# The Use of Telemetry to Investigate Residence Time and Survival of Fraser River Chinook Salmon in the Strait of Georgia, 2016

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

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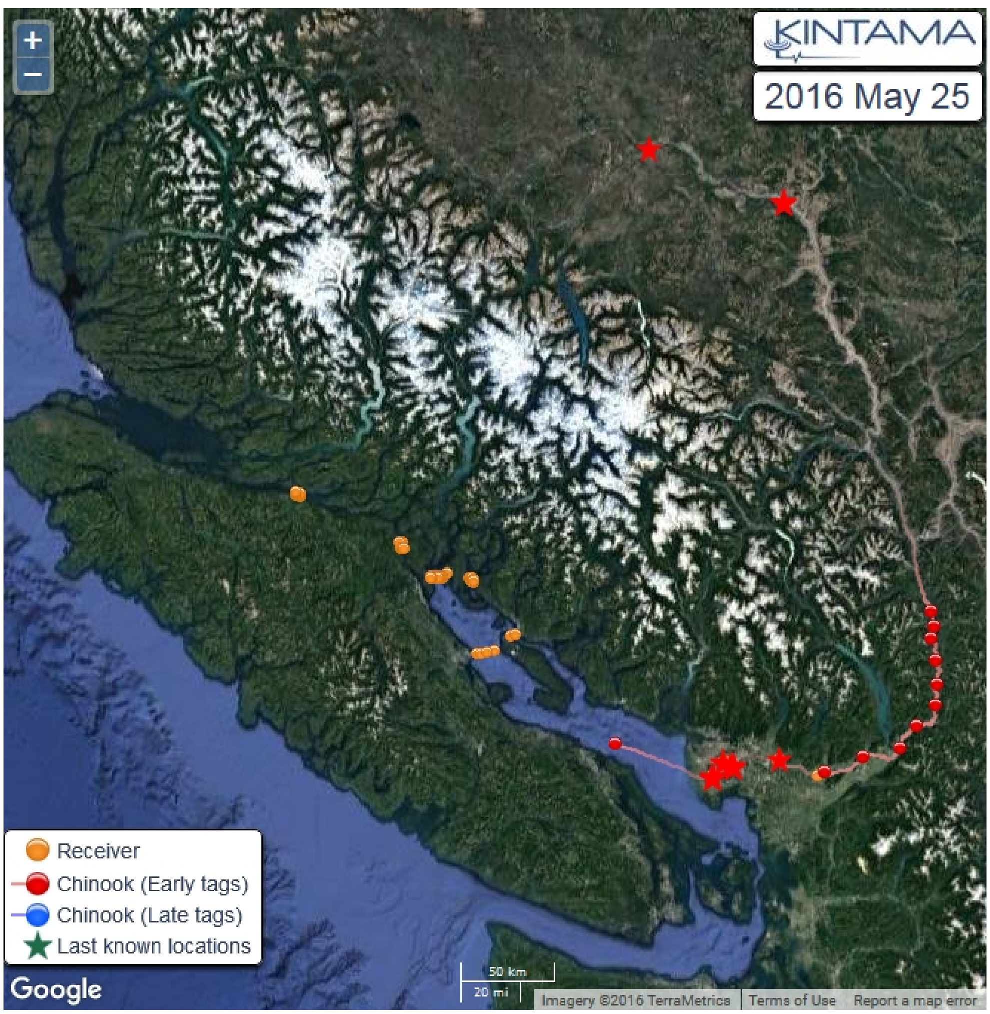


**Screen capture from the animation of Chilko River Chinook movements in 2016. The animation is available from Kintama's website: http://kintama.com/visualizations**

# The Use of Telemetry to Investigate Residence Time and Survival of Fraser River Chinook Salmon in the Strait of Georgia, 2016

Salish Sea Marine Survival Project

marinesurvivalproject.com

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KINTAMA

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# Executive Summary

Marine survival of Fraser River Chinook salmon stocks has decreased to <1% in recent years and lack of information on downstream and early marine survival hampers their effective management. We conducted a small acoustic telemetry pilot study on hatchery-origin Chilko River Chinook, using 100 acoustic-tagged smolts to 1) estimate freshwater survival, 2) investigate residence timing in the Strait of Georgia, and 3) begin to investigate early marine survival. Because acoustic receiver arrays capable of detecting smolts implanted with small 180 kHz acoustic tags only monitor the northern exit from the Strait of Georgia (SOG), residence time and early marine survival could only be potentially estimated if smolts migrated north before tag batteries expired five months after ocean entry.

Freshwater survival of acoustic-tagged Chinook to the Fraser River mouth (49%) was comparable to other populations or species which migrate the same distance downstream; however, their downstream migration rate (only 18 km/day) was dramatically slower than that of wild Chilko Lake sockeye, which migrate rapidly to the ocean after exit from Chilko Lake (100-170 km/day). Thus, Chinook smolts took more than one month on average to reach the SOG, in contrast to wild Chilko Lake sockeye which generally take under a week. It is unknown whether this behavioural difference is the result of their hatchery origin and transport to Chilko Lake.

Only one fish was subsequently detected in the SOG and none were detected exiting the SOG. Combined with the results from trawl surveys, the complete lack of detections in the Discovery Islands and Johnstone Strait suggest that Chilko Chinook do not migrate directly north after river exit. Instead, they likely remain in the SOG for at least several months. With only a single fish detected in the SOG, we were not able to estimate early-marine survival or residence time. It is unclear if smolts eventually exited the Strait via the southern route, died during their summer residence, or simply ceased migration to reside in the SOG. This uncertainly can be resolved by either 1) increasing the number of tagged smolts released and instrumenting the southern exit from the SOG with acoustic receivers capable of detecting 180 kHz tags, or 2) capturing larger juvenile salmon in the SOG later in the season (by micro-trolling or seine) and implanting them with longer-lived, low-frequency tags that are compatible with all of the receivers in the greater Salish Sea area.

# 1. Introduction

Over the past quarter century, there have been significant decreases in marine survival of most Chinook salmon stocks entering the Salish Sea. Despite their importance, little is known about freshwater or early marine survival of Fraser River Chinook and whether residence in the Strait of Georgia (SOG) is a critical period for establishing productivity of the adults returning 2-3 years after ocean entry. Without this information it is difficult to discern where and when in the life cycle mortality occurs and how best to focus population restoration efforts.

Trawl survey data suggest that stream-type Fraser River Chinook remain in the Strait of Georgia for at least three to five months after ocean entry (Beamish et al. 2011), but the proportion of fish that survive to leave the SOG is unknown. This summer residence behaviour was also documented by Welch et al. (2011) and is distinct from that of stream-type (or yearling) Chinook from the Columbia River which quickly migrate north along the continental shelf after ocean entry (Rechisky et al. 2009; Fisher et al. 2014), as well as from Fraser River sockeye and steelhead which also migrate directly north (Welch et al. 2009, 2011).

Two previous acoustic telemetry studies attempted to quantify early marine survival of Fraser River Chinook salmon, but the extended residence time of smolts in the Strait and the sparse telemetry array available for tracking fish in the Strait presented challenges. Welch et al. (2011) tagged 367 Chinook at Fraser River hatcheries (Thompson River tributary), but only two fish were detected leaving the Salish Sea, one via Queen Charlotte Strait and one via Juan de Fuca Strait, despite relatively high survival to the Fraser River mouth (Welch et al. 2008). Similarly, Neville et al. (2015) captured and tagged nearly 300 Chinook salmon in the SOG but only eight fish were ever detected leaving the Salish Sea, and six of these were identified as South Thompson River Chinook. Thus, across both studies, most fish that were detected leaving the SOG (8 of 10) originated from the South Thompson River in the lower Fraser River basin, a population that is thought to migrate to sea later than other Fraser River populations and may have different migratory and survival patterns than middle and upper Fraser populations (Beamish et al. 2011). Of the remaining two fish tagged by Neville et al. (2015), one was from the Big Qualicum River (an east coast Vancouver Island population) and the other was of unknown origin. Therefore, middle and upper Fraser River Chinook salmon stocks have never been detected migrating from the Salish Sea, and residence time and early marine survival remain uncertain.

As part of an effort to establish an indicator stock for management of middle Fraser River summer run $5_2$ Chinook salmon, the Sentinel Stocks Program of the Pacific Salmon Commission provided funding to the Department of Fisheries and Oceans (DFO) and the Tsilhqot'in National Government Fisheries Program to develop a coded wire tag (CWT) indicator project for Chilko River Chinook, which are a component of the middle Fraser River summer run (DFO 2013). Low return rates for Fraser River Chinook precluded CWT tagging wild juvenile Chinook in the Chilko River, as the number of adults ultimately returning to spawn 2-3 years later would require that several hundred thousand juveniles be captured and tagged. Therefore, in 2014 adult Chinook were captured in the Chilko River and their offspring reared in a DFO Salmonid Enhancement Program (SEP) hatchery facility. Approximately 95,000 fry were tagged with CWTs and then released in the Chilko River as yearlings in April 2016. This project provided a unique opportunity to acoustic tag and monitor a proportion of these smolts as they migrated downstream and into the ocean, and to provide information on post-release and downstream mortality for management of the $5_2$ yearling summer Chinook run to the Middle Fraser River.

Most wild Chilko River Chinook smolts enter the Strait of Georgia via the Fraser River in late April and early May (Table 1; per. comm. Matt Townsend, DFO Fraser River Stock Assessment, Delta BC). The downstream migration for wild smolts is likely very rapid and one might assume that little mortality occurs, but the Chilko and Chilcotin rivers have been identified as mortality hotspots for sockeye smolts leaving Chilko Lake (Clark et al. 2016). Like other Fraser River stocks, Chilko Chinook probably reside in the SOG over the summer although the residence time and early marine survival for this specific stock is unknown because no individuals have been detected leaving the Strait. Several Chilko Lake juveniles have been captured in the SOG and Gulf Islands when sampling occurs from June to September (per. comm. 2016, Chrys Neville, Pacific Biological Station, Nanaimo BC), and two larger individuals were captured in Juan de Fuca Strait and on the west coast of Vancouver Island in late winter (per. comm. Strahan Tucker, DFO Molecular Genetics Lab, Pacific Biological Station, Nanaimo BC).

Study Objectives:

1. Provide freshwater survival estimates for Chilko River yearling Chinook smolts from release in the Chilko River to the lower Fraser River and compare this to past published data for other species and populations originating from the Fraser River.

2. For Chilko River Chinook smolts *that migrate north* after ocean entry during the hypothesized timeframe, fill in the critical uncertainty regarding residence time of upper Fraser River Chinook in the Strait of Georgia.

3. For Chilko River Chinook smolts *that migrate north* after ocean entry during the hypothesized timeframe, provide estimated survival in the Strait of Georgia and Discovery Islands and compare to past published data.

# 2. Methods

## *2.1. Transmitter Programming*

We tagged smolts with VEMCO V5-1H acoustic transmitters (12.7 x 5.6 x 4.3 mm; 0.65 grams in air; 180 kHz). These transmitters have a limited battery life, but are small enough to be implanted into hatchery-reared Chilko River Chinook smolts with little size grading and low tag burden. Because the residence time in the Strait of Georgia is poorly understood and transmitter battery life is limited, we used two groups of tags that had staggered programming: half transmitted during the freshwater migration and very early marine phase of smolt life history (until battery expiry in mid-summer), and the other half began transmitting in mid-summer (at about the time tags in the first group were expected to expire), and ran until battery expiry in early fall (Table 1). These programming choices ensured that we would detect smolts in the first five months after release if they 1) survived, and 2) migrated north via Johnstone Strait by early fall.

The first group of tags ("early tags") was programmed to transmit at random time intervals between 25 and 35 sec (30 sec average) for 14 days beginning two days after tags were activated on the day of surgery (April 9-10$^{th}$ 2016). On day 16, the tags began transmitting at random intervals between 35 and 45 sec (40 sec average) until battery exhaustion. The initial quiet period was to preserve battery life after tagging and before the fish were transported and released. We used a faster transmission interval for the first two weeks to improve the probability of detection during the presumed rapid downstream migration. The transmitter manufacturer (VEMCO) estimated that with this programming 95% of tags were active 90 days after activation (estimated tag lifespan), or until July 8-9$^{th}$, and that 50% were active 105 days after activation, or until July 23-24.

The second group of tags ("late tags") was programmed to remain silent for the first 106 days after activation (also on April 9-10th). On July 24-25th, they then began transmitting randomly every 35 to 45 sec (40 sec average) until battery death. VEMCO estimated that 95% of these tags were active 154 days after activation, or until Sept 10-11th.

**Table 1. Acoustic transmitter programming for Chilko River Chinook salmon. The vertical red dashed line represents the expected migration date from the Fraser River based on data from the lower Fraser River smolt trap. R=release group.**

| | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| R1 | 2 d OFF | 14 d @ 30 sec | | | | | | | @ 40 sec to tag death | | | | | 95% life (90 d) | 50% life (105 d) | | | | | | | | | | | |
| R2 | ← | | | | | | 106 days OFF | | | | | | | | | → | @ 40 sec to tag death | | | | | | 95% life (154 d) | | 50% life (168 d) | |
| Days | 1 | 8 | 15 | 22 | 29 | 36 | 43 | 50 | 57 | 64 | 71 | 78 | 85 | 92 | 99 | 106 | 113 | 120 | 127 | 134 | 141 | 148 | 155 | 162 | 169 | 176 |
| Week of… | 10-Apr-16 | 17-Apr-16 | 24-Apr-16 | 01-May-16 | 08-May-16 | 15-May-16 | 22-May-16 | 29-May-16 | 05-Jun-16 | 12-Jun-16 | 19-Jun-16 | 26-Jun-16 | 03-Jul-16 | 10-Jul-16 | 17-Jul-16 | 24-Jul-16 | 31-Jul-16 | 07-Aug-16 | 14-Aug-16 | 21-Aug-16 | 28-Aug-16 | 04-Sep-16 | 11-Sep-16 | 18-Sep-16 | 25-Sep-16 | 02-Oct-16 |

## 2.2. *Tagging*

Chilko River Chinook smolts were reared at the Chehalis River Hatchery, and were the offspring of summer-run, wild Chinook that were captured in 2014 as adults in the Chilko River. Several days before tagging commenced, the Chehalis River Hatchery Staff moved 186 smolts from a large raceway to a net pen to facilitate tagging. We dip-netted fish randomly from the net pen and tagged 100 of them with VEMCO V5-1H transmitters using our standard surgical protocols (Rechisky and Welch 2010) on April 9-10, 2016 (Figure 1; Figure 2); however, we excluded any smolts that weighed less than 12 grams in order maintain low tag burdens. Fifty smolts were implanted with early tags and 50 smolts were implanted with late tags (see 2.1 Transmitter Programming). Fish were allocated to the two groups randomly but were tagged in batches of 10 or 20 to keep track of transmitter type.

Tagged smolts ranged between 104-124 mm fork length at tagging, and weighed between 12.2-23.4 grams, which resulted in a tag burdens of 2.8-5.3% (in air; Figure 3). Based on the final length frequency sample taken at the hatchery on April 5th (per. comm. Jayme Hills, DFO Cultus Lake Salmon Research Laboratory) and the number of fish that were smaller than 12 grams during tagging, we estimate that we tagged the upper 68-75% of the size distribution.

Tagged smolts were held in a recovery net pen for 4-5 days prior to release. They were transported by truck by SEP staff and released into the Chilko River at Henry's Crossing Bridge (Figure 4) at 9:30 pm PDT on April 14, 2016 with the rest of the hatchery fish (~94,000 smolts).

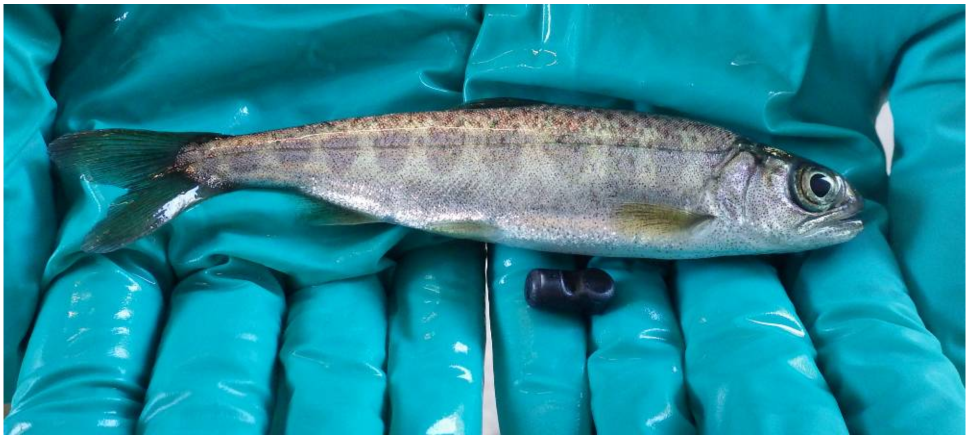

**Figure 1. Chilko River Chinook smolt reared at the Chehalis River Hatchery in comparison with a V5 transmitter.**

**Figure 2. Kintama's Erin Rechisky and Paul Winchell tagging Chilko River Chinook smolts at Chehalis River Hatchery.**

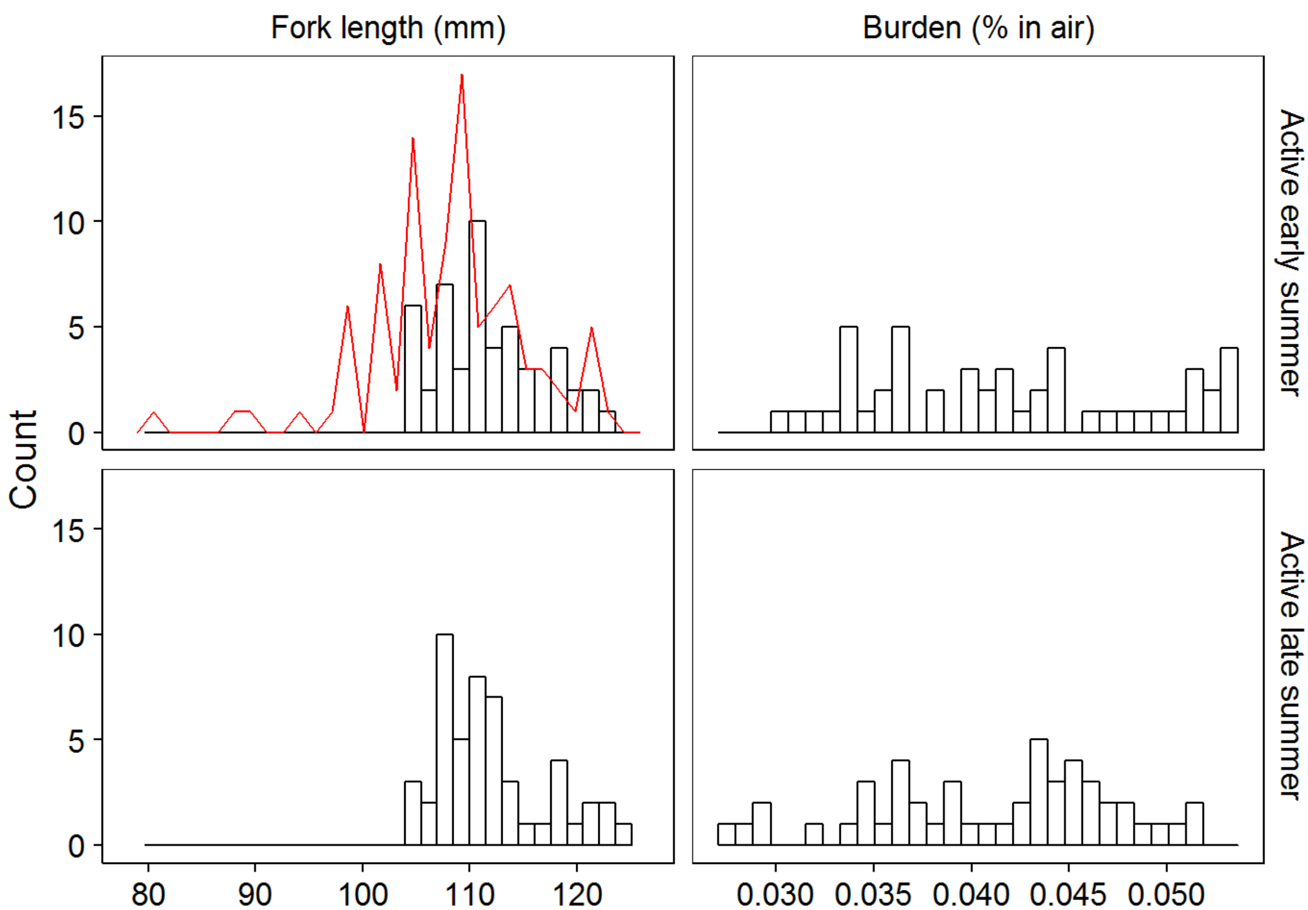


**Figure 3. Fork length and tag burden distributions for acoustic tagged Chilko River Chinook smolts tagged with early summer and late summer tags. The red line in the top left panel is the length distribution of 98 Chilko River Chinook sampled at the Chehalis River Hatchery on April 5th 2016, and represents the general hatchery population (per. comm. Jayme Hills, DFO Cultus Lake Salmon Research Laboratory).**

## *2.3. Acoustic Array*

The overall acoustic array is composed of a series of "sub-arrays" of receivers spaced along the migration route (Figure 4; Figure 5). The 180 kHz tags used in this study can be detected at multiple sites in the Fraser River basin, and on new, dual frequency sub-arrays in the Discovery Islands (DI) and Johnstone Strait (JS). The northern Strait of Georgia (NSOG) sub-array has six dual frequency receivers (of 27), and the Queen Charlotte Strait (QCS), and Strait of Juan de Fuca (JDF) sub-arrays can detect only 69 kHz tags. The lack of 180 kHz receivers to the south of the Fraser River at JDF was a known limitation of this study because we were not able to unambiguously determine for those smolts that did not migrate north whether they remained in the Strait of Georgia or exited the Strait to the south.

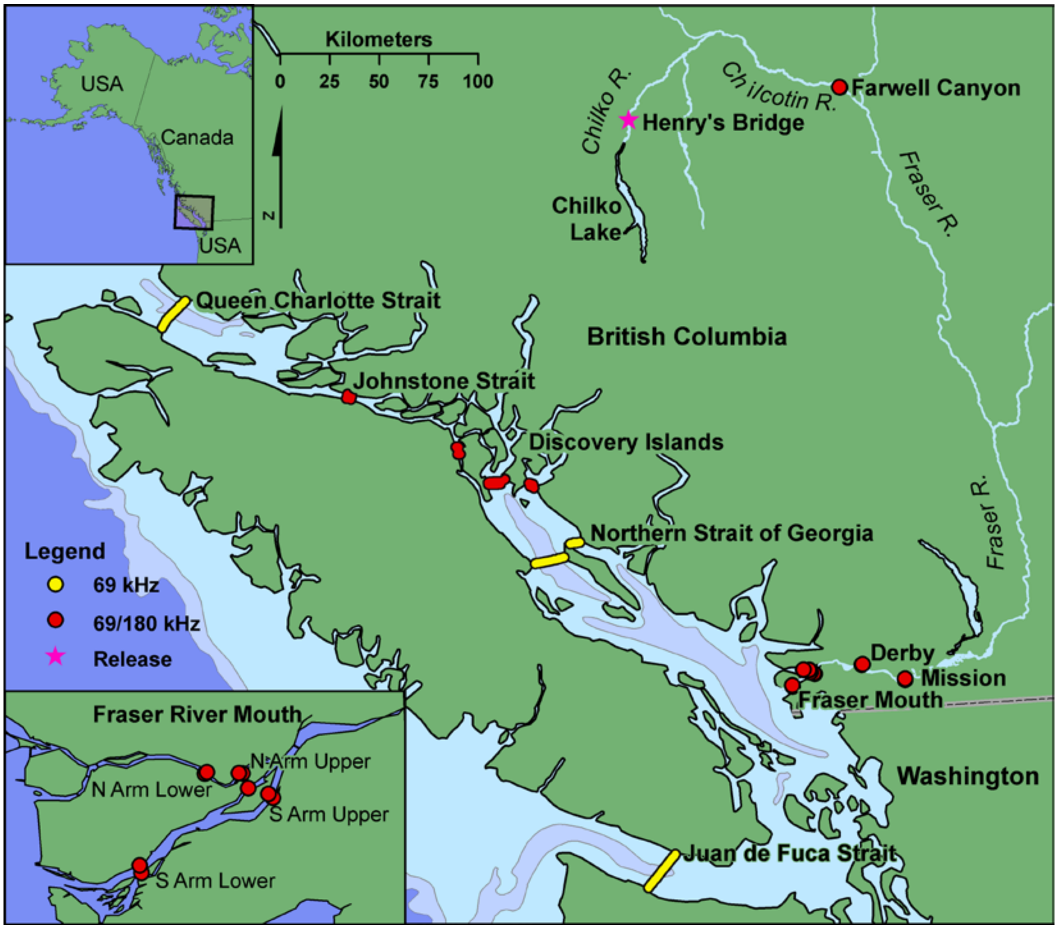


**Figure 4. Map of the acoustic array and release location of Chilko River Chinook. Not shown are six receivers capable of detecting the 180 kHz tags on the NSOG sub-array. See Figure 5 for a zoomed in view.**

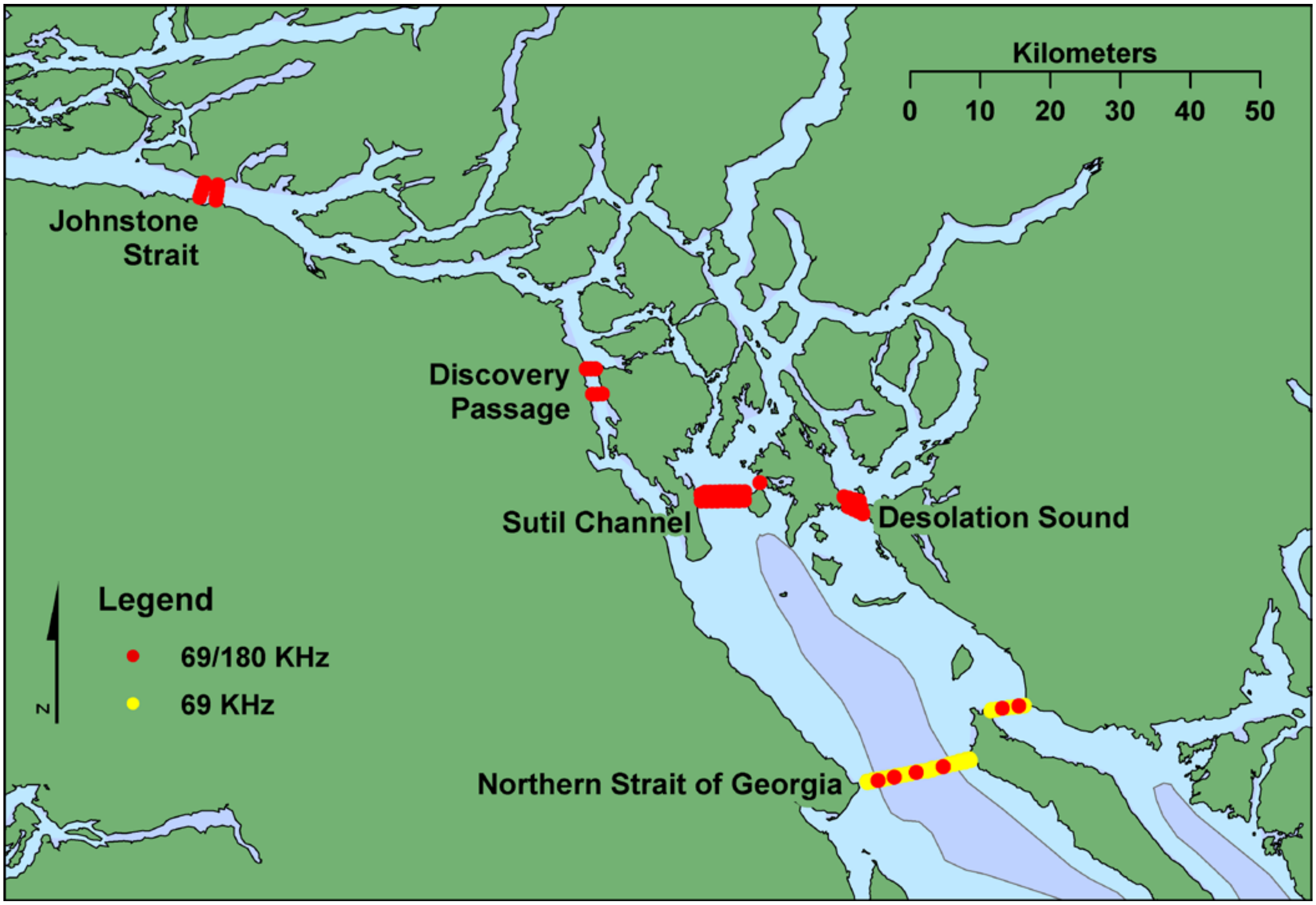


**Figure 5. Map of dual frequency sub-arrays of the northern Salish Sea region.**

In the Chilcotin River, we deployed two temporary pairs of VEMCO VR2W 69 and 180 kHz receivers just upstream of the confluence with the Fraser River (in the Farwell Canyon area) on April 12th 2016. In past years, receivers at this site were deployed by the Hinch Lab (UBC) to track Chilko Lake sockeye; however in 2016, Chilko Chinook smolts were released prior to Chilko sockeye tagging and release. Therefore, responsibility for deployment and recovery of this site was shifted to Kintama for this year. All receivers were successfully recovered on May 18th 2016.

In the Lower Fraser River, Kintama maintains a sub-array of VEMCO VR2W 69 and 180 kHz acoustic receivers at Mission (two pairs at rkm 80), Derby (two pairs at rkm 51), and at several sites near the river Mouth (nine pairs at rkms 9-22). We have maintained receivers at these stations (or nearby) since 2004. All units were successfully recovered (and redeployed) on June 25th, 2016.

In the spring of 2015, the PSF funded Kintama to design and deploy new sub-arrays in the Discovery Islands (DI) and Johnstone Strait (JS). These sub-arrays were comprised of VEMCO VR4 dual-frequency (69 and 180 kHz) receivers mounted in Kintama-designed floatation collars, which can remain continuously deployed for multiple years with data access via remote upload. All of the DI receivers (35), and 6 of the 8 receivers deployed in JS are on long-term loan to the PSF from the Ocean Tracking Network (OTN). The other two JS receivers were owned and supplied by Kintama as part of this project. The OTN-owned receivers will remain in place for the duration of the SSMSP, but for logistical reasons the Kintama receivers were recovered in the fall of 2015 and then redeployed April 18$^{th}$-19$^{th}$ 2016 with 1 dual-frequency VR4, and a pair of VR2W 69 and 180 kHz receivers. Between Oct 12$^{th}$ -20$^{th}$ 2016, we successfully uploaded data from both sub-arrays. We also recovered the Kintama-owned receivers on the JS sub-array, and then redeployed the sites with two VR4 units.

Oct 19$^{th}$-20$^{th}$, we uploaded the six receivers on the NSOG sub-array that were equipped to detected 180 kHz tags. This sub-array is maintained by OTN, but they were unable to service the dual frequency units in fall 2016 because of gear failure. The early upload provided us with immediate access to the data.

## 2.4. Data Management

Prior to analysis, we screened all 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 (>0.5 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 segment was within the 10$^{th}$-90$^{th}$ percentiles of travel times for each treatment. None of the 1319 detections of Chilko River Chinook were classed as false.

## 2.5. Survival Analysis

We used a mark-recapture approach to estimate survival of acoustic-tagged smolts, where detection at each acoustic receiver sub-array along the migration path was interpreted as “recapture”. Estimates of survival ($\varphi$), detection probability ($p$), and their associated variances were calculated using the Cormack-Jolly-Seber (CJS) model (and special cases of the CJS model) for live recaptured animals (Cormack 1964, 429-438; Jolly 1965, 225-247; Seber 1965, 249-259). This model jointly estimates survival and detection probability within a maximum likelihood framework. We used R (R Core Team 2015) with the package RMark (Laake 2015) to construct CJS models using Program MARK (White and Burnham 1999; 120-139) model assumptions apply for all analyses: equal survival probability, equal probability of detection, and instantaneous sampling. The survival analysis is described in four steps.

### *2.5.1. Step 1: Capture History Sequencing*

A capture history is a sequence of 1s and 0s that indicates whether an individual smolt was detected or not at each acoustic sub-array during their migration. Because only one fish was detected in the ocean (Table 2), the capture history sequence for Chilko River Chinook was limited to the freshwater sites: release in the Chilko River followed by detection at the sub-arrays at Farwell Canyon, Mission, Derby, and the Fraser River Mouth. CJS models confound φ and *p* at the final detection site, so we divided the Fraser River Mouth sites into two sub-arrays (Upper and Lower Mouth; Figure 4) in order to obtain survival estimates to the Upper Mouth.

### *2.5.2. Step 2: Goodness of Fit Testing*

We used the capture histories to test goodness-of-fit (GOF) of the data to a fully parameterized CJS model (φ and *p* estimated at each detection site) using the bootstrapped GOF test within Program MARK with 1000 simulations. After bootstrapping, there are two approaches to estimating the over-dispersion parameter $\hat{c}$: one approach is based on the deviance and the second is based on $\hat{c}$. To be conservative, we used the higher of the two values: deviance $\hat{c}$=1.14. We adjusted the AIC values and SEs of the survival and detection probability estimates to account for this lack of fit.

### *2.5.3. Step 3: Estimating survival and detection probability, and testing if fork length or tag burden affected survival.*

We used four candidate hypotheses to estimate survival (φ) and detection probability (*p*) for Chilko River Chinook. First, we built a base model where φ and *p* were estimated independently in each migration segment and on each sub-array (φ(segment) *p*(sub-array)). Next, we explored the effects of fork length and tag burden on survival by constructing several candidate models that included fork length at tagging (FL), and the tag to body mass in air ratio (tag burden) as individual covariates each year. We used the tag burden parameter to investigate the potential effects of the acoustic tags; however, for a given tag size it was correlated with fork length (Spearman's rho=-0.913; p=<0.001). Given this relationship, we did not investigate any second-order or interaction effects. Instead, we hypothesized that tag burden and/or FL might cause a consistent shift in survival without changing the relative mortality between migration segments (φ (segment+FL or segment+burden)). We also thought that any tag burden effects might manifest most strongly in the Chilko River shortly after release as the result of the tagging process (φ (segment+$\text{burden}_{\text{Release-Farwell}}$)). When length or weight was not recorded (one occurrence for each), we fit a linear regression to the length and weight data (weight = 0.49*length-38.8; R^2=0.81, p<0.001 for both intercept and slope) and used this relationship to populate the two missing values.  We used Akaike's Information Criteria corrected for overdispersion and low sample size (QAICc) to compare the performance of these four models. Since the evidence that either length or burden affected survival was weak (see Table 3), we extracted the final estimates of survival and detection probability from the base model.

To calculate cumulative survival estimates from release to the Fraser Mouth, we multiplied survival probabilities for each consecutive migration segment. We derived the variance for each cumulative survival estimate using the Delta Method:

$$\widehat{\mathrm{var}(\mathrm{Y})} = \left(\frac{\partial(\hat{\mathrm{Y}})}{\partial\hat{\varphi}}\right) \cdot \hat{\Sigma} \cdot \left(\frac{\partial(\hat{\mathrm{Y}})}{\partial\hat{\varphi}}\right)^{\mathrm{T}}$$

where Y is the product of the survival estimates, the first term is a row vector containing the partial derivatives of Y with respect to each of the survival parameters, the middle term is the variance-covariance matrix from the model output, and the last term is the transpose of the row vector. We then calculated the standard error, $\sqrt{\widehat{\mathrm{var}(\mathrm{Y})}}$ , and the 95% confidence interval, $95\%\ \mathrm{CI} = \mathrm{Y} \pm 1.96 \cdot \mathrm{SE}$, for the cumulative survival estimates.

### 2.5.4. Step 4: Calculating Survival Rates

To allow a more direct comparison of the importance of the Chilko and Chilcotin rivers relative to the Fraser River mainstem, we adjusted the survival estimates for these habitats by segment length and distance. We calculated survival rates per week as

$$S^{\frac{x}{d}}$$

where S=survival, x=7 days, and d=median travel time in days. Travel times were calculated as described below (see 2.6 Residence and Travel Times). To calculate the spread around the rate estimates, we substituted the upper and lower 95% confidence interval on the survival estimate for S, and we used the delta method to estimate the standard error:

$$\widehat{var(S_{Rate})} = \left(\frac{\partial S_{Rate}}{\partial \hat{\varphi}}\right)^2 \cdot \widehat{var}(\hat{\varphi})$$

or

$$SE(S_{Rate}) = \frac{x}{d} * \hat{\varphi}^{\left(\frac{x}{d}-1\right)} * SE_{\varphi}$$

We then calculated survival rates per 100 km using the same formulas but substituting x=100, and d=shortest distance in water between the sub-arrays in km.

## 2.6. Residence and Travel Times

Segment travel time (days) was calculated for each fish from release to arrival on the first sub-array, and then from departure from each sub-array until arrival at the next sub-array along the migratory path. These calculations could only be made for smolts detected on both sub-arrays bracketing the segment in question. Cumulative travel time was calculated for each fish from release until departure from each sub-array where it was detected. Arrival and departure were defined as the first and last detections respectively on each relevant sub-array.

# 3. Results

A dynamic animation of the movements of the Chilko River Chinook smolts released in 2016 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. Check it out!

## *3.1. Number Detected*

Of the 50 Chilko Chinook smolts released with early tags, 30 were detected on the acoustic array (Table 2). Only one individual from this group was detected in the ocean. None of the 50 smolts released with late activation tags were detected on the array.

**Table 2. Count of Chilko River Chinook smolts detected migrating over the acoustic array in 2015. Counts are not adjusted to include fish that were not detected but known to be present because they were detected further downstream. Sub-arrays are mapped in Figure 4. The sample size at release was 50.**

| Sub-array | Number Detected |
|---|---|
| Siwash Bridge [a] | 5 |
| Farwell Canyon | 12 |
| Mission | 8 |
| Derby | 13 |
| Fraser Mouth Southarm | 19 |
| Fraser Mouth Northarm | 4 |
| Fraser Mouth Upper | 21 |
| Fraser Mouth Lower | 15 |
| Northern Strait of Georgia | 1 |
| Discovery Islands | 0 |
| Johnstone Strait | 0 |

**[a]The Siwash Bridge sub-array was deployed by the Hinch Lab (UBC) ~65 km downstream from our release site 4 days after the Chilko Chinook were released. These detections were not used in this analysis, but are included here for completeness.**

## *3.2. Model Selection*

There is some evidence that larger fish survived better than smaller fish (Table 3; Figure 6). Model selection results indicated that the effect of the added FL parameter was weak, i.e., the length model performed only slightly better than the base model (evidence ratio of 1.4). Additionally, the 95%

CI on the FL beta value (0.094) was -0.0081to +0.19, i.e., the 95% CIs just included 0, but the 90% CIs excluded zero, suggesting some evidence of a survival advantage for larger fish.

It is unlikely that tag burden reduced survival of these smolts because the addition of the burden parameter did not improve model fit over the base model (evidence ratio of 0.92). When we limited the effect of burden to only the segment after release (when we would expect most direct tag effects to manifest), model probability dropped even further. Thus, any effects of burden were probably related to the correlation between fish length and weight rather than to the tags or tagging process.

**Table 3. Model selection results to test the effects of fork length and tag burden on the survival of Chilko River Chinook smolts during freshwater migration in 2016. FL=fork length; QAICc= Quasi-likelihood Akaike Information Criterion adjusted for small sample sizes; K= number of parameters.**

| Model Description | Model | K | QAICc | Delta QAICc | weight |
|---|---|---|---|---|---|
| Plus length | φ(segment[a] + FL) *p*(sub-array[b]) | 10 | 231.94 | 0.00 | 0.37 |
| Base | φ(segment) *p*(sub-array) | 9 | 232.55 | 0.61 | 0.27 |
| Plus burden | φ(segment + burden) *p*(sub-array) | 10 | 232.70 | 0.76 | 0.25 |
| Plus burden 1st seg. | φ(segment + $\text{burden}_{\text{Release-Farwell}}$) *p*(sub-array) | 10 | 234.38 | 2.44 | 0.11 |

[a] Estimates differ for each migration segment

[b] Estimates differ for each sub-array

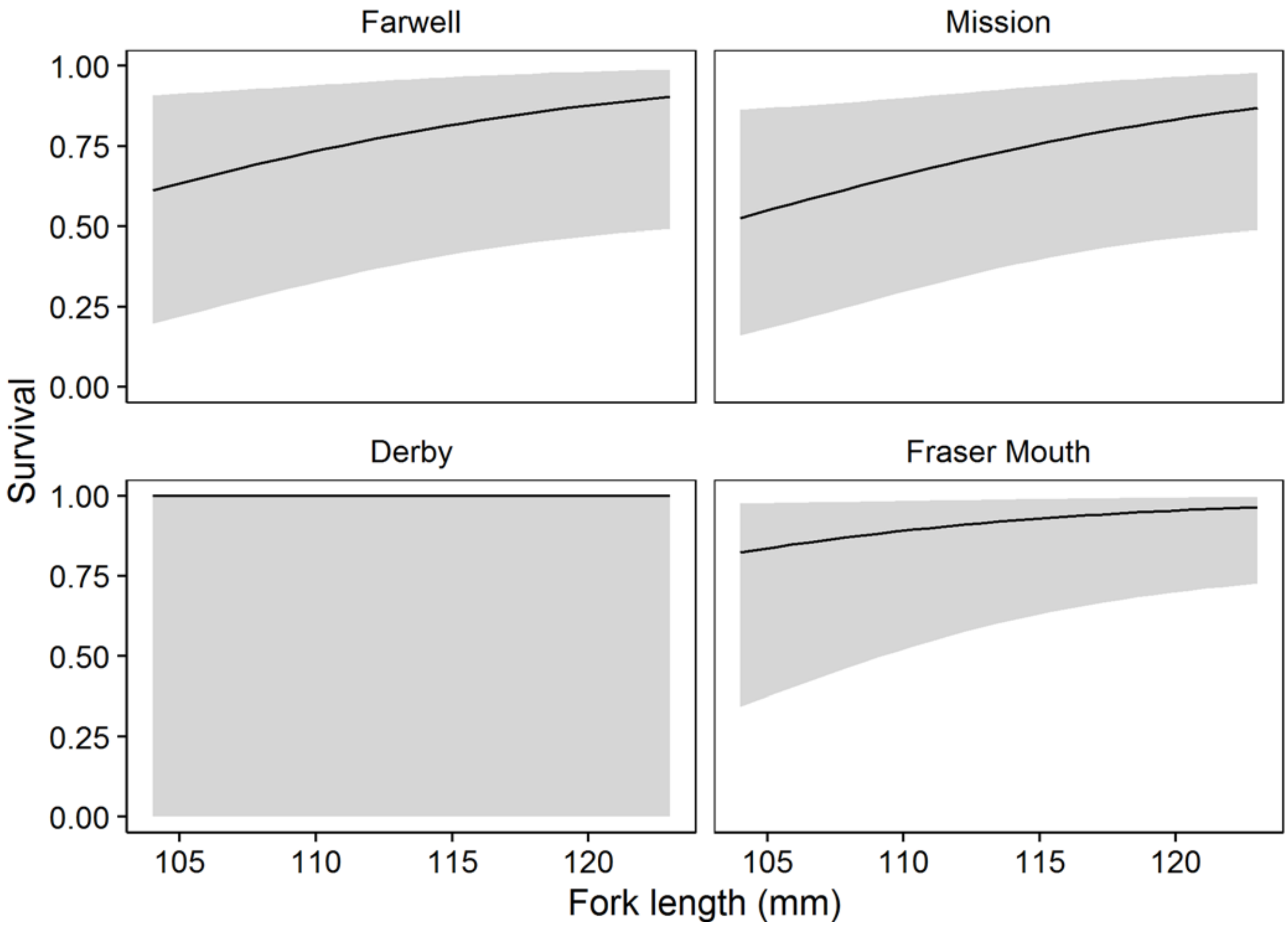


**Figure 6. Survival predicted across the range of fish lengths (mm) of Chilko River Chinook smolts in 2016. Survivals were predicted using the φ(segment + FL) model (Table 3) which was weakly supported in the survival analysis. Given the weak evidence, this figure should be used to indicate the direction of a possible effect and otherwise interpreted with caution.**

## *3.3. Survival Estimates*

Survival in the Chilko and Chilcotin rivers between release and the confluence with the Fraser River (165 kms) was 75% (SE=15%; Figure 7; Table 4). In the Fraser mainstem, survival was 70% (SE=15%) in the 420 km segment between the confluence with the Chilcotin River and arrival at the lower river at Mission. Subsequent survival in the lower Fraser River was high (91%; SE=8.8%; 55 kms between Mission and the Fraser River mouth). Overall freshwater survival from release to the Fraser River mouth was 49% (SE=8.2%; 640 kms; Figure 8). Since only one fish was detected in the ocean, we were not able to estimate marine survival. It is uncertain whether the remainder of the tagged Chilko

Chinook died, took up residence in the Strait of Georgia, or migrated south to exit the Salish Sea through Juan de Fuca Strait.

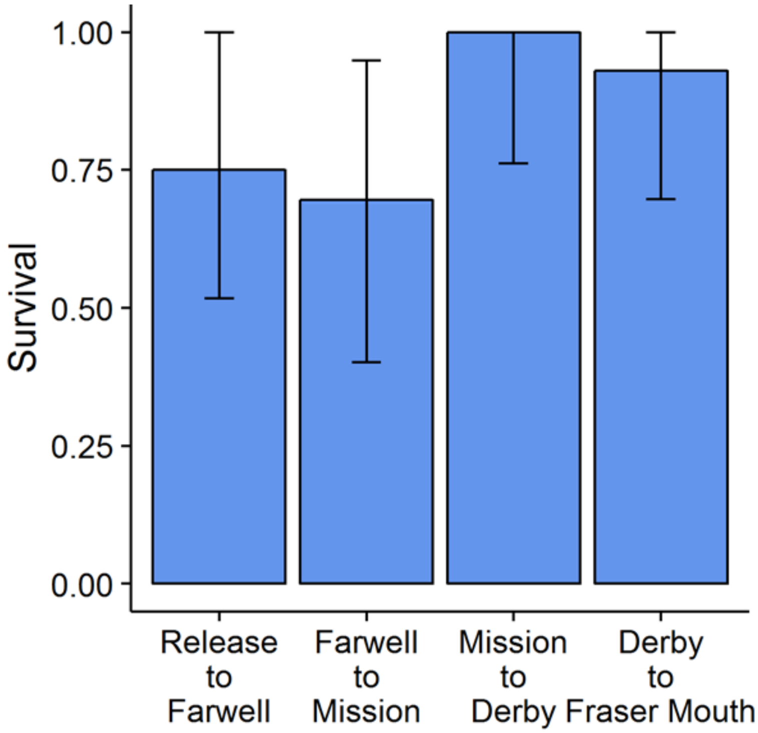


**Figure 7. Segment-specific survival estimates (95% CIs) in freshwater for Chilko River Chinook smolts released in 2016.**

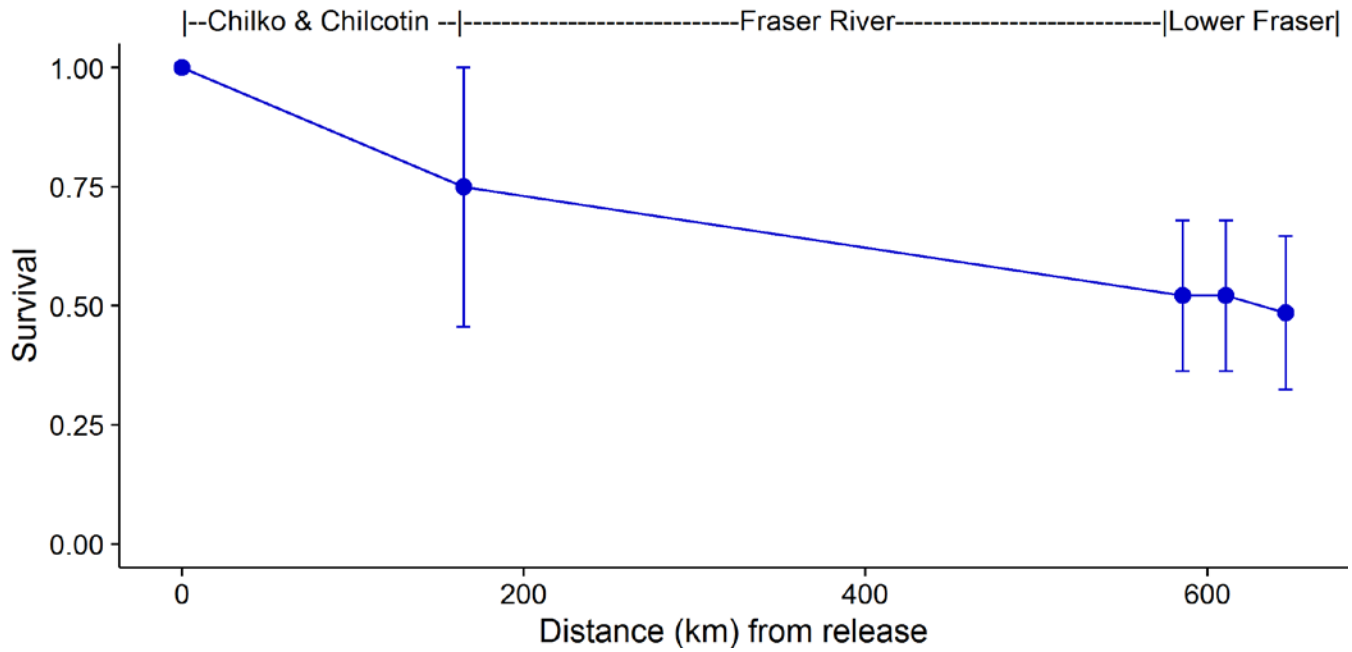


**Figure 8. Cumulative survival estimates (95% CIs) with distance for Chilko River Chinook smolts during freshwater migration in 2016.**

**Table 4. Survival and detection probability estimates (with SE) for Chilko River Chinook smolts during freshwater migration in 2016. Segment survivals are from release to Farwell, and then between each set of sub-arrays. Cumulative survivals are from release to each sub-array.**

| Sub-array | Segment Survival | Cumulative Survival | Detection Probability |
|---|---|---|---|
| Farwell | 0.75 (0.15) | 0.75 (0.15) | 0.32 (0.10) |
| Mission | 0.70 (0.15) | 0.52 (0.08) | 0.31 (0.10) |
| Derby | 1 (0) | 0.52 (0.08) | 0.50 (0.11) |
| Fraser Mouth | 0.93 (0.1) | 0.49 (0.08) | 0.87 (0.09) |

## *3.4. Survival Rates*

In order to compare survival between the two main habitats (the Chilko and Chilcotin rivers vs the Fraser River mainstem) which are of different lengths and required different amounts of time to migrate through, we calculated survival rates per unit distance and per unit time (Figure 9). Although there is considerable overlap of the confidence intervals, these rate estimates indicate that the Chinook smolts likely did not survive as well in the tributaries as they did in the Fraser mainstem, especially when considered on a per unit time basis. Unfortunately, the reduced sample size of tags active during the freshwater migration (N=50), and the poor detection efficiency of the Farwell subarray limit (see below) resulted in large confidence intervals on the estimates.

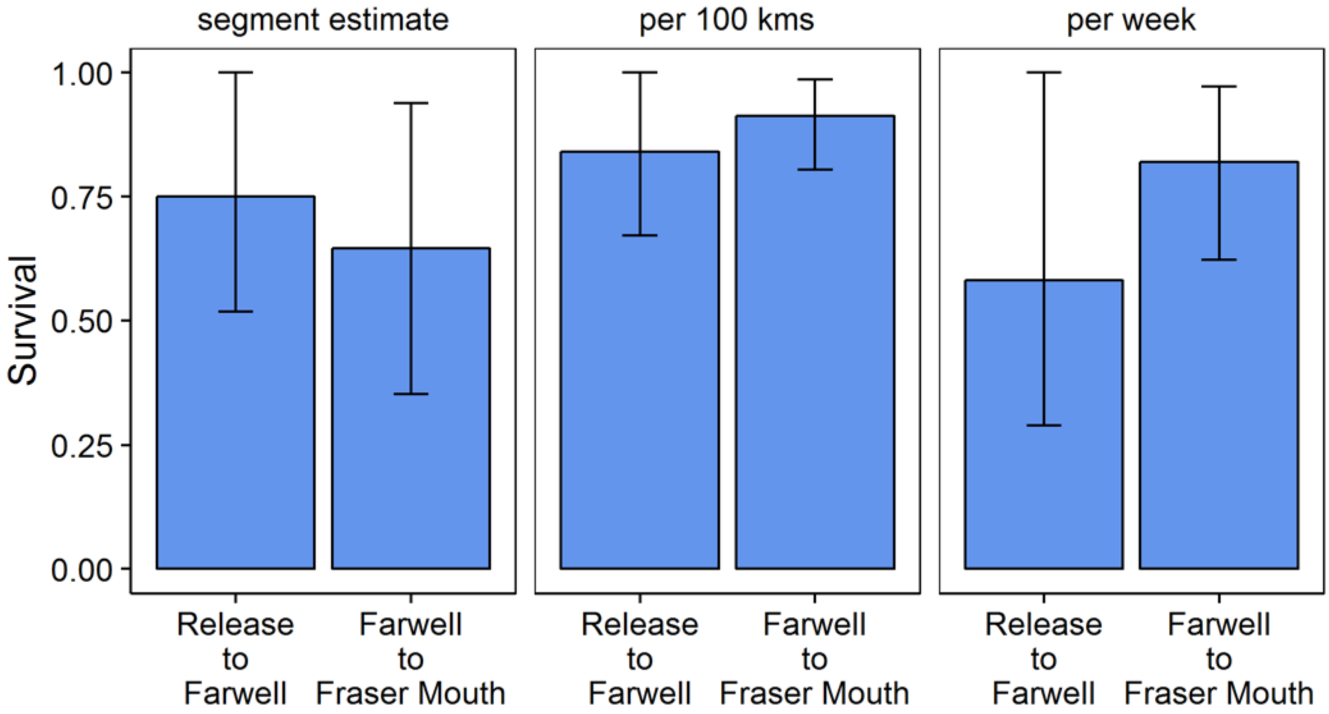


**Figure 9. Survival rates estimates per unit time and distance (95% CIs) for the main habitats encountered by the Chilko River Chinook smolts during freshwater migration. The release to Farwell segment contains the Chilko and Chilcotin rivers; the Farwell to Fraser Mouth segment contains the Fraser River mainstem.**

## 3.5. Detection Estimates

The detection probability for the V4 tags was relatively low at Farwell, and in the lower Fraser at Mission and Derby (≤50%; Table 4; Figure 10). It improved substantially at the Fraser River Mouth (to 87%; SE=9%).

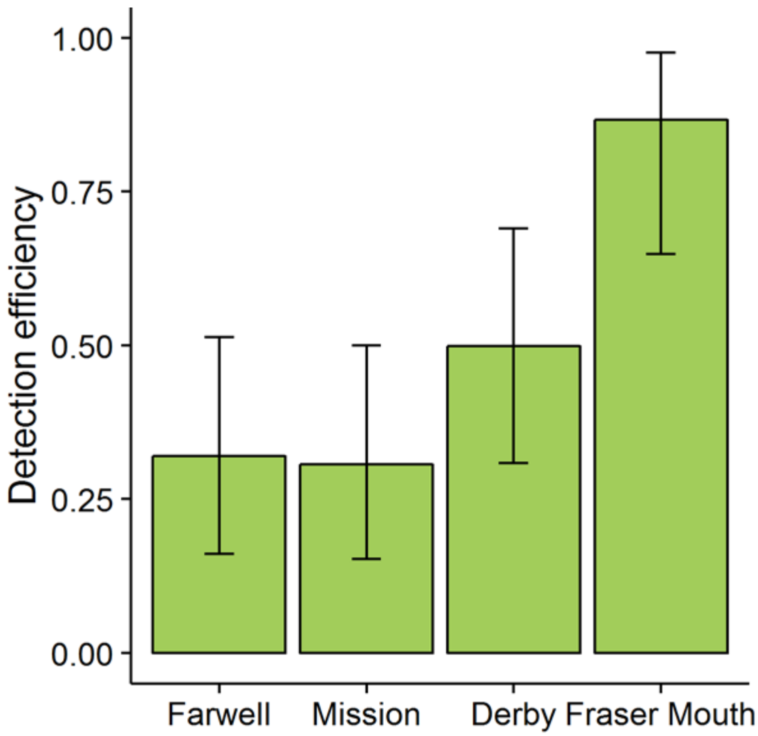


**Figure 10. Estimated detection probabilities for Chilko River Chinook smolts implanted with VEMCO V5-1H acoustic transmitters in 2016.**

## 3.6. Residence and Travel Times

The median travel time between release and Farwell Canyon (165 km) was 3.7 days (Figure 11; Figure 12); however, of the 12 individuals that were detected on Farwell, four lingered for considerably longer periods in this area (12-30 days). Cumulative travel time to the lower Fraser River (Mission and Derby, and an additional 420 km) increased dramatically to 38-39 days on average (median). Because only two individuals detected at Farwell were subsequently detected at Mission (tag 42403 took 8.8 days to travel between Farwell and Mission) or Derby (tag 42394 took 33.8 days to travel between Farwell and Derby), it is unclear if fish resided in the Chilko and Chilcotin rivers, the Fraser mainstem, or both for this extended period. The segment travel times in the lower river from Mission to the Fraser River mouth (55 kms) were fast (<0.75 days).

Only one Chilko River Chinook smolt was detected in the ocean (tag 42394). This individual left the Fraser River on May 22nd and was detected on the east side of the NSOG sub-array 8.4 days later on May 31st. It was within detection range of the NSOG sub-array for just over 9 minutes. On June 2nd it was detected again on the NSOG sub-array over a period of 20 minutes. These periods of detection spaced by a gap suggest that the fish passed over the sub-array at least twice. Since this fish was not subsequently detected on the DI or JS sub-arrays, it probably did not leave the Strait of Georgia via the northern route.

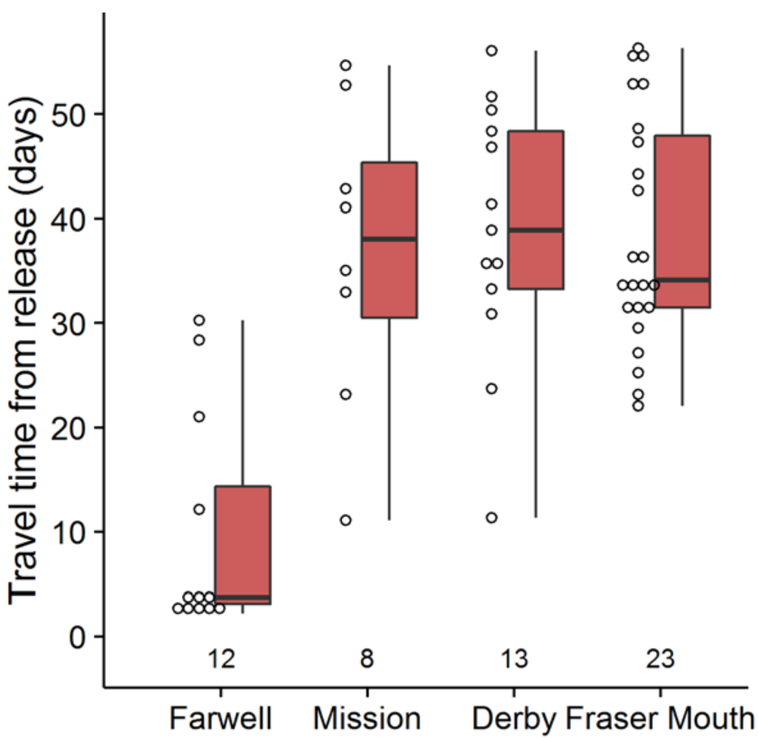


**Figure 11. Cumulative travel times (days) between release and arrival at acoustic sub-arrays along the migratory path for Chilko River Chinook smolts.**

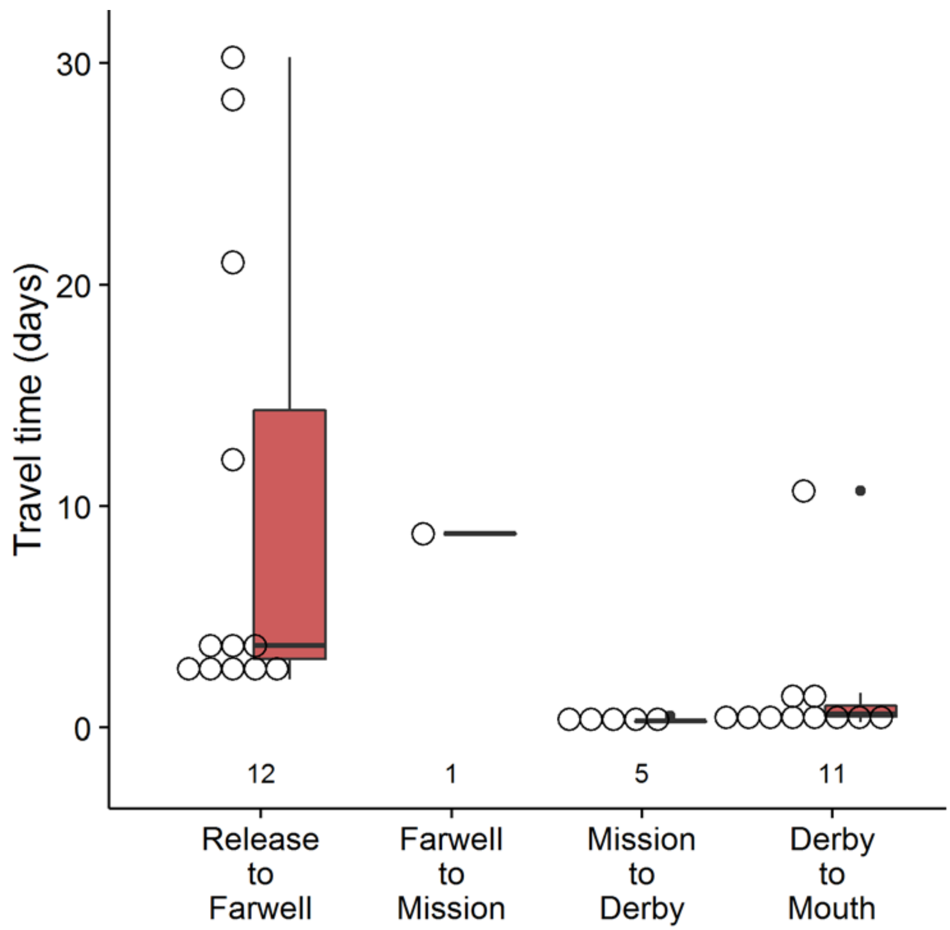


**Figure 12. Travel times (days) between release and the sub-array near Farwell Canyon, and then from departure from each sub-array until arrival at the next sub-array along the migratory path for Chilko River Chinook smolts. Calculations could only be made for smolts detected on both sub-arrays bracketing the segment in question, reducing sample size.**

## 4. Discussion

Freshwater survival of hatchery-reared Chilko River Chinook smolts from release into the Chilko River at Henry's Bridge to the Fraser River mouth (640 km downstream) was 49%. This is comparable to wild Chilko Lake sockeye tracked over the same area between 2010-2016 (640 kms; Figure 13), and better than three populations of lower Fraser River Chinook tracked from the South Thompson system in 2005-2006 (22-32%) that travelled a shorter distance to reach the ocean (330-400 kms; Welch et al. 2011). Chilko River Chinook survival was also comparable to freshwater survival of hatchery-reared Chinook smolts tracked from tributaries in the Columbia River from 2008-2009: Yakima River Chinook smolts (46-47%) migrated a similar distance to the ocean (~590 kms) and passed through four major hydrodams, and Snake River Chinook (29-33%) migrated an additional 200 km and passed through eight hydrodams (Rechisky et al. 2013). Thus, freshwater survival of Chilko Chinook was consistent with estimates available for other populations, species and even from other rivers.

The downstream migration of tagged Chinook smolts took more than one month on average (a migration rate of only 18 km/day). This is in contrast to wild Chilko Lake sockeye which generally only take one week to travel this distance (a migration rate of 100-170 km/day; Figure 14; Clark et al. 2016). Based on sparse data from the smolt trap in the lower Fraser River at Mission, the peak migration date past Mission for wild Chilko Chinook smolts was late April in 2012 and 2013 (per. comm. Matt Townsend, DFO). Therefore the wild smolts may migrate more quickly, but because we do not know the onset of the wild smolt migration it is unclear. It is possible that the extended migration time for Chilko Chinook was an artifact of their hatchery-origin and/or their transportation and release process. Hatchery-origin Chinook from the South Thompson River system (Coldwater, Nicola, and Spius rivers) also travelled more slowly in 2005 and 2006 (20-59 km/day; Welch et al. 2011).

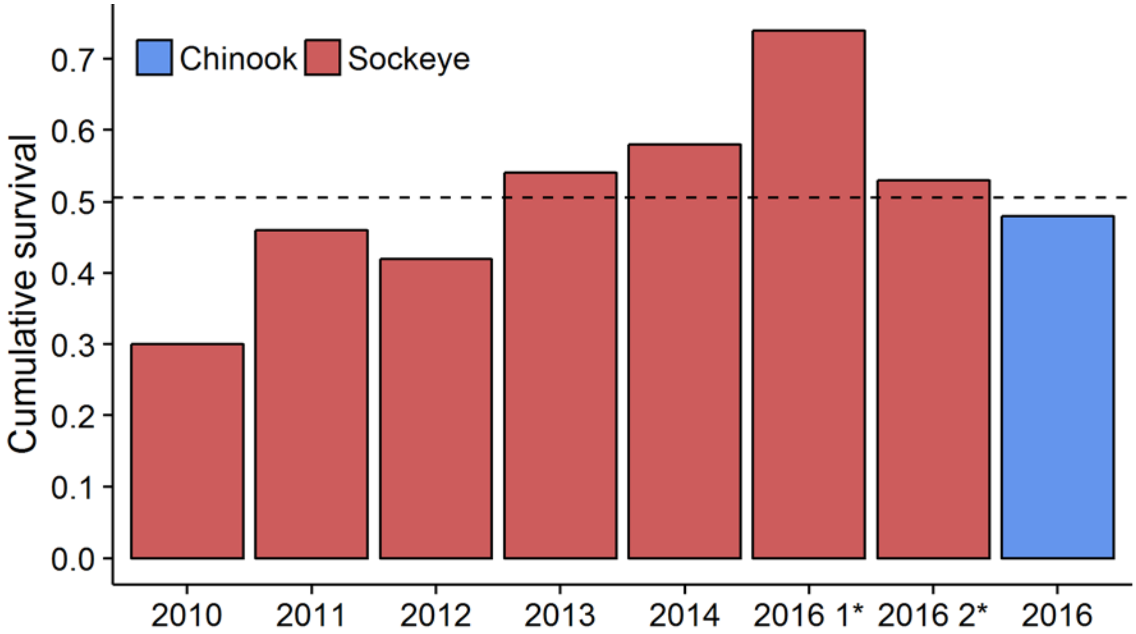


**Figure 13. Survival estimates for Chilko Lake sockeye and Chilko River Chinook between Henry's Bridge and the Fraser River mouth. Chilko Lake sockeye were released ~13 km upstream at the outlet of Chilko Lake and were detected on the sub-array at Henry's Bridge; Chinook smolts were released at Henry's Bridge. The dotted line shows the multiyear average for the sockeye. *1=age 1 smolts; 2= age 2 smolts. Smolts were age 2 in all previous years.**

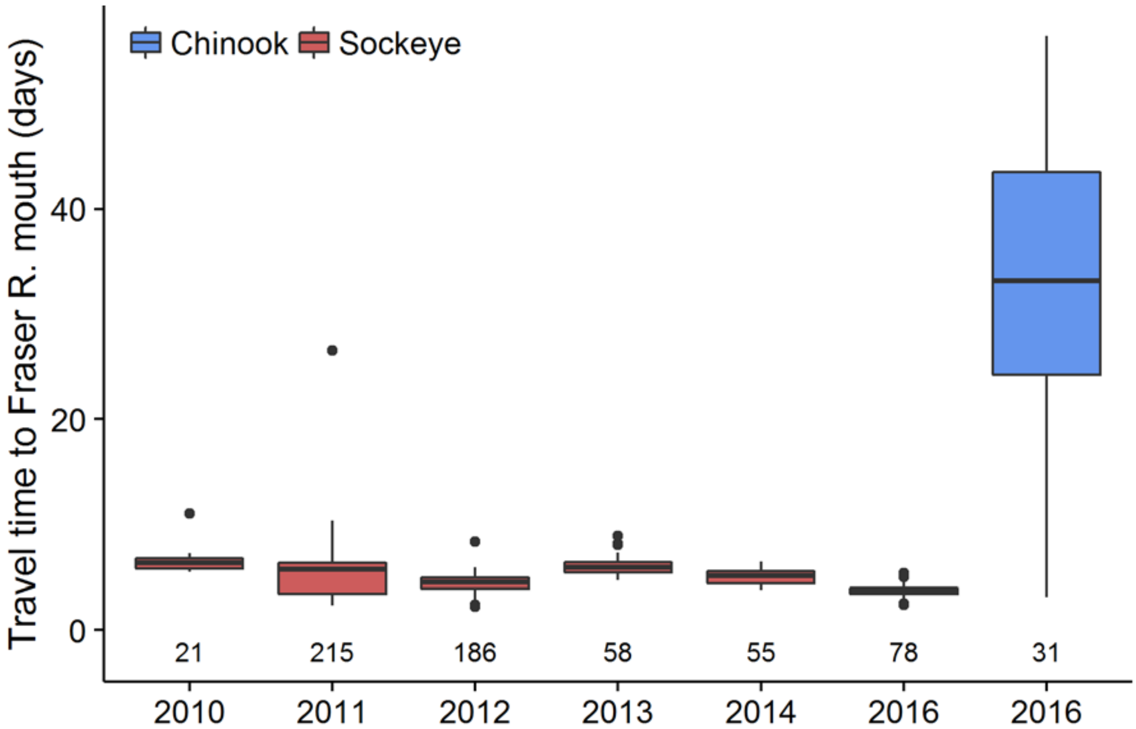


**Figure 14. Travel time (days) for Chilko Lake sockeye and Chilko River Chinook between Henry's Bridge and the Fraser River mouth. The numbers along the bottom are sample sizes.**

We would ordinarily expect that if hatchery-released smolts were going to delay migration to the sea that they would do so near the area in which they were released, but there is some evidence that many Chilko Chinook smolts likely resided in the Fraser River mainstem rather than the Chilko and Chilcotin rivers. For 8 of 12 smolts detected near the confluence of the Chilcotin and Fraser rivers (at Farwell Canyon), the travel time from release to Farwell was quite fast (2-4 days). Four of these these eight were subsequently detected at the mouth 23-33 days after passing Farwell. Travel time from release to Farwell for the remaining smolts detected at Farwell was considerably longer and ranged between 12-30 days. All were subsequently detected at the mouth 3-11 days after passing Farwell. Since the cumulative travel time for the fish detected at Farwell from release to the mouth (median=30.6 days) was similar to travel time for tagged fish as a whole (34.1 days), these fish are probably indicative of the fish not detected at Farwell and many smolts likely migrated quickly from the tributaries and resided in the Fraser River before entering the SOG.

Despite the longer residence time, survival in freshwater was relatively high, and the comparative importance of the Chilko and Chilcotin rivers as a mortality hotspot is uncertain for these

Chilko Chinook. Survival was higher in the tributaries than in the mainstem as a whole (Figure 9), but these habitats differed substantially in both segment length and the travel time. Survival rates per unit distance and especially per unit time showed the reverse pattern with lower survival rates in the tributaries than in the mainstem; however, there was extensive overlap of the 95% confidence intervals on all estimates because of the low detection efficiency of receivers at Farwell, which bounds the two regions. Additionally, these confidence intervals are underestimated for survival rate per week because they do not take into account variability in the median travel time. For wild Chilko sockeye, the Chilko and Chilcotin rivers have been identified as zones of high mortality (Clark et al. 2016), and the steepest decline in survival occurred between Chilko Lake and Henry's Bridge. As Chinook smolts were released just downstream of this area, they were able to avoid some of the substantial predation that typically occurs there (Furey et al. 2016).

Only one Chilko Chinook was subsequently detected on the ocean sub-arrays and we were therefore unable to estimate early-marine survival or residence time within the Strait of Georgia. Since sub-arrays capable of detecting high frequency transmitters were deployed only to the north of the Fraser River, this one fish (and the ~23 other smolts implanted with early tags that were not detected) provides evidence that Chilko River Chinook do not exit the Strait of Georgia via the northern route. As none of the smolts tagged with late activation tags were ever detected, this provides strong evidence that smolts do not exit to the north within the five months after ocean entry. This conclusion is supported by trawl surveys which suggest that Chinook salmon remain in the SOG for 3-4 months with populations that entered the Strait in spring (including Chilko Chinook) being replaced by South Thompson stocks by mid-September (Beamish et al. 2011).

It seems unlikely that the single Chilko Chinook detected in the ocean actually left the Strait via the northern route. This individual migrated quickly to the north and was detected at NSOG on May 31st, but made a second pass two days later indicating some milling behaviour or a return to the southern Strait. The probability is low that fish exited the Strait without detection because there are two sub-arrays deployed to the north of NSOG in the Discovery Islands and Johnstone Strait[1,2]. Trawl surveys

[1] The detection efficiency of the Discovery Islands sub-array was 75% for VEMCO V4-1H acoustic tags implanted in Seymour River steelhead in 2015 (Porter et al. 2016). This value may be somewhat different for Chilko Chinook since they were implanted V5-1H tags which transmit at a higher power (143 vs 134 dB), but were programmed with longer intervals between transmissions in order to conserve battery life (average of 30 vs 20 transmissions per minute). Additionally, the steelhead used in 2015 were significantly larger than the Chinook (207 vs 112 mm average fork length) and could expected to be swimming much faster and thus remain within range of the receivers for substantially less time (assuming no growth since

suggest that most Chilko Chinook identified in the catch are captured in the southern strait near the Gulf Islands (per. comm. 2016, Chrys Neville, Pacific Biological Station, Nanaimo BC). Thus, it is possible that Chilko Chinook left via the Strait of Juan de Fuca to the south, similar to a small number of Thompson River Chinook (and a single Big Qualicum River Chinook) that were detected at the JDF sub-array in previous studies (using tags that could be detected to the north and south; Welch et al. 2011; Neville et al. 2015).

We explored the possibility that our sample size was too small to expect sufficient numbers to survive to reach the northern detection sites. To do so, we extrapolated the early marine survival rate calculated in 2016 for Age 1 Chilko sockeye (59% per 100 kms) that migrated directly north, to the sample size available for Chinook at ocean entry (n=24). Using these values, we would expect that 8.5 of 50 released Chilko Chinook smolts should have survived the 200 km migration to the Discovery Islands sub-array in 2016 if they migrated directly north. If the detection efficiency at Discovery Islands was 75%, then we should have detected approximately six Chinook smolts rather than none. Although these numbers are small, they indicate that some smolts should have been detected exiting the Strait of Georgia if the Chinook smolts migrated directly north after river exit. The probability of detecting zero of eight expected (when the joint probability of survival and detection at DI is $(0.59)^2 \cdot 0.75=0.26$) is $(1-0.26)^8=0.09$. The survival rate for smolts that reside in the SOG is unknown, but is presumably much higher than during active migration.

Another consideration is that natural mortality within the river or strait could have been increased by the effects of the tags or the tagging process; however, tag burdens averaged only 4.1% (range 2.8-5.3% in air) which is below recommended limits (Chittenden et al. 2009; Brown et al. 2010; Rechisky and Welch 2010; Collins et al. 2013), and the fish had several days to recover prior to release. There was also no evidence of an effect of tag burden on survival when we tested this hypothesis using tag burden as an individual covariate in our survival models. Finally, survival was relatively high in the Chilko River after release when effects of tag burden are most likely manifest.

Finally, transition to saltwater imposes an additional stress that may augment any tag effects (Boeuf 1994; reviewed in Hinch et al. 2006) Acoustic-tagged Chilko Lake sockeye smolts experienced

tagging and a swim speed of 1 body length per second (Drenner et al. 2012), the steelhead would be migrating at 0.74 km/hr versus 0.4 km/hr for the Chinook).

[2] Assuming a detection probability of 75% at both Discovery Islands and Johnstone Strait (Porter et al. 2016), the probability of one tag passing both sub-arrays undetected is 25%^2=6%.

elevated mortality relative to controls after transition to saltwater in one captive study (Clark et al. 2016); however, the authors expressed concern that many fish failed to feed while in captivity even before transition to saltwater, and that the saltwater concentration may have been too high. No additional mortality was seen on transition to saltwater in acoustic-tagged smolts for Capilano Chinook (Porter et al. 2010; Appendix A) or Cultus sockeye (Collins et al. 2013). Because our Chilko Chinook smolts moved slowly in the river, they had over a month on average to recover from tagging before reaching the ocean in addition to 4-5 days between tagging and release to the river. Thus, it seems unlikely that tag effects reduced the survival probability of Chilko Chinook relative to their untagged counterparts.

## 5. Conclusion

Half (49%) of the Chilko Chinook smolts survived freshwater migration, which is comparable to estimates available for other populations or species migrating similar distances downstream. Most of these hatchery-origin smolts remained in freshwater for over a month (and up to 56 days) which is markedly different from the rapid downstream migration observed in wild sockeye smolts. Because we did not detect any Chilko Chinook smolts exiting northwards out of the Strait of Georgia, we were not able to estimate early-marine survival or residence time. The most parsimonious conclusion is that the Chilko Chinook, similar to the Thompson River Chinook we tagged earlier (Welch et al. 2011), did not migrate directly north after river exit. The tag battery lifespan was sufficient to detect smolts that exited the Strait using the northern route before mid-September. Lack of detection indicates that the Salish Sea could be a mortality hotspot for Fraser River Chinook, but we caution that the sample size was modest and that smolts may have either left via the unmonitored southern route or resided in the Strait beyond September. It is possible that Chilko Chinook smolts may reside in the Strait of Georgia beyond the summer since Neville et al. (2015) caught and tagged at least one Chilko Chinook in late September in the central SOG.

## 6. 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.*

Although we were not able to estimate survival and residence time of Chilko River Chinook in the SOG to "*determine whether the survival of salmon and steelhead in the ocean can be quantified and separated from their survival in the Salish Sea to try to isolate the survival impacts of factors related to ocean processes versus those related to Salish Sea processes*", we did estimate freshwater survival during migration which can be used to *"improve the accuracy of adult return forecasting for natural spawning, harvest, and hatchery management"*. We also demonstrated that Chilko Chinook appear to have similar marine behaviour to several South Thompson River Chinook stocks, in that very few fish were ever detected leaving the SOG. Further, we extended the range of tagged smolts down to smolts ≥10 cm from the previous 14 cm limit.

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

The objectives were partially met. We estimated survival and travel time of Chilko River Chinook during the downstream migration. Without much empirical data, we hypothesized during the development of the proposal that smolts may migrate north quickly, and if so we would have the ability to estimate survival and residence time in the SOG; however, we found that smolts likely do not migrate quickly to exit the SOG via Johnstone Strait.

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

There were no differences. We identified in the proposal the possible outcomes (see Introduction).

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

There were no major unexpected outcomes. We suspected that detection in the ocean would be low given the sample size and sparse nature of the 180 kHz telemetry array. We were surprised by the long travel time from the Chilko River to the mouth of the Fraser River, and the comparatively high freshwater survival observed.

## 7. Lessons Learned

*Key lessons learned from this activity:*

- Migration time of acoustic tagged hatchery-reared Chilko River Chinook was over a month on average (median of 34 days) which is dramatically longer than observed for wild Chilko Lake sockeye over the same area (median of <6 days 2010-2016).

- Despite this extended residence, freshwater survival was 49% (±8% SE) to the Fraser River mouth.

- The lack of detections on the Discovery Islands and Johnstone Strait sub-arrays provides good evidence that this population of Chinook likely does not leave the Strait of Georgia via the northern route before mid-September.

*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.*

Early marine survival and residence timing of Chinook smolts in the SOG can be better resolved in future studies by either 1) increasing the number of tagged smolts released and instrumenting the southern exit from the SOG (at JDF) with acoustic receivers capable of detecting 180 kHz tags, or 2) capturing larger juvenile salmon in the SOG (by micro-trolling or seine) later in the summer. These fish can be implanted with 69 kHz tags that are compatible with all of the receivers in the greater Salish Sea area and can be programmed to last years. This would permit determining the exit timing from the SOG, the return timing to the SOG, the entry timing into the Fraser River, and survival during in each phase. Additional receivers or mobile surveys within the Strait of Georgia (Gulf Islands region) would also help to distinguish between smolt mortality and residence.

*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.*

This project builds off of the recent expansion and testing of new telemetry arrays. In 2015, OTN agreed to a long-term loan of 41 VR4 receivers to the PSF and the SSMSP. The PSF then funded

Kintama to design and deploy dual-frequency sub-arrays in the Discovery Islands and Johnstone Strait, and to test the performance of the array at detecting 180 kHz tags.

The 2016 project was conducted in cooperation with DFO's Salmonid Enhancement Program. DFO management approved our request to tag at a SEP facility on relatively short notice (Chehalis Hatchery), and SEP staff worked with us on tagging logistics. We hope the survival and travel time estimates reported here will be considered when the population is assessed as an indicator stock. Finally, survival during the 600 km migration downstream was previously unknown and can be incorporated into stock assessment models.

## 8. Deliverables

The deliverables for this project are complete:

- Progress reports to SSMSP submitted May 27$^{th}$, 2016
- Final report to SSMSP (this document)
- An animation of the movements of the Chilko River Chinook smolts released in 2016 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.

These results will also be reported in DFO's State of the Ocean Technical Report in 2017.

# Dissemination of Results

## 8.1. Conference Presentations

Use of Telemetry to Investigate Residence Time and Survival of Fraser River Chinook in the Strait of Georgia Salish Sea. Salish Sea Marine Survival Project Workshop (2016), Bellingham, WA, USA. Dec 2016.

Use of Telemetry to Investigate Residence Time and Survival of Fraser River Chinook in the Strait of Georgia Salish Sea. Salish Sea Marine Survival Project Workshop (2016), Nanaimo, BC, Canada. Nov 2016.

## 8.2. Potential upcoming presentations

WA-BC Chapter of the American Fisheries Society 2017 Annual General Meeting, Spokane, WA, USA. State of the Pacific Ocean: 2017 Workshop, Nanaimo, BC, Canada.

BC Salmon Farmers Association Research Review Workshop, Nanaimo, BC, Canada.

Salmon Ocean Ecology Meeting, Seattle, WA, USA.

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## 10. Financial Summary

Kintama requested $127,293 from the SSMSP to "Investigate Residence Time and Survival of Fraser River Chinook Salmon in the Strait of Georgia". This project builds off of the recent expansion and testing of new telemetry arrays. In 2015, OTN agreed to a long-term loan of 41 VR4 receivers to the PSF and the SSMSP. The PSF then funded Kintama to design and deploy dual-frequency sub-arrays in the Discovery Islands and Johnstone Strait, and to test the performance of the array at detecting 180 kHz tags. The project conducted in 2016 is detailed in the May 13$^{th}$ 2016 agreement between the PSF and Kintama.

Aproximately $22K was provided in-kind by Kintama, which primarily covered staff time during the planning phase and truck use during field operations.

Kintama submitted invoice #2016-005 ($104,655) to the PSF for 100 transmitters, tagging, equipment lease, and deployment/recovery of Chilcotin River receivers. 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 ($22,638).

**Expenses**

Professional fees, labour: $60,360
Materials, supplies, equipment: $49,850
Overhead: $11,021
Taxes GST (for services): $6,062
Total from SSMSP: $127,293