Kintama Research Corp.
10-1850 Northfield Road
Nanaimo, British Columbia
Canada V9S 3B3
T: (250) 729-2600
F: (250) 729-2622

**"Creating a Revolution in Marine Science"**

# *Acoustic Telemetry Measurements of Survival and Movements of Adult Steelhead (Oncorhynchus mykiss) within the Skeena and Bulkley Rivers, 2008*

## *PROJECT # 5310-30 Skeena LR (Sonic Telemetry Investigations-2008)*

May 20, 2009

**Location of the POST acoustic telemetry array in 2008.** Base map credit: *GLOBE Task Team et al., eds., 1999. The Global Land One-kilometer Base Elevation (GLOBE) Digital Elevation Model, Version 1.0. National Oceanic and Atmospheric Administration, National Geophysical Data Center, 325 Broadway, Boulder, Colorado 80305-3328, U.S.A. (URL:http://www.ngdc.noaa.gov/mgg/topo/globe.html).* Bathymetric and topographic data courtesy of the Department of Natural Resources, Canada. 

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## Executive Summary

A pilot project using acoustic telemetry was designed and deployed in the Skeena and Bulkley River system in summer 2008 by Kintama Research, with the assistance of Ministry of Environment staff and local river guides. This project was intended to test the technical feasibility of using acoustic technology in the free-flowing Skeena River to answer several important questions about the survival and migratory behaviour of returning adult steelhead (*Oncorhynchus mykiss*). We deployed twelve acoustic receivers in the river 19-21 August 2008, and we subsequently tagged and released 84 returning wild steelhead from two collection sites in early September: (a) the Tyee sockeye test fishery near the Skeena River mouth and (b) a site located 300 m below the Moricetown Falls in the Bulkley River canyon. Individually identifiable Vemco acoustic tags (V9-2H or V13-1H) were externally attached just below the dorsal fin of 34 steelhead at Tyee and 50 steelhead at Moricetown. We recovered all receivers 24-26 November 2008 approximately three months later. Over the deployment period, a total of 118,159 detections were recorded from 61 individual steelhead. The data were compiled and we estimated survival and detection efficiency using two methods: 1) a simple division of the number detected by the number released (adjusted for detection efficiency [Jolly 1982] and 2) for the Tyee release group we were able to use a Cormack-Jolly-Seber model where survival, φ, was constrained to be a function of distance $\varphi_{(distance)}p_{(segment)}$. This constrained model performed better than a model where survival was allowed to vary freely at each sub-array.

Most steelhead released at Tyee travelled upstream in a unidirectional manner with the majority passing the lower Skeena receivers by 30 September. "Apparent survival" estimates of the rate of decline in fish numbers with distance followed a smooth curve of exponential decline (apparent survival/km = 0.992, 95% confidence interval: 0.988-0.997). We define "apparent survival" in its normal technical sense; that is, if all tags operate without premature failure, and no tag loss from the animal, emigration to side tributaries, or behavioural switches to cause the animal to take up residence in the river occurs, then the "apparent survival" measures the actual probability of survival for an animal migrating up the river.

Although there were no receivers downstream of the Tyee release site, the relationship between survival and distance suggests that downstream movement was minimal after release. Nineteen of the 34 steelhead (estimated apparent survival 51% ± 11%) tagged at Tyee reached the first sub-array (at RKm 109), and

four of these nineteen were subsequently detected in the Bulkley River 270 km (RKm 285) upstream of the release site (estimated apparent survival 14% ± 9%). Only four fish tagged at Tyee were detected on downstream receivers after first being detected at upstream locations. Owing to the configuration of the 2008 array, it is not possible to determine what proportion of the general decline in numbers with distance ("apparent survival") represents losses due to mortality after release or due to migration into tributaries.

Forty-two of 50 fish tagged and released in the Bulkley River at Moricetown (RKm 314) were subsequently detected on the array; the estimated apparent survival to the most upstream line (RKm 352) was 68%. Nine steelhead initially moved >11 km downstream to RKm 303 after release (four moved 21 km; two moved 29 km downstream); five of those nine then moved back upstream to the up-river Bulkley detection sites (8% of the fish released remained downstream). No steelhead released at Moricetown were detected on the Skeena River receivers. It is not possible to determine what proportion of the steelhead tagged and released at Moricetown moved downstream for less than 11 km based on the 2008 study design; however, the average travel rate between release and the first upstream array was extremely low (average of 12 days to move ten kilometres) which suggests that many fish did not move directly upriver after release. This evidence coupled with the extensive movements some steelhead made downstream and then upstream past the release site may be of importance for the interpretation of data from the Moricetown mark and recapture program which is used to estimate the abundance of steelhead in the Bulkley River.

For both release groups, estimated steelhead abundance along the array route declined with upstream distance. Potential causes include: (1) movement into side tributaries; (2) overwintering in the mainstem river; (3) removal in fisheries; (4) mortality from other causes. To distinguish between mortality and emigration into lower river tributaries, future studies should include additional receiver sites below side tributaries known to support significant steelhead runs.

The performance of the pilot array in the Skeena River was high with all units recovered and functional upon download. Although sample sizes for some sites were small, the estimated detection efficiencies were over 90% for four of five lines estimable for the Tyee release group (three lines were 100%) and were 100% for two of three lines estimable for the Moricetown fish. Overall acoustic conditions were poorer for two sites (RKm 325 and 118). Our results demonstrate that it is feasible to use acoustic telemetry with high detection efficiencies to measure survival post release of returning Skeena River steelhead.

# 1.0 Introduction

The Skeena River is one of the largest watersheds flowing entirely in British Columbia and drains an area of 54,000 $km^2$. All five Pacific salmon species and 30 other fish species, including multiple populations of steelhead trout, use the Skeena's spawning and rearing habitats. Many of the salmon and trout populations face intense harvest exploitation during the summer while returning to these spawning grounds. Chudyk and Narver (1976) reported that fishing pressure from commercial, recreational and aboriginal fisheries have been causes for declines in Skeena River steelhead. Currently, the two main commercial fisheries in the Skeena watershed are the sockeye and pink salmon gillnet fisheries. Skeena River steelhead are subject to significant fishing pressure as a result of incidental capture in these gillnet fisheries (Oguss and Evans 1978).

Despite the many different management strategies, stock assessment techniques, and research programs that have been implemented since the 1970s on Skeena River fish populations, the Skeena steelhead are thought to still be declining (Department of Fisheries and Oceans 2008). In 2006, the Tyee Test Fishery, located at the mouth of the Skeena River, identified an unexpectedly large sockeye run while steelhead numbers appeared relatively low. A commercial sockeye opening in Area 4 subsequently exposed co-migrating Skeena steelhead to fishing pressure for 11 consecutive days. This decision caused immense public debate and controversy and led to a demand for review of Skeena River salmon and steelhead management strategies. In 2007, an independent science review panel (ISRP) reviewed these strategies and other issues facing the Skeena River watershed (Walters et al 2008).

Walters et al (2008) issued a review containing 23 recommendations for the management of Skeena River steelhead. A pilot project was subsequently initiated by the Ministry of Environment (MOE), local non-governmental organizations (NGO's), and Kintama Research Corporation to establish if acoustic telemetry could address recommendation 13 in the review (and other issues concerning Skeena River salmonids): "*There should be a large-scale radio tracking experiment to directly estimate the proportion of steelhead removed from the water in the Area 4 fisheries, and the proportion of non-captured fish escaping past Tyee. This experiment would settle two issues, the overall exploitation rate of steelhead, and the proportion of those captured that survive the live-release process.*" Collecting data in these areas would compliment multiple steelhead studies previously conducted in this area (Beere 1991a-d; 1995, 1996, 1997).

Acoustic telemetry has a significant advantage over radio telemetry in that the signals transmit effectively in both salt and freshwaters, potentially allowing much broader geographic study of the species. Offsetting this potential advantage, the deployment of large-scale acoustic arrays is more complex than when radio frequencies are used because of the nature of acoustic propagation in water. In recent years, large-scale acoustic telemetry systems have been used to study the survival and migratory behaviours of many fish species (e.g., Chittenden et al 2008, Welch et al 2008, Melnychuk et. al 2007) and the large-scale Pacific Ocean Shelf Tracking acoustic array "POST" www.postcoml.org) has been deployed semi-permanently along the Pacific Shelf (including two major rivers) between northern Oregon and southeast Alaska. However, in fast-flowing and turbulent river systems like the Skeena and Bulkley, the detection efficiency of the receivers may be degraded and both the deployment and successful recovery of the units is more challenging.

To test these performance concerns and to obtain preliminary data on the apparent survival and migratory behaviours of returning Skeena River steelhead, a pilot sub-array of 12 VR2 acoustic receivers was deployed in the Skeena and Bulkley rivers (Figure 1-Figure 3) in the summer of 2008. Adult steelhead were captured in two locations (Tyee and Moricetown) and tagged externally with acoustic transmitters. The equipment functioned effectively and all units were recovered and successfully uploaded. Results showed that the apparent survival and movements of adult steelhead trout could be monitored using acoustic telemetry throughout the Skeena River system successfully and cost effectively. This report details our findings.

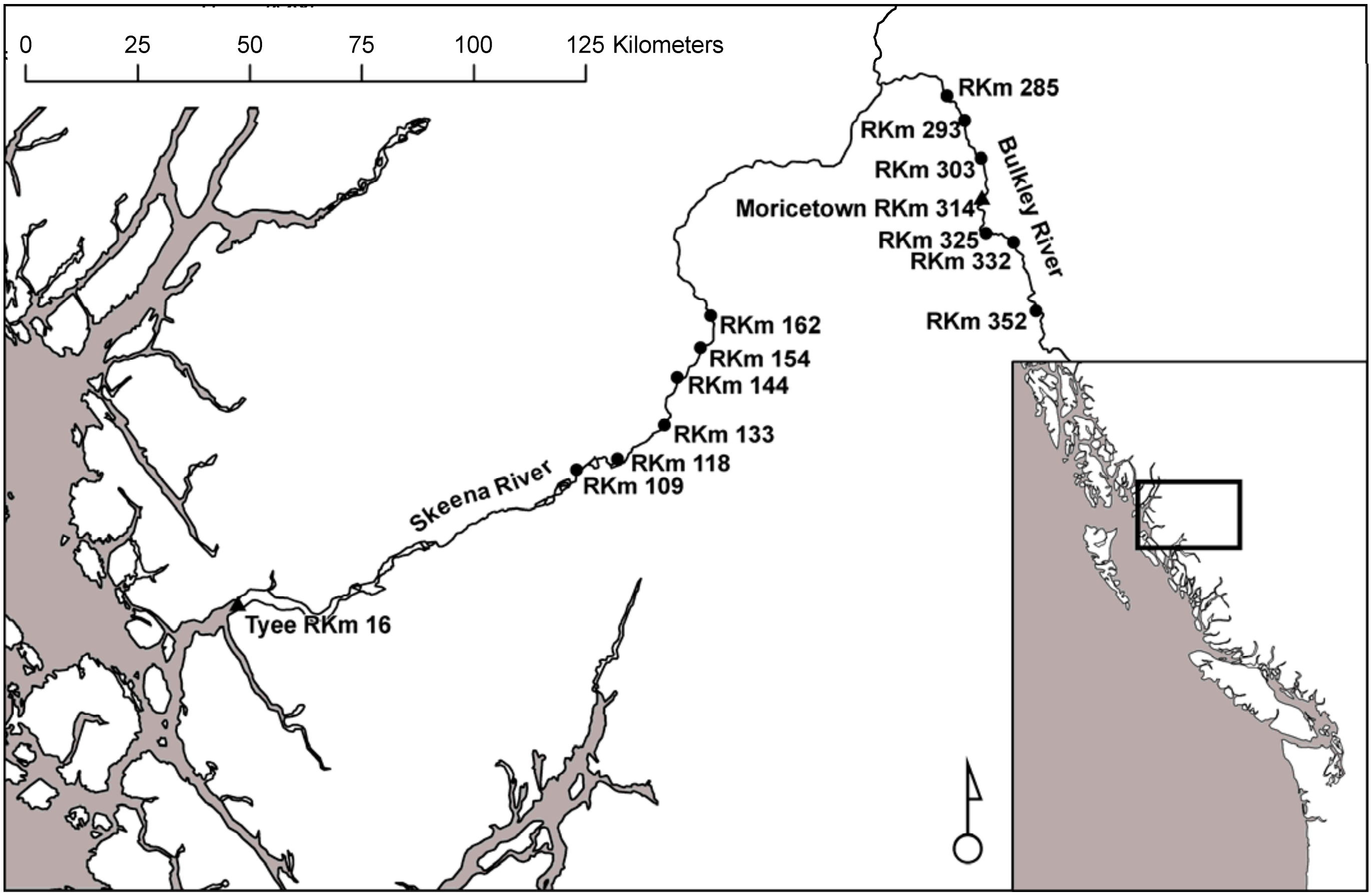



**Figure 1. Location of acoustic receivers deployed in the Skeena and Bulkley River. The black dots indicate the twelve receiver locations used to monitor acoustically tagged steelhead during the fall of 2008. These distances are estimated as river kilometer (RKm) from the Skeena River mouth. Inserts provide details of the Skeena array in relation to the entire Pacific Ocean Shelf Tracking (POST) array during the 2008 field season. Bathymetric and topographic data ©Department of Natural Resources Canada. All rights reserved.**

# 2.0 Methods

## 2.1 Acoustic Sub-array

An acoustic sub-array consisting of twelve Vemco VR2 acoustic receivers was deployed in the Skeena and Bulkley Rivers to monitor movements and migratory patterns of adult Skeena steelhead in 2008. The Vemco VR2 receivers consist of a transducer; internal electronics with clock capable of measuring and logging validated detections to flash memory; and a battery, all housed in a submersible case. These receivers are capable of detecting and recording the passage of fish implanted with tags which transmit unique ID codes, potentially allowing for the reconstruction of the complete movement and apparent survival record of individual tagged animals.

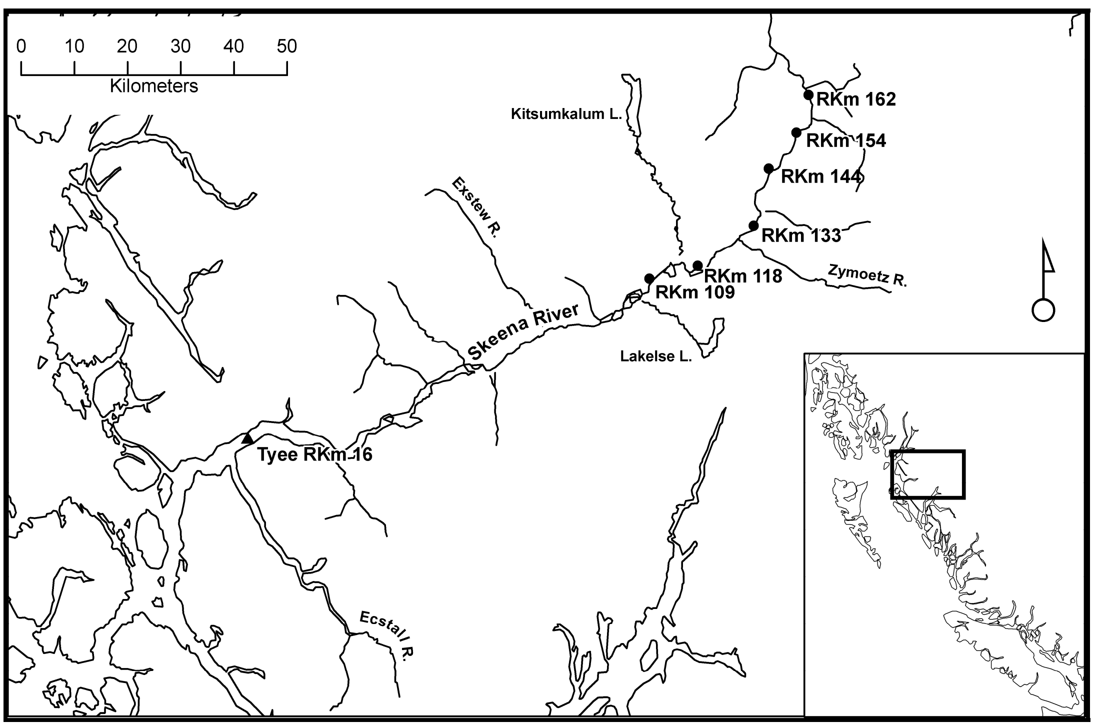



**Figure 2. Location of acoustic receivers deployed in the Skeena River in relation to local tributaries. The black dots indicate the six receiver locations. Bathymetric and topographic data ©Department of Natural Resources Canada. All rights reserved.**

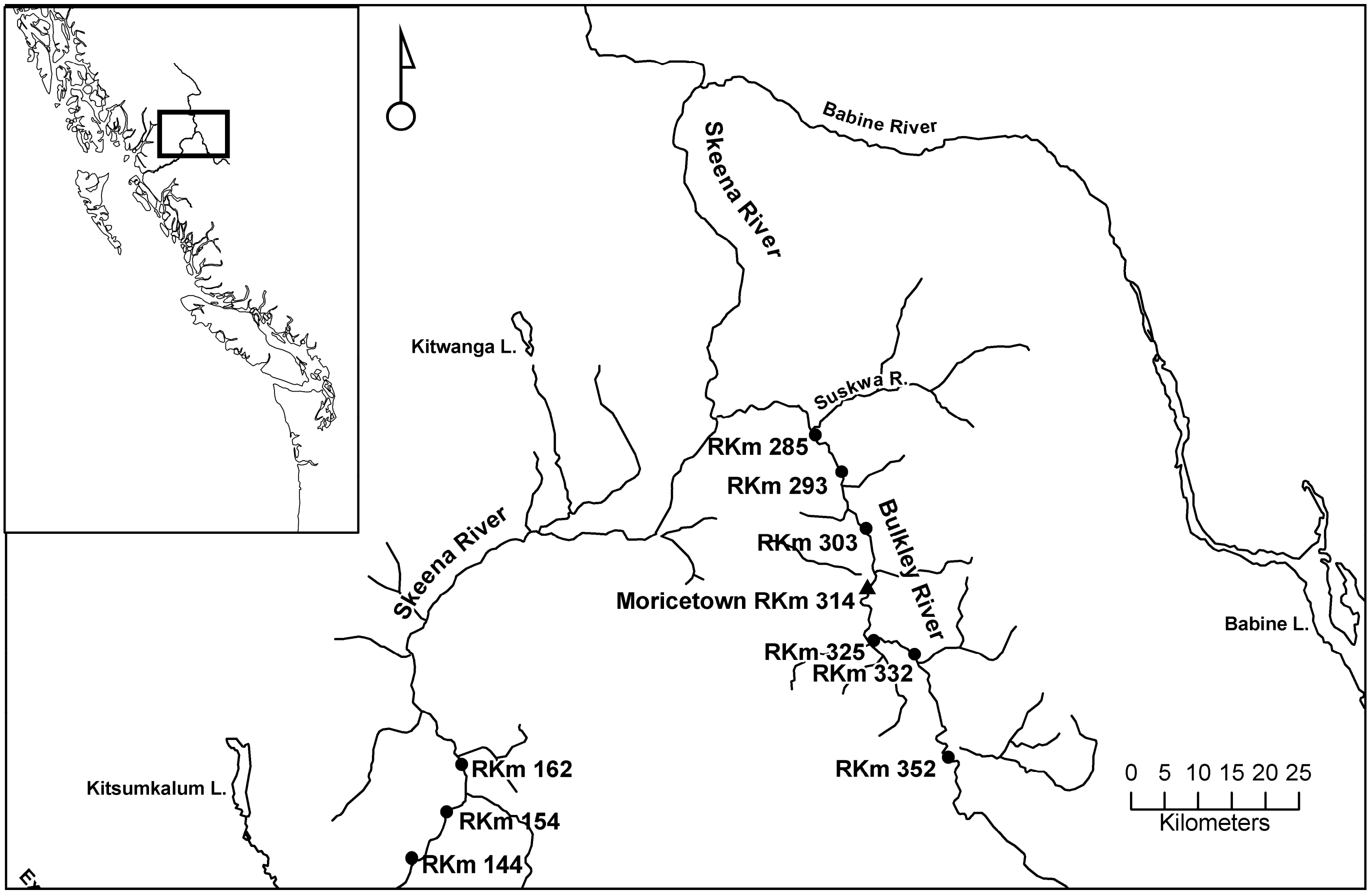



**Figure 3. Location of acoustic receivers deployed in the Bulkley River in relation to local tributaries. The black dots indicate the six receiver locations. Bathymetric and topographic data ©Department of Natural Resources Canada. All rights reserved.**

The sub-array in the Skeena and Bulkley Rivers was compatible with the Pacific Ocean Shelf Tracking (POST) array; POST is a large scale marine acoustic tracking network which extends from northern Oregon, throughout coastal British Columbia, and up to southeast Alaska (Figure 1; www.postcoml.org). Acoustic receivers are deployed in specific locations in the coastal ocean with set spacing with the goal of providing complete coverage of coastal marine shelf areas from the beach to the shelf break as well as in multiple locations within several river systems.

During 19-21 August 2008, Kintama Research, with the assistance of local river guides, deployed six acoustic receivers within the Skeena River. These receivers were deployed from river kilometer (RKm) 109 to 162 from the Skeena River mouth (Table 1, Figure 1, Figure 2). From 20-21 August 2008, another six receivers were deployed in the Bulkley River. Three receivers were deployed downriver of the

Moricetown Canyon from 285 to 303 RKm and three above the canyon from 325 to 352 RKm from the Skeena River mouth (Table 1, Figure 1, and Figure 3). Locations which appeared to have a high probability of detecting the acoustically tagged steelhead were selected and positions recorded using a WAAS enabled handheld GPS receiver. All units were successfully recovered three months later on 24-26 November 2008.

**Table 1. Detail of receiver and tagging locations within the Skeena and Bulkley Rivers during the 2008 field season. Numbers in parentheses indicate estimated distance (km) from release site.**

| River | Site Description | Position in River RKm | Distance to Skeena River Mouth Km | Latitude | Longitude |
|---|---|---|---|---|---|
| Skeena | Tyee tag and release | 16 | 16 | 54.20559 | -129.90310 |
| | Receiver locations | 109 | 109 (93) | 54.47767 | -128.74283 |
| | | 118 | 118 (102) | 54.49922 | -128.60217 |
| | | 133 | 133 (117) | 54.56613 | -128.43874 |
| | | 144 | 144 (131) | 54.66154 | -128.39310 |
| | | 154 | 154 (141) | 54.72178 | -128.31149 |
| | | 162 | 162 (149) | 54.78541 | -128.27533 |
| Bulkley | Receiver locations | 19 | 285 (29) | 55.22025 | -127.43857 |
| | | 27 | 293 (21) | 55.16977 | -127.37907 |
| | | 37 | 303 (11) | 55.09317 | -127.32496 |
| | Moricetown tag and release | 48 | 314 | 55.01540 | -127.32510 |
| | Receiver locations | 59 | 325 (11) | 54.94212 | -127.31337 |
| | | 66 | 332 (18) | 54.92228 | -127.21872 |
| | | 86 | 352 (38) | 54.78308 | -127.14644 |

## 2.2 Tagging

Adult steelhead were caught and tagged between August 24 and September 21 at two locations. Thirty-four steelhead were tagged at the Tyee Test Fishery while 50 additional steelhead were tagged 300 meters below the Moricetown Canyon Falls. Each fish was externally tagged just below the dorsal fin with an individually identifiable Vemco V9-2H or V13-1H coded transmitter (Table 2). Vemco V9-2H transmitters are 9 mm in diameter and weigh 3.5 grams; V13-1H are 13 mm in diameter and weigh 6.0 grams. Both tag types used in the Skeena study operate at 69 KHz frequency and were coded for the POST code map.

**Table 2. Summary of sample size, tag type, local release date, and release site for wild, adult steelhead externally tagged with Vemco acoustic tags during the fall 2008 field season.**

| Tagging and Release Location | Distance to Skeena River Mouth (Km) | Number Released | Tag Type | Release Dates (2008) | Span of Release Dates |
|---|---|---|---|---|---|
| Tyee (Skeena RKm 16) | 16 | 25 | V13-1H | Aug 24 - Sept 5 | 13 days |
| Tyee (Skeena RKm 16) | 16 | 9 | V9-2H | Sept 7 - 21 | 15 days |
| Moricetown (Bulkley RKm 48) | 314 | 50 | V9-2H | Aug 26 - Sept 3 | 9 days |

The acoustic tags were attached externally using braided Spiderwire line. Prior to the actual tagging event, individual Spiderwire harnesses were created for each tag and fastened using epoxy. The harness location was distal to the transmission end of the tag such that the signal was not compromised by the attachment (Figure 4).

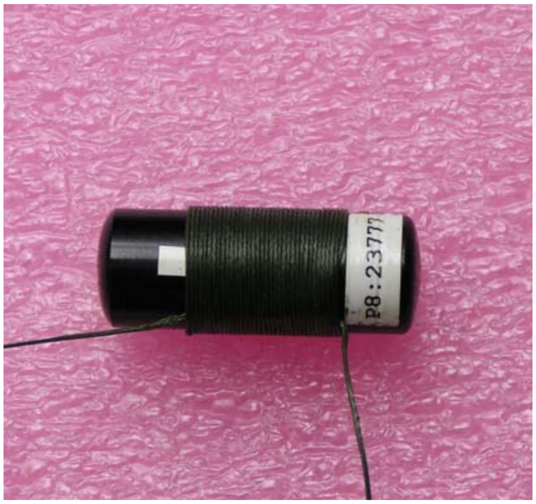



**Figure 4. A Vemco V9-2H tag after attaching the spiderwire line as a harness.**

The tagging trough was lined with 5 mm Thinsulate foam and a hole was drilled at one end to accommodate a hose used to supply a constant flow of water through the trough. Acoustic tags were applied on the left side of the steelhead with the transmission end directed posterior. Needles were threaded between the pterygiophores and surgeon's knot were used to securely join the ends (Figure 5). Tag number, sex, nose-fork length, and time of release were recorded. The condition of the fish or health release code was also recorded for each individual fish where one was a vigorous response and five was a moribund or a dying fish.

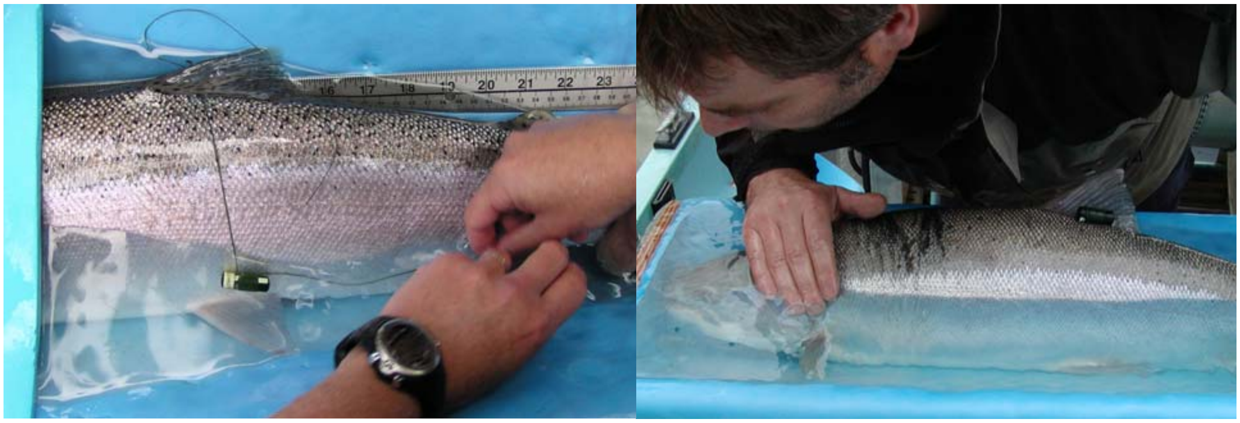



**Figure 5**. **Left: attaching an acoustic tag on the left side of the steelhead. Right: inspecting a recently captured Skeena steelhead in the tagging trough.**

### *2.2.1 Tyee tagging*

The Department of Fisheries and Oceans was responsible for the operations of the Tyee Test Fishery. The test fishing vessel deployed a 366 meter gill net, comprised of six strand monofilament, configured in ten, 36.6 meter panels (ranging from 89 mm to 203 mm mesh) to capture adult salmonids migrating into the Skeena River as an annual index of fish abundance. For the Skeena acoustic tagging project, steelhead were carefully removed from the gillnet soon after capture (net material was cut or manually broken). Specimens in relatively good condition were placed in a fish tote (approximately 1 cubic meter) which was filled with ambient, re-circulated water, for further evaluation. The majority of the fish at Tyee were caught and held until the end of the fishing set. Steelhead were then individually removed from the tank and placed in a tagging trough for tagging (Figure 5). A secondary mark was made using a paper hole punch to remove a small disk of adipose fin tissue. Once the fish were tagged and sampled, they were released immediately.

### 2.2.2 Moricetown tagging

The second tagging site was in the Bulkley River at Moricetown Canyon Falls. Wet'suwet'en Fisheries conduct an annual mark-recapture program to estimate adult salmon abundance. The program utilizes a jet-boat to deploy a beach seine and then mark caught salmonids (Figure 6). Recapture is accomplished via a dip net fishery approximately 300 meters upstream of the tagging site. In 2008, acoustic tags were applied in the manner described above. At Moricetown, the fish were caught, and immediately tagged and released. Prior to release, an individually numbered, coloured anchor-T tag was placed at the base of the dorsal fin and a secondary mark was made using a paper hole punch to remove a small disk of caudal fin tissue.

**Figure 6. Deploying a beach seine in the Moricetown Canyon in the Bulkley River.**

## 2.3 Data Analysis

All data files collected from the array underwent quality assurance and quality control procedures. System data recorded in the file header from the receivers were reviewed, and the data files checked for gaps or inconsistencies. Detections data were then compiled into an Access database for false detection screening and analysis of array performance, fish survival, and migratory behaviour.

### *2.3.1 False detection screening*

We identified and excluded any detection likely to be false using the First and Second Acceptance Criteria recommended by VEMCO (Pincock 2008). Detections met the first criteria if there was at least one short interval (<0.5 hour) between successive detections of an ID code on a receiver and if there were more short intervals between detections than long ones (>0.5 hour). Detections that did not meet the first criteria were then examined individually to determine if there was possible collision activity on the receiver (i.e. the second criteria). Collision can happen if two tags transmit at the exact same time. We considered there to be possible collision activity if there was another detection recorded within five minutes on either side of the detection in question.

### *2.3.2 Survival analysis*

**Method 1**

We used the number of fish detected at each receiver to estimate apparent survival to that location. (Apparent survival is the joint probability of survival, tag retention, and migration upstream to the receivers). Without receivers placed in tributaries to the Skeena and Bulkley Rivers, it is not possible to distinguish fish that failed to migrate up the mainstem from fish that died.

Minimum cumulative apparent survival estimates at each location were calculated by dividing the number of fish detected on each acoustic receiver by the number released. These values underestimate survival because they do not account for fish that may have passed the array but which were not detected. To correct for limitations in equipment performance at each detection site we calculated the estimates of detection efficiency (*p*) of each sub-line using the ratio of fish detected at each line ($m_i$) divided by the total number that swam past them ($m_i$ plus the number missed at the line but detected later, $z_i$) as described by Jolly (1982). The minimal survival estimates were then adjusted by dividing by the detection efficiency to obtain cumulative apparent survival estimates. Note that we were only able to make this adjustment for sub-arrays with (1) other sub-arrays further upstream and (2) with sufficient sample size. Detection efficiency was estimated using Method 1 for the sub-arrays at RKm 109 through 154 for the Tyee steelhead and for RKm 303 through 332 for the Moricetown fish. Sub-array RKm 293 probably had too limited a sample size, but is presented anyway.

**Method 2**

We used the Cormack-Jolly-Seber model (CJS) for live recaptures to estimate apparent survival ($\phi$) and detection probabilities (*p*) for the Tyee release group. CJS models, where tagged animals are detected at fixed locations along a migration route rather than re-captured at fixed sampling times, are widely used for modelling survival in migrating salmon smolts (e.g., Burnham et al. 1987; Skalski et al. 2001; Zabel and Achord 2004). The model assumes a linear migratory sequence and so we applied this technique only to the Tyee release group; the steelhead released at Moricetown migrated both upstream and downstream. We considered RKm 325 to be the last location because no Tyee released steelhead were detected further upstream. All mark-recapture models were implemented with Program MARK (ver. 5.1; White and Burnham 1999).

We considered two candidate models. Detection probabilities in all models were line-specific $p_{(time)}$, where the 'time' factor represents re-capture locations at receiver lines. One survival model was the fully varying CJS model, $\phi_{(segment)}$, with separate survival estimates for each segment. The second model tested survival as a function of distance, $\phi_{(distance)}$. We estimated a variance inflation factor ($\hat{c}$) to compensate for over dispersion, or extra-binomial variation, in estimated probabilities (Burnham et al. 1987). We estimated $\hat{c}$ (=3.0) using the median c-hat procedure available in program MARK. Because the sample size was limited in this study, we were only able to run this test on the least-parameterized model $\phi_{(.)}\, p_{(.)}$ where all segments were assumed to have the same survival and detection probabilities. Assuming that our candidate models fit the data better than the constant model, this should provide an overestimate of the standard errors, and thus the statistical uncertainty in the results. $QAIC_c$ values, corrected for extra-binomial variation and sample sizes, were computed for model comparison. The segment-specific survival rates were multiplied to obtain cumulative apparent survival estimates. The variance around the cumulative estimates was calculated using the Delta method.

### *2.3.3 Analysis of migratory behaviour*

We conducted a series of simple analyses on movement behaviour. Travel rate was estimated as the difference in time between the last detection on a sub-line (departure date) and the first detection on the next sub-line (arrival date) divided by the distance between sub-lines. These estimates were only conducted for fish heard on both lines bracketing the segment in question.

# 3.0 Results

## 3.1 False Detection Screening

The false detection screening excluded a small number of sporadic detections (0.03% of total) and the vast majority of the retained data consisted of multiple detections closely spaced in time on a given sub-array. Most of the false detections (84%) were from a single receiver that was recording frequent signals from several dead or resident Moricetown-tagged fish. In fact, 82% of the total detections recorded in the Skeena and Bulkley rivers were from this one unit.

## 3.2 Unique ID Codes Detected at Each Location

### *3.2.1 Tyee steelhead detections*

Thirty-four adult steelhead were externally tagged with either a V9-2H or a V13-1H tag and released at the Tyee location. Of these, 19 (56%) were subsequently detected in either the Skeena or Bulkley rivers (Table 3; Table 4). Five of the 19 carried V9-2H tags (56% of V9s released) and the remaining 14 carried V13-1H (56% of V13s released). Four fish migrated beyond the Skeena and were detected in the Bulkley River (11% of V9 tags; 12% of V13 tags).

Most of the fish released at Tyee were health codes 1 (59%) and 2 (32%); no individuals were tagged with codes above 3 (Table 5). Of the four fish that were detected as far upriver as the Bulkley, three were health code 1 and one was a health code 3.

**Table 3. Number of unique acoustically-tagged adult wild Skeena steelhead recorded at detection sites in 2008.**

| Release Location | Tag Type | # Released | # Detected on Skeena receivers | # Detected on Bulkley receivers |
|---|---|---|---|---|
| Tyee | V9-2H | 9 | 5 | 1 |
| | V13-1H | 25 | 14 | 3 |
| *Tyee Total* | | 34 | 19 (56%) | 4 (12%) |
| Moricetown | V9-2H | 50 | 0 | 42 (84%) |

### 3.2.2 *Moricetown steelhead detections*

In the Bulkley River, 50 adult steelhead were tagged with a V9-2H tag and released at Moricetown (RKm 314). Eighteen (36%) were heard on the first upstream location while 34 (68%) reached the most upstream sub-array (RKm 352; Table 3, Table 4). Nine (18%) released steelhead travelled immediately downstream of the release location. Of these nine, five were subsequently detected on at least one of the receivers above the Moricetown release location. No steelhead tagged and released at Moricetown were detected in the Skeena River.

The majority of the Moricetown steelhead were health code 2 (84%) with the remainder being code 3 (Table 5). Over 64% percent of the code 2 adults (n=27) and 88% of the code 3 adults (n=7) were detected at the most upstream receiver.

**Table 4. Number of acoustically-tagged, wild, adult steelhead recorded at detection sites in the Skeena and Bulkley rivers in 2008. Distances estimated as river kilometres (RKm) from the Skeena River mouth (ocean).**

| Release Location | Tagging Location | Tag Type | Number Released | Skeena | | | | | | Bulkley | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | RKm 109 | RKm 118 | RKm 133 | RKm 144 | RKm 154 | RKm 162 | RKm 285 | RKm 293 | RKm 303 | RKm 325 | RKm 332 | RKm 352 |
| Skeena | T | V9-2H | 9 | 4 (44%) | 1(11%) | 3(33%) | 3(33%) | 3(33%) | 3(33%) | 1(11%) | 1(11%) | 1(11%) | 1(11%) | 0 | 0 |
| | | V13-1H | 25 | 14(56%) | 5(20%) | 11(44%) | 11(44%) | 10(40%) | 10(40%) | 3(12%) | 3(12%) | 2(8%) | 0 | 0 | 0 |
| | | **Total** | **34** | **18(53%)** | **6(18%)** | **14(41%)** | **14(41%)** | **13(38%)** | **13(38%)** | **4(12%)** | **4(12%)** | **3(9%)** | **1(3%)** | **0** | **0** |
| | | | | | | | | | | | | | | | |
| Bulkley | M | V9-2H | 50 | 0 | 0 | 0 | 0 | 0 | 0 | 2(4%) | 4(8%) | 9(18%) | 18(36%) | 37(74%) | 34(68%) |
| **GRAND TOTALS** | | | **84** | **18(21%)** | **6(7%)** | **14(17%)** | **14(17%)** | **13(15%)** | **13(15%)** | **6(7%)** | **8(10%)** | **12(14%)** | **19(23%)** | **37(44%)** | **34(40%)** |

T = Tyee Release at RKm16; M = Moricetown Release at RKm314

**Table 5. Number of acoustically tagged wild adult steelhead recorded at detection sites in the Skeena and Bulkley rivers in 2008, categorized by initial health assessment code at time of release. Health release code was recorded as level 1 representing a vigorous fish and 5 was moribund. Distances estimated as river kilometres (RKm) from the Skeena River mouth (ocean).**

| Release Location | Tagging Location | Tag Type | Health Release Code | Number Released | Skeena | | | | | | Bulkley | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | **RKm 109** | **RKm 118** | **RKm 133** | **RKm 144** | **RKm 154** | **RKm 162** | **RKm 285** | **RKm 293** | **RKm 303** | **RKm 325** | **RKm 332** | **RKm 352** |
| Skeena | T | V9-2H | 1 | 8 | 3 | 1 | 2 | 2 | 2 | 2 | 1 | 1 | 1 | 1 | 0 | 0 |
| | | | 2 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | V13-1H | 1 | 12 | 7 | 3 | 5 | 5 | 4 | 4 | 2 | 2 | 1 | 0 | 0 | 0 |
| | | | 2 | 10 | 5 | 0 | 4 | 4 | 4 | 4 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | | 3 | 3 | 2 | 2 | 2 | 2 | 2 | 2 | 1 | 1 | 1 | 0 | 0 | 0 |
| | | **Total** | | **34** | **18** | **6** | **14** | **14** | **13** | **13** | **4** | **4** | **3** | **1** | **0** | **0** |
| | | | | | | | | | | | | | | | | |
| Bulkley | M | V9-2H | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | | 2 | 42 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 3 | 6 | 13 | 30 | 27 |
| | | | 3 | 8 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 3 | 5 | 7 | 7 |
| | | **Total** | | **50** | **0** | **0** | **0** | **0** | **0** | **0** | **2** | **4** | **9** | **18** | **37** | **34** |
| **GRAND TOTALS** | | | | **84** | **18** | **6** | **14** | **14** | **13** | **13** | **6** | **8** | **12** | **19** | **37** | **34** |

Release Code: 1=vigorous, 5=moribund; T = Tyee Release at RKm16; M = Moricetown Release at RKm314.

## 3.3 Apparent Survival Estimates

We estimated apparent survival in two ways (see Methods). Method one was a simple division of the number detected on each sub-array by the number released (times 100 for percent) and then divided by the detection efficiency for that site. For method two, we used the recaptures-only CJS model as implemented in program Mark. The model assumes a linear migratory sequence and so we applied this technique only to the Tyee release group; the steelhead released at Moricetown migrated both upstream and downstream. In the CJS analysis, we tested two candidate models; the model where survival was tested as a function of distance had nearly 100% of the support within the set of the two models considered (Table 6). We used only this model to generate estimates of survival and detection probability.

**Table 6. Model selection results for recaptures-only survival and detection probability estimates for returning Skeena river steelhead released at the Tyee test fishery in 2008.**

| Model | Number of parameters | QAICc | ΔQAICc | Akaike weight |
|---|---|---|---|---|
| $\varphi_{(distance)}\, p_{(segment)}$ | 11.00 | 70.82 | 0.00 | 1.00 |
| $\varphi_{(segment)}\, p_{(segment)}$ | 18.00 | 86.33 | 15.51 | 0.00 |

### *3.3.1 Tyee steelhead apparent survival estimates*

Cumulative apparent survival estimates for returning adult steelhead follow a smooth exponential decline with distance upstream (survival/km = 0.992, 95% confidence intervals 0.988-0.997; Figure 7). The estimates obtained using the simple calculation (Method one: number detected over number released [times 100] and adjusted for detection efficiency where possible; Table 7; Figure 8) are very similar to those obtained using the CJS model (Table 8; Figure 9), but are somewhat more variable because they were not constrained to be a function of distance. (Very few steelhead were detected at RKm 118 and the resulting detection efficiency estimate [via Jolly 1982] artificially inflated the cumulative survival estimate above that obtained for the more downstream site.). The 95% confidence intervals are extremely large for all estimates because of the small sample size used in the pilot study.

The CJS method allowed us to estimate segment-specific apparent survivals rates for the Tyee release group (Table 9; Figure 10). Estimates are high and consistent (85-94%) with the exception of RKm 109 and 285. The lower values at these two sites reflect the greater distance the fish had to travel before arrival.

### *3.3.2 Moricetown steelhead apparent survival estimates*

The majority of the adult steelhead released at the Moricetown site swam upriver soon after release. However, nine individuals swam downstream far enough (>11 km) to be detected on the sub-arrays sited below the release site. Five of these nine subsequently turned around and were detected above the release site. The apparent survival estimates for the Moricetown fish thus reflect the split migration pattern (Table 7; Figure 8). The steelhead that swam downstream and then upstream are included in the estimates for both directions. Apparent survival to the first upstream receiver was 78% and minimum apparent survival at the last sub-array (38 km from release) was 68%. The survival estimates show a rapid drop with distance for the first upriver detection site, followed by a gradual decline. At least a portion of this initial drop may be caused by fish that swam downstream without returning upriver.

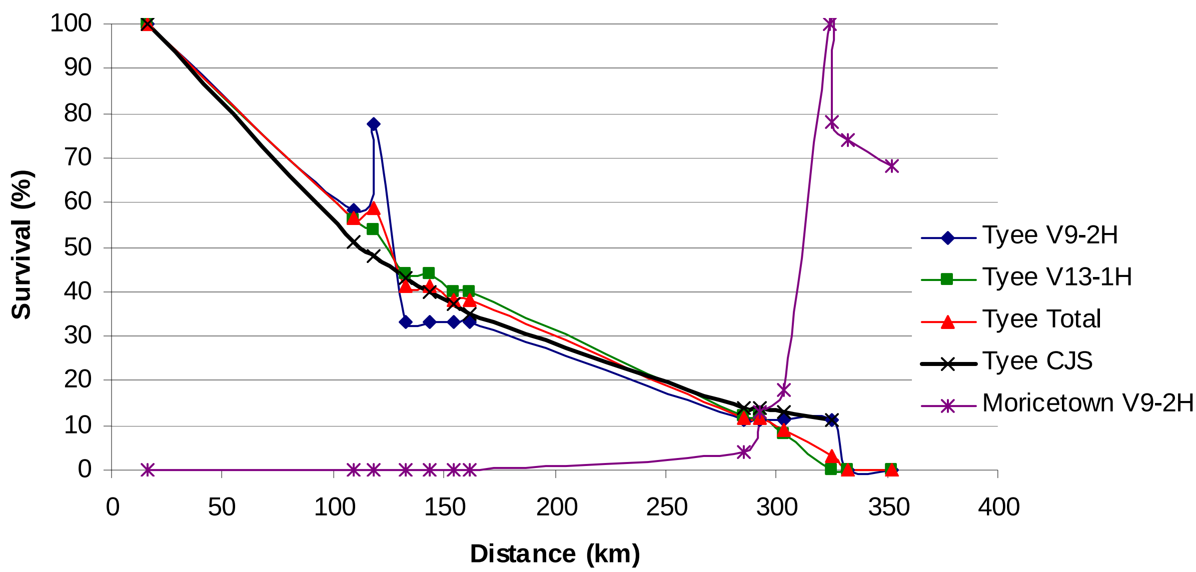



**Figure 7. Estimated cumulative apparent survivals of acoustically tagged wild adult Skeena River steelhead reaching each detection site in 2008 plotted against distance. Tyee V9-2H, Tyee V13-1H, Tyee Total, and Moricetown V9-2H were estimated using Method 1; Tyee CJS was estimated using Method 2.**

**Table 7. Cumulative apparent survival (%) estimated as number detected divided by number released (Method 1) for acoustically tagged wild adult steelhead in the Skeena and Bulkley Rivers in 2008. For the Tyee release group, estimates are corrected for detection efficiency until RKm 162. The sample size is too small to include this adjustment further upstream. For the Moricetown release group, estimates are corrected for detection efficiency between RKm 293-332.**

| Release Location | Tagging Location | Tag Type | Number Released | Skeena | | | | | | Bulkley | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | RKm109 | RKm118 | RKm133 | RKm144 | RKm154 | RKm162 | RKm285 | RKm293 | RKm303 | RKm325 | RKm332 | RKm352 |
| **Skeena** | T | V9-2H | 9 | 58 | 78 | 33 | 33 | 33 | 33 | 11 | 11 | 11 | 11 | 0 | 0 |
| | | V13-1H | 25 | 56 | 54 | 44 | 44 | 40 | 40 | 12 | 12 | 8 | 0 | 0 | 0 |
| | | **Total** | **34** | **56** | **59** | **41** | **41** | **38** | **38** | **12** | **12** | **9** | **3** | **0** | **0** |
| | | | | | | | | | | | | | | | |
| **Bulkley** | M | V9-2H | 50 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 13 | 18 | 78 | 74 | 68 |

T = Tyee Release at RKm16; M = Moricetown Release at RKm314.

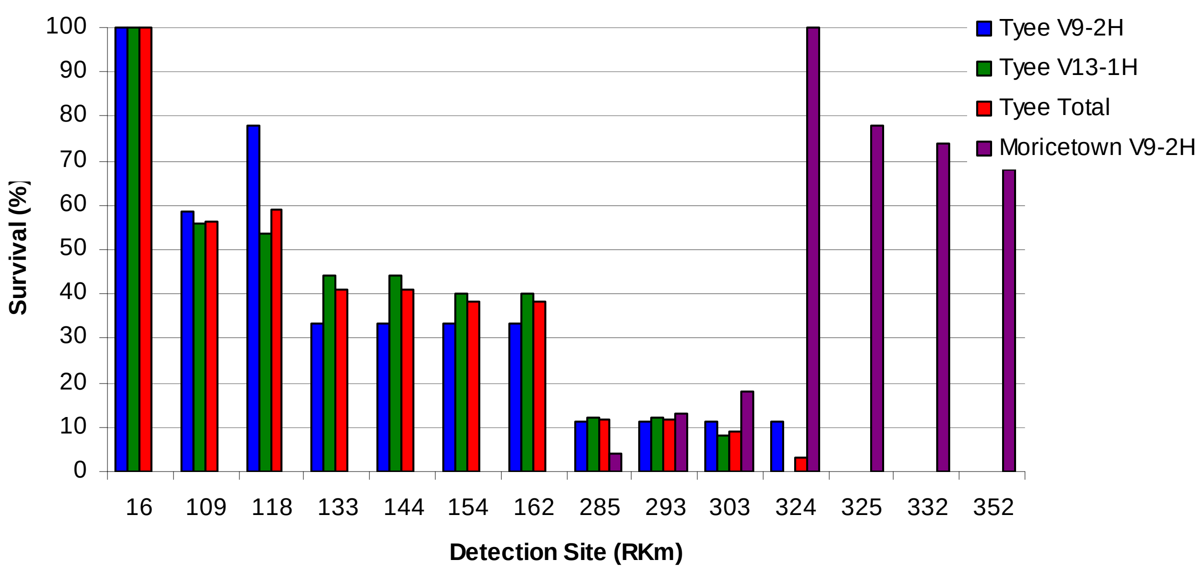



**Figure 8. Cumulative apparent survival values estimated as number detected divided by number released (Method 1) for returning wild Skeena River steelhead released at both the Tyee Test Fishery and the Moricetown Canyon sites and then detected at acoustic receivers in the Skeena and Bulkley Rivers in 2008. For the Tyee release group, estimates are corrected for detection efficiency until RKm 162. The sample size is too small to include this adjustment further upstream. For the Moricetown release group, estimates are corrected for detection efficiency between RKm 293-332.**

**Table 8. Cumulative apparent survival values estimated using a CJS maximum-likelihood approach (Method 2) for returning wild Skeena River steelhead released at the Tyee Test Fishery and detected at acoustic receivers in the Skeena and Bulkley Rivers in 2008. LCI, UCI: Lower & Upper 95% Confidence Intervals.**

| River | RKm | Estimate | SE | LCI | UCI |
|---|---|---|---|---|---|
| **Skeena** | **109** | 0.51 | 0.11 | 0.30 | 0.73 |
| | **118** | 0.48 | 0.11 | 0.26 | 0.70 |
| | **133** | 0.43 | 0.12 | 0.20 | 0.66 |
| | **144** | 0.40 | 0.12 | 0.17 | 0.63 |
| | **154** | 0.37 | 0.12 | 0.14 | 0.60 |
| | **162** | 0.35 | 0.12 | 0.12 | 0.58 |
| **Bulkley** | **285** | 0.14 | 0.09 | -0.03 | 0.32 |
| | **293** | 0.14 | 0.09 | -0.04 | 0.31 |
| | **303** | 0.13 | 0.08 | -0.04 | 0.29 |
| | **325** | 0.11 | 0.08 | -0.04 | 0.26 |

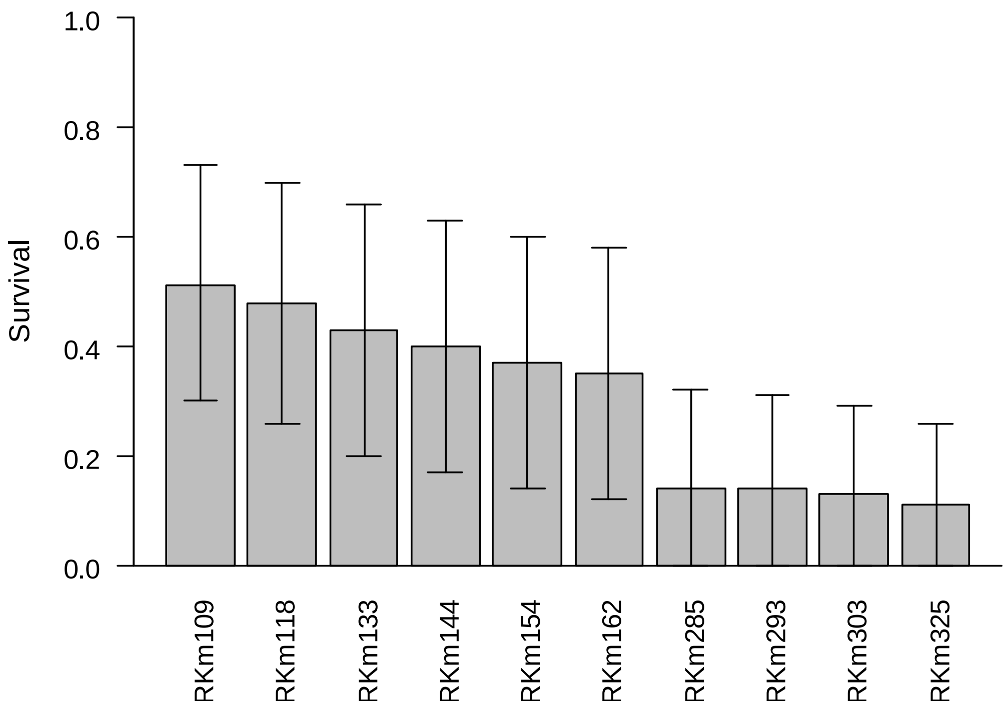



**Figure 9. Cumulative apparent survival values (with 95% confidence intervals) estimated using a CJS maximum-likelihood approach (Method 2) for returning wild Skeena River steelhead released at the Tyee Test Fishery and detected at acoustic receivers in the Skeena and Bulkley Rivers in 2008.**

**Table 9. Segment-specific apparent survival values estimated using a CJS maximum-likelihood approach (Method 2) for returning Skeena River steelhead released at the Tyee Test Fishery and detected at acoustic receivers in the Skeena and Bulkley Rivers in 2008. LCI, UCI: Lower & Upper 95% Confidence Intervals.**

| River | RKm | Estimate | SE | LCI | UCI |
|---|---|---|---|---|---|
| **Skeena** | **109** | 0.51 | 0.11 | 0.31 | 0.71 |
| | **118** | 0.94 | 0.02 | 0.89 | 0.97 |
| | **133** | 0.90 | 0.03 | 0.82 | 0.94 |
| | **144** | 0.92 | 0.02 | 0.86 | 0.96 |
| | **154** | 0.93 | 0.02 | 0.87 | 0.96 |
| | **162** | 0.94 | 0.02 | 0.90 | 0.97 |
| **Bulkley** | **285** | 0.41 | 0.12 | 0.21 | 0.65 |
| | **293** | 0.94 | 0.02 | 0.90 | 0.97 |
| | **303** | 0.93 | 0.02 | 0.87 | 0.96 |
| | **325** | 0.85 | 0.04 | 0.75 | 0.92 |

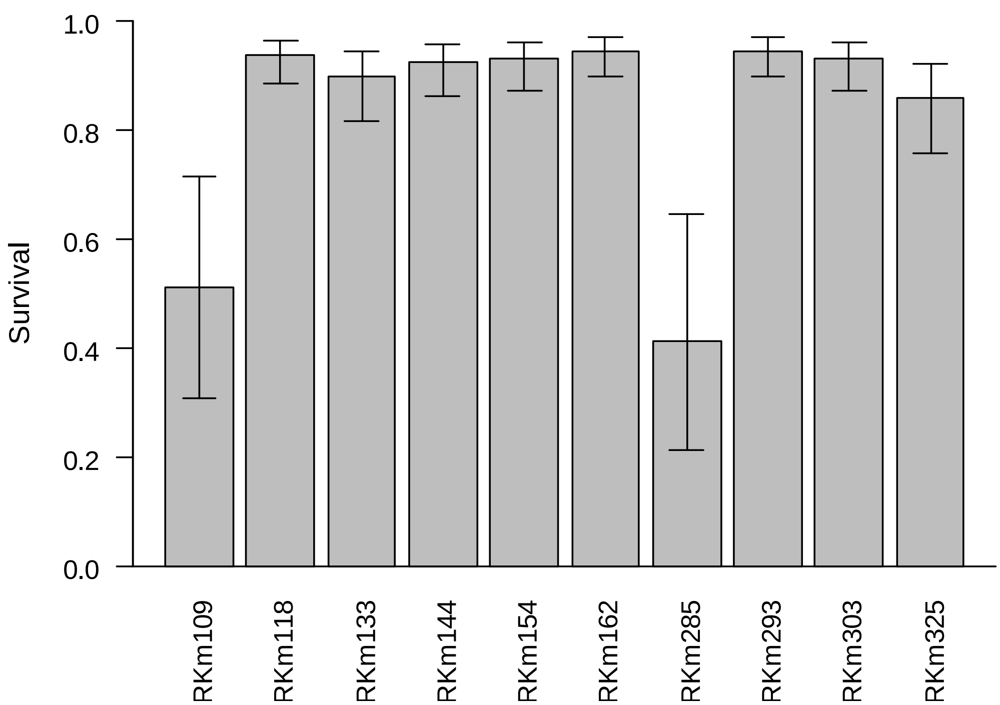



**Figure 10. Segment-specific apparent survival apparent survival values (with 95% confidence intervals) estimated using a CJS maximum-likelihood approach (Method 2) for returning wild Skeena River steelhead released at the Tyee Test Fishery and detected at acoustic receivers in the Skeena and Bulkley Rivers in 2008.**

## 3.4 Detection Efficiency

As with survival, we estimated the detection efficiency at each receiver location using two methods. For method one, we used a modification of the ratio of fish detected at each line ($m_i$) divided by the total number that swam past them (mi plus the number missed at the line but detected later $z_i$) to estimate detection efficiency as described by Jolly (1982). For method two, we present the detection efficiency values that were estimated simultaneously with the apparent survival values using the CJS model ($\varphi_{(distance)}\, p_{(segment)}$) as implemented in program Mark. In this model, the detection efficiency estimates were allowed to vary independently at each receiver location. Method two was only applicable to the steelhead released at the Tyee Test Fishery.

### *3.4.1. Tyee Steelhead detection efficiency estimates*

The detection efficiency estimates were high (>94%) for RKm 109-154 with the exception of RKm 118 (Table 10; Table 11; Figure 11). Both methods returned similar results. Beyond RKm 154, the sample size was too small to estimate detection efficiency using Method 1 and the confidence intervals on the CJS estimates (Method 2) are extremely broad. Similarly, the estimates for the Tyee release V9-2H were done using a very small sample size. The confidence intervals of 1 for the CJS estimates result from the difficulty of estimating parameters near the boundaries (of 0 or 1) using maximum-likelihood techniques. All the fish detected by the sub-arrays with confidence intervals of 1 were detected further along the migratory path.

### *3.4.2. Moricetown steelhead detection efficiency estimates*

The detection efficiency estimates for the steelhead captured and released at Moricetown were high (100%) for RKm 303 and 332 (Table 10). In contrast, the sub-array at RKm 325 was probably located in an acoustically poor environment (detection efficiency 42%). The sample size was too small to estimate detection efficiency at the remaining locations.

**Table 10. Estimated detection efficiency (*pi*) of the 2008 POST Skeena array (Method 1) for Skeena River adult wild steelhead released at both Tyee and Moricetown. Number of fish detected at site i = $m_i$; Number of fish missed at site i = $z_i$; Number of fish detected both at and beyond site i = $r_i$; Detection Efficiency = $p_i$; NA= not applicable.**

| River | Tag Type | Location (RKm) | $m_i$ | $z_i$ | $r_i$ | $p_i$ |
|---|---|---|---|---|---|---|
| Skeena | Combined | 109 | 18 | 1 | 15 | 94% |
| | | 118 | 6 | 10 | 4 | 30% |
| | | 133 | 14 | 0 | 14 | 100% |
| | | 144 | 14 | 0 | 13 | 100% |
| | | 154 | 13 | 0 | 13 | 100% |
| | | 162 | 13 | NA | NA | NA |
| | V9-2H | 109 | 4 | 1 | 3 | 76% |
| | | 118 | 1 | 3 | 0 | 14% |
| | | 133 | 3 | 0 | 3 | 100% |
| | | 144 | 3 | 0 | 3 | 100% |
| | | 154 | 3 | 0 | 3 | 100% |
| | | 162 | 3 | NA | NA | NA |
| | V13-1H | 109 | 14 | 0 | 12 | 100% |
| | | 118 | 5 | 7 | 4 | 37% |
| | | 133 | 11 | 0 | 11 | 100% |
| | | 144 | 11 | 0 | 10 | 100% |
| | | 154 | 10 | 0 | 10 | 100% |
| | | 162 | 10 | 0 | 3 | |
| Bulkley | V9-2H | 285 | 2 | NA | NA | NA |
| | | 293 | 4 | 1 | 1 | 62% |
| | | 303 | 9 | 0 | 5 | 100% |
| | | 325 | 18 | 20 | 17 | 46% |
| | | 332 | 37 | 0 | 34 | 100% |
| | | 352 | 34 | NA | NA | NA |

**Table 11. Detection efficiency estimated using a CJS maximum-likelihood approach (Method 2) for Skeena and Bulkley receiver locations in 2008 using wild, adult steelhead released at the Tyee Test Fishery.**

| River | RKm | Estimate | SE | LCI | UCI |
|---|---|---|---|---|---|
| **Skeena** | 109 | 0.94 | 0.10 | 0.33 | 1.00 |
| | 118 | 0.34 | 0.20 | 0.08 | 0.75 |
| | 133 | 1.00 | 0.00 | 1.00 | 1.00 |
| | 144 | 1.00 | 0.00 | 1.00 | 1.00 |
| | 154 | 1.00 | 0.00 | 1.00 | 1.00 |
| | 162 | 1.00 | 0.00 | 1.00 | 1.00 |
| **Bulkley** | 285 | 1.00 | 0.00 | 1.00 | 1.00 |
| | 293 | 1.00 | 0.00 | 1.00 | 1.00 |
| | 303 | 0.83 | 0.42 | 0.02 | 1.00 |
| | 325 | 0.32 | 0.49 | 0.01 | 0.97 |

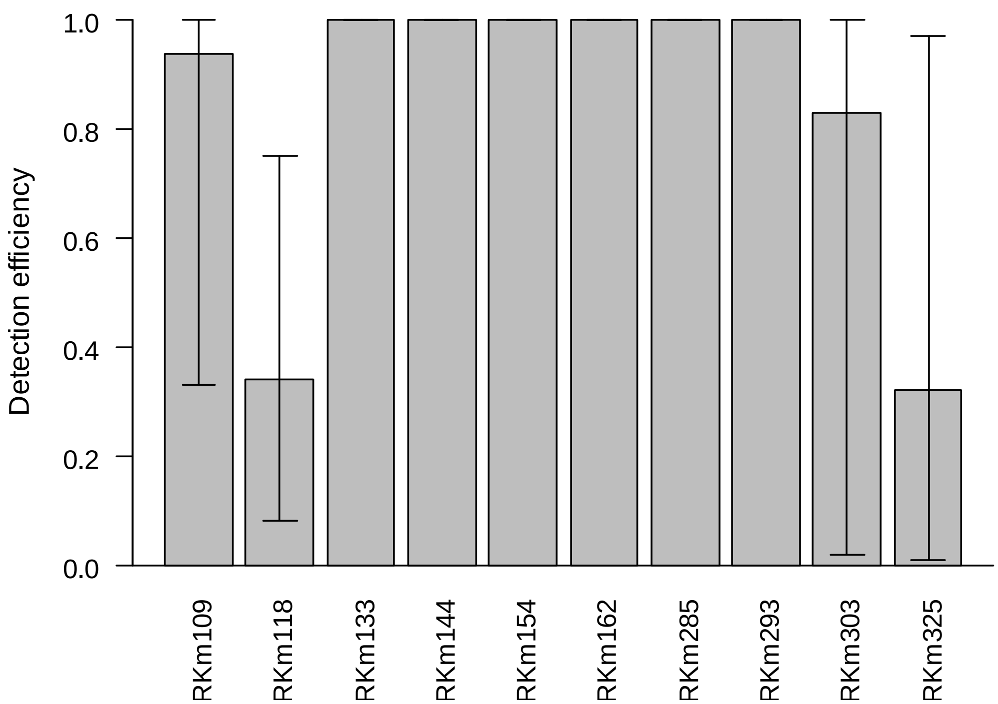



**Figure 11. Detection efficiency estimated using a CJS maximum-likelihood approach (Method 2) for Skeena and Bulkley receiver locations in 2008 using wild, adult steelhead released at the Tyee Test Fishery.**

## 3.5 Migratory Behaviour

### *3.5.1 Tyee steelhead migratory behaviour*

In general, the majority of the Tyee tagged steelhead travelled swiftly past all receiver locations within the Skeena River. Thirteen individuals were detected on the last receiver in the Skeena (RKm 162) between 9-18 days after release (6-30 September 2008). Average travel rate for the fish within the Skeena River varied between 9 and 26 km/day (Table 12; Figure 12), which encompasses the range previously reported by English et al. (2006). Travel rates were lower for the small number of steelhead that reached the Bulkley River at 1-8 km/day. Only four Tyee steelhead milled back and forth between sub-arrays rather than migrating directly upstream:

1) Fish ID 23774: detected at RKm 109, 118, 133, 144 then turned back and was last heard at RKm 118.
2) Fish ID 23782: detected at RKm 109, 118 then turned back and was last heard at RKm 109.
3) Fish ID 23782: detected at RKm 109, 118 then turned back and was last heard at RKm 109.
4) Fish ID 23801: detected at RKm 109, not detected at 118, detected at 133, 144, 154, 162 then turned back and was last heard at RKm 133.

**Table 12. Travel rates (km/day) for adult, wild Skeena River steelhead released at the Tyee Test Fishery in 2008.**

| Departure (RKm) | Arrival (RKm) | Count | Average | St. Dev. | Min | Max | 25th percentile | 75th percentile | Median |
|---|---|---|---|---|---|---|---|---|---|
| Release | 109 | 18 | 8.9 | 2.4 | 4.0 | 12.9 | 7.5 | 10.3 | 9.3 |
| 109 | 118 | 6 | 14.6 | 9.2 | 3.0 | 27.6 | 9.9 | 20.9 | 11.8 |
| 118 | 133 | 4 | 16.0 | 4.2 | 10.2 | 20.1 | 14.7 | 18.1 | 16.8 |
| 133 | 144 | 14 | 11.9 | 5.9 | 6.1 | 28.3 | 8.9 | 12.8 | 10.4 |
| 144 | 154 | 13 | 26.3 | 10.2 | 12.3 | 39.4 | 15.0 | 37.5 | 25.7 |
| 154 | 162 | 13 | 18.7 | 8.8 | 9.2 | 32.4 | 11.2 | 26.0 | 12.4 |
| 162 | 285 | 4 | 17.4 | 4.0 | 14.1 | 23.1 | 14.9 | 18.6 | 16.1 |
| 285 | 293 | 4 | 8.7 | 0.8 | 7.6 | 9.4 | 8.6 | 9.2 | 9.0 |
| 293 | 303 | 3 | 5.0 | 1.2 | 3.7 | 6.1 | 4.5 | 5.7 | 5.3 |
| 303 | 325 | 1 | 1.3 | NA | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 |

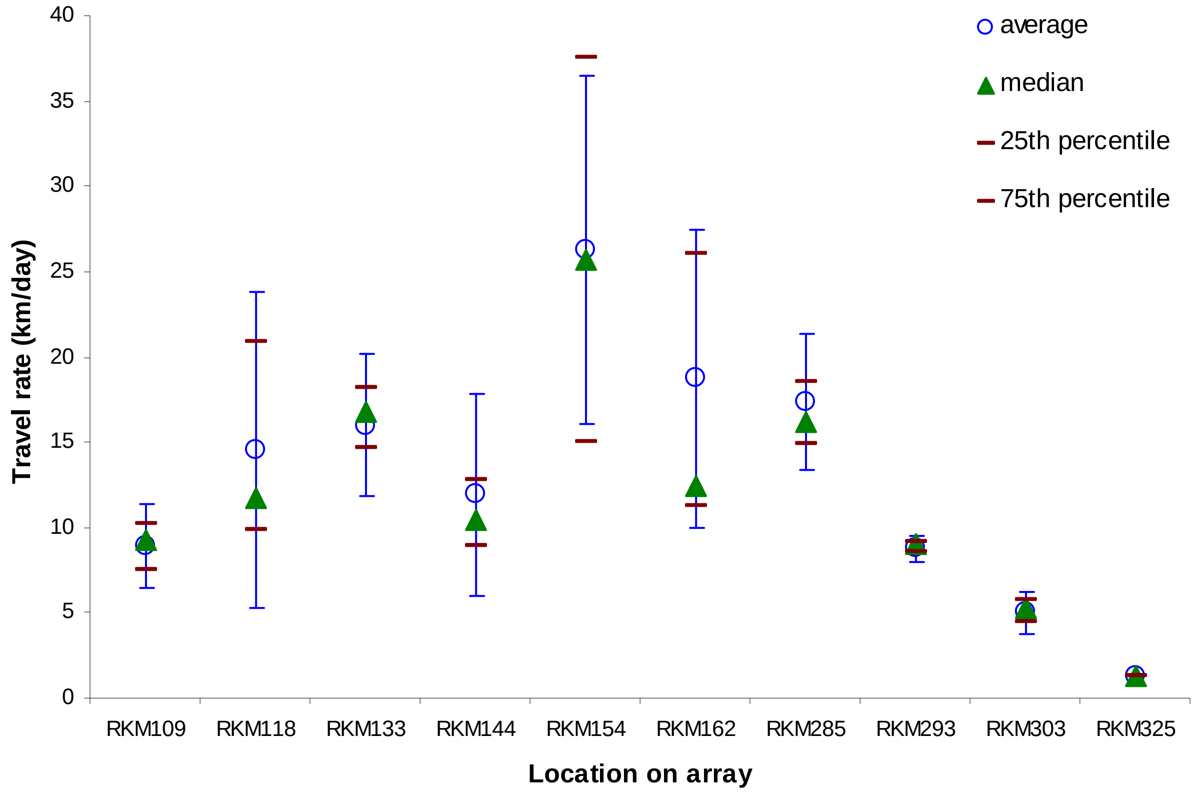



**Figure 12**. **Travel rates (km/day) for adult, wild Skeena River steelhead released at the Tyee Test Fishery in 2008. Rates are measured from departure of one location to the arrival at the next location.**

### *3.5.2 Moricetown steelhead migratory behaviour*

Most of the Moricetown steelhead appeared to travel upstream after release. Some of these fish moved quickly and were detected at the furthest upstream location (28 km upstream) within seven days of release (range: 7 to 36 days). The travel rate for the first ten kilometres of upstream migration was slow with individuals taking an average 12 days to move ten kilometres (Table 13; Figure 13). The rate of movement increased upriver from RKms 325 to 332 and from RKm 332 to 352. (Travel rates were not calculated for the sub-arrays below the release site.) Three steelhead held for long periods near sub-array sites and thus were still detected on the day the receivers were recovered. (One tag was detected 6,039 times at the Bulkley RKm 332 location between 32 to 84 days after release while the other two fish were detected over 16,000 times each at the Bulkley RKm 352 location; these two fish were detected over a period of 56 to 92 days post-release). It is unclear if these three fish were holding at these locations, had died, or had lost their external tag in the vicinity of the acoustic receivers; however, upon retrieval of the acoustic receiver at RKm 352, several adult steelhead were seen holding in the area near the receiver.

Of the 50 adult steelhead tagged at the Morristown location (48 km from Bulkley-Skeena River confluence and 314 RKm from the mouth of the Skeena), nine (18%) were observed going downriver after release (Figure 14; Figure 15; Figure 16). Following the initial drop back, five of the nine steelhead (10% of total) travelled upstream over the acoustic array. These five fish all reached RKm 66 (Sept 10-17) and four reached RKm 86 (Sept 13-Oct 1). Thus 4 of 50 fish (8%) were last detected downstream after tagging. An additional eight individuals were not detected on any of the sub-arrays.

**Table 13. Travel rates (km/day) for adult, wild Skeena River steelhead released at the Moricetown site in 2008.**

| Departure | Arrival | Count | Average | STDEV | Min | Max | 25th percentile | 75th percentile | Median |
|---|---|---|---|---|---|---|---|---|---|
| Release | RKm 325 | 17 | 1.09 | 0.57 | 0.26 | 2.06 | 0.67 | 1.50 | 0.88 |
| RKm 325 | RKm 332 | 17 | 11.07 | 9.20 | 0.47 | 34.69 | 6.12 | 17.04 | 9.06 |
| RKm 332 | RKm 352 | 34 | 9.63 | 8.65 | 0.48 | 27.96 | 2.10 | 15.29 | 5.73 |

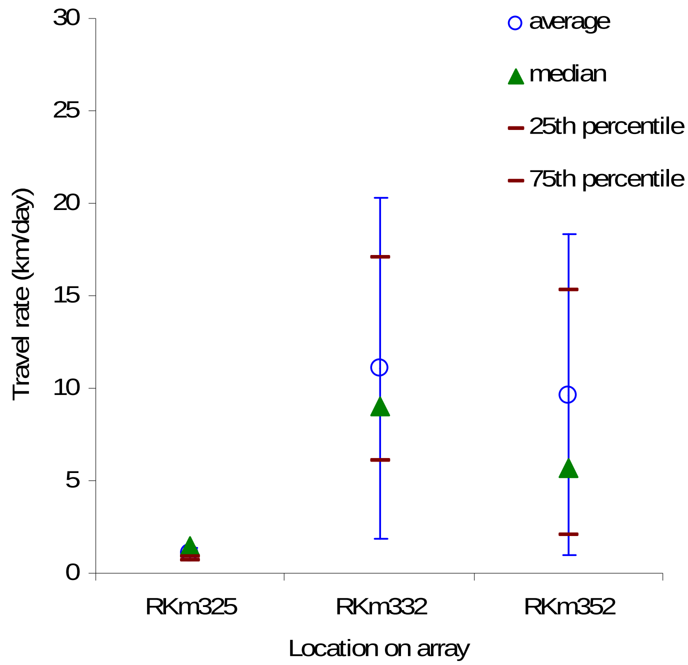



**Figure 13. Travel rates (km/day) for adult, wild Skeena River steelhead released at Moricetown in 2008. Rates are measured from departure of one location to the arrival at the next location.**

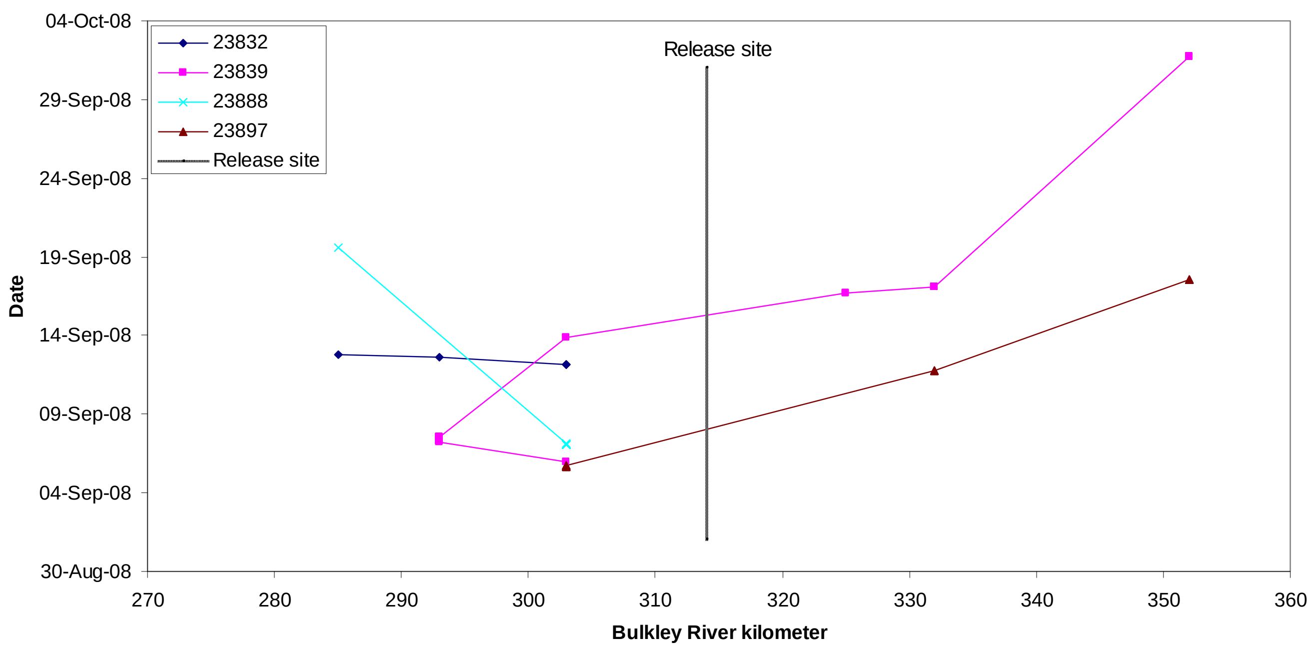



**Figure 14. Of the 50 fish tagged at Moricetown, nine fish dropped back after release. The movement of four fish is shown in relation to the release site at RKm 314. River kilometer refers to the estimated distance to the Skeena River mouth.**

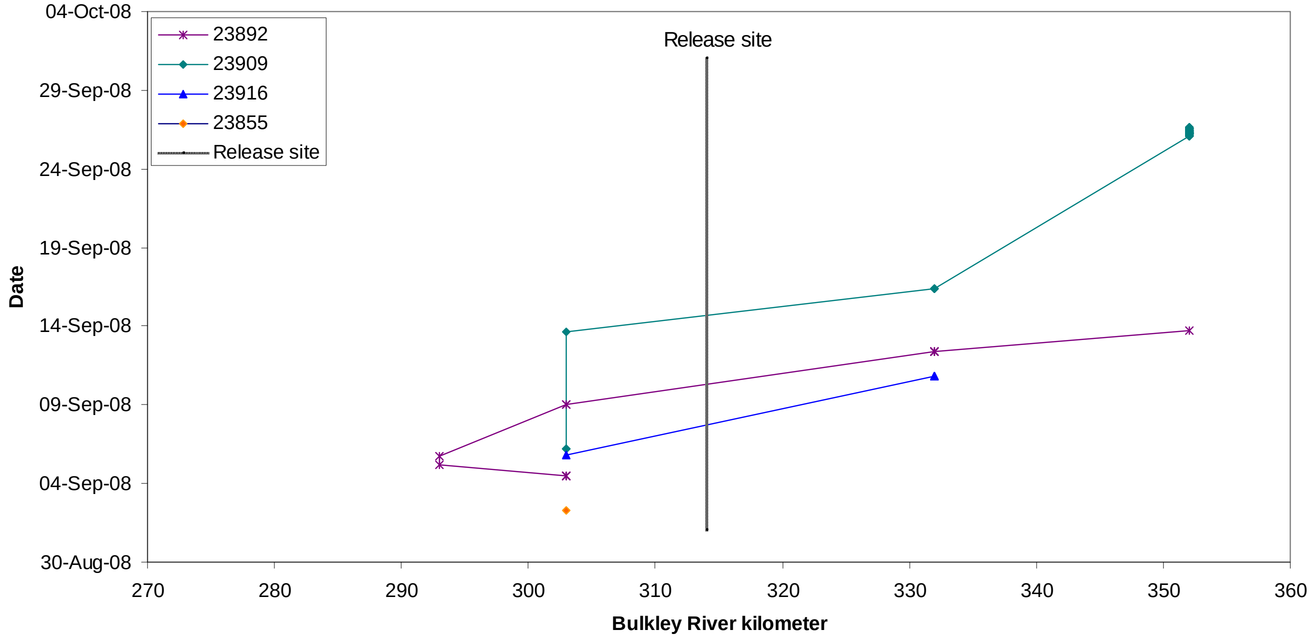



**Figure 15. Of the 50 fish tagged at Moricetown, nine fish dropped back after release. The movement of four fish is shown in relation to the release site at RKm 314. River kilometer refers to the estimated distance to the Skeena River mouth.**

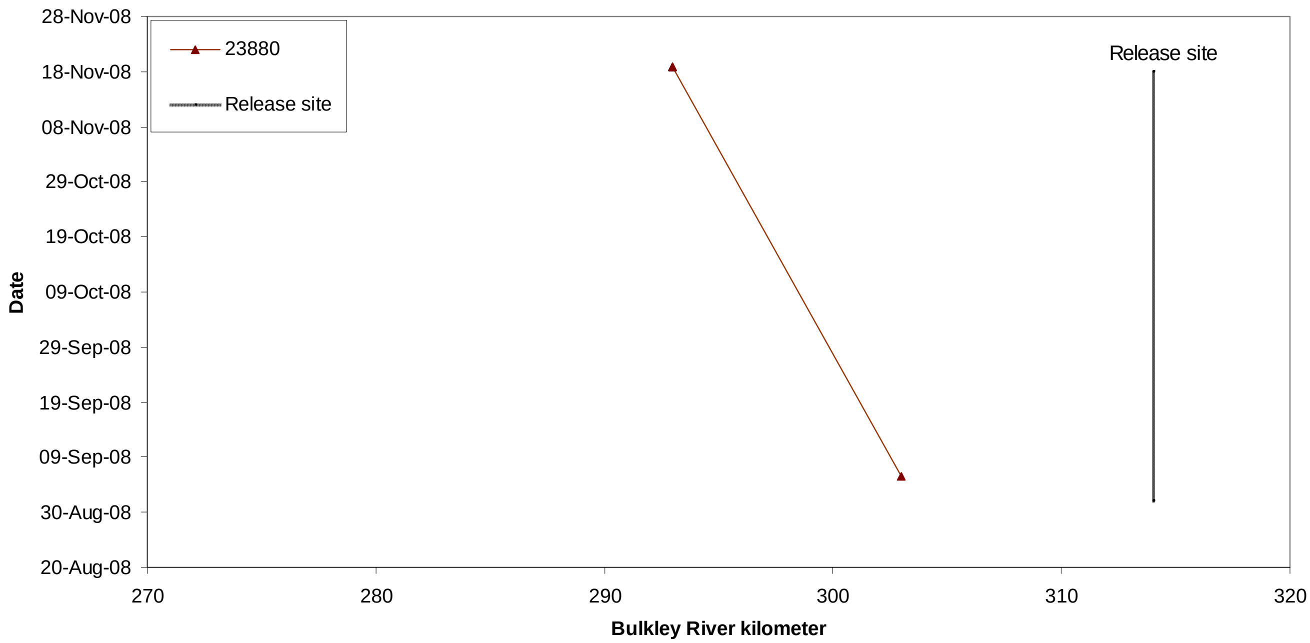



**Figure 16. Of the 50 fish tagged at Moricetown, nine fish dropped back after release. The movement of one fish is shown in relation to the release site at RKm 314. Note the change in scale. River kilometer refers to the estimated distance to the Skeena River mouth.**

# 4.0 Discussion

Beginning in August 2008, we conducted a pilot study to assess the feasibility of using acoustic technology to monitor the survival and movement of wild steelhead returning to the Skeena and Bulkley Rivers. Acoustic receivers were deployed in six locations in the Skeena River and six locations in the Bulkley River. From August 24 until September 21, 2008 a total of 84 adult wild steelhead were caught and tagged at two separate locations by MOE staff and contractors. The fish were tagged externally, below the dorsal fin, with a Vemco V9 or V13 acoustic tag. All twelve receivers were recovered and successfully uploaded in late November 2008. The units contained a total of 118,159 detections from 61 of the 84 tagged steelhead.

Thirty-four adult steelhead were caught and tagged in the Tyee gill-net test fishery at the mouth of the Skeena River in September 2008. Apparent survival estimates followed a smooth exponential decline with distance (apparent survival/km = 0.992, 95% confidence intervals 0.988-0.997) and there was no evidence of immediate post-release mortality related to the capture and tagging process. After 93 km of upstream migration, 19 steelhead were detected reaching the array at RKm 109 (estimated apparent survival 51% ± 11%). Apparent survival to the last sub-array in the Skeena River was 35% ± 12% and four individuals were detected as far as RKm 325 in the Bulkley River (estimated apparent survival 11% ± 8%). The sample size was insufficient to rigorously test for effects of V13 versus V9 tags but similar percentages of animals tagged with the two tags reached the upstream locations (Table 4). Survival estimates are called "apparent survival" because it is not possible to distinguish mortality from emigration into river tributaries or over wintering in the mainstem with the current array configuration. Future studies could include additional receiver sites below side tributaries known to support significant steelhead runs such as the Kitsumkalum, Zymoetz, Lakelse, Kitwanga, Suskwa and Kispiox Rivers. Receivers could also be located to ascertain the cause of possible mortalities such as above and below areas of high fishing pressure.

The upstream movement of the steelhead released at the Tyee Test Fishery appeared to be mostly unidirectional. The majority of the tagged fish were heard on the array and moved quickly upstream past the last receiver between 9-18 days after tagging. The average travel rate in the Skeena varied between 9 and 27 km/day. Only four individuals migrated upstream and then turned around to be detected downstream again. Although 16 fish were not detected on the array, the close relationship between apparent survival and distance suggests that the processes of loss (e.g. mortality, emigration from the mainstem) were similar throughout the river. Thus, although there was no array below the release site, downstream migration into the ocean after release seems unlikely to be a major source of disappearance. To confirm this supposition, a sub-array could be located downstream of the Tyee release site in the future.

At Moricetown Canyon Falls, 50 adult steelhead were tagged and 42 were subsequently detected on the array. Most fish moved upstream; apparent survival to the first upstream sub-array was 78% and minimum apparent survival at the last sub-array (38 km from release) was 68%. The drop in apparent survival over the first migration segment is high (22% decline over ten kilometres); however, it is not clear if this represents tagging-induced mortality or failure to migrate (either downriver migration or holding in-river). Nine fish were detected downstream of the release site. Of those nine, five were subsequently detected on receivers upstream of the Moricetown release site.

As the 2008 pilot study was designed to primarily gather larger-scale migratory data on travel speed and survival, it is not possible to deduce the detailed downstream movement immediately below the Morristown tagging site. Only steelhead that moved at least 21 km downstream of tagging site could be identified. However, the extremely slow travel speed between release and arrival on the first upstream line (average of 12 days to travel ten kilometres) suggests that many fish may have milled near the release site or moved short distances (<11 km) downstream. Additionally, despite the relative proximity of the first upstream line, eight Moricetown fish were never heard on the array. This evidence that a significant fraction of captured steelhead may not move upstream may have significant implications for the interpretation of the capture-recapture data collected from the Moricetown site, as a significant non-migratory component to the tagged population could bias population abundance estimates high. A more detailed acoustic monitoring program could be employed in the Bulkley River to accurately identify steelhead movement patterns on a finer scale and thereby help reduce uncertainties in data interpretation from conventional seine studies at Moricetown.

One of the assumptions of this type of survival analysis is that tags are not lost and that neither the tags themselves nor the tagging process affect the fish. While we have no direct data, a previous study using external anchor tags suggests an approximate tag loss of 5% (SKR Consultants 2004). The SKR study did not attempt to measure whether mortality occurred due to handling. Regardless, unless tested, our results should be interpreted with the understanding that tag effects may result in underestimates of survival in the general population.

The ability to deploy, recover, and analyze results from an acoustic array within the Skeena watershed was demonstrated with the 2008 pilot study. All the units were recovered from the turbulent water and successfully downloaded. Although sample sizes for some sites were small, the estimated detection efficiencies were over 90% for four of five lines estimable for the Tyee release group (three lines were 100%) and were 100% for two of three lines estimable for the Moricetown fish. Overall detection efficiency was poor for only two sites (RKm 325 and 118). This performance illustrates the power of a broad-scale acoustic monitoring program for measuring fish migrations. Such a program could be used for studying many different fish species simultaneously, addressing the concerns of multiple groups and bringing significant cost efficiencies.

## 5.0 Recommendations

1. A more detailed listening array should be deployed below the Tyee test fishery and in the lower-middle Skeena River to better identify post-release mortality rates for steelhead intercepted by either the commercial or the Tyee test fisheries. Additional receivers placed in tributary rivers below the current first detection site would establish whether the measured up-river steelhead loss (47%) to RKm 109 is the result of mortality soon after release or emigration into tributary streams in the lower river. This would also aid in establishing baseline survival information before potential large-scale changes in commercial fishing practices and areas of exploitation were initiated.

2. Our pilot study indicates that a surprisingly large proportion of the steelhead captured and tagged at Moricetown did not migrate upstream to the next receiver (which was located only ten kms away). If this behaviour is caused by the capture or tagging process, then there is significant potential to overestimate the abundance of Bulkley River steelhead, because the ratio of tagged to untagged fish captured at the upstream dipnet site determines the abundance estimate. If the fish caught at the Moricetown seine site hold after release rather than continuing to migrate upstream (as assumed) then the re-capture site cannot capture them and abundance estimates will be skewed high. A more detailed acoustic array could be deployed in the Bulkley River to more closely address questions concerning the Moricetown Beach seine operation.

3. The 2008 pilot study provided reasonable initial measurements of apparent survival rates (approximate standard errors on survival estimates of ±11%; Table 8). For receiver locations with 100% detection efficiency the standard error on the survival estimates scales as $1/\sqrt{N}$, where N is the number of tags. In future studies the 2008 study design should be re-assessed in terms of the biological questions to be examined, and trade-offs between the number of tagged fish used and the use of a more extensive array should be formally considered.

## 6.0 Acknowledgements

We would like to thank Mark Beere and Dean Peard for their support and advice throughout this project. We also thank our boat operators and guides, Michael Whelpley and Fred Seiler, for their invaluable insight and suggestions during the deployment and recovery phases of the study.

During the recovery of the receivers in November there were some reaches of the Bulkley River that had become inaccessible due to low flows and exposure of an infinite amount of "rock gardens" and access to some of the deployment sites was obtained through private properties, and in one instance a private boat launch. The local support for this project was encouraging and we are grateful for all the assistance we encountered during the recovery.

## 7.0 References

Beere, M.C. 1991a. Steelhead migration behaviour and timing as evaluated from radio tagging at the Skeena River test fishery, 1989. Unpublished M.S. Skeena Fisheries Report #SK-69. Ministry of Environment, Lands and Parks, Smithers, B.C. 24 pp.

Beere, M.C. 1991b. Radio telemetry investigations of steelhead tagged in the lower Bulkley River,1989. Unpublished M.S. Skeena Fisheries Report #SK-70. Ministry of Environment, Lands and Parks, Smithers, B.C. 18pp.

Beere, M.C. 1991c. Radio telemetry investigations of Babine River steelhead, spring 1990. Unpublished M.S. Skeena Fisheries Report # SK 71. Ministry of Environment, Lands and Parks, Smithers, B.C. 17 pp.

Beere, M.C. 1991d. Memo to file. Re: Results of flight to Kitnayakwa River - Monitoring radio tagged steelhead, April 24, 1991. Ministry of Environment, Lands and Parks, Smithers, B.C. File No. 34560-27/ZYM/KITNAY.

Beere, M.C. 1995. Movements of summer run steelhead trout tagged with radio transmitters in the Zymoetz River during spring, 1994. Unpublished M.S. Skeena Fisheries Report #93. Ministry of Environment, Lands and Parks, Smithers, B.C. 22 pp.

Beere, M.C. 1996. Movements of summer run steelhead trout tagged with radio transmitters in the Babine River during spring, 1994. Unpublished M.S. Skeena Fisheries Report #94. Ministry of Environment, Lands and Parks, Smithers, B.C. 36 pp.

Beere, M.C. 1997. Movements of wild summer run steelhead tagged with radio transmitters in the Babine River during fall, 1994. Unpublished M.S. Skeena Fisheries Report #96. Ministry of Environment, Lands and Parks, Smithers, B.C. 42 pp.

Burnham, K.P., Anderson, D.R., White, G.C., Brownie, C., and K.H. Pollock. 1987. Design and analysis methods for fish survival experiments based on release-recapture. Am. Fish. Soc. Monogr. No. 5. Bethesda, MD. 437p.

Chittenden, C.M., S. Sura, K.G. Butterworth, K.F. Cubitt, N. Plantalech Manel-La, S. Balfry, F. Økland, and R.S. McKinley. 2008. Riverine, estuarine and marine migratory behaviour and physiology of wild and hatchery-reared coho salmon *Oncorhynchus kisutch* (Walbaum) smolts descending the Campbell River, BC, Canada. Journal of Fish Biology 72:614–628.

Chudyk, W.E. and D.W. Narver. 1976. Commercial interceptions of steelhead trout in the Skeena River: A preliminary review. B.C. Fish and Wildlife Branch. Unpublished Report. 25 pp.

Department of Fisheries and Oceans. 2008. Skeena River management of salmon and steelhead Stocks. Accessed on May 20, 2009 from http://www.dfo-mpo.gc.ca/media/back-fiche/2008/pr08-eng.htm

English, K.K., D. Robichaud, C. Sliwinski, R.F. Alexander, W.R. Koski, T.C. Nelson, and B.L. Nass. 2006. Comparison of adult steelhead migrations in the mid-Columbia hydrosystem and in large naturally flowing British Columbia Rivers. Transactions of the American Fisheries Society 135: 739-754.

Jolly, G.M. 1982. Mark-recapture models with parameters constant in time. Biometrics 38: 301-321.

Melnychuk. M.C., D.W. Welch, C.J. Walters, and V. Christensen. 2007. Riverine and early ocean migration and mortality patterns of juvenile steelhead trout (*Oncorhynchus mykiss*) from the Cheakamus River, British Columbia. Hydrobiologia 582: 55–65.

Oguss, E. and L.K. Evans. 1978. Incidental catches of steelhead trout in the commercial salmon fisheries of Barkley Sound, Johnstone Strait, and the Skeena and Fraser Rivers. Fish. Mgmt. Report No. 14. British Columbia Marine Resources Branch, Victoria, B.C.

Pincock, D.G. 2008. False detections: What they are and how to remove them from detection data. Document #: DOC-004691 Version 01. Amerix Systems Inc. VEMCO Division. (http://www.vemco.com/pdf/false_detections.pdf).

Skalski, J.R., Lady, J., Townsend, R., Giorgi, A.E., Stevenson, J.R., Peven, C.M., and R.D. McDonald. 2001. Estimating in-river survival of migrating salmon smolts using radiotelemetry. Can. J. Fish. Aquat. Sci. 58: 1987-1997.

SKR Consultants Ltd. and Wet'suwet'en Fisheries. 2004. 2003 Steelhead tagging project at Moricetown Canyon. Data Analysis and Recommendations. (http://www.skeenafisheries.ca/2003%20Steelhead%20Tagging%20Project.pdf)

Walters, C.J., J.A. Lichatowich, R.M. Peterman, and J.D. Reynolds. 2008. Report of the Skeena Independent Science Review panel. A report to the Canadian Department of Fisheries and Oceans and the British Columbia Ministry of the Environment. 144 pp.

Welch, D., E. Rechisky, M. Melnychuk, A. Porter, C. Walters, S. Clements, B Clemens, R. McKinley and C. Schreck. 2008. Survival of migrating salmon smolts in large rivers with and without dams. PLOS Biology 6 (10).

White, G.C. and K.P. Burnham. 1999. Program MARK: Survival estimation from populations of marked animals. Bird Study 46 Supplement: 120-138.

Zabel, R.W. and S. Achord. 2004. Relating size of juveniles to survival within and among populations of Chinook salmon. Ecology 85: 795-806.

## 8.0 List of Appendices

Appendix 1. Summary of detections data in the Skeena River

Appendix 2. Summary of detections data in the Bulkley River

Appendix 3. Number of detections by date

Appendix 4. Number of fish detected by date

**Appendix 1. Summary of detections of adult, wild Skeena River steelhead heard on the acoustic array in the Skeena River in 2008**

| Tag code | RKm 109 | | | RKm 118 | | | RKm 133 | | | RKm 144 | | | RKm 154 | | | RKm 162 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Date Detected | | | Date Detected | | | Date Detected | | | Date Detected | | | Date Detected | | | Date Detected | |
| | Num | First | Last | Num | First | Last | Num | First | Last | Num | First | Last | Num | First | Last | Num | First | Last |
| **Tyee Release** | | | | | | | | | | | | | | | | | | |
| 23770 | | | | | | | | | | | | | | | | | | |
| 23771 | | | | | | | | | | | | | | | | | | |
| 23772 | | | | | | | | | | | | | | | | | | |
| 23773 | 9 | 9-14 18:50 | 9-14 19:01 | | | | 52 | 9-16 19:31 | 9-16 20:18 | 31 | 9-17 22:59 | 9-17 23:25 | 17 | 9-18 17:51 | 9-18 18:01 | 20 | 9-19 00:26 | 9-19 00:59 |
| 23774 | 8 | 9-12 03:21 | 9-12 03:29 | 6 | 9-13 02:04 | 9-16 08:10 | 56 | 9-14 13:15 | 9-15 22:19 | 45 | 9-15 02:47 | 9-15 15:10 | | | | | | |
| 23775 | 10 | 9-09 23:06 | 9-09 23:11 | | | | 86 | 9-11 07:06 | 9-11 08:34 | 48 | 9-12 15:11 | 9-12 16:09 | 15 | 9-13 01:30 | 9-13 01:38 | 4 | 9-13 19:35 | 9-13 19:44 |
| 23776 | | | | | | | | | | | | | | | | | | |
| 23777 | | | | | | | | | | | | | | | | | | |
| 23778 | 15 | 9-08 14:25 | 9-08 14:38 | 10 | 9-08 23:46 | 9-08 23:52 | 35 | 9-09 22:05 | 9-09 22:28 | 24 | 9-10 20:49 | 9-10 21:03 | 12 | 9-11 03:23 | 9-11 13:40 | 16 | 9-11 21:03 | 9-11 21:10 |
| 23779 | 7 | 9-06 03:21 | 9-06 03:25 | 3 | 9-06 20:17 | 9-06 20:18 | 13 | 9-07 14:11 | 9-07 14:22 | 23 | 9-07 23:41 | 9-07 23:55 | 7 | 9-08 15:56 | 9-08 16:00 | 11 | 9-08 21:55 | 9-08 22:01 |
| 23780 | | | | | | | | | | | | | | | | | | |
| 23781 | 52 | 9-19 17:00 | 9-21 20:00 | | | | | | | | | | | | | | | |
| 23782 | 22 | 9-08 15:06 | 9-12 14:51 | 6 | 9-11 14:48 | 9-11 14:51 | | | | | | | | | | | | |
| 23783 | 12 | 9-10 17:38 | 9-10 17:44 | 6 | 9-11 01:34 | 9-11 01:37 | 14 | 9-11 22:14 | 9-11 22:22 | 23 | 9-12 18:17 | 9-12 18:31 | 5 | 9-13 00:39 | 9-13 00:43 | 7 | 9-13 16:24 | 9-13 16:29 |
| 23784 | | | | | | | | | | | | | | | | | | |
| 23785 | 14 | 9-07 15:55 | 9-07 16:03 | | | | 28 | 9-09 15:08 | 9-09 15:40 | 44 | 9-10 17:45 | 9-10 18:19 | 6 | 9-11 02:34 | 9-11 02:45 | 14 | 9-11 18:12 | 9-11 18:20 |
| 23786 | 10 | 9-08 17:14 | 9-08 17:20 | | | | 8 | 9-10 19:55 | 9-10 20:03 | 48 | 9-12 14:50 | 9-12 15:21 | 8 | 9-12 23:51 | 9-12 23:58 | 1 | 9-13 20:51 | 9-13 20:51 |
| 23787 | | | | | | | | | | | | | | | | | | |
| 23788 | 3 | 9-05 19:09 | 9-05 19:10 | | | | 9 | 9-06 23:29 | 9-06 23:36 | 22 | 9-07 19:45 | 9-07 20:05 | 12 | 9-08 02:10 | 9-08 02:17 | 2 | 9-08 18:07 | 9-08 18:08 |
| 23789 | | | | | | | | | | | | | | | | | | |
| 23790 | 1 | 9-02 22:50 | 9-02 22:50 | | | | 9 | 9-04 19:56 | 9-04 20:13 | 33 | 9-05 21:48 | 9-05 22:16 | 6 | 9-06 14:36 | 9-06 14:40 | 1 | 9-06 21:23 | 9-06 21:23 |
| 23791 | | | | | | | | | | | | | | | | | | |
| 23792 | | | | | | | | | | | | | | | | | | |
| 23793 | 17 | 9-18 22:27 | 9-18 22:50 | | | | | | | | | | | | | | | |
| 23794 | 13 | 9-09 14:41 | 9-09 14:50 | | | | 72 | 9-11 02:00 | 9-11 02:52 | 51 | 9-12 13:18 | 9-12 14:16 | 16 | 9-12 23:53 | 9-13 00:04 | 16 | 9-13 17:09 | 9-13 17:18 |
| 23796 | 4 | 9-18 01:12 | 9-18 01:16 | | | | 7 | 9-19 22:26 | 9-19 22:33 | 4 | 9-20 23:03 | 9-20 23:08 | 5 | 9-21 18:35 | 9-21 18:40 | 1 | 9-22 02:07 | 9-22 02:07 |
| 23797 | 8 | 9-18 19:22 | 9-18 19:28 | | | | | | | | | | | | | | | |
| 23799 | 23 | 9-18 02:03 | 9-20 18:48 | 3 | 9-18 22:09 | 9-18 22:11 | | | | | | | | | | | | |
| 23800 | | | | | | | | | | | | | | | | | | |
| 23801 | 4 | 9-19 21:44 | 9-19 21:48 | | | | 17 | 9-21 20:49 | 9-29 07:27 | 10 | 9-23 16:07 | 9-28 23:12 | 11 | 9-24 02:05 | 9-28 21:52 | 5 | 9-24 19:47 | 9-24 19:58 |
| 23802 | | | | | | | | | | | | | | | | | | |
| 23803 | | | | | | | | | | | | | | | | | | |
| 23806 | | | | | | | 156 | 9-28 08:18 | 9-28 14:39 | 20 | 9-29 15:49 | 9-29 16:12 | 6 | 9-29 22:36 | 9-29 22:42 | 1 | 9-30 07:33 | 9-30 07:33 |
| 23853 | | | | | | | | | | | | | | | | | | |
| **Moricetown Release** | | | | | | | | | | | | | | | | | | |
| 23795 | | | | | | | | | | | | | | | | | | |
| 23827 | | | | | | | | | | | | | | | | | | |
| 23832 | | | | | | | | | | | | | | | | | | |
| 23833 | | | | | | | | | | | | | | | | | | |
| 23834 | | | | | | | | | | | | | | | | | | |
| 23835 | | | | | | | | | | | | | | | | | | |

| Tag code | RKm 109 | | | RKm 118 | | | RKm 133 | | | RKm 144 | | | RKm 154 | | | RKm 162 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Date Detected | | | Date Detected | | | Date Detected | | | Date Detected | | | Date Detected | | | Date Detected | |
| | Num | First | Last | Num | First | Last | Num | First | Last | Num | First | Last | Num | First | Last | Num | First | Last |
| 23838 | | | | | | | | | | | | | | | | | | |
| 23839 | | | | | | | | | | | | | | | | | | |
| 23840 | | | | | | | | | | | | | | | | | | |
| 23841 | | | | | | | | | | | | | | | | | | |
| 23848 | | | | | | | | | | | | | | | | | | |
| 23849 | | | | | | | | | | | | | | | | | | |
| 23854 | | | | | | | | | | | | | | | | | | |
| 23855 | | | | | | | | | | | | | | | | | | |
| 23860 | | | | | | | | | | | | | | | | | | |
| 23861 | | | | | | | | | | | | | | | | | | |
| 23866 | | | | | | | | | | | | | | | | | | |
| 23867 | | | | | | | | | | | | | | | | | | |
| 23872 | | | | | | | | | | | | | | | | | | |
| 23873 | | | | | | | | | | | | | | | | | | |
| 23878 | | | | | | | | | | | | | | | | | | |
| 23879 | | | | | | | | | | | | | | | | | | |
| 23880 | | | | | | | | | | | | | | | | | | |
| 23881 | | | | | | | | | | | | | | | | | | |
| 23884 | | | | | | | | | | | | | | | | | | |
| 23886 | | | | | | | | | | | | | | | | | | |
| 23887 | | | | | | | | | | | | | | | | | | |
| 23888 | | | | | | | | | | | | | | | | | | |
| 23889 | | | | | | | | | | | | | | | | | | |
| 23890 | | | | | | | | | | | | | | | | | | |
| 23891 | | | | | | | | | | | | | | | | | | |
| 23892 | | | | | | | | | | | | | | | | | | |
| 23894 | | | | | | | | | | | | | | | | | | |
| 23895 | | | | | | | | | | | | | | | | | | |
| 23896 | | | | | | | | | | | | | | | | | | |
| 23897 | | | | | | | | | | | | | | | | | | |
| 23898 | | | | | | | | | | | | | | | | | | |
| 23904 | | | | | | | | | | | | | | | | | | |
| 23909 | | | | | | | | | | | | | | | | | | |
| 23910 | | | | | | | | | | | | | | | | | | |
| 23911 | | | | | | | | | | | | | | | | | | |
| 23912 | | | | | | | | | | | | | | | | | | |
| 23913 | | | | | | | | | | | | | | | | | | |
| 23914 | | | | | | | | | | | | | | | | | | |
| 23915 | | | | | | | | | | | | | | | | | | |
| 23916 | | | | | | | | | | | | | | | | | | |
| 23917 | | | | | | | | | | | | | | | | | | |
| 23918 | | | | | | | | | | | | | | | | | | |
| 23919 | | | | | | | | | | | | | | | | | | |
| 23920 | | | | | | | | | | | | | | | | | | |

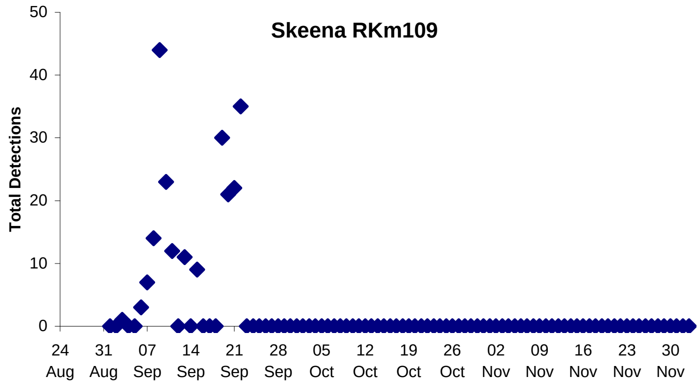
**Appendix 2. Summary of detections of adult, wild Skeena River steelhead heard on the acoustic array in the Bulkley River in 2008**

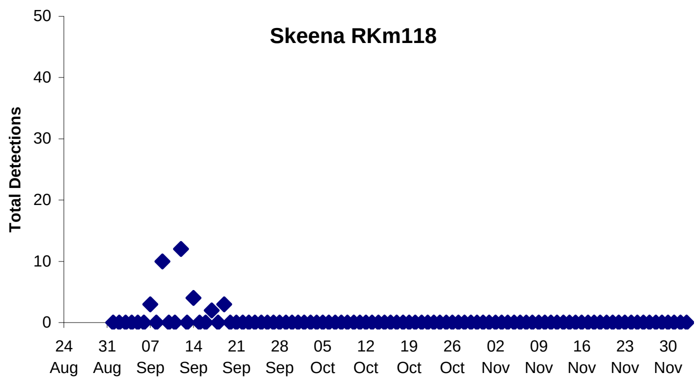
| Tag code | RKm 285 | | | RKm 293 | | | RKm 303 | | | RKm 325 | | | RKm 332 | | | RKm 352 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Date Detected | | | Date Detected | | | Date Detected | | | Date Detected | | | Date Detected | | | Date Detected | |
| | Num | First | Last | Num | First | Last | Num | First | Last | Num | First | Last | Num | First | Last | Num | First | Last |
| **Tyee Release** | | | | | | | | | | | | | | | | | | |
| 23770 | | | | | | | | | | | | | | | | | | |
| 23771 | | | | | | | | | | | | | | | | | | |
| 23772 | | | | | | | | | | | | | | | | | | |
| 23773 | | | | | | | | | | | | | | | | | | |
| 23774 | | | | | | | | | | | | | | | | | | |
| 23775 | | | | | | | | | | | | | | | | | | |
| 23776 | | | | | | | | | | | | | | | | | | |
| 23777 | | | | | | | | | | | | | | | | | | |
| 23778 | 9 | 9-19 02:12 | 9-19 02:19 | 5 | 9-19 22:46 | 9-19 22:50 | 36 | 9-21 14:16 | 10-20 08:37 | | | | | | | | | |
| 23779 | | | | | | | | | | | | | | | | | | |
| 23780 | | | | | | | | | | | | | | | | | | |
| 23781 | | | | | | | | | | | | | | | | | | |
| 23782 | | | | | | | | | | | | | | | | | | |
| 23783 | 5 | 9-19 00:26 | 9-19 00:29 | 5 | 9-19 21:37 | 9-19 21:40 | 16 | 9-21 18:55 | 9-21 20:12 | | | | | | | | | |
| 23784 | | | | | | | | | | | | | | | | | | |
| 23785 | | | | | | | | | | | | | | | | | | |
| 23786 | | | | | | | | | | | | | | | | | | |
| 23787 | | | | | | | | | | | | | | | | | | |
| 23788 | 13 | 9-16 20:07 | 9-16 20:14 | 4 | 9-17 21:24 | 9-17 21:26 | | | | | | | | | | | | |
| 23789 | | | | | | | | | | | | | | | | | | |
| 23790 | | | | | | | | | | | | | | | | | | |
| 23791 | | | | | | | | | | | | | | | | | | |
| 23792 | | | | | | | | | | | | | | | | | | |
| 23793 | | | | | | | | | | | | | | | | | | |
| 23794 | | | | | | | | | | | | | | | | | | |
| 23796 | | | | | | | | | | | | | | | | | | |
| 23797 | | | | | | | | | | | | | | | | | | |
| 23799 | | | | | | | | | | | | | | | | | | |
| 23800 | | | | | | | | | | | | | | | | | | |
| 23801 | | | | | | | | | | | | | | | | | | |
| 23802 | | | | | | | | | | | | | | | | | | |
| 23803 | | | | | | | | | | | | | | | | | | |
| 23806 | 10 | 10-09 00:23 | 10-09 00:33 | 3 | 10-09 22:08 | 10-09 22:10 | 5 | 10-12 15:18 | 10-12 15:24 | 502 | 10-29 13:05 | 10-30 01:53 | | | | | | |
| 23853 | | | | | | | | | | | | | | | | | | |
| **Moricetown Release** | | | | | | | | | | | | | | | | | | |
| 23795 | | | | | | | | | | 1 | 9-07 23:56 | 9-07 23:56 | 24 | 9-08 08:31 | 9-08 08:58 | 11 | 9-16 23:59 | 9-17 00:11 |
| 23827 | | | | | | | | | | | | | 15 | 9-08 01:12 | 9-08 01:27 | 4 | 9-08 21:42 | 9-08 21:46 |
| 23832 | 1 | 9-12 18:46 | 9-12 18:46 | 1 | 9-12 15:10 | 9-12 15:10 | 4 | 9-12 03:34 | 9-12 03:37 | | | | | | | | | |
| 23833 | | | | | | | | | | | | | 12 | 9-04 11:31 | 9-04 11:42 | 6 | 9-05 08:14 | 9-05 08:18 |
| 23834 | | | | | | | | | | | | | 8 | 9-10 01:07 | 9-10 01:15 | 3 | 10-01 11:21 | 10-01 11:26 |
| 23835 | | | | | | | | | | | | | 6 | 9-08 13:08 | 9-08 13:13 | 4 | 9-09 09:13 | 9-09 09:16 |
| 23838 | | | | | | | | | | | | | 10 | 9-05 19:21 | 9-05 19:32 | 6 | 9-07 03:20 | 9-07 03:25 |
| 23839 | | | | 397 | 9-07 06:14 | 9-07 13:29 | 3 | 9-05 23:31 | 9-13 20:52 | 2 | 9-16 16:26 | 9-16 16:28 | 13 | 9-17 02:19 | 9-17 02:33 | 11 | 10-01 17:11 | 10-01 17:21 |
| 23840 | | | | | | | | | | | | | 13 | 9-06 14:17 | 9-06 14:32 | 60 | 9-08 04:23 | 9-08 05:50 |

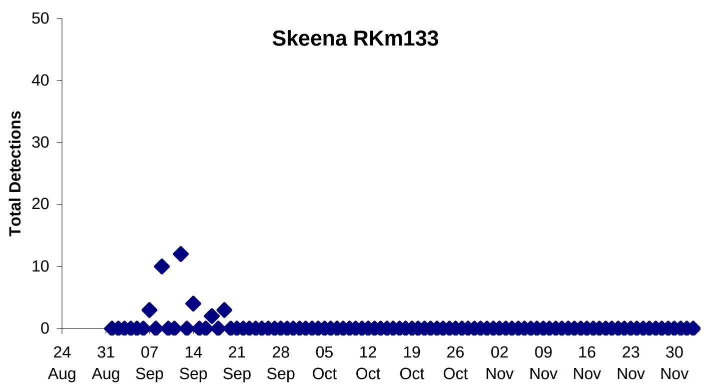
| Tag | RKm 285 | | | RKm 293 | | | RKm 303 | | | RKm 325 | | | RKm 332 | | | RKm 352 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Date Detected | | | Date Detected | | | Date Detected | | | Date Detected | | | Date Detected | | | Date Detected | |
| code | Num | First | Last | Num | First | Last | Num | First | Last | Num | First | Last | Num | First | Last | Num | First | Last |
| 23841 | | | | | | | | | | | | | 11 | 9-04 20:22 | 9-04 20:33 | 3 | 9-08 15:05 | 9-08 15:07 |
| 23848 | | | | | | | | | | 2 | 9-03 13:35 | 9-03 13:36 | 9 | 9-04 15:55 | 9-04 16:04 | 7 | 9-06 06:57 | 9-06 07:03 |
| 23849 | | | | | | | | | | | | | | | | | | |
| 23854 | | | | | | | | | | 3 | 9-13 14:41 | 9-13 14:43 | 11 | 9-15 16:35 | 9-15 16:55 | 8 | 9-30 01:34 | 9-30 01:42 |
| 23855 | | | | | | | 1 | 9-02 06:27 | 9-02 06:27 | | | | | | | | | |
| 23860 | | | | | | | | | | | | | 8 | 9-17 12:27 | 9-17 12:34 | 7 | 9-18 10:40 | 9-18 10:45 |
| 23861 | | | | | | | | | | 5 | 9-15 18:24 | 9-15 18:27 | 8 | 9-16 17:02 | 9-16 17:09 | 32 | 10-04 01:30 | 10-04 02:55 |
| 23866 | | | | | | | | | | 2 | 9-05 18:22 | 9-05 18:24 | 27 | 9-06 21:52 | 9-06 22:22 | 25 | 9-19 14:54 | 9-19 15:23 |
| 23867 | | | | | | | | | | | | | 10 | 9-06 17:36 | 9-06 17:44 | 2 | 9-07 17:24 | 9-07 17:25 |
| 23872 | | | | | | | | | | | | | | | | | | |
| 23873 | | | | | | | | | | | | | 6 | 9-12 06:15 | 9-12 06:22 | 4 | 9-15 12:22 | 9-15 12:28 |
| 23878 | | | | | | | | | | 1 | 9-03 03:36 | 9-03 03:36 | 7 | 9-03 19:14 | 9-03 19:22 | 2 | 9-04 15:25 | 9-04 15:26 |
| 23879 | | | | | | | | | | | | | | | | | | |
| 23880 | | | | 5 | 11-18 21:39 | 11-18 21:43 | 1 | 9-05 13:27 | 9-05 13:27 | | | | | | | | | |
| 23881 | | | | | | | | | | | | | 8 | 9-09 19:30 | 9-09 19:39 | 3 | 9-10 22:37 | 9-10 22:39 |
| 23884 | | | | | | | | | | 12 | 9-07 04:47 | 9-07 04:58 | 10 | 9-07 18:36 | 9-07 18:48 | 11 | 9-10 11:10 | 9-10 11:19 |
| 23886 | | | | | | | | | | 2 | 9-08 12:40 | 9-08 12:41 | 6 | 9-09 07:14 | 9-09 07:23 | 4 | 9-11 10:16 | 9-11 10:20 |
| 23887 | | | | | | | | | | | | | | | | | | |
| 23888 | 1 | 9-19 14:36 | 9-19 14:36 | | | | 65 | 9-07 01:11 | 9-07 02:31 | | | | | | | | | |
| 23889 | | | | | | | | | | 3 | 9-16 21:47 | 9-16 21:49 | 10 | 9-17 20:40 | 9-17 20:54 | 6 | 9-22 03:59 | 9-22 04:05 |
| 23890 | | | | | | | | | | 1 | 9-09 09:56 | 9-09 09:56 | 6 | 9-09 14:46 | 9-09 14:51 | 5 | 9-10 08:01 | 9-10 08:05 |
| 23891 | | | | | | | | | | 2 | 9-08 03:03 | 9-08 03:05 | 17 | 9-08 10:57 | 9-08 11:15 | 6 | 9-10 01:58 | 9-10 02:04 |
| 23892 | | | | 2 | 9-05 04:04 | 9-05 17:34 | 6 | 9-04 11:25 | 9-08 23:41 | | | | 10 | 9-12 08:57 | 9-12 09:07 | 1 | 9-13 16:24 | 9-13 16:24 |
| 23894 | | | | | | | | | | 17 | 9-19 18:33 | 9-19 18:49 | 6039 | 10-04 14:16 | 11-25 00:23 | | | |
| 23895 | | | | | | | | | | | | | | | | | | |
| 23896 | | | | | | | | | | 3 | 9-17 17:28 | 9-17 17:30 | 12 | 9-27 11:32 | 9-27 11:46 | 6 | 10-03 02:41 | 10-03 02:47 |
| 23897 | | | | | | | 6 | 9-05 16:35 | 9-05 16:49 | | | | 4 | 9-11 17:45 | 9-11 17:49 | 4 | 9-17 14:13 | 9-17 14:18 |
| 23898 | | | | | | | | | | | | | 12 | 9-10 06:15 | 9-10 06:25 | 9 | 9-12 00:21 | 9-12 00:29 |
| 23904 | | | | | | | | | | | | | 15 | 9-17 16:27 | 9-17 16:39 | 16099 | 10-29 03:16 | 11-25 22:31 |
| 23909 | | | | | | | 4 | 9-06 05:25 | 9-13 15:51 | | | | 12 | 9-16 09:03 | 9-16 09:16 | 572 | 9-26 02:48 | 9-26 16:03 |
| 23910 | | | | | | | | | | | | | | | | | | |
| 23911 | | | | | | | | | | | | | | | | | | |
| 23912 | | | | | | | | | | 15 | 9-17 22:50 | 9-17 23:15 | 8 | 10-01 15:29 | 10-01 15:38 | 3175 | 10-25 14:34 | 10-29 05:48 |
| 23913 | | | | | | | | | | | | | 2 | 9-07 18:07 | 9-07 18:09 | | | |
| 23914 | | | | | | | | | | | | | | | | | | |
| 23915 | | | | | | | | | | | | | 13 | 9-15 16:10 | 9-15 16:23 | 166 | 9-19 23:28 | 9-20 02:47 |
| 23916 | | | | | | | 1 | 9-05 19:03 | 9-05 19:03 | | | | 9 | 9-10 18:54 | 9-10 19:03 | | | |
| 23917 | | | | | | | | | | 1 | 9-10 13:54 | 9-10 13:54 | 6 | 9-10 21:41 | 9-10 21:46 | 7 | 9-21 16:13 | 9-21 16:19 |
| 23918 | | | | | | | | | | 11968 | 10-07 19:29 | 10-31 02:11 | | | | | | |
| 23919 | | | | | | | | | | 1 | 9-06 22:42 | 9-06 22:42 | 8 | 9-07 16:28 | 9-07 16:36 | 76756 | 9-12 01:28 | 11-25 22:32 |
| 23920 | | | | | | | | | | | | | 30 | 9-06 20:04 | 9-06 20:38 | 68 | 9-15 18:19 | 9-15 19:37 |

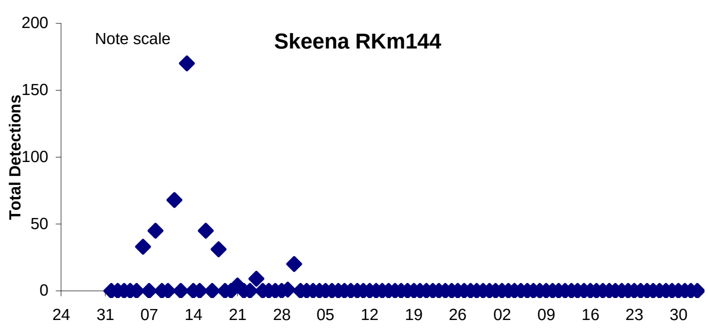
Appendix 3. Total number of detections of adult wild steelhead recorded per day at each sub-array in the Skeena and Bulkley rivers in 2008. These data were screened for false detections.

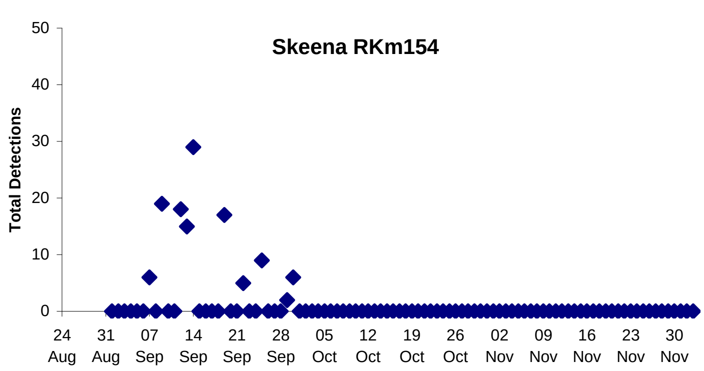
Tyee Release at Skeena RKm16
(16 Km from Mouth of Skeena)

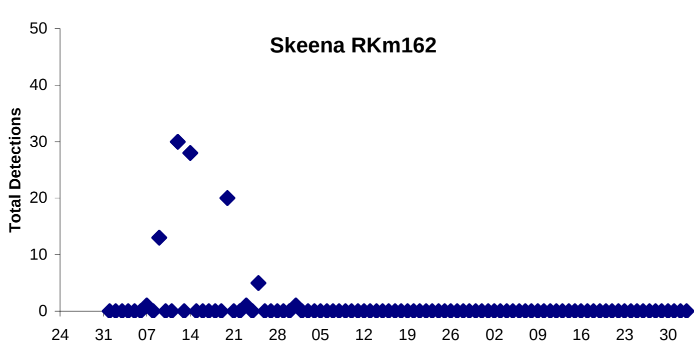


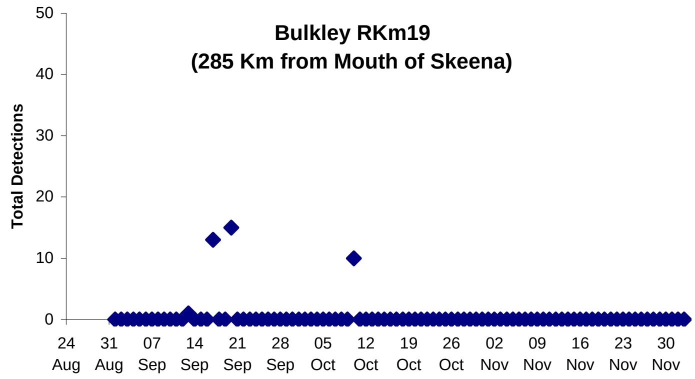



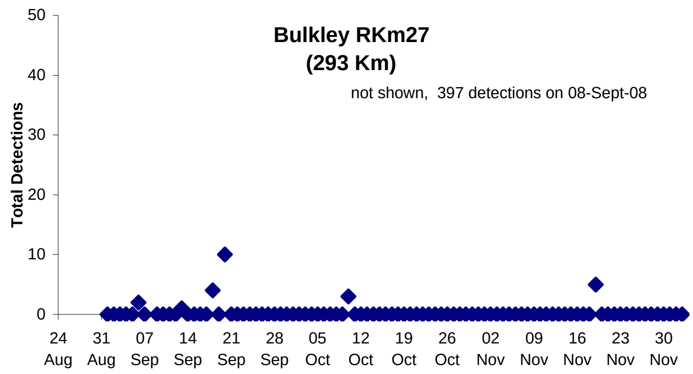



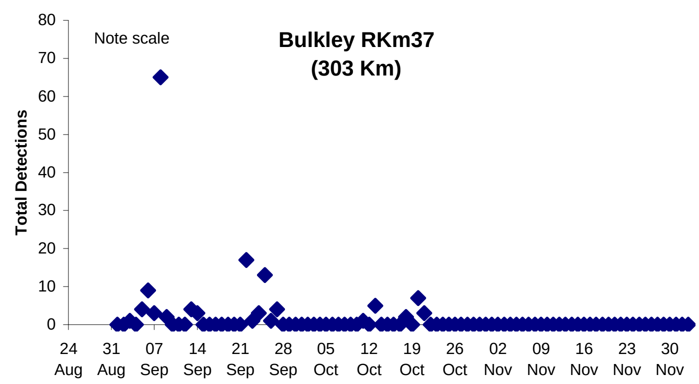



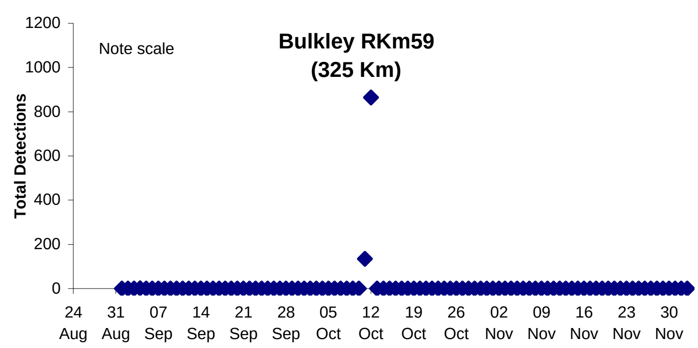



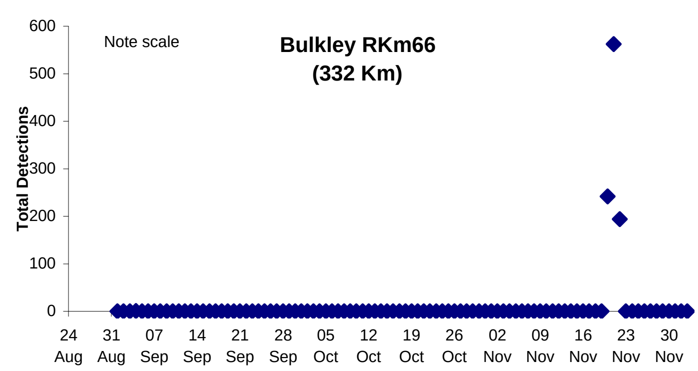



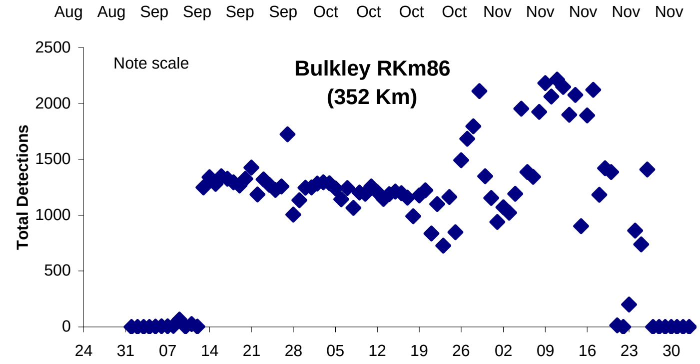




Moricetown Release at Bulkley RKm58
(314 KM from Mouth of Skeena)



Appendix 4. Number of wild, adult steelhead detected per day at each sub-array in the Skeena and and Bulkley rivers in 2008. These data were screened for false detections.