dead). Parsimony suggests some of the unaccounted fish were alive which means that over-winter residence was probably more common in our sample than departure. There are a number of papers that demonstrate partial migration for salmon, particularly in the Puget Sound region (e.g., Kagley et al. 2017).

5.2. Residency

Our data indicate that some Cowichan or lower Strait of Georgia Chinook salmon reside in the Southern Gulf Islands and/or greater Salish Sea at least into the spring of their second ocean year (Figure 20). Eight of the 80 tagged fish (10%; or 12% after dead early fish are removed) were detected alive in the new year (2018) in the SGI or Salish Sea. The last detection was in mid-May on JDF 2.5 months after the predicted date of tag expiry and a year after ocean entry.

By the end of the study, only six individuals (7.5%; or 9% if we account for early dead fish) presumably migrated out of the Salish Sea to the south through the Strait of Juan de Fuca; however, it is unclear if fish continued migrating or simply moved out of detection range and remained resident in the outer region of Juan de Fuca Strait or off the west coast Vancouver Island, as commonly assumed.

5.3. Predation

Expressed in terms of known dead fish, at least 5 of 40 fish (12.5% or18% after the 12 early dead fish are removed) exhibited seal-like behavior or the tag was stationary near a seal haul-out. This is the minimum seal predation that could be estimated from this study thus far, although some of the early mortalities shortly after release may be due to predation on smolts still-disoriented from handling and surgery. Further analysis of movement rates and detections near seal haul-outs may reveal additional seal-like behavior.

5.4. Disease

Of 47 infectious agents screened, 13 agents were detected. The prevalence of these agents across the population sampled was generally very low except *Candidatis Branchiomonas cysticola* (prevalence=45%), *Paranucleospora theridion* (31%), and a recently identified virus Arenavirus I MGL (22%). Arenavirus was more prevalent in fish that died, however, there were too few fish with Arenavirus (15 of 77 in the screening) to reasonably relate to fate. Gene expression and biomarkers have not yet been analyzed.

Describe whether and how you met the objectives of your particular research activity.

Short term objectives from our proposal (eight of these) were met using an acoustic array, mobile tracking, GIS, and genomics (see Methods). Our long term objective (estimate smolt to adult return rate) will be met after tagged Chinook return to the Cowichan River.

Briefly explain differences between what actually happened compared to what was anticipated to happen.

No differences to report.

Provide any further information (such as unexpected outcomes) important for understanding project activities and outcome results.

There was evidence of tagging-related mortality. During the first two days of tagging we followed our standard protocol of 1.0 ppm Aquacalm sedative followed by 70 ppm of TMS; however, some fish were taking longer to recover from the anesthesia than what we have typically observed in the past (only a few minutes for over 12,000 fish); therefore, we reduced the doses to 0.5 ppm and 40 ppm, respectively, for the remainder of tagging (days 3 and 4). At this level, most fish regained equilibrium as expected although several fish still appeared sluggish even after 10 minutes or longer.

The delayed recovery time for some fish could be due to several factors:

- Salmon in this study were ocean caught juveniles (not freshwater smolts).
- Fish were caught via microtrolling which increased overall handling (2/3 of the salmon smolts we have tagged in the past have been obtained directly from hatcheries, reducing handling to a minimum).
- In addition to implanting a transmitter, gill tissue samples and scales were obtained which increased the time under anesthesia.
- Water temperature was intentionally kept low (11-12° C) to attempt to match ambient temperature (or make less than) at the depth in which fish were captured; perhaps the water was cooler than ambient.

There were some uncertainties in the assignments of fate and death date:

- Fish were identified as dead because they were relocated repeatedly in the same location. This is reasonable because the majority moved frequently between detection sites, but it is possible that some individuals were actually residing in a limited area. For example, the fish which remained in the SGI area until the end of March and subsequently returned to the Cowichan River was detected at the same site on its final two detections and would have been considered dead using our protocol without the subsequent in-river detection.

- Residence could cause the date of death to be underestimated; this is particularly likely for the four individuals that were located dead in Saanich Inlet because it is a relatively large area that was unmonitored by the passive array.

- We could not determine the fate of the individual that was last detected residing in Saanich Inlet. This fish was detected on coarse (1 km) resolution surveys that were split over multiple days (it was not possible to cover the entire inlet in a single day); it is possible that additional fish remained alive within Saanich Inlet that were not detected by these surveys.

- Small uncertainties in the death dates were more noticeable for fish that died early because of the short timeframe. First, death dates were assigned to specific days while release dates were known to the hour; this difference caused a small underestimate in residence times. Secondly, five fish were identified as dead on September 16th which was the first date of the systematic mobile tracking survey. Three of these were tagged on the 15th, but the other two were tagged on the 14th and may have died anytime between release and their detection two days later.

- We assumed that fish were alive if their tags were detected moving through the study area; however, it is not possible to know if they were actually inside a predator.

6. Lessons Learned

Key lessons learned from this activity:

During tagging we had multiple buckets of seawater on the go which needed to be chilled to ~12° C prior to use. One additional person on the dock would have been helpful for chilling and monitoring the temperature of all of the various water baths. The surgeon and assistant performed this task.

Mobile tracking proved to be a valuable complement to a study of this sort where extensive milling of tagged fish and local mortality occurred in the SGI array area. Mobile tracking was very effective at locating stationary tags in the SGI area and into Saanich Inlet, some of which would otherwise have been classified as survivors based on final detections on SGI outer arrays. Mobile tracking also identified one fish which would have been classified as having departed but which had in fact turned back and was resident with the Cowichan Bay area.

Include how the results of this project should influence next steps toward the overarching objectives of the Salish Sea Marine Survival Project, and describe what you think those next steps should be.

The residence times were limited by both the resolution of the acoustic array outside the SGI, and by tag battery expiry. Only three receivers were deployed in the Salish Sea east of JDF which detected 14 individuals; it seems likely the counts would have been higher with additional deployments which may have extended the residence times. Also, three fish were detected alive well after Feb 24th, when tag batteries began to fail. Their residence times were calculated using their last dates of detection, but may have been longer if tags had continued transmission. It is unknown if additional fish were resident after tag expiry. A more extensive array in the Strait of Georgia and southern Gulf Islands would improve residency and survival estimates. A greater number of tags, and tagging of additional populations in other areas of the Strait of Georgia, would be useful to better quantify the partial migration behaviour and the extent to which it applies to other populations. In particular, a study contrasting the behaviour of South Thompson Chinook, which are increasing in abundance and other Salish Sea Chinook stocks, which are decreasing (Beamish et al. 2010), would be useful to understand whether or not early marine phase differences in migration behaviour are related to differential productivity.

If your research activity was associated with other research activities within (and outside) the scope of the Salish Sea Marine Survival Project, please describe how effective you think the collaboration was, whether you think the activities were appropriately integrated, and whether the data/results collected in this activity have informed related activities and vice-versa.

Three of the ONC buoys provided very useful information on residence and survival. The ONC buoy data boosted the number of fish detected outside of the SGI array from 7 to 18 and extended the residence time estimates. This result suggests that single acoustic receivers moored as part of a widely distributed sparse grid within the Strait of Georgia could provide very useful data. OTN provided POST detection data as soon as it was processed. BCCF and DFO (Kevin Pellett) provided PIT tag return information to the Cowichan River and will continue to send updates as mature fish return in future years. The Miller Lab (DFO-PBS) used high-throughput genomic profiling to evaluate infectious agents and gene upregulation in acoustic-tagged Chinook. This work was an in-kind contribution to the project which also contributed to the DFO growing database. Genetic stock identification (GSI) was a fee-based service provided by the Beacham Lab at DFO-PBS.

7. Deliverables

The deliverables for this project are on schedule:

- Progress reports to SSMSP were submitted November 2017 and May 2018.
- Final report to SSMSP (this document).
- A technical report to DFO State of the Ocean may not be relevant; however, results may be submitted to the NPAFC Bulletin if it does not conflict with submission to a peer-reviewed journal.
- An animation of the movements of the juvenile Chinook salmon in 2017 is available on our website (http://kintama.com/visualizations/). The animation can be panned and zoomed, and the display output can be customized by the user. Tags and receivers can also be queried to obtain summary statistics as well as full detection histories.

8. Dissemination of Results

8.1. Presentations

- 2 posters at the SSMSP in spring 2018

- Duguid et al. 2018. Growing Pains: Trials of Chinook Salmon in their first year in the Salish Sea. Presentation to the Cowichan Watershed Board and Vancouver Island University Lecture Series, 27 Sept 2018.

- Duguid et al. 2018. Herring and Salmon in the Salish Sea. Invited talk to Goldstream Volunteer Salmonid Enhancement Association AGM, 19 Apr 2018.

8.2. Potential upcoming presentations

- Rechisky et al. 2019. Survival, Migration, and Partial Residency in the Salish Sea of Cowichan River Chinook Salmon: The First Fall and Winter. Joint meeting of the North Pacific Anadromous Fish Commission & Salmon Ocean Ecology, Portland, OR, 2019. (Abstract submitted).

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10. Financial Summary

Kintama requested $123,741 and UVic requested $7,920 from the SSMSP for this project. This project builds on previous SSMSP-funded studies, brings together novel techniques (microtrolling, acoustic telemetry, and genomic disease profiling), and relies on cooperation and collaboration with numerous organizations (UVic, DFO, OTN, ONC, BCCF, and Kintama).

More than $45K was provided in-kind by Kintama (mostly for equipment and for diver deployments and recovery), $14K by UVic (UVic vessel use and salary), and $10,500 by DFO (genomics). The evaluation of adult returns from this project will be provided in kind by DFO (Kevin Pellett).

Kintama has submitted three invoices thus far for equal amounts (1/4 of the total for each invoice). As per the Service Agreement between the PSF and Kintama, one additional payment will be made by the PSF following receipt of this Final Report ($30,935.25).

Kintama Expenses
Professional fees, labour: $47,400
Materials, supplies, equipment: $59,962
Overhead: $10,486
Taxes GST (for services): $5,892
Total to Kintama from SSMSP: $123,741

UVic Expenses
Professional fees, labour: $7,200
Materials, supplies, equipment:
Overhead: $720
Taxes GST (for services):
Total to UVic from SSMSP: $7,920

A. Appendix

Description and assigned fate of juvenile Chinook salmon captured and acoustic-tagged in Maple Bay and Sansum Narrows in 2017.

Tag	Sex	H/W	GSI Stock	GSI Probability	Assigned Fate	Reason for Assigned Fate	Date Dead/ Emigrated	Reason for Date
Maple Bay								
2510	M	W	Cowichan	99%	Dead	detected stationary by mobile tracking	05-Oct-17	last passive date
2511	F	W	Cowichan	43%	SGI-emigrant	last detected on outer lines in SGI array	05-Oct-17	emigrated
2512	M	W	Cowichan	99%	Dead Early	stationary on SGI passive array	13-Sep-17	first date stationary on passive
2513	M	W	Cowichan	90%	SGI-emigrant	last detected outside of SGI array	22-Sep-17	emigrated
2514	F	W	Cowichan	70%	SGI-emigrant	last detected on outer lines in SGI array	16-Oct-17	emigrated
2515	F	W	Cowichan	83%	Dead	stationary on SGI passive array	14-Nov-17	first date stationary on passive
2516	F	W	Cowichan	99%	SGI-emigrant	last detected outside of SGI array	10-Oct-17	emigrated
2517	M	W	Cheakamus	55%	SGI-emigrant	last detected on outer lines in SGI array	07-Oct-17	emigrated
2518	F	U	Cowichan	100%	Dead	disappeared within SGI array	12-Oct-17	last passive date
2519	M	H	Cowichan	70%	Unknown	last detected alive in Saanich Inlet Jan 2, 2018	02-Jan-18	last mobile date
2520	M	W	Cowichan	100%	Dead	detected stationary by mobile tracking in Saanich Inlet Jan 2	28-Sep-17	last passive date
2521	M	H	Cowichan	100%	Dead	detected stationary by mobile tracking in Saanich Inlet Jan 2	29-Sep-17	last passive date
2522	F	H	Cowichan	100%	SGI-emigrant	last detected outside of SGI array	08-Oct-17	emigrated
2523	F	W	Cowichan	96%	SGI-emigrant	last detected on outer lines in SGI array	03-Oct-17	emigrated
2524	F	H	Cowichan	98%	SGI-emigrant	last detected outside of SGI array	22-Oct-17	emigrated
2525	M	W	Cowichan	94%	Dead	detected stationary by mobile tracking	01-Oct-17	last passive date
2526	F	H	Cowichan	95%	SGI-emigrant	last detected on outer lines in SGI array	08-Oct-17	emigrated
2527	U	H	Cowichan[3]		Alive	detected alive on SGI array March 30		live at study end
2528	F	W	Cowichan	85%	Dead	detected stationary by mobile tracking	09-Oct-17	last passive date
2529	M	W	Cowichan	99%	Dead Early	disappeared within SGI array	16-Sep-17	last passive date
2530	F	U	Cowichan	49%	SGI-emigrant	last detected on outer lines in SGI array	22-Jan-18	emigrated
2531	M	W	Cowichan	100%	Dead	stationary on SGI passive array	22-Sep-17	first date stationary on passive
2532	M	W	Puntledge	51%	Dead	detected stationary by mobile tracking	10-Oct-17	last passive date

[3] This fish did not amplify through GSI; however, it was detected returning to the Cowichan River.

Tag	Sex	H/W	GSI Stock	GSI Probability	Assigned Fate	Reason for Assigned Fate	Date Dead/ Emigrated	Reason for Date
2533	M	W	Cowichan	100%	Dead	detected stationary by mobile tracking	18-Sep-17	first date stationary on mobile
2534	F	H	Cowichan	100%	SGI-emigrant	last detected on outer lines in SGI array	22-Sep-17	emigrated
2535	F	H	Cowichan	100%	Dead	detected stationary by mobile tracking	07-Oct-17	last passive date
2536	M	W	Cowichan	93%	SGI-emigrant	last detected outside of SGI array	19-Oct-17	emigrated
2537	M	W	Cowichan	100%	Dead	detected stationary by mobile tracking	08-Oct-17	last passive date
2538	F	H	Cowichan	95%	SGI-emigrant	last detected on outer lines in SGI array	09-Nov-17	emigrated
2539	F	W	Cowichan	100%	Dead	disappeared within SGI array	26-Sep-17	last mobile date
2540	M	W	Cowichan	98%	SGI-emigrant	last detected outside of SGI array	24-Sep-17	emigrated
2541	F	W	Cowichan	99%	SGI-emigrant	last detected on outer lines in SGI array	20-Sep-17	emigrated
2542	F	W	Cowichan	100%	Dead	disappeared within SGI array	16-Oct-17	last passive date
2543	F	W	Cowichan	97%	Dead	detected stationary by mobile tracking	22-Sep-17	last passive date
2544	M	W	Cowichan	100%	SGI-emigrant	last detected outside of SGI array	23-Sep-17	emigrated
2545	M	W	Cowichan	100%	Dead Early	disappeared within SGI array	14-Sep-17	last passive date
2546	M	W	Cowichan	100%	SGI-emigrant	last detected on outer lines in SGI array	09-Oct-17	emigrated
2547	F	W	Cowichan	70%	Dead Early	disappeared within SGI array	15-Sep-17	last passive date
2548	F	W	Cowichan	99%	Dead	detected stationary by mobile tracking	23-Sep-17	last passive date
2549	F	H	Cowichan	100%	Dead Early	detected stationary by mobile tracking	16-Sep-17	first date stationary on mobile
2550	M	W	Cowichan	94%	SGI-emigrant	last detected outside of SGI array	08-Oct-17	emigrated
Sansum Narrows								
2551	F	W	Cowichan	100%	SGI-emigrant	last detected outside of SGI array	02-Oct-17	emigrated
2552	M	W	Harrison	100%	Dead Early	disappeared within SGI array	17-Sep-17	last passive date
2553	U	W	Unknown		SGI-emigrant	last detected outside of SGI array	21-Sep-17	emigrated
2554	M	W	Puntledge	90%	SGI-emigrant	last detected outside of SGI array	18-Sep-17	emigrated
2555	M	W	Cowichan	100%	SGI-emigrant	last detected on outer lines in SGI array	04-Oct-17	emigrated
2556	F	H	Cowichan	100%	Dead	detected stationary by mobile tracking	09-Oct-17	last passive date
2557	F	W	Cowichan	82%	SGI-emigrant	last detected outside of SGI array	20-Sep-17	emigrated
2558	M	W	Cowichan	100%	SGI-emigrant	last detected on outer lines in SGI array	16-Sep-17	emigrated
2559	F	W	Cowichan	99%	SGI-emigrant	last detected on outer lines in SGI array	03-Oct-17	emigrated
2560	U	W	Unknown		Dead	detected stationary by mobile tracking	07-Oct-17	last passive date
2561	M	H	Cowichan	72%	SGI-emigrant	last detected outside of SGI array	24-Feb-18	emigrated

Tag	Sex	H/W	GSI Stock	GSI Probability	Assigned Fate	Reason for Assigned Fate	Date Dead/ Emigrated	Reason for Date
2562	M	W	Cowichan	100%	SGI-emigrant	last detected on outer lines in SGI array	07-Oct-17	emigrated
2563	M	H	Cowichan	68%	SGI-emigrant	last detected on outer lines in SGI array	14-Jan-18	emigrated
2564	M	W	Cowichan	100%	Dead	detected stationary by mobile tracking	16-Oct-17	last passive date
2565	F	H	Cowichan	100%	Dead	detected stationary by mobile tracking	09-Nov-17	last passive date
2566	F	W	Cowichan	100%	SGI-emigrant	last detected outside of SGI array	29-Sep-17	emigrated
2567	M	H	Cheakamus	67%	Dead Early	detected stationary by mobile tracking	16-Sep-17	first date stationary on mobile
2568	M	W	Cowichan	100%	SGI-emigrant	last detected outside of SGI array	20-Sep-17	emigrated
2569	M	W	Cowichan	99%	Dead	stationary on SGI passive array	03-Oct-17	first date stationary on passive
2570	F	W	Cowichan	100%	SGI-emigrant	last detected outside of SGI array	18-Sep-17	emigrated
2571	F	H	Cowichan	100%	Dead	detected stationary by mobile tracking	03-Oct-17	last passive date
2572	U	W	Unknown		Dead	detected stationary by mobile tracking in Saanich Inlet Jan 3	29-Oct-17	last passive date
2573	M	W	Cowichan	95%	Dead	detected stationary by mobile tracking	19-Sep-17	first date stationary on mobile
2574	M	W	Cowichan	95%	Dead Early	detected stationary by mobile tracking	16-Sep-17	first date stationary on mobile
2575	M	W	Cowichan	100%	Dead	stationary on SGI passive array	25-Sep-17	first date stationary on passive
2576	F	H	Puntledge	91%	SGI-emigrant	last detected outside of SGI array	22-Sep-17	emigrated
2577	M	W	Puntledge	56%	Dead	detected stationary by mobile tracking	20-Sep-17	last passive date
2578	F	W	Cowichan	100%	Dead Early	detected stationary by mobile tracking	16-Sep-17	first date stationary on mobile
2579	M	W	Cowichan	100%	SGI-emigrant	last detected on outer lines in SGI array	21-Oct-17	emigrated
2580	F	W	Cowichan	97%	SGI-emigrant	last detected on outer lines in SGI array	19-Oct-17	emigrated
2581	F	W	Cowichan	100%	SGI-emigrant	last detected outside of SGI array	20-Sep-17	emigrated
2582	F	W	Cowichan	81%	Dead Early	stationary on SGI passive array	16-Sep-17	first date stationary on passive
2583	F	W	Cowichan	99%	SGI-emigrant	last detected on outer lines in SGI array	24-Sep-17	emigrated
2584	F	W	Cowichan	99%	SGI-emigrant	last detected on outer lines in SGI array	19-Sep-17	emigrated
2585	M	H	Cowichan	95%	Dead	detected stationary by mobile tracking in Saanich Inlet Jan 2	17-Sep-17	last passive date
2586[4]	M	W	Cowichan	100%	SGI-emigrant	last detected on outer lines in SGI array	13-Oct-17	emigrated
2587	M	H	Cowichan	100%	Dead Early	detected stationary by mobile tracking	16-Sep-17	first date stationary on mobile
2588	F	W	Cowichan	97%	SGI-emigrant	last detected on outer lines in SGI array	17-Sep-17	emigrated
2589	M	W	Cowichan	100%	Dead Early	detected stationary by mobile tracking	18-Sep-17	first date stationary on mobile

[4]Last detected 11 Dec 2017 ~650 m from a seal haul-out at Channel Islets between Saltspring and Prevost islands.