Improvements to estimates of daily sockeye and pink salmon abundance migrating in the Fraser River: integration of estimates from two sonar sites, Mission and Qualark

Year 1 Interim Project Report to Southern Boundary Restoration and Enhancement Fund

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ABSTRACT

The Qualark Creek hydroacoustic site was developed in the 1990s to use digital split-beam technology to monitor adult salmon returning to the Fraser River. The Applied Technology Section of DFO reactivated the Qualark hydroacoustic site in 2008 to test the feasibility of estimating daily salmon escapement in-season with dual-frequency imaging sonar (DIDSON) on each bank of the river and to assist the hydroacoustic program at Mission during challenging estimation periods. The value of additional sampling effort at the longest range in the ensonified water volume on the robustness of escapement estimates at Qualark was assessed in 2011. The modified sampling involved doubling the sampling effort from 5 to 10 minutes hourly in the long range window (e.g. 20m-30m) on each bank based on previous findings concerning on the precision of estimates from temporal sub-sampling of DIDSON data and a recommendation from the DFO/PSC Hydroacoustic Working Group. The additional sampling improved measurements of an offshore shift in fish distribution that occurs during fishery openings downstream of Qualark and was noted in 2008-2010. However, the additional sampling effort did not materially alter the workload of site staff since only 1-2% of the fish migrate through these long-range bins when nets are in the water and few to no fish when the nets are not in the water. Fish passage behaviour in 2011 was consistent with behaviour recorded in the 2008 to 2010 seasons, in that the migration of all salmon species was near shore within the ensonified area of a standard DIDSON using one aiming configuration and multiple range bins. During First Nations fishing opportunities in the immediate area of the Qualark site (between Hope River Bridge and Sawmill Creek) there is a noticeable change in the distribution of migrating salmon relative to the shoreline, with more fish at longer ranges than when nets are not in the water. This offshore shift in the location of migrating fish does not appear to alter the upstream movement, but it increases the number of fish detected in the mid-range bin of our sampling range (Bin 2 - 9.2 m to 19.2 m) to 9-20% and a reduces the number of fish in the close range bin (Bin 1 – 4.2 to 9.2 m) from 98.6% to 78-90% of detected fish. Regardless of the presence or absence of nets, the majority of migrating salmon (96% overall) pass through the close-range bin (Bin 1) in the standard Qualark sampling scheme, which is optimal for manual counting of files since the DIDSON images are collected in high frequency mode (1.8 MHz) with the highest image resolution. The offshore shift in fish migration during fishing periods means a higher number of fish are detected in the mid- (Bin 2) and long-range (Bin 3) bins, which is less desirable for manual counting of files because these files are collected in low frequency mode (1.1 MHz) with poorer image resolution. However, the impact of these counts on daily escapement estimates is negligible since the number of salmon in the two low frequency sampling bins (Bins 2 and 3) is low. Research is ongoing to develop a model linking salmon movements at Mission and Qualark. Preliminary results are promising in that they point to common signals in the two datasets (e.g., a diurnal signal associated with daylight) that potentially can be exploited to develop the corrections or adjustments for Mission under specific conditions. During Year 2 of this project, we will be seeking a contractor or casual with the appropriate analytical expertise to advance this analysis in collaboration with the joint DFO/PSC Hydroacoustic Working Group.

INTRODUCTION

Background

The Applied Technologies Section of the Department of Fisheries and Oceans re-activated the Qualark Creek Acoustic Site on the mainstem of the Fraser River in 2008 using multi-beam (DIDSON) technology to monitor the escapement of adult anadromous salmonids (*Oncorhynchus* spp.) to terminal spawning areas in the upper Fraser River watershed (Enzenhofer et al., 2010). A test fishery was also implemented to provide daily biological and species composition data for the acoustic estimates. The Qualark site was developed using split-beam technology between 1993 and 1998 and employed a similar test fishing program to apportion the acoustic estimate by species (Enzenhofer and Cronkite, 1998). All six Pacific salmon species return to spawn in the Fraser River and pass the Qualark site. Sockeye salmon (*O. nerka*) is the dominant species in even numbered years (e.g., 2008) while in odd numbered years (e.g., 2009), pink salmon (*O. gorbuscha*) are often more abundant than sockeye salmon. The Qualark site is located above most of the major in-river fisheries and below the Fraser Canyon, which is considered the most difficult portion of the river for salmon migration and the likely area of highest in-river mortality.

The Pacific Salmon Commission estimates gross escapement of Fraser River sockeye salmon at Mission, BC and this acoustic site is strategically located to provide key information for in-season management of salmon fisheries to meet multiple obligations under the Pacific Salmon Treaty. Reliable estimates of sockeye salmon escapement in the Fraser River are a prerequisite for achieving spawning escapement goals and harvest allocations. The Mission site poses technical challenges for the acoustic enumeration of salmon that contribute to the concerns among managers and other clients about the reliability of the Mission estimates. These challenges include:

(1) A large cross section of up to 420 m in river width in which current velocities migrating salmon face are relatively slow;

(2) Large tidal influences in late August and early September that can change the upstream swimming behaviour of fish by slowing down their migration speed or in the worst case cause them to hold or mill;

(3) Migrating salmon exhibit avoidance behaviour in the presence of the mobile transect vessel, even when the vessel is stationary;

(4) Species composition is determined from test fisheries that are far downstream of the hydroacoustic site and negatively affected by seal predation in recent years;

(5) Changes in local fishing efforts at the acoustic site in recent years have altered fish behaviour and cross-river distribution; and,

(6) Dense near-shore migration behaviour of pink salmon (*O. gorbuscha*) during odd years blocks acoustic signals to and from fish migrating further offshore, i.e., sockeye, decreasing detection.

In contrast to Mission, Qualark has site characteristics that are closer to the ideal for reliably detecting and tracking sockeye salmon as they move upstream, including:

(1) Fish migrate within 20 m of both banks regardless of the discharge or water level, to avoid strong currents in the mid-channel, which allows a single fixed aim with a DIDSON system;

(2) The strong currents and absence of tidal effects at the site result in consistent upstream migratory behaviour in salmon. Holding or milling behaviour, which hamper acoustic enumeration, have been observed at Qualark on only one occasion during a high water event in July 1997;
(3) Both river banks were re-profiled and paved with sand bags at the site to create a non-obstructive and non-reflective acoustic environment that is optimal for side-looking acoustic detection and counting of fish. The deployment platforms on both banks for the acoustic transducers are on tracks and can be moved up or down by winch-controlled cables to change position of the transducers as the water level changes;
(4) Human activities that can bias acoustic estimates of fish passage, particularly vessel traffic, are minimal relative to conditions at Mission; and
(5) Many of the pink salmon that migrate past Mission spawn in the lower river and do not migrate past Qualark, which reduces the impact of the dense nearshore behaviour of pink salmon on the detection and counting of migrating salmon. However, if gross pink salmon escapement data are required for management, then a site such as Mission in the lower river would be more appropriate since Qualark enumerates the upstream stocks only and these stocks appear to comprise a variable fraction of the returning pinks.

Project goals

The 2011 operations at Qualark were the first year of a two-year project funded by SEF and the fourth year of parallel operations with Mission.

The goals of this project are to:

1. Produce reliable and timely estimates of gross salmon passage in the Fraser River using three study design elements that are complementary to work conducted by PSC staff:
   - Operation of the Qualark DIDSON hydroacoustic enumeration system in a manner consistent with practices developed from 2008 to 2010 (Enzenhofer et al., 2010);
   - Implementation of the Qualark test fishery consistent with procedures developed during the period 2008-2010; and
   - Further evaluation of fish flux occurring outside the normal acoustic monitoring window at Qualark. Acoustic sampling on each bank between 20 and 30 m range was conducted for 10 min per hour throughout the migration period; and

2. Develop, in collaboration with PSC staff, analytical methods to either modify or combine estimates from the Mission and Qualark acoustic sites to provide a more robust estimate of salmon escapement into the Fraser River based on four years of data from 2008 to 2011 when both sites were operating.

Here we report on the operations of Qualark in Year 1 of the SEF project (2011). We also provide some preliminary results and observations related to the analysis of Mission and Qualark data to improve Fraser River sockeye escapement estimates, but this work is ongoing and will be reported more fully at the termination of this project.

MATERIALS & METHODS

Study site

The Qualark Creek hydroacoustic facility is located on the Fraser River in British Columbia, Canada and is 15 km north of Hope, BC, and 95 km upstream of Mission, BC. The Qualark site is below many, but not all of the major sockeye salmon spawning areas in the Fraser River watershed (Figure 1).

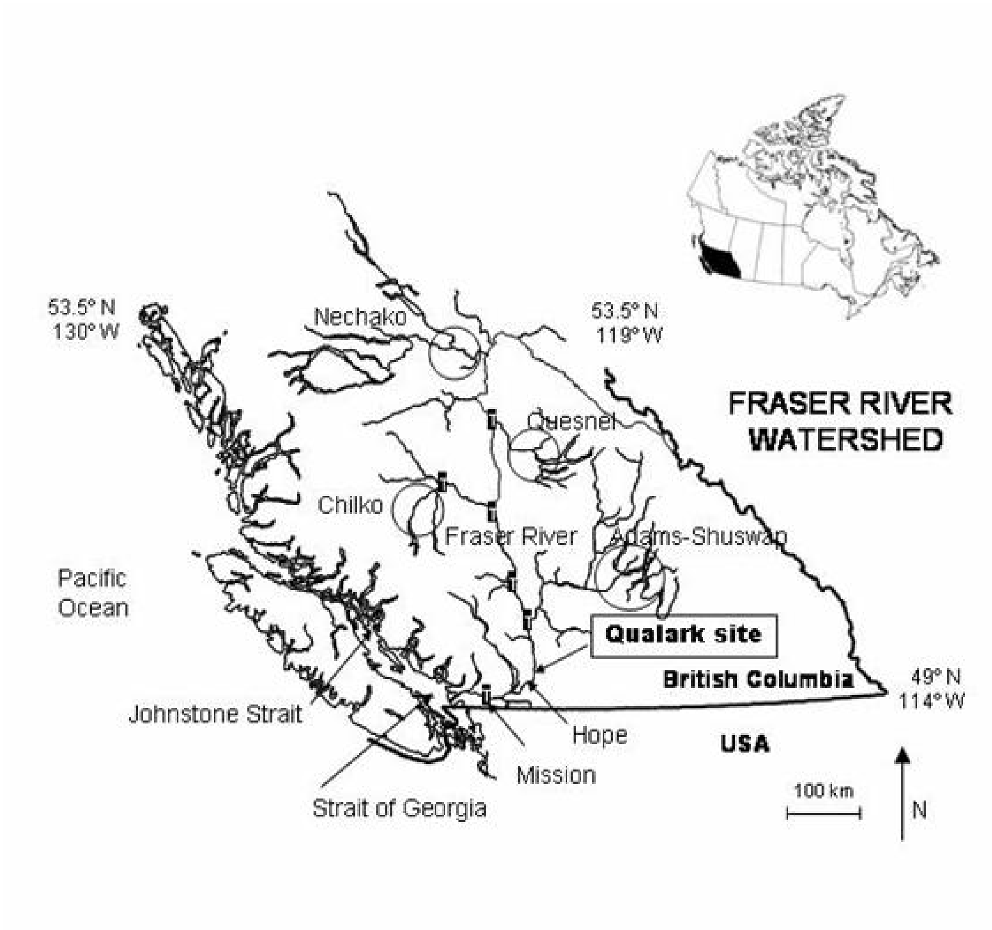


Figure 1: Map showing the Fraser River watershed and location of the Qualark Creek hydroacoustic site near Hope, BC. Some of the major spawning areas including the Nechako, Quesnel, Chilko, and Adams-Shuswap Lake systems are circled.

The Qualark site was originally chosen as an experimental site because it was on a straight stretch of river with laminar flow, water velocity was high, flows were not tidally-influenced, and substrate and bank configurations were planar and free of obstructions (scalloping, benches, large boulders) that might impair fish detection or introduce noise to the acoustic system and there was minimal human activity that would alter fish behaviour (Enzenhofer and Cronkite, 2000). These characteristics ensure that fish actively migrate through this area rather than holding or milling, which is key to the success of a riverine acoustic site. The relatively high water velocities and consistent bank slopes combined with the energy conserving migration schemes of salmon, result in most salmon, including sockeye, migrating through the Qualark site within 15 m of the shore regardless of discharge and water level. Consequently it is not necessary to ensonify the middle of the river where the signal to noise ratio is not favourable for the acoustic detection of fish.

The Fraser River is 150 m wide at the Qualark site with discharge ranging from 10,000 $m^3 s^{-1}$ during spring freshet to 500 $m^3 s^{-1}$ during the low water period in winter. The river banks have a natural slope of 21° (right-bank) and 20° (left-bank) with the surface layer consisting of 30-50 cm diameter rock and some large boulders (Figure 2) (left-and right-banks are relative to an observer facing downstream). Water velocities at the site range from 1.0 m s^{-1} near shore to 3-4 m s^{-1} in the middle of the river. Flow patterns vary from bank to bank, but in general fine materials are scoured along the right-bank and sand is deposited along the left-bank.

The right-bank is accessible by road and heavy equipment was used to refurbish the bank for acoustic work during the low water period in early 2008. The left-bank site is approximately 150 m downstream of the right-bank site and is only accessible via boat or railway. Equipment and supplies were moved to the left-bank by boat and the refurbishment of the acoustic ramp and reinstallation of in-river equipment was done manually during the low water period in early 2008.

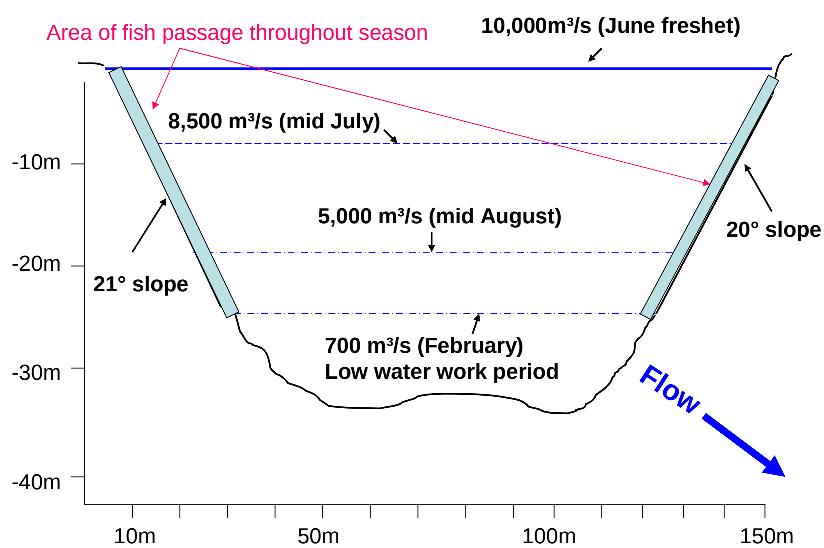


Figure 2. Fraser River cross section at the Qualark Creek site showing average discharge rates throughout the salmon migration period. Note that the vertical and horizontal scales differ. River flow is toward the viewer.

<u>Acoustic data collection</u>

Acoustic data are collected with two standard DIDSON imaging systems (one on each bank) affixed to a track-mounted 6 m long fish deflection weir that can be adjusted in response to changes in river water levels with a remotely controlled winch. The standard DIDSON imaging systems have high frequency (1.8 MHz) and low frequency modes (1.1MHz) and their output consists of images created by multiple sound beams focused through a moveable lens giving a field of view that is 14° vertical and 29° horizontal (Belcher et al., 2001; Sound Metrics 2007).

Sampling strategy and data processing

Based on split-beam sonar work at the Qualark site in the 1990s (Enzenhofer and Cronkite, 2000), the majority of fish passage was expected to occur within a range of 4 m to 9 m from the DIDSON system as fish were forced offshore to pass around the fish deflection weir with the remainder passing between 9 m to 19 m. We used a systematic sampling design on each bank that utilized one aiming configuration of the DIDSON with a 35° roll angle relative to the water surface (outlined in Enzenhofer et al., 2010) to sample between 4.2 m to 29.2 m in range, divided into three range bin files each hour (Figure 3). The aiming configuration was verified with a target suspended in the ensonified region to ensure that there were no blind zones near the surface or bottom through which fish could pass undetected and is consistent with protocols outlined by Holmes et al. (2006). On each bank three files were recorded hourly consisting of:

- 20 minute 5 m window length (4.2 m to 9.2 m) at high frequency mode (1.8 MHz utilizing 96 beams) producing the best available image resolution for counting the majority of fish passage (close-range Bin 1)
- 20 minute10 m window length (9.2 m to 19.2 m) at low frequency mode (1.1 MHz utilizing 48 beams) (mid-range Bin 2)
- 10 minute 10 m window length (19.2 m to 29.2 m) at low frequency mode (long-range Bin 3).

DIDSON data files were counted by site personnel applying pre-determined counting criteria to estimate net upstream flux (a product of the upstream count minus the downstream count), then entered in an Excel spreadsheet. Counting criteria (Figure 4) addressed the potential for double counting of fish which may move out of or into an adjoining range bin (Figure 5). Counts for each range bin were expanded to the hour and summed to represent total passage. Data were collected for a total of 50 minutes out of each hour.

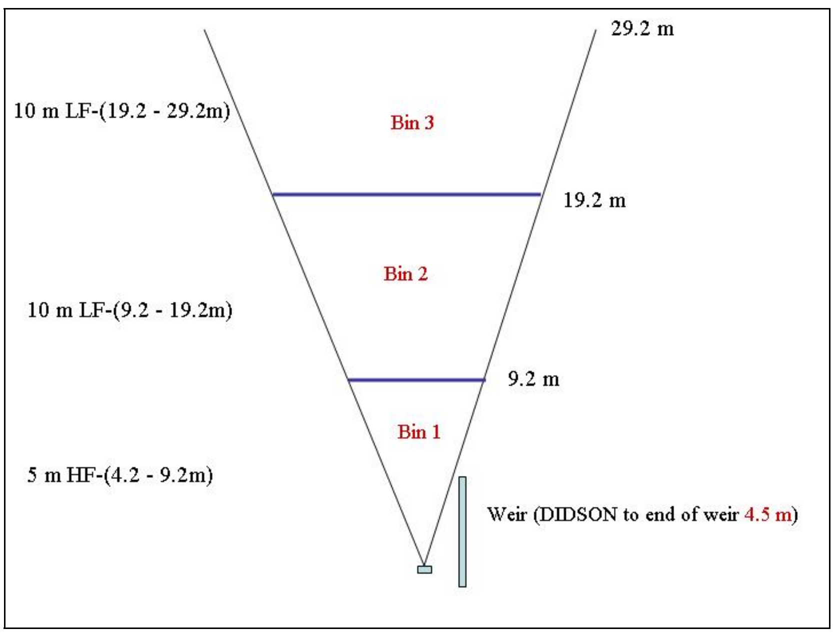


Figure 3. Plan view of the sampling strategy showing one aim configuration of the DIDSON and three range bins to sample 29.2 m range at the Qualark Creek site. Bin 1 is shown using a 5 m window length at high frequency (HF) starting at 4.2 m from the DIDSON (small blue rectangle). Bin 2 is shown with a 10 m window length in low frequency (LF) mode, from 9.2 m to 19.2 m from the DIDSON. Bin 3 is a 10 m window length in low frequency mode covering a range between 19.2 m to 29.2 m.

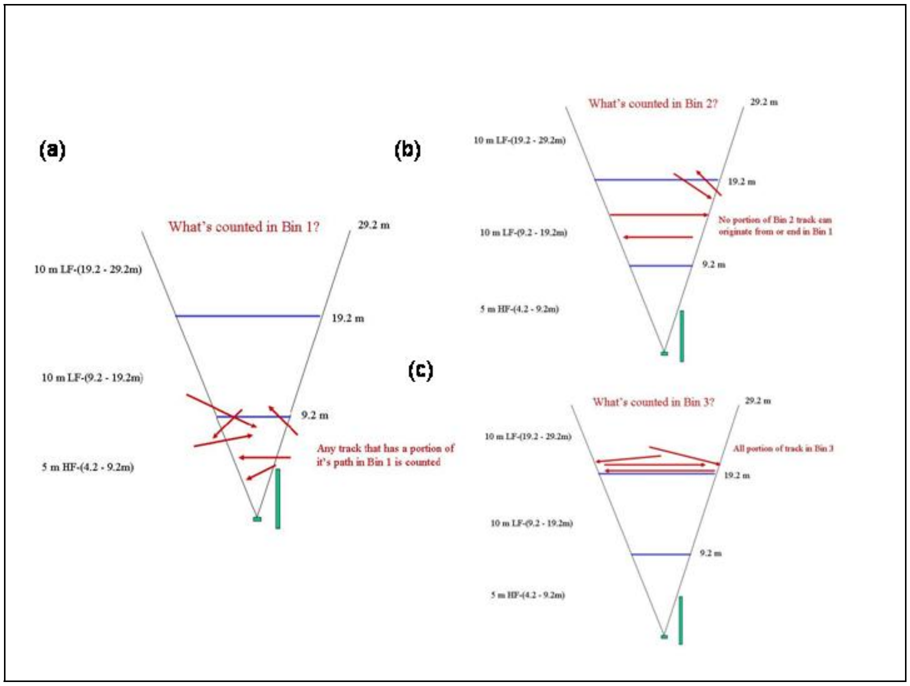


Figure 4. Counting criteria for manual counts of range bins to avoid double counting fish passing through more than one range bin. (a) Any portion of a fish trajectory is included in the Bin 1 count, (b) fish included in Bin 2 counts can not have any portion its track in Bin 1, and (c) fish included in the Bin 3 count must have entire portion of track in Bin 3.

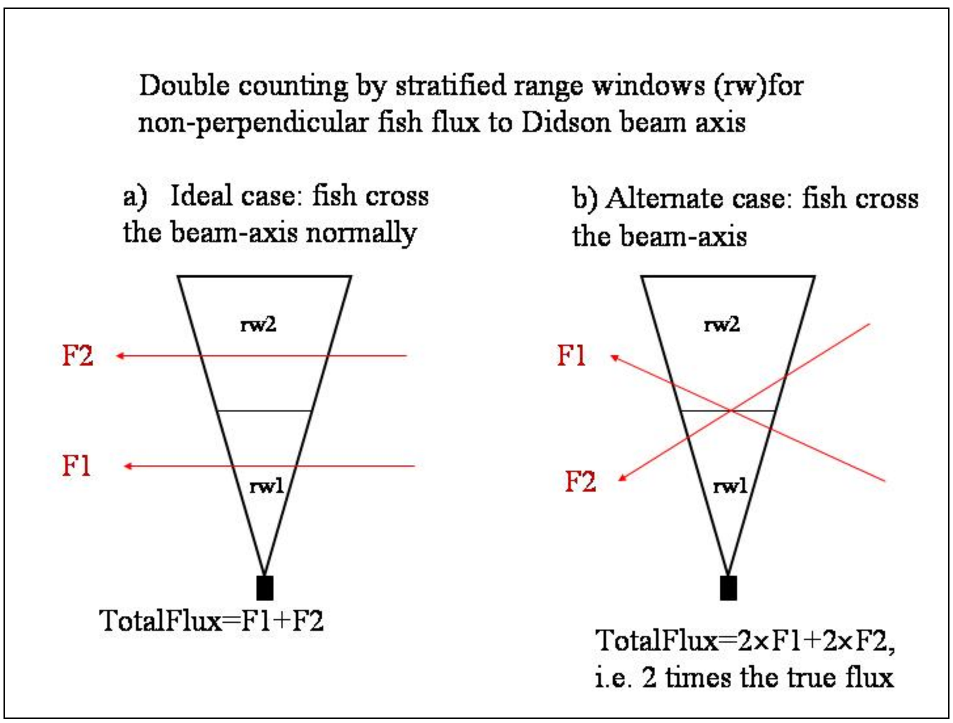


Figure 5. Illustration of fish passage moving through a fixed location DIDSON imaging sonar configured with one aim and two range windows (rw1 & rw2). a) Two fish tracks (F1 & F2) each passing through only one range window resulting in a correct flux estimate of two, and b) Two fish tracks (F1 & F2) crossing through both range windows potentially resulting in an incorrect double count of four if the counting criteria protocols in Figure 4 are not applied.

Test fishing program

The test fishery consisted of a drift sequence in the morning (07:00-08:00) and another drift sequence in the evening (about one hour before dusk). The drift series consisted of 6 drifts per day, seven days per week, one 3-drift set in the morning and one 3-drift set in the evening. Each set of 3 drifts was made close to shore along the right bank and directed at capturing salmon. Two additional drifts per week, spaced out over the week, were made beyond 25 m from the right bank using the 5¼ inch mesh net to test for presence/absence of migrating salmon in the offshore regions. The mesh sizes used for the drifts included 4, 4 ¾, 5 ¼, 5 ¾, 6 ¾ and 8 inch (stretched mesh, 70 mesh hang, and 30 m length). The morning drifts began on the first day using the 4, 5 ¼, and 6 ¾ inch meshes in sequence, and the evening drifts began using the 4 ¾, 5 ¾ and 8 inch meshes in sequence. On the second day the morning and evening sequences were reversed and on each subsequent day the pattern of drifts was alternated to allow some randomisation of the sampling. Each drift was approximately 4 minutes in duration and began 150 m upstream of the acoustic system and terminated approximately 700 m downstream of the Qualark site.

All fish were counted and sex, length and weight were recorded for retained fish. In addition, scale samples and DNA samples (adipose fin punch) from up to 50 sockeye salmon per day were taken for PSC stock identification needs and up to 50 pink salmon per day were sampled for sex, length and weight.

RESULTS

Estimate of total salmon passage for 2011

The Qualark Creek site began reporting daily estimates of fish passage on July 13 (12:00 hrs) for the right-bank system and August 1 (15:00 hrs) for the left-bank system for a total operating period of 83 days ending on October 3, 2011. The left-bank system had a later start date as high water did not allow access to the track mounted fish deflection weir for setup of DIDSON system. For the period that the left-bank system was not operational (July 13 to August 1) the right-bank system estimates of net upstream passage were substituted and the total passage of salmon is shown in Figure 6. Overall the total number of salmon estimated for the operational period at Qualark in 2011 was 6,761,076 fish (3,853,973 right-bank and 2,907,103 left-bank).

Estimate of salmon population by species apportioned through test fishing results

We used the results from the daily test fishing catches to apportion the acoustic estimate by species (Figure 7). This was accomplished by summing the total catch for a given day and applying the catch ratios for each species as a percentage, multiplied by the total passage for the same day (00:00 to 23:00 hrs).

The test fishing program began on July 22 and did not coincide with the start of the acoustic program (July 13) due to conservation concerns for Early Stuart sockeye. Species composition data are not available for the period that test fishing did not occur (July 13 – July 21) and as a result only total salmon estimates are reported. The test fishery operated from July 22 to October 3 for a total of 74 days. The raw data are attached in Appendix 1.

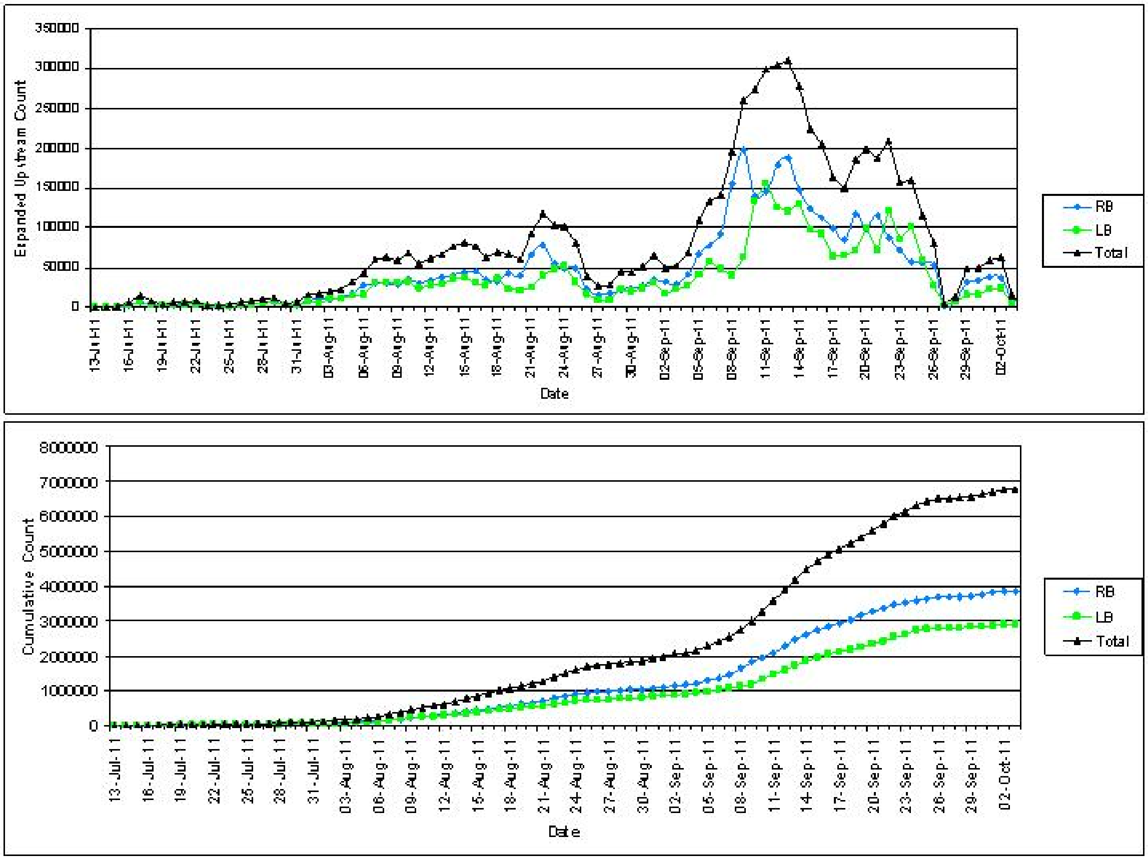
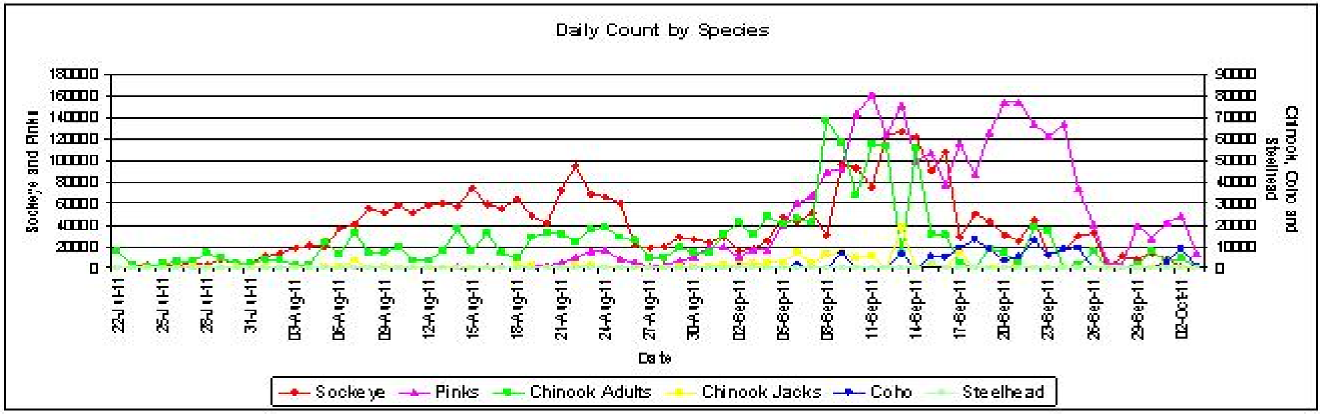


Figure 6. Daily upstream passage of Pacific salmon for the Qualark Creek hydroacoustic site on the Fraser River for 2011. The top graph shows the daily net upstream passage and the bottom graph shows the cumulative total. The solid black line represents both banks, the solid blue line right-bank and the green line left-bank.



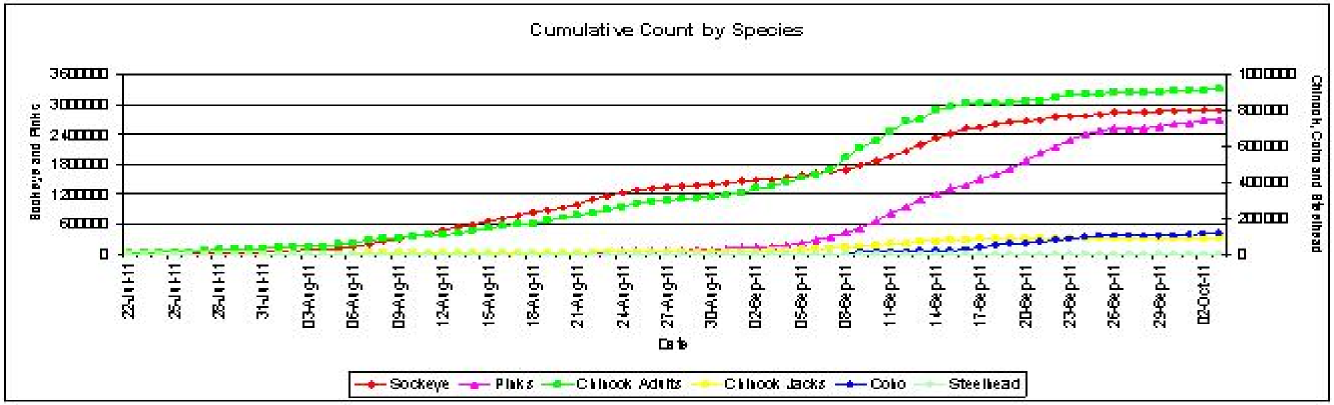


Figure 7. Estimate of salmon population by species apportioned through test fishing results for Qualark Creek 2011. The top graph shows daily passage and the bottom graph shows the cumulative passage by species. Note that sockeye and pink salmon scale values are on the left and other species scale values are on the right.

Evaluation of fish flux occurring outside the standard acoustic monitoring window

The amount of time monitoring Bin 3 (19.2 m to 29.2 m) on both banks was increased to 10 minutes per hour to assess fish flux occurring outside the standard acoustic monitoring window. The increased collection of DIDSON data within this long range window is in accordance with DFO research on the precision of estimates from temporal sub-sampling (Cronkite et al., 2006; Lilja et al., 2008).

Fish passage occurring from 9.2 m to 29.2 m (Bin 2 and Bin 3 combined) beyond the normal acoustic monitoring window of Bin 1 (DIDSON in high frequency mode using a 5 m window from 4.2 m – 9.2 m) is shown in Figure 8.

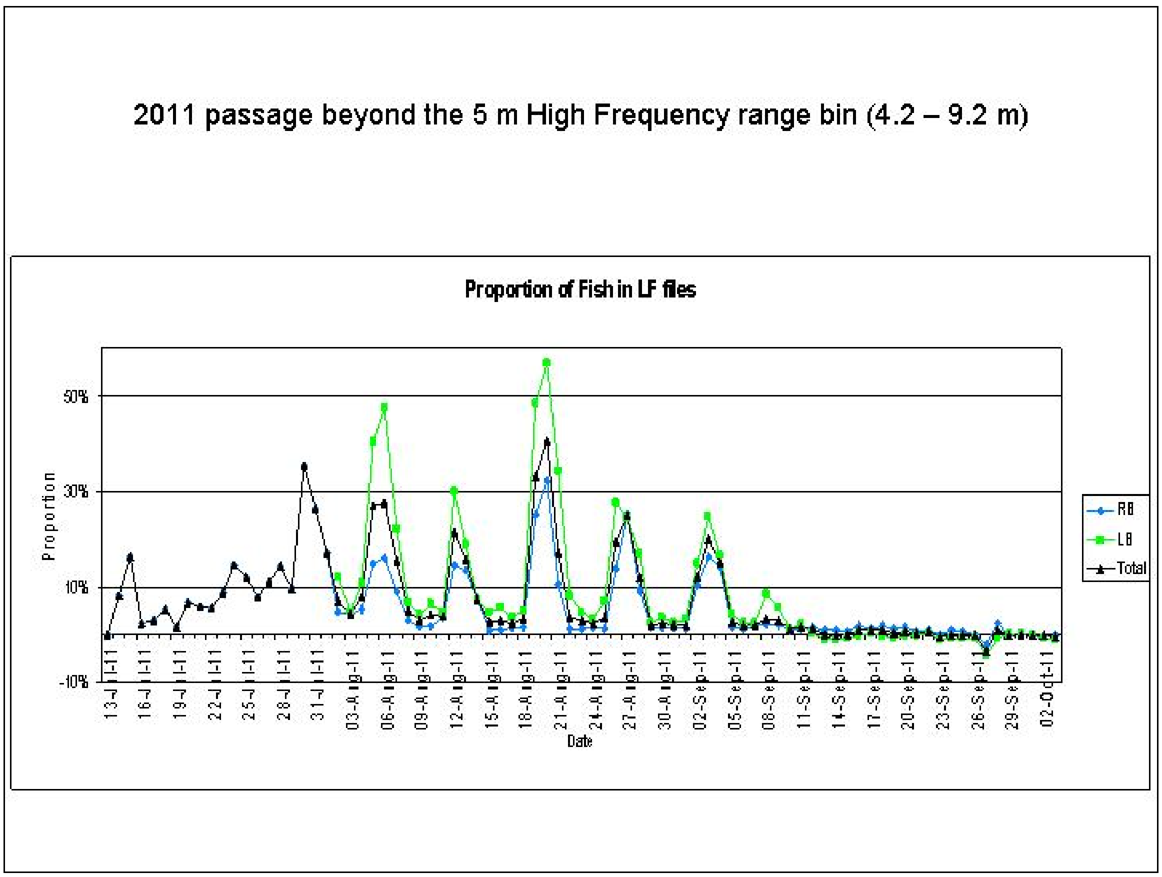


Figure 8. Passage occurring beyond the 9.2 m range in the low frequency files (LF) counted from the DIDSON systems at Qualark Creek expressed as a percentage of the estimated daily total salmon flux.

The passage data in Figure 8 are overlaid with dates of fishery openings for Yale First Nations gill-net fishing opportunities that occurred between the Hope River Bridge (lower boundary) and Sawmill Creek upstream of Yale, BC (upper boundary) for the period of July 29 to September 9, 2011 (Figure 9). The overlay shows a strong visual correlation between openings and an increase in fish migrating further offshore through the long-range sampling bins at Qualark.

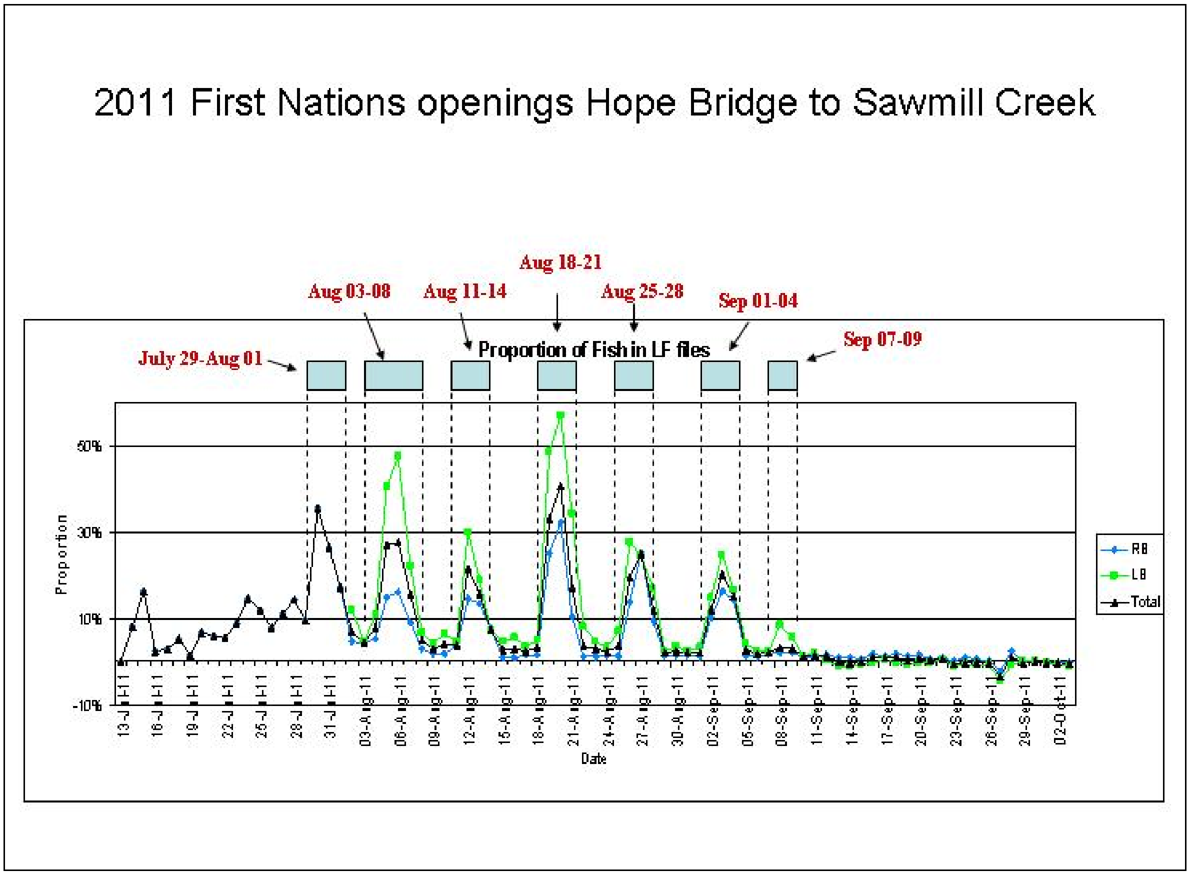


Figure 9. Fish passage occurring beyond 9.2 m range low frequency files counted from the DIDSON systems at Qualark Creek as a percentage of the total daily salmon passage with Yale First Nations gill net fishing period overlaid. Dashed areas under the blue rectangles coincide with the opening and closure time periods.

Table 1. Passage estimated at Qualark Creek for 2011 showing the overall passage recorded for the period from July 13 to October 3, 2011 broken down by percentage recorded in each of three range bins used.

Period	Bank	Fish passage	Bin 1 (4.2 m – 9.2m)	Bin 2 (9.2 m – 19.2m)	Bin 3 (19.2 m – 29.2m)
Overall	Right	3,853,973	96.7%	3.0%	0.3%
Overall	Left	2,907,103	95.5%	4.3%	0.2%
No nets	Right	2,956,686	98.7%	1.3%	0%
No nets	Left	2,436,260	98.6%	1.4%	0%
Nets in	Right	897,287	90%	9%	1%
Nets in	Left	470,843	78%	20%	2%

Development of analytical methods to provide a more robust estimate of salmon escapement into the Lower Fraser River

Initial work in conjunction with PSC hydroacoustics staff has focused on understanding the data time series at both Mission and Qualark, relationships with external forcing factors (e.g., discharge, temperature, in-river fishery removals) and simple linkages between the sites. Much of this work focuses on sockeye salmon and assumes that species compositions based on test fishery data (and other methods at Mission) are correct. Four years of data are currently available from 2008 to 2011. These migration years are classified based on pink and sockeye abundances (Table 2). The most challenging period for Mission estimates of sockeye escapement occurs during pink dominant years when both pink and sockeye salmon migrations overlap in the river, which usually occurs in the later part of August and into September. Over the last four years, we had two pink-dominant years in which sockeye abundance was relatively low and no sample from a year in which high sockeye abundance coincided with high pink salmon abundance in the river, which is likely to be the most challenging scenario for Mission acoustic estimates of gross sockeye salmon escapement.

Table 2. Classification of migration years based on sockeye and pink salmon abundance

	Sockeye Abundance	
Pink Abundance	Low	High
Low[A]	2008	2010
High	2009, 2011	

A – Fraser River has odd-year pink salmon migration so low abundance means an even numbered year when no pink salmon return.

Time series analysis in both the time (cross correlations or lag analysis) and frequency (spectral) domains were performed on total salmon counts at Qualark after $\log_{10}$ transforming these data (Figure 10) to remove scaling differences in absolute counts. This transformation was necessary because daily escapement estimates in 2008 were, on average, at least an order of magnitude lower than in 2009, 2010 and 2011. Total salmon are used in this preliminary analysis to remove noise associated with species composition estimates. Each annual escapement time series was detrended with empirically fitted second-order polynomial regressions (Table 3) to achieve stationarity of the mean over time (a necessary condition for time series analysis), This procedure is equivalent to applying a high pass filter to remove low frequency variation, which for these data is the normal increase to a peak and then decline of the spawning migration. The result is a time series varying about a mean of zero for each year (Figure 11). Cross-correlations between the Qualark and Mission time series lagged up to 30-d (Figure 12) show strong positive correlations at 2-7 d lag, peaking at 3-4 days when Mission is lagged relative to Qualark (bottom row of panels in Figure 12). This finding is broadly consistent with previous experience suggesting that sockeye salmon travel times between Mission and Qualark are 3-4 days. A more precise estimate of travel time

Table 3. Second order polynomial regressions empirically fitted to total escapement data at Qualark, 2008-2011 and used to detrend these data as shown in Figure 11.

Year	Equation	R^2
2008	$\hat{y} = -0.0011x^2 + 0.0918x + 2.5838$	0.8324
2009	$\hat{y} = -0.0002x^2 + 0.0384x + 3.0525$	0.6763
2010	$\hat{y} = -0.0006x^2 + 0.0745x + 3.1668$	0.7588
2011	$\hat{y} = -0.0008x^2 + 0.0869x + 2.7319$	0.7033

Second order polynomials where $\hat{y}$ is the predicted escapement and *x* is Julian day; July 1 is Julian day 183.

can be developed using hourly escapement data. These data are readily available for both banks at Qualark, but only the left-bank split-beam data at Mission can be analyzed on an hourly basis.

A plot of estimated mean hourly passage rates at Qualark shows that passage is strongly diurnal in all four years (Figure 13). Most passage occurs during daylight hours between 06:00 and 21:00 hours daily, and exhibits a small peak early in the morning (06:00-07:00) and then builds to a larger peak in mid-afternoon around 15:00. This diurnal pattern of passage persists in both sockeye-dominant and pink-dominant years (Figure 13). There were no differences between banks at Qualark and in most years the ratio of passage along each bank was approximately 1:1. Spectral analyses of hourly data at Qualark and from the left-bank at Mission by PSC staff are consistent with the finding in Figure 11. There is a strong diurnal frequency signal to salmon movements past Qualark. In contrast, salmon movements at Mission exhibit both semi-diurnal and diurnal frequency signals, at least in September 2011 (see Figure 12 in Xie et al. 2012). The semi-diurnal signal is related to tidal modulation of movements, which occur primarily on slack tides. There is a vestigial remnant of a semi-diurnal signal in the Qualark data, but the diurnal signal is far stronger. The strength of the diurnal signal in the left-bank data from Mission may vary between years but requires further research to confirm.

Mean daily discharge data for the Fraser River at Hope for 2008-2011 were detrended with an empirically fitted exponential regression and the residuals plotted against daily escapement at Qualark for the same periods (Figure 14). Variation in discharge accounts from more than 50% of the variation in daily escapement in sockeye-dominant years (2008, 2010), but less than 20% of the variation in escapement in pink-dominant years (2009, 2011) at Qualark. In sockeye-dominant years, escapement increases during periods of below average discharge (Figure 14) and declines as discharge increases. In contrast, in pink-dominant years the relationship between discharge and escapement is not very strong as other factors influence salmon migration and variation in these years.

Principal components analysis was conducted on detrended escapement, discharge and water temperature data stratified by pink-dominant and sockeye-dominant years (Figure 15). The first two principal component axes (PC1, PC2) account for 77% of the variance in these data during sockeye dominant years and 81% of the variance in pink-dominant years. Escapement is strongly positively correlated with PC1 while discharge is strongly negatively correlated on the same axis during sockeye-dominant years. Water temperature is strongly positively correlated with PC2 in these years. In contrast, water temperature and

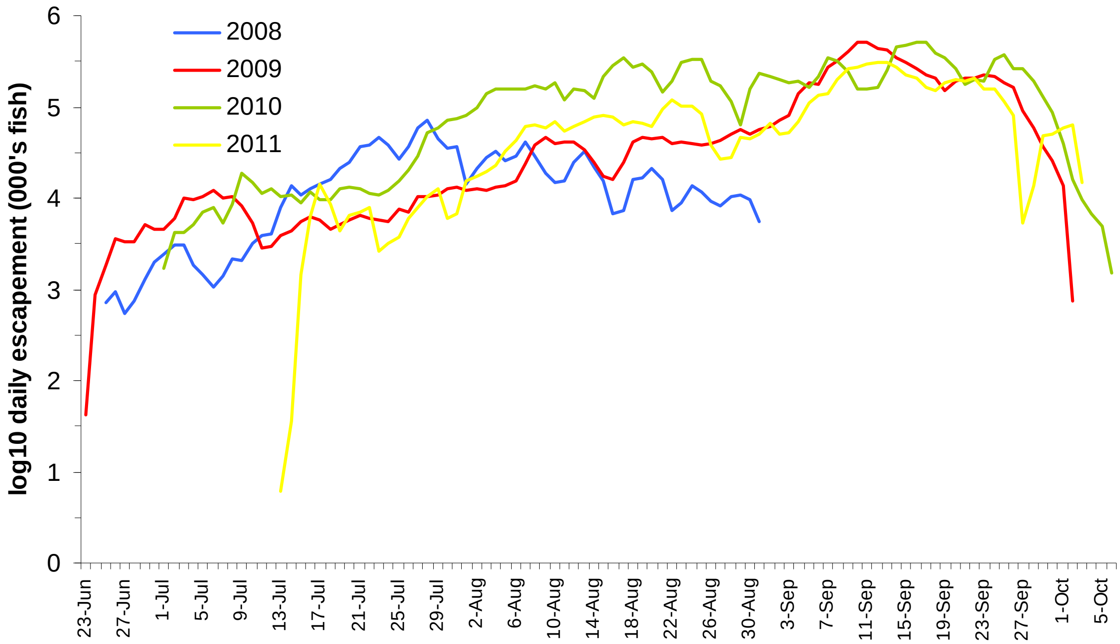


Figure 10. Daily total salmon escapement estimates at Qualark, 2008 to 2011. Data are log_{10} transformed to equalize the scale. Length of time series varies between years.

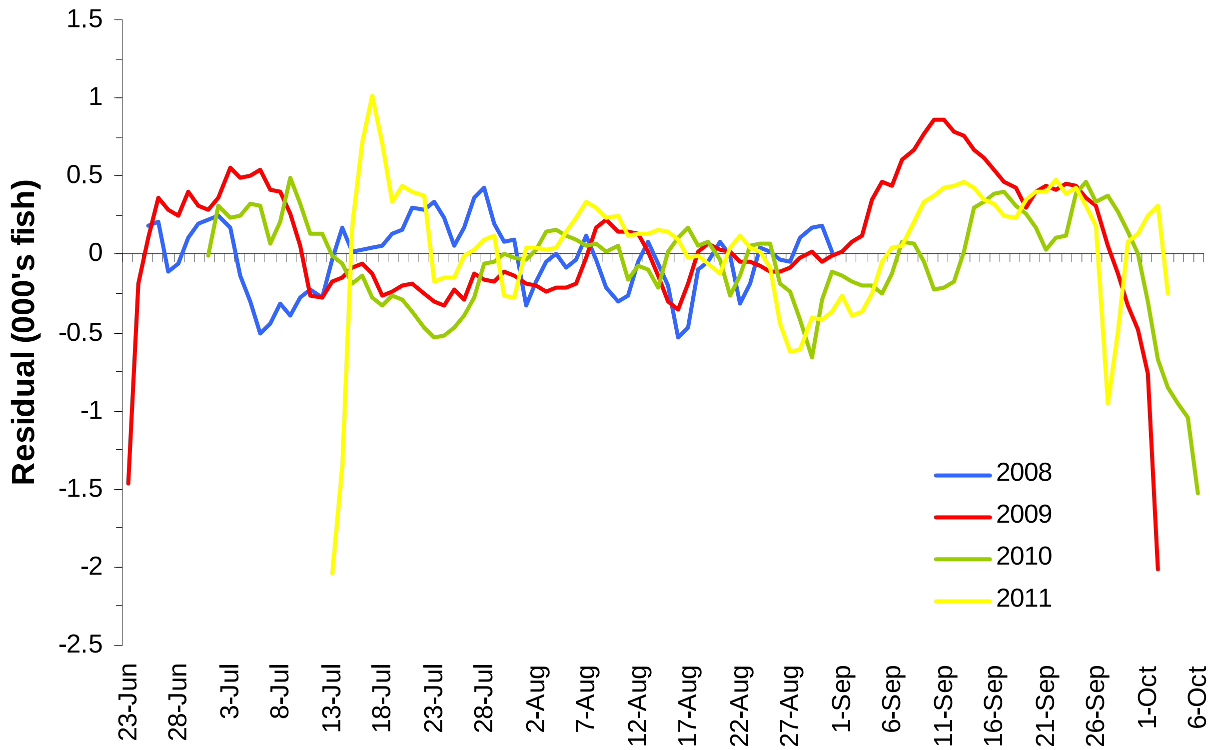


Figure 11. Detrended log_{10} transformed daily escapement time series at Qualark, 2008-2011. Data are total salmon counts and were detrended using the polynomial equations shown in Table 3.

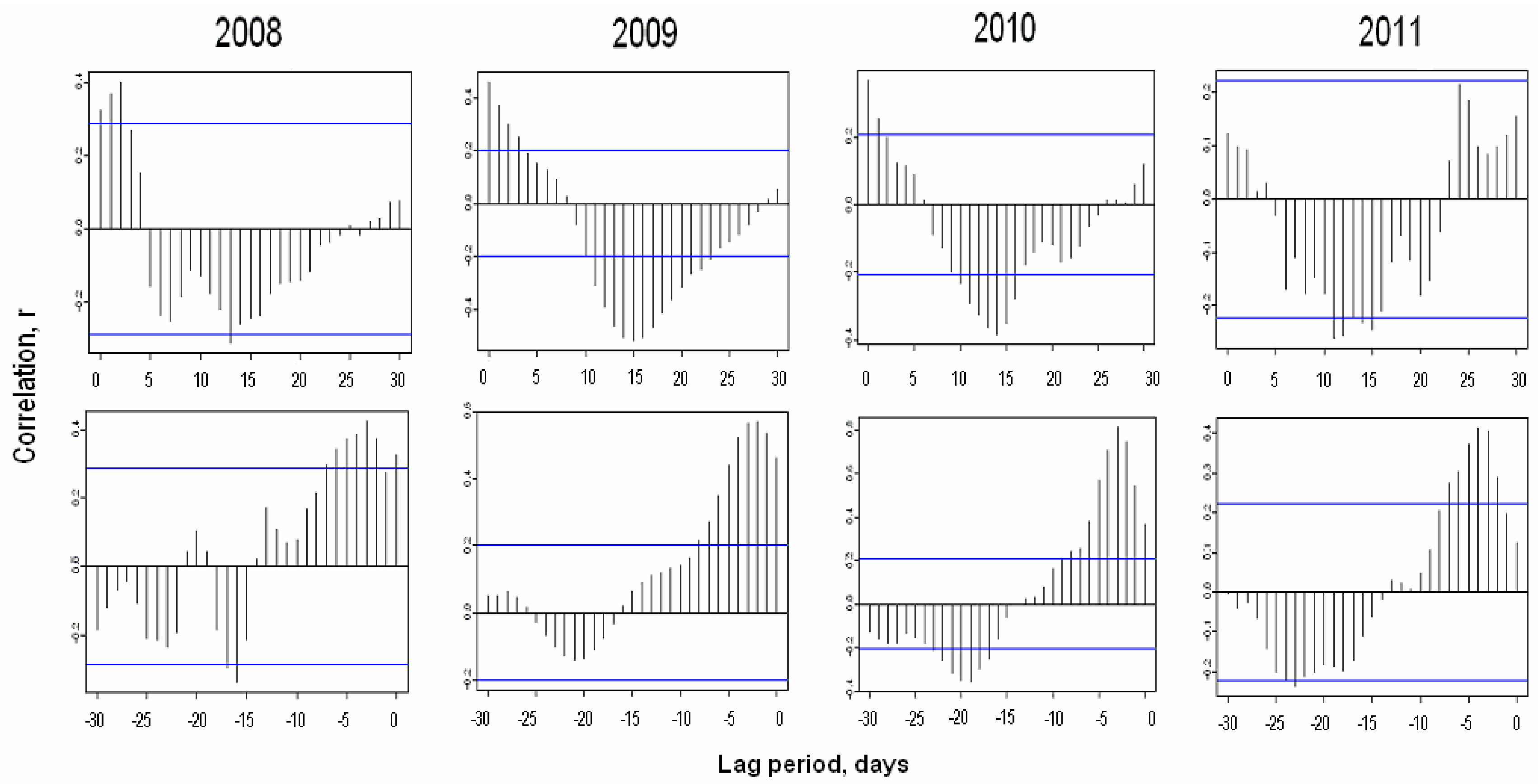


Figure 12. Cross-correlation analysis between total salmon counts at Mission and Qualark at 30 to -30 day lag periods. Standard errors (blue lines) are white-noise estimates. Top row Qualark data are lagged relative to Mission and bottom row Mission data are lagged relative to Qualark.

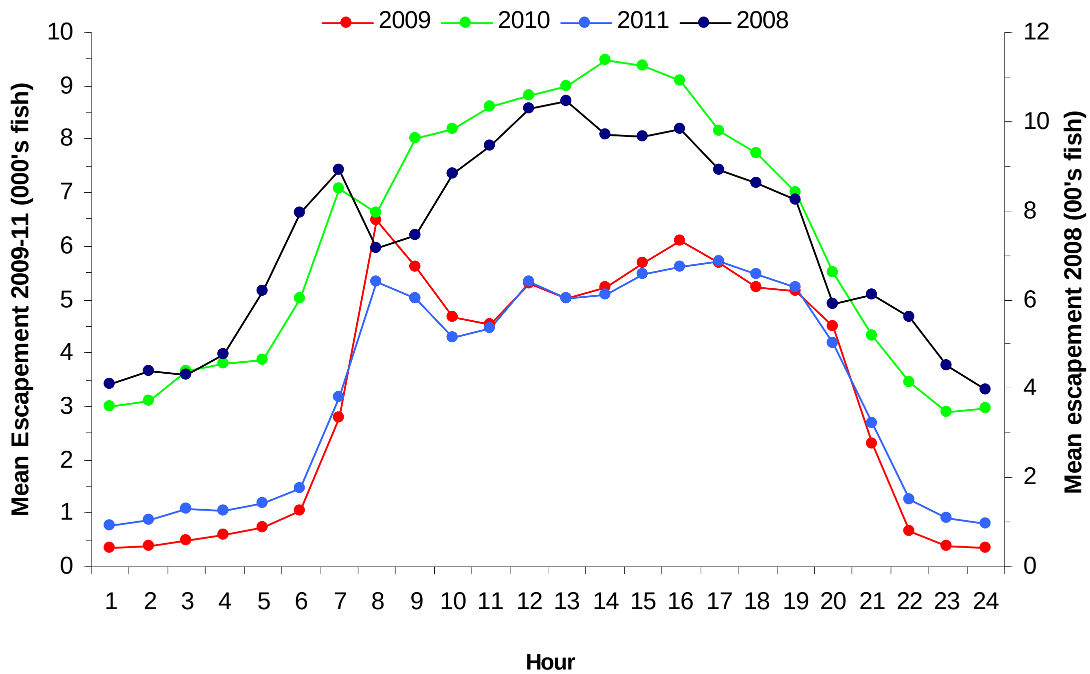


Figure 13. Estimated mean hourly escapement of all salmon species at Qualark, 2008-2011. Note that 2008 is plotted on separate scale.

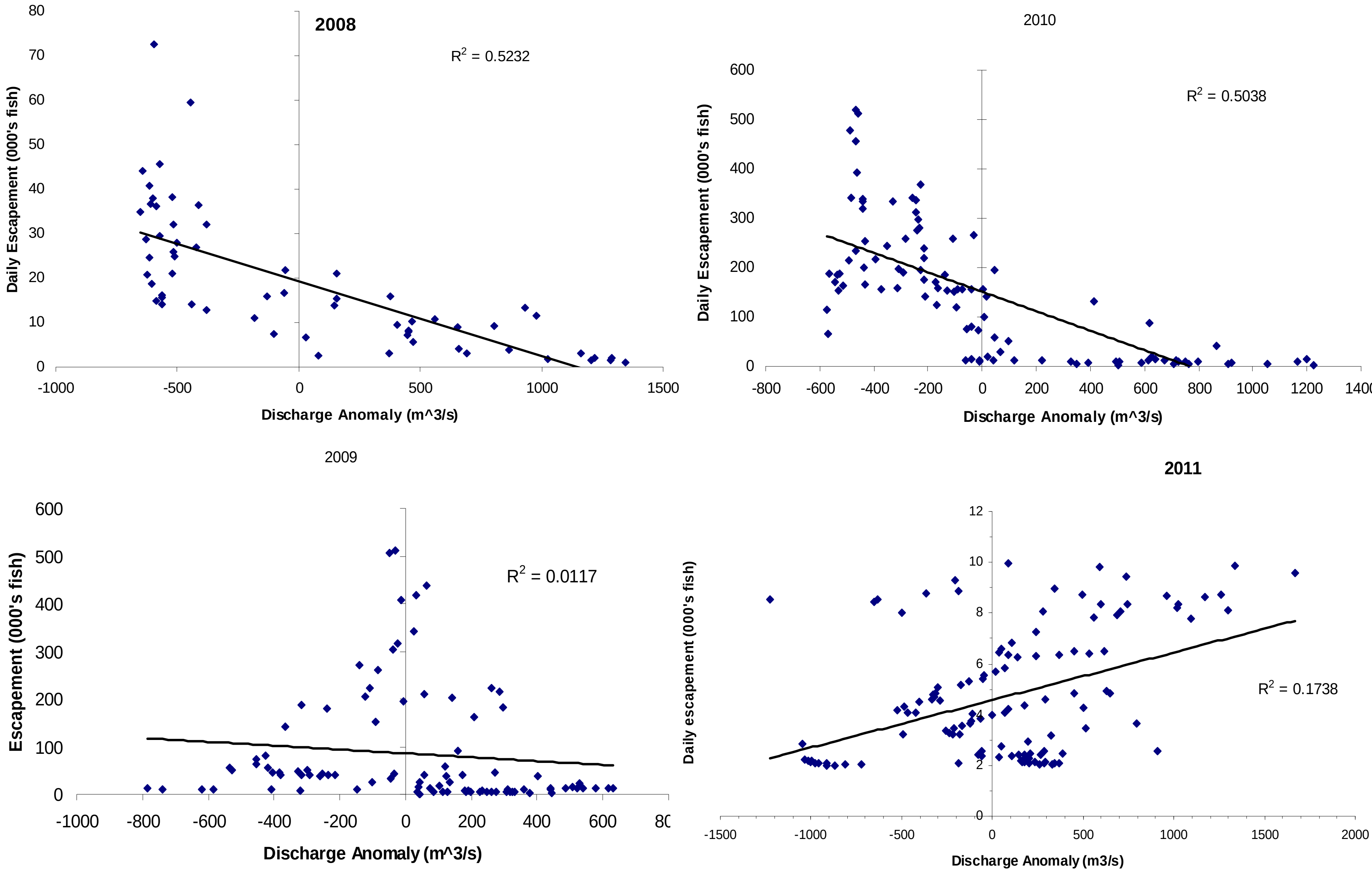
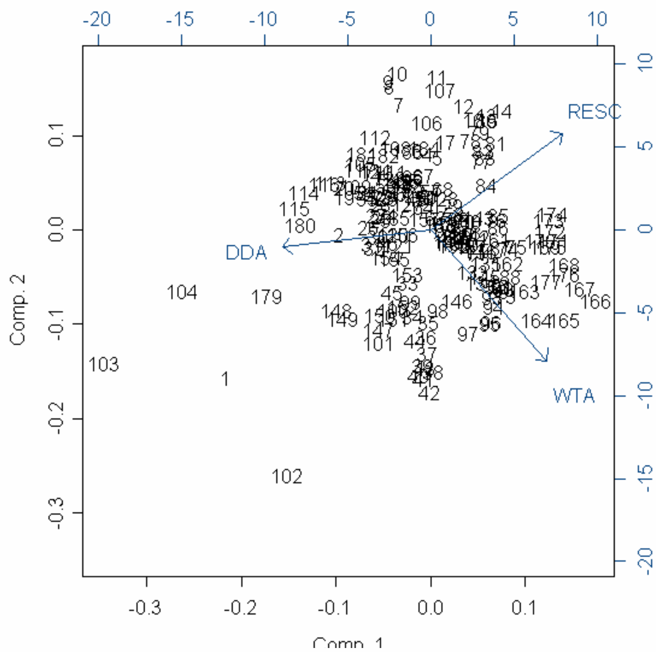


Figure 14. Plots of residuals from discharge regressions against total daily salmon escapement at Qualark, 2008-2011. Note differences in scales on both axes.

A.



B.

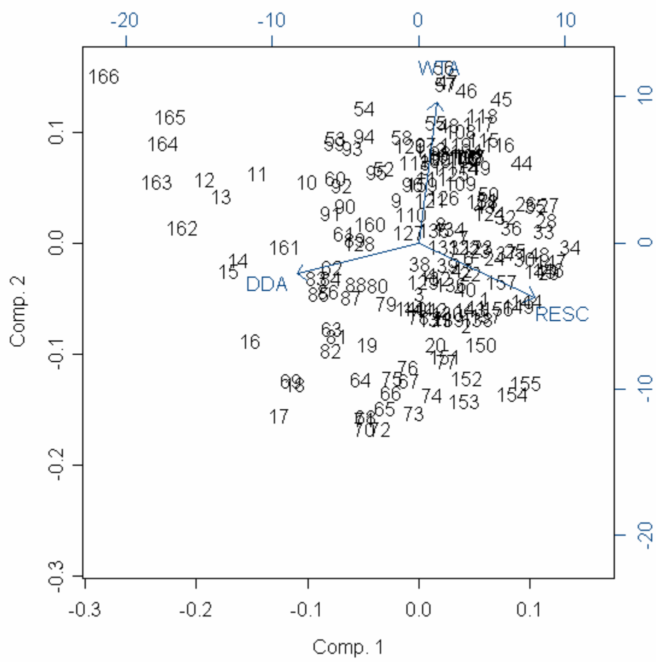


Figure 15. Principal components analysis of (A) pink-dominant (2009, 2011) years, and (B) sockeye-dominant years (2008, 2010). Data are escapement residuals (RESC), discharge residuals (DDA) and water temperature residuals (WTA).

escapement are moderately positively correlated and discharge is strongly negatively correlated with PC1 during pink-dominant years (Figure 15A) and water temperature is strongly negatively correlated and escapement is moderately positively correlated with PC2. These findings are consistent with the bivariate plots in Figure 14 in that they tend to confirm a relatively clear effect related to discharge, with escapement increasing when below average discharge events occur. The absence of a clear water temperature effect in either pink- or sockeye-dominant years may be related to the fact that in all four years the maximum mean daily temperature did not exceed 21°C, which is a physiological threshold for sockeye salmon (e.g., Brett 1964).

Research is ongoing to develop a model linking salmon movements at Mission and Qualark. The intent of this research is to develop methodology that can be used to adjust or correct Mission estimates of sockeye escapement into the lower Fraser River during periods that are considered challenging for producing these estimates, i.e., the period in which pink salmon and sockeye salmon overlap in the river. Preliminary results shown here and in Xie et al. (2012) point to periods in which passage past the two sites exhibits coherence and other periods where deviations occur. Factors to consider when attempting to explain the deviations include species composition effects on acoustic estimates at both sites, sockeye returning to the Harrison and Chilliwack-Vedder systems pass Mission but not Qualark, in-river fisheries between Mission and Qualark, variation in the number of pink salmon moving upstream past Qualark to spawn (i.e., the proportion is not consistent), and variations in fish density and impacts of these variations on acoustic performance.

CONCLUDING REMARKS

The operation of the Qualark Creek hydroacoustic and test fishing programs for the 2011 described within this report met the objective of producing reliable and timely estimates of gross salmon passage in the Fraser River:

1. Fish passage behaviour for 2011 was consistent with passage behaviour recorded in 2008 to 2010 seasons, in that their passage is near shore within the ensonified area of a standard DIDSON using one aiming configuration and multiple range bins (Table 1 and Figure 3).
2. Fish passage during periods of First Nations fishing opportunities that occur in the immediate area of the Qualark site (between Hope River Bridge and Sawmill Creek) react to the nets by moving further offshore by several meters (Figure 8 and 9). This behaviour may force fish into a higher current velocity regime thus increasing energy demands, but these fish continue to move upstream through the long range bins. This offshore movement of fish passage increases the counts detected in Bin 2 (9.2 m to 19.2 m) which is less desirable for producing flux estimates by manual counting because these DIDSON files are low frequency mode with poorer image resolution. However, the impact of this shift on overall counts is small since the number of fish in these low frequency sampling bins is low overall. Regardless of the presence/absence of nets in the water, the majority of fish passage (96% overall) is detected in Bin 1 (4.2 m to 9.2) which is a high frequency mode DIDSON file with better image resolution.
3. Research is ongoing to develop a model linking salmon movements at Mission and Qualark. Preliminary results are promising in that they point to common signals in the two datasets that potentially can be exploited to develop the corrections or adjustments for Mission under specific conditions. During year 2, we will be seeking a contractor or casual with the appropriate expertise to advance this analysis.

ACKNOWLEDGMENTS

This work was funded by the 2011 Southern Boundary Restoration and Enhancement Fund of the Pacific Salmon Commission. Water temperature data at Qualark were provided by David Patterson and the Environmental Watch Program at DFO. We thank Yale First Nation and Chief Robert Hope for their continued support for the Qualark Creek hydroacoustic project and their assistance in providing administrative support. Constructive meetings with PSC hydroacoustics staff have significantly advanced the analysis of linkages between Qualark and Mission, as reported here and by Xie et al. (2012).

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Appendix 1. Qualark 2011 Test Fishery Daily Summary

	Total	Sockeye				Chinook				Pink				Coho			
Date	Drifts	Retained	Released	Total	Cumulative	Retained	Released	Total	Cum.	Retained	Released	Total	Cum.	Ret.	Rel.	Total	Cum.
22-Jul-11	6	0	0	0	0	1	2	3	3	0	0	0	0	0	0	0	0
23-Jul-11	6	7	0	7	7	1	3	4	7	0	0	0	0	0	0	0	0
24-Jul-11	6	4	2	6	13	0	1	1	8	0	0	0	0	0	0	0	0
25-Jul-11	7	3	0	3	16	0	3	3	11	0	0	0	0	0	0	0	0
26-Jul-11	6	4	2	6	22	2	4	6	17	0	0	0	0	0	0	0	0
27-Jul-11	6	10	0	10	32	3	6	9	26	0	0	0	0	0	0	0	0
28-Jul-11	7	8	0	8	40	9	5	14	40	0	0	0	0	0	0	0	0
29-Jul-11	6	42	0	42	82	14	11	25	65	0	0	0	0	0	0	0	0
30-Jul-11	6	14	0	14	96	3	4	7	72	0	0	0	0	0	0	0	0
31-Jul-11	6	9	0	9	105	2	2	4	76	0	0	0	0	0	0	0	0
1-Aug-11	7	25	0	25	130	5	5	10	86	0	0	0	0	0	0	0	0
2-Aug-11	6	42	0	42	172	6	6	12	98	0	0	0	0	0	0	0	0
3-Aug-11	6	40	0	40	212	1	1	2	100	0	0	0	0	0	0	0	0
4-Aug-11	7	53	0	53	265	4	0	4	104	0	0	0	0	0	0	0	0
5-Aug-11	6	34	0	34	299	11	10	21	125	0	0	0	0	0	0	0	0
6-Aug-11	6	77	0	77	376	11	4	15	140	0	0	0	0	0	0	0	0
7-Aug-11	3	22	0	22	398	4	6	10	150	0	0	0	0	0	0	0	0
8-Aug-11	7	116	0	116	514	12	4	16	166	0	0	0	0	0	0	0	0
9-Aug-11	6	76	1	77	591	8	4	12	178	0	0	0	0	0	0	0	0
10-Aug-11	6	70	0	70	661	11	2	13	191	0	0	0	0	0	0	0	0
11-Aug-11	7	72	0	72	733	1	3	4	195	0	0	0	0	0	0	0	0
12-Aug-11	6	104	0	104	837	4	2	6	201	0	0	0	0	0	0	0	0
13-Aug-11	6	86	0	86	923	10	1	11	212	0	0	0	0	0	0	0	0
14-Aug-11	6	48	0	48	971	15	0	15	227	0	1	1	1	0	0	0	0
15-Aug-11	7	102	2	104	1075	8	3	11	238	0	0	0	1	0	0	0	0
16-Aug-11	6	69	0	69	1144	13	6	19	257	1	0	1	2	0	0	0	0
17-Aug-11	6	80	0	80	1224	7	3	10	267	1	0	1	3	0	0	0	0
18-Aug-11	7	75	0	75	1299	5	1	6	273	0	0	0	3	0	0	0	0
19-Aug-11	6	44	0	44	1343	13	1	14	287	2	0	2	5	0	0	0	0
20-Aug-11	6	51	0	51	1394	19	1	20	307	3	0	3	8	0	0	0	0
21-Aug-11	6	90	0	90	1484	17	3	20	327	6	0	6	14	0	0	0	0
22-Aug-11	7	106	0	106	1590	14	1	15	342	11	0	11	25	0	0	0	0
23-Aug-11	6	80	0	80	1670	13	4	17	359	18	0	18	43	0	0	0	0
24-Aug-11	6	81	0	81	1751	26	2	28	387	20	0	20	63	0	0	0	0
25-Aug-11	6	92	0	92	1843	19	3	22	409	12	0	12	75	0	0	0	0
26-Aug-11	7	36	0	36	1879	19	3	22	431	8	0	8	83	0	0	0	0
27-Aug-11	6	41	0	41	1920	8	2	10	441	5	0	5	88	0	0	0	0
28-Aug-11	6	38	2	40	1960	6	4	10	451	5	0	5	93	0	0	0	0

	Total	Sockeye				Chinook				Pink				Coho			
Date	Drifts	Retained	Released	Total	Cumulative	Retained	Released	Total	Cumulative	Retained	Released	Total	Cumulative	Retained	Released	Total	Cumulative
29-Aug-11	7	82	0	82	2042	26	3	29	480	20	0	20	113	0	0	0	0
30-Aug-11	6	82	0	82	2124	19	6	25	505	29	0	29	142	0	0	0	0
31-Aug-11	6	71	0	71	2195	18	6	24	529	59	0	59	201	0	0	0	0
1-Sep-11	7	38	0	38	2233	18	4	22	551	26	0	26	227	0	0	0	0
2-Sep-11	6	25	0	25	2258	27	8	35	586	16	0	16	243	1	0	1	1
3-Sep-11	6	26	0	26	2284	22	4	26	612	26	0	26	269	0	0	0	1
4-Sep-11	6	23	0	23	2307	18	5	23	635	15	0	15	284	0	0	0	1
5-Sep-11	7	21	0	21	2328	7	3	10	645	18	0	18	302	0	0	0	1
6-Sep-11	6	28	0	28	2356	15	5	20	665	40	0	40	342	1	0	1	2
7-Sep-11	6	29	0	29	2385	11	2	13	678	39	0	39	381	0	0	0	2
8-Sep-11	7	14	0	14	2399	27	7	34	712	40	0	40	421	0	0	0	2
9-Sep-11	6	28	0	28	2427	14	5	19	731	27	0	27	448	1	1	2	4
10-Sep-11	6	22	0	22	2449	7	2	9	740	34	0	34	482	0	0	0	4
11-Sep-11	6	13	0	13	2462	8	3	11	751	28	0	28	510	0	0	0	4
12-Sep-11	7	13	0	13	2475	6	0	6	757	11	2	13	523	0	0	0	4
13-Sep-11	6	20	0	20	2495	3	1	4	761	24	0	24	547	0	1	1	5
14-Sep-11	6	11	0	11	2506	4	1	5	766	9	0	9	556	0	0	0	5
15-Sep-11	7	34	0	34	2540	5	2	7	773	40	0	40	596	0	2	2	7
16-Sep-11	6	21	0	21	2561	3	1	4	777	15	0	15	611	0	0	0	7
17-Sep-11	6	12	0	12	2573	4	0	4	781	48	0	48	659	2	2	4	11
18-Sep-11	6	14	0	14	2587	0	0	0	781	26	0	26	685	3	1	4	15
19-Sep-11	7	11	0	11	2598	2	0	2	783	29	0	29	714	0	2	2	17
20-Sep-11	6	9	0	9	2607	3	0	3	786	45	0	45	759	1	0	1	18
21-Sep-11	6	10	0	10	2617	1	0	1	787	50	9	59	818	1	1	2	20
22-Sep-11	7	7	0	7	2624	3	0	3	790	22	0	22	840	1	1	2	22
23-Sep-11	6	2	0	2	2626	2	1	3	793	21	0	21	861	0	1	1	23
24-Sep-11	6	4	0	4	2630	0	0	0	793	30	0	30	891	1	1	2	25
25-Sep-11	6	22	0	22	2652	1	0	1	794	54	0	54	945	3	4	7	32
26-Sep-11	4	8	0	8	2660	1	1	2	796	10	0	10	955	0	0	0	32
27-Sep-11	6	0	0	0	2660	0	0	0	796	17	0	17	972	0	0	0	32
28-Sep-11	6	4	0	4	2664	0	0	0	796	1	0	1	973	0	0	0	32
29-Sep-11	7	6	0	6	2670	1	0	1	797	31	0	31	1004	0	0	0	32
30-Sep-11	6	7	0	7	2677	3	1	4	801	14	0	14	1018	0	0	0	32
1-Oct-11	6	6	0	6	2683	3	0	3	804	27	0	27	1045	1	1	2	34
2-Oct-11	6	1	0	1	2684	5	0	5	809	55	0	55	1100	3	7	10	44
3-Oct-11	3	0	0	0	2684	1	0	1	810	27	0	27	1127	1	1	2	46