Implementation of stationary sampling systems to estimate salmon passage in the Lower Fraser River:

Year 1 of 2011 and 2012 project report to Southern boundary restoration and enhancement fund

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ABSTRACT

Following a series of field experiments and studies carried out in 2006, 2008, 2009 and 2010 (Xie et al. 2007, 2008, 2010, 2011), a stationary sub-sampling method was further tested during the 2011 salmon migration using 4 side-looking DIDSON imaging sonar systems deployed at the Pacific Salmon Commission's Mission hydroacoustic fish counting site. The data collection activities and the subsequent data analyses reported in this document are the year-one research efforts funded by the Southern Boundary Restoration and Enhancement Fund for a 2-year project. The ultimate goal of the project is to develop a hydroacoustic sampling system with multiple stationary sub-sampling components extending from both shores to provide accurate estimation of salmon passage in extended near-shore areas of the river. With the existing left-bank side-looking split-beam sonar, these multiple stationary sub-sampling systems are able to sample a total of 120-m cross-river range from the shorelines (80m from the left bank and 40m from the right bank). Historically, these near-shore areas accommodate 70% of sockeye and nearly 90% of pink salmon migrations past Mission. This report presents key results and major findings from the 2011 data. The estimated daily salmon passage for the months of August and September was compared with the estimates from the current sampling system. Preliminary analyses of hourly salmon flux time series are also reported here and compared with the salmon flux time series estimated at Department of Fisheries and Oceans hydroacoustic site at Qualark Creek (95km upstream of Mission). The study identifies two major advantages of incorporating DIDSON into the sampling system:

1. The DIDSON based stationary system is much more effective for the sampling and monitoring of extremely bottom- and shore-oriented pink salmon than the conventional split-beam sonar system, and
2. The DIDSON system confirms that the current left-bank split-beam system performs well and produces similar estimates of salmon flux to DIDSON based flux when the migration is dominated by sockeye salmon.

INTRODUCTION

Background

The Pacific Salmon Commission (PSC) conducts a hydroacoustic program near Mission B.C. on the Fraser River to estimate the daily influx of adult sockeye and pink salmon to the lower river. The near-shore salmon flux is estimated directly from the shore-based, side-looking sonar systems over ranges up to 80m from the left bank and 40m from the right bank. Fish migrating in offshore areas of the river are surveyed by a downward looking transducer from a moving vessel that transects the river. The offshore salmon flux is estimated via a density based flux model that assumes (1) uniform fish behaviour across the river (Xie et al. 2005) and, (2) fish do not avoid the mobile survey vessel. Studies in recent years have shown that fish can behave differently across the river due to the inhomogeneous flow field and tidal effects (Xie et al. 2010), and fish do avoid the survey vessel within a 4-m range from the propeller (Xie et al. 2008). The violation of the two basic assumptions can bias estimates of offshore fish flux by the mobile survey system.

To improve the accuracy and precision of salmon flux estimation in the offshore area, a stationary sub-sampling method for offshore fish was tested during the 2008-2010 field seasons with funding from the Southern Boundary Restoration and Enhancement Fund (SEF). The findings and results from the 2008-2010 sampling seasons concluded that the strong and varying currents in the mid-channel posted severe challenges for vessel-based stationary acoustic sampling (Xie et al. 2010, 2011). In fact, the acquired data was so noisy that the estimated offshore fish flux by the vessel-based stationary system was highly uncertain. The adverse outcomes from the vessel-based stationary sampling approach led to a search for a more robust approach for the improvement of estimation accuracy of daily salmon flux at Mission. After careful review of the historical data and cost-benefit analyses, the PSC hydroacoustic group proposed an alternative sampling strategy that extends the sampling by the shore-based sonar systems from both banks towards offshore water while still leaving the mid-channel fish flux to be sampled by the transecting vessel with an upgraded split-beam system that can provide unfiltered echo data to improve target recognition between fish and noise. Based on this strategy, 4 side-looking DIDSON imaging sonar systems (dual-frequency identification sonar) were deployed at the PSC Mission hydroacoustic monitoring site on both banks in the 2011 sampling season for the months of August and September to record fish passage using systematic hourly sampling schemes. In addition, a Biosonics DT-X4 split-beam sonar system was deployed from the transecting vessel to test its performance on the detection and target recognition of fish targets in offshore water. Figure 1 is a schematic illustration of deployment locations and sampling geometry of the 2 split-beam systems and the 4 DIDSON imaging sonar units.

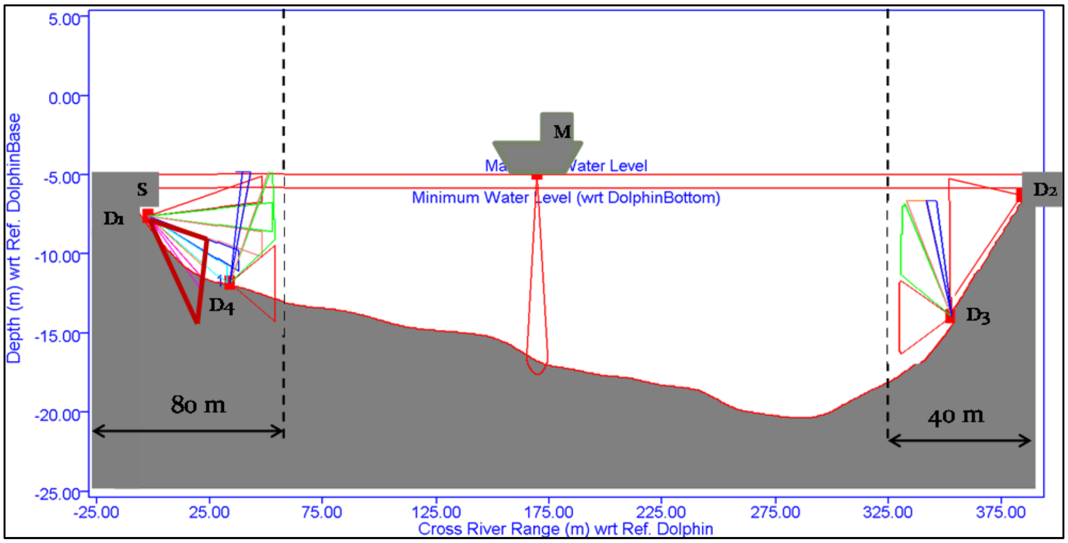

Figure 1. Deployment locations and sampling geometry of left-bank (S) and mobile (M) split-beam systems and 4 DIDSON imaging sonar units (D1, D2, D3, D4). The 6 sonar systems formed the proposed estimator.

Project goals

The goal of this project was to develop and implement a robust sampling system that will accurately enumerate the majority of total fish flux with shore- or bottom-mounted side-looking or side-scanning sonar while using the current mobile sampling method to estimate only a very small portion of the total flux (in offshore water) at the Mission hydroacoustic site. To achieve this goal, we deployed 4 DIDSON units (shore-based and bottom-mounted) to sample migrating fish in near-shore waters off both the left and right banks and installed a Biosonics DT-X split-beam system on the mobile sounding vessel. The DT-X system provided not only the single-target filtered data but also the unfiltered echo data, thus allowing operators to better discern fish targets than the current HTI system. Year 2011 was the first sampling season under the 2-year project. The objectives for Year 2011 were:

1. to assess the improvement of estimation accuracy of total salmon passage by the proposed estimator during times when migration is dominated by sockeye (early August) or pink salmon (late August to September),
2. to explore potential uses and values of the Qualark estimate (funded by SEF in the 2011 season) to assess bias in the Mission estimate, and
3. to assess the cost and effort of the proposed estimator for in-season use.

In this document, we report major findings from, and present various analyses of the 2011 data to fulfill the 3 objectives.

MATERIALS AND METHODS

Study site

The PSC Mission hydroacoustic station is located 80 km upstream from the mouth of the Fraser River (Figure 2). The maximum river width at the site is approximately 450 metres during periods of high river discharge. The maximum water depth varies from approximately 18 m in June during high run-off to 12 m in October at low discharge. The river flow is influenced by tides and during extreme high tides the river may occasionally reverse its flow. The flow field is non-uniform with stronger currents occurring in the deepest channel near the right bank (see Figs. 1 and 4 in Xie, et al. 2010). The turbid water of the lower Fraser River prevents visual detection and counting of fish passage. Figure 3 is a site photo taken from the left bank. The iron dolphin in the photo is the geographic reference point for the site.

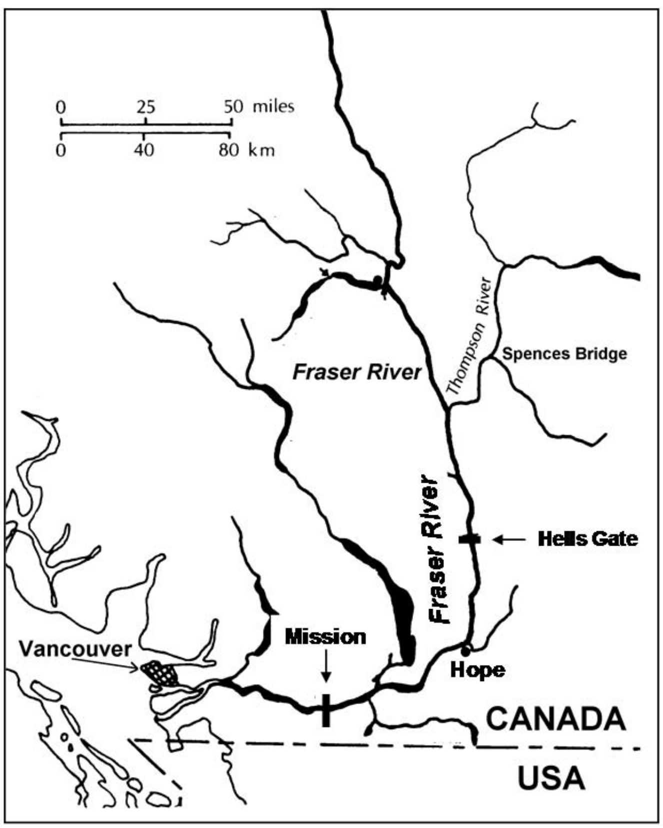

Figure 2. Site map of the PSC Mission hydroacoustic station.

Figure 3. A left-bank view of the PSC Mission hydroacoustic site. The iron dolphin, located at 49°08.175'N; 122°16.466'W, is the geographic reference for positioning all sampling apparatus for the field program at the site. Also shown are the mobile survey vessel and a fish-deflection weir (approximately 35 metres in length) on the left bank. The weir prevents fish from swimming behind the shore-based sonar beams.

Equipment

The following sonar equipment was used in this study:

- Three standard DIDSON units, two of which were equipped with SMC interfaced rotators that can be programmed within the DIDSON software to perform scheduled aim changes;
- One long-range DIDSON unit;
- One Biosonics DT-X split-beam echo-sounder with a 5.7-deg transducer;
- One HTI Model 243 split-beam echo-sounder with a 2×10 and 4×10 degree elliptical-beam transducers;
- One HTI Model 241 split-beam echo-sounder with a 15-deg transducer.

Sampling schemes and data acquisition parameters of fix-mounted sonar systems

Systematic hourly sampling schemes were implemented for all the fix-mounted sonar systems. The sampling geometry of each of the systems is illustrated in Figure 1.

Left-bank split-beam system (S)

This system was deployed on July 12th, 2011. Tables 1 and 2 show the details of the sampling scheme and data collection parameters used in the 2011 season.

Table 1. Summary of hourly sampling scheme of left-bank split-beam system.

Sampling time (min)	*Vertical aim (deg)*	*4×10 transducer status*	*2×10 transducer status*	*Sounding range (m)*		*Ping rate (pps)*	
				07/12 – 08/22	**08/22 – 09/27**	**07/12 – 08/22**	**08/22 – 09/27**
0-6	-8	**active**	silent	30	25	10	20
6-12	-4	**active**	silent	45	30	10	20
12-18	0	**active**	silent	50	30	10	20
18-24	0	silent	**active**	55	50	5	10
24-30	-2	silent	**active**	55	55	5	10
30-36	-4	silent	**active**	60	50	5	10
36-42	-6	silent	**active**	50	40	5	10
42-48	-8	silent	**active**	40	35	5	10
48-54	-10	silent	**active**	35	25	5	10
54-60	-12	silent	**active**	30	24	5	10

Table 2. Summary of left-bank split-beam data acquisition parameters for the 2011 season.

Transducer Sn	**Beam-width (deg)**	**Source level (dB re uPa@1m)**	**Pulse-width (millisecond)**	**Transmit Power Level (dBW)**	**Receiver Gain (dB)**	**Voltage (V)**	**Data threshold (dB)***
926448	4x10	219.83	0.2	25	-18	0.264	-45
925038	2x10	221.08	0.2	25	-18	0.27	-45

* See calibration manual for Model 243 system (March 2010).

Left-bank inshore DIDSON (D_1)

This system was deployed on July 12th, 2011. Table 3 shows the details of the sampling scheme.

Table 3. Summary of the hourly sampling scheme of left-bank inshore DIDSON.

Sampling time (min)	*Vertical aim (deg)*		*Bearing (deg)*	*Sonar Status**	*Operating frequency (MHz)*	*Range window (m)*	*Frame rate (frames per second)*
	07/12-08/31	**09/01-09/28**					
0-25	-8	-12	340	TR	1.8	2-12	8
25-30				TNR	-	-	-
30-55	-8	-12	340	TR	1.8	12-22	4
55-60				TNR	-	-	-

*TR = Transmitting and Recording; TNR = Transmitting but Not Recording

Left-bank offshore DIDSON (D_4)

This system was deployed from September 6 - 22, 2011. Table 4 shows the details of the sampling scheme.

Table 4. Summary of the hourly sampling scheme of the left-bank offshore DIDSON.

Sampling time (min)	*Vertical aim (deg)*	*Bearing (deg)*	*Sonar Status**	*Operating frequency (MHz)*	*Sounding range window (m)*	*Frame rate (frames per second)*
0-12	2.6	344	TR	1.1	1.67-21.67	8
12-14			TNR	-	-	-
14-26	8.2	347	TR	1.1	1.67-21.67	8
26-28			TNR	-	-	-
28-40	19	351	TR	1.1	1.67-21.67	8
40-42			TNR	-	-	-
42-54	37	0	TR	1.1	1.67-21.67	8
54-60			TNR	-	-	-

Right-bank inshore DIDSON (D_2)

This long-range unit was deployed from August 11 – September 28, 2011. Table 5 shows the details of the sampling scheme.

Table 5. Summary of the hourly sampling scheme of the right-bank inshore long-range DIDSON.

Sampling time (min)	*Vertical aim (deg)*		*Bearing (deg)*	*Sonar Status**	*Operating frequency (MHz)*	*Sounding range window (m)*	*Frame rate (frames per second)*
	08/11-09/03	**09/03-09/28**					
0-15	0	-8	134	TR	1.2	1.67-11.67	10
15-20				TNR	-	-	-
20-35	0	-8	134	TR	0.7	12.5-32.5	5
35-40				TNR	-	-	-
40-55	0	-8	134	TR	0.7	10-50	4
55-60				TNR	-	-	-

Right-bank offshore DIDSON (D_3)

This system was deployed from August 15 – September 28, 2011. Table 6 shows the details of the sampling scheme.

Table 6. Summary of the hourly sampling scheme of the right-bank offshore DIDSON.

Sampling time (min)	*Vertical aim (deg)*	*Compass Bearing (deg)*	*Sonar Status**	*Operating frequency (MHz)*	*Sounding range window (m)*	*Frame rate (frames per second)*
0-12	-4	130	TR	1.1	1.67-21.67	8
12-14			TNR	-	-	-
14-26	11	130	TR	1.1	1.67-21.67	8
26-28			TNR	-	-	-
28-40	26	130	TR	1.1	1.67-21.67	8
40-42			TNR	-	-	-
42-54	41	130	TR	1.1	1.67-21.67	10
54-60			TNR	-	-	-

Data acquisition parameters of the mobile sampling systems

Fish migrating beyond the sounding ranges of shore-based sonar systems were sampled by a transecting vessel, with 2 downward looking split-beam transducers. Deployed on July 12th, 2011 from the port-side was a 200-kHz, 15-deg circular beam HTI transducer. Deployed on September 9th, 2011, from the starboard side was a 210-kHz, 5.7-deg Biosonics transducer mounted on a plate modified from a tow-body plate originally designed for a previously used single-beam transducer. Both systems recorded GPS location data of the vessel. Table 7 summarizes key data acquisition parameters of the 2 systems.

Table 7. Summary of key data acquisition parameters of the 2 mobile split-beam systems.

Sounder system	*Transducer sn*	*Beam-width (deg)*	*Sounding range (m)*	*Source level (dB re uPa@1m)*	*Pulse-width (millisecond)*	*Ping rate (pps)*	*Data threshold (dB)*	*Source level Reduction (dB)*
HTI	1425506	15	22	213.4	0.2	20	-45*	-
DT-X	DT206144	5.7	17	222.2	0.2	20	-130**	0

* This is the threshold used for single-target filtering based on the transmitting power level of 20 dBWand receiver gain of -18 dB. Please see calibration manual for Model 241 system (April 2007).
** This is the threshold used for the collection of raw echo data (unfiltered).

Estimation of left-bank near-shore fish flux

Fish flux in the inshore water sampled by the left-bank fix-mounted sonar systems was estimated from the data acquired from the left-bank split-beam (S) and the inshore DIDSON (D1). Since the split-beam transducers and the DIDSON unit only sampled a portion (about 75% for the split-beam and 50% for the DIDSON) of the cross-section in the shore area, the split-beam flux in the un-sampled area was extrapolated using a nearest-neighbor method (Xie et al. 2005). For the DIDSON estimator, if the 14-deg vertical field of view only covers a portion of the angular area of the split-beam estimator (as is illustrated in Figure 1), the DIDSON based fish count would be expanded to the entire split-beam angular area using an expansion factor inferred from the split-beam data. The DIDSON based flux in the un-sampled area was projected using a linear extrapolation method.

Estimation of offshore fish flux

Fish flux in the offshore area was estimated by the mobile split-beam transducers with fish behaviour statistics (downstream ratio, migrating speeds, etc) acquired from shore-based fix-mounted systems of either the left-bank split-beam or the 2 offshore DIDSON units D3 and D4.

Estimation of right-bank near-shore fish flux

Fish flux in the inshore area sampled by the 2 right-bank fix-mounted DIDSON systems was estimated from the data acquired from the long-range DIDSON unit D2 and the offshore unit D3.

RESULTS

The 2011 hydroacoutics program started on July 12th and ended on September 27th. The in-season estimates were produced mainly from the data collected with the split-beam sonar based estimator (left-bank plus the mobile split-beam systems) with the addition of a partial dataset from the right-bank long-range DIDSON unit D2 in early August. The full datasets collected from the 5 systems (denoted as S, M, D1-3 in Figure 1) were processed post-season which produced the post-season total salmon estimate for the 2011 season.

In-season estimator

The in-season estimator was based on datasets acquired from the 3 systems:

- Left-bank split-beam system (fish counts from the full sounding range),
- HTI mobile split-beam system (fish counts based solely on single-target filtered echo data), and
- Right-bank inshore DIDSON (D2) (fish counts from the 2nd range-bin only).

The offshore fish flux was estimated using the HTI mobile split-beam data (for fish density) and the behavioural statistics estimated from the left-bank split-beam data. The daily salmon abundance from the in-season estimator for August and September is presented in Figure 4, which estimated a total of 13.6 million salmon past Mission in the 2011 season.

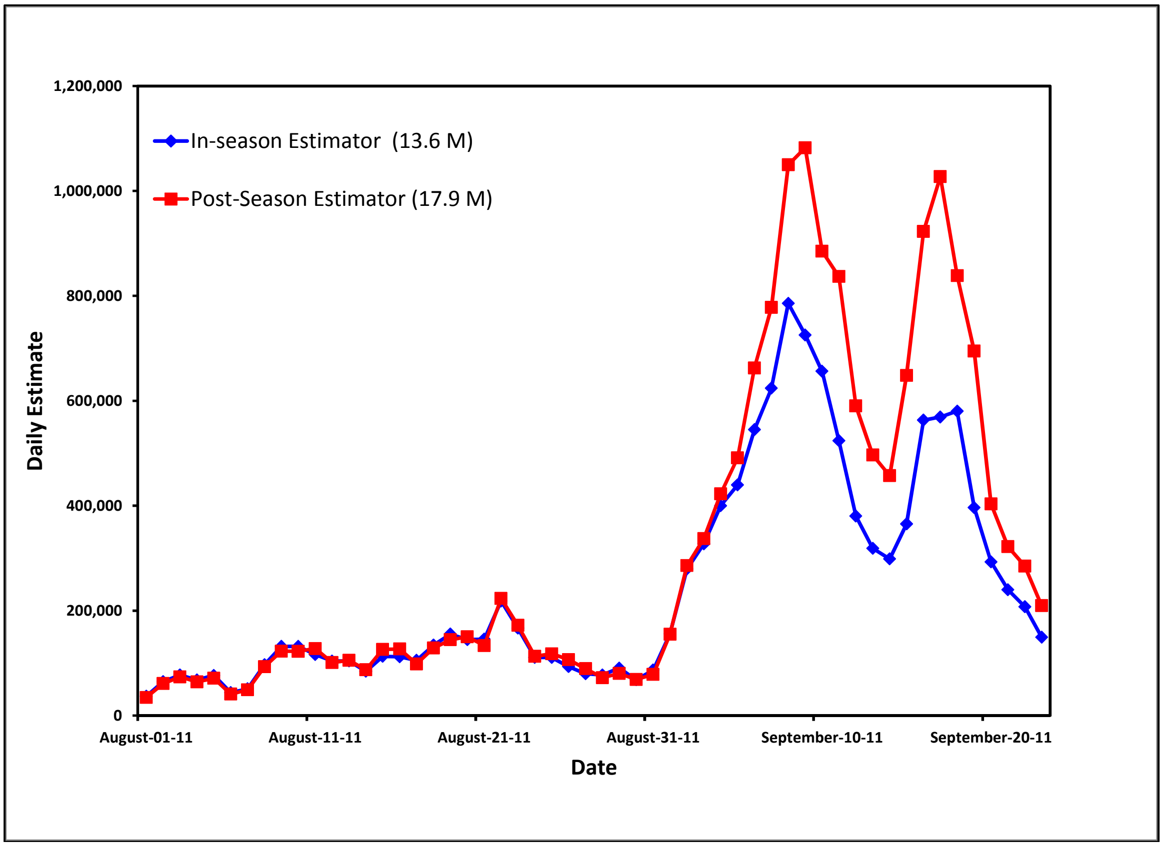

Figure 4. Daily salmon estimates produced by the 2 estimators for August and September 2011 season.

Post-season estimator (proposed estimator)

The post-season estimator was based on datasets acquired from the 6 systems:

- Left-bank inshore DIDSON (D1) (fish counts from a range window of 0-20m),
- Left-bank split-beam system (fish counts from the sounding ranges beyond the range window of D1),
- Biosonics DT-X mobile split-beam system (raw echo data acquired at a threshold of -130 dB),
- Right-bank inshore DIDSON (D2) (fish counts from 2 range bins for a total distance of 20m from the right bank),
- Right-bank offshore DIDSON (D3) (fish counts from 4 Aims), and
- Left-bank offshore DIDSON (D4) (only behavioural data was used for the estimation).

The daily salmon abundance from the post-season estimator is also presented in Figure 4, which estimated a total of 17.9 million salmon past Mission in the 2011 season.

The offshore fish flux was estimated using estimated fish density derived from the DT-X raw data (for fish density) and the averaged behavioural statistics observed from D3 and

D4. The DT-X split-beam raw data was post-processed using an in-house developed single-target detector with a set of key parameters shown in Figure 5. The single-target processed data allow for target tracking of individual fish while the availability of the raw data provides operators with visualized echo intensity to assist them to better separate fish tracks from non-fish targets such as river bottom or debris as illustrated in Figure 6.

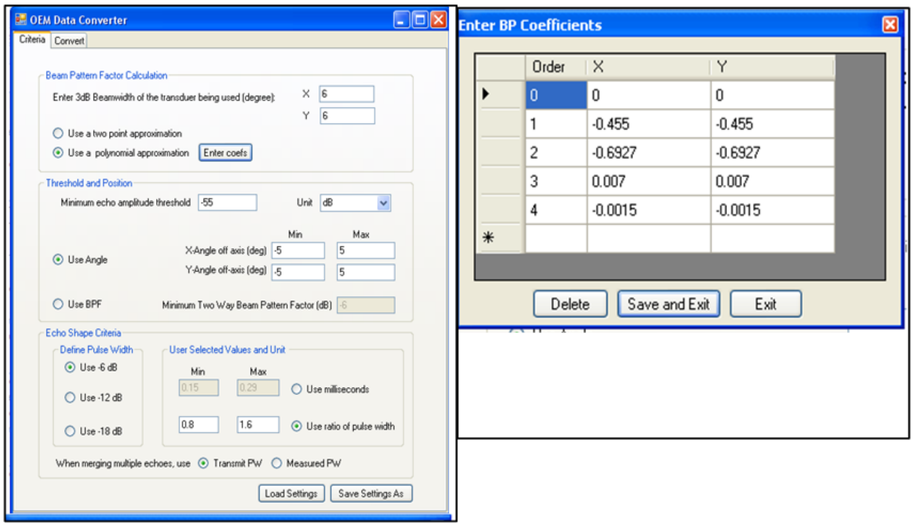

Figure 5. Single-target selection parameters for the mobile DT-X data in 2011.

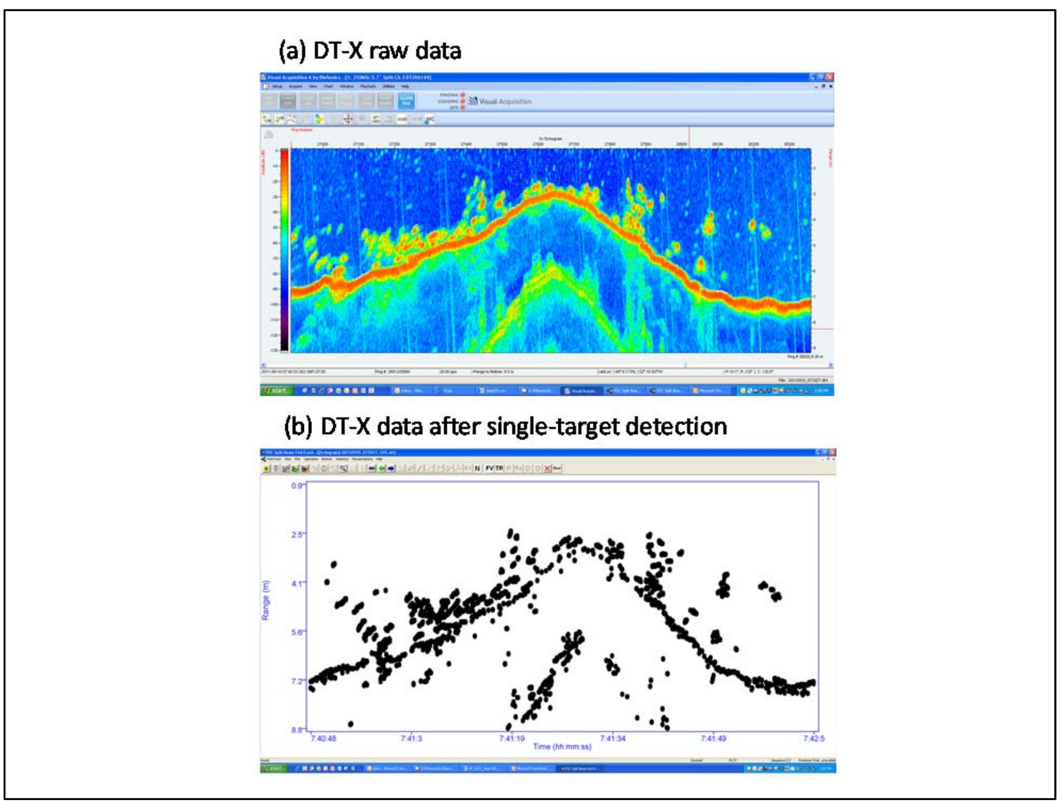

Figure 6. (a) DT-X split-beam raw data vs. (a) after single-target detection using criteria shown in Fig. 5. Data source: 20110910_071827.

Improvement of estimation accuracy by the proposed estimator

The proposed estimator produced nearly 4 million more salmon for the month of September than the in-season estimator, largely due to the fact that the 2 inshore DIDSON units (D2 and D3) from both banks were more effective in the sampling of pink salmon which are known to be extremely shore- and bottom-oriented. Table 8 summarizes the numerical differences between the 2 estimators for the estimation of daily total salmon flux on September 10, 2011.

Table 8. Numerical differences of daily salmon estimation between the current and the proposed estimators for September 10, 2011.

Estimator	*Left-bank area*	*Offshore area*	*Right-bank area*	*Cross-river Total*
Proposed	652,032	79,968	153,024	885,038
Current	561,096	52,872	42,288	656,292

The numerical difference between the 2 estimators is much smaller for the month of August with proposed and current estimators producing 3,183,329 and 3,198,305 total salmon, respectively. This indicates the gain by the proposed estimator is most pronounced during pink salmon (or perhaps late run sockeye) migration. The time series of daily difference between the 2 estimators is shown in Figure 7.

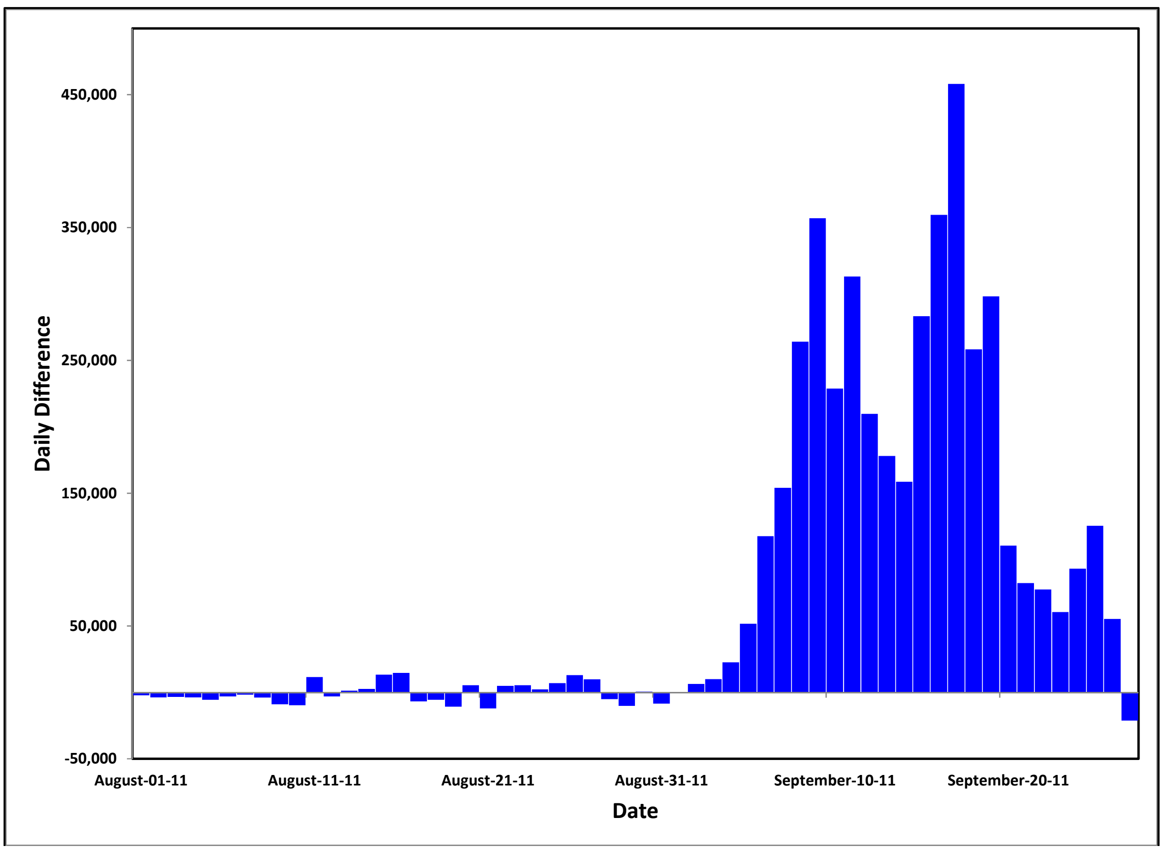

Figure 7. Difference of daily salmon estimates between the proposed and current estimators.

Cross river fish distributions at Mission

Migrating salmon at Mission are known to be shore-oriented to avoid strong currents in the mid-channel (Xie et al 2005). In addition, the migration flux is unevenly distributed in near-shore waters off the 2 banks with a cross-river distribution usually skewed towards the left-bank, especially during pink salmon migrations. The estimated cross-river distributions for the 3 areas sampled by the 2 near-shore systems and the mobile system for August and September 2011 are shown in Figures 8 and 9 using the post-season estimate.

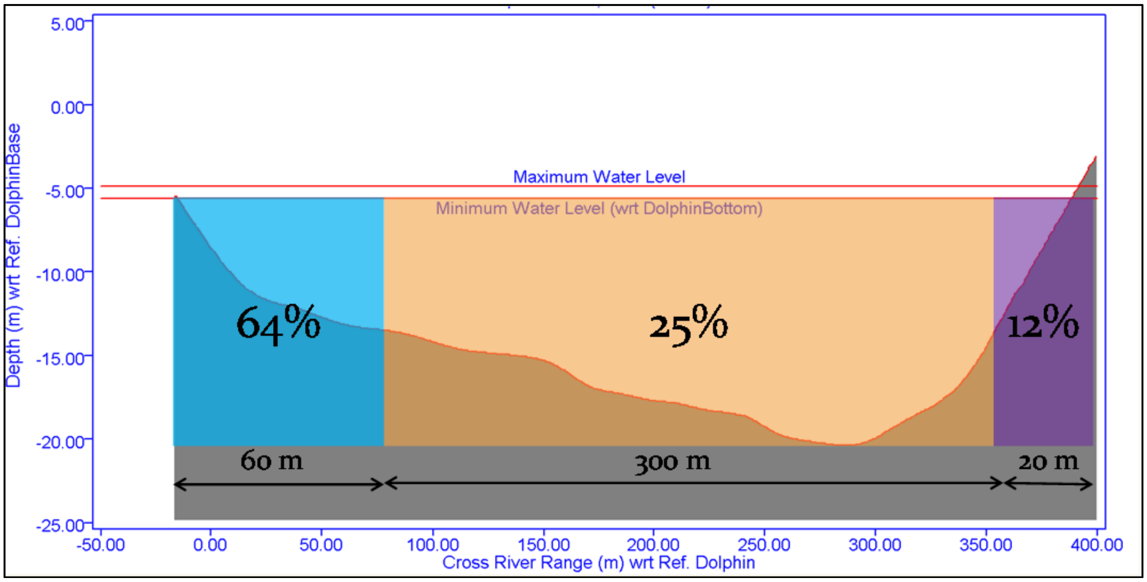

Figure 8. Cross-river fish flux distribution for August 12-31, 2011 (sockeye dominated migrations).

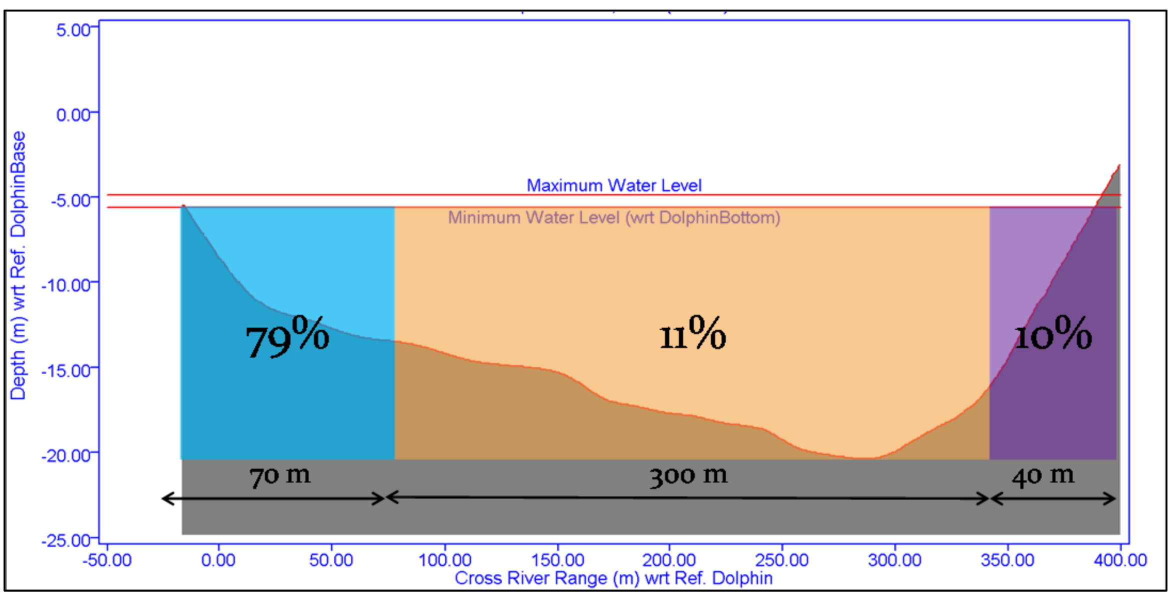

Figure 9. Cross-river fish flux distribution for September 2011 (pink dominated migrations).

Both plots show heavily skewed distributions towards the left-bank. The flux sampled by the 2 near-shore systems accounted for > 75% of the total flux while the offshore area (sampled by the mobile system) accounted for less than 25% of the flux.

Comparisons with salmon flux estimates at Qualark hydroacoustic site

Year 2011 is the 4th consecutive season the Department of Fisheries and Oceans (DFO) operated a hydroacoustic site at Qualark Creek (95 km upstream of Mission) to enumerate daily salmon passage with DIDSON sonar (Enzenhofer et al 2010). The SEF funded the 2011 Qualark program. The Qualark-based estimate of total salmon flux allows for qualitative, or under certain special scenarios, semi-quantitative time series analyses to compare the Mission estimate with that of Qualark. Due to the spatial separation of the 2 sites, there are a number of important factors that divert the 2 estimates. These are:

1. sockeye stocks that pass Mission but spawn below the Qualark site; most notably are the Harrison, Weaver, Birkenhead, Cultus and Chilliwack stocks,
2. a significant portion of pink salmon (more than 60%) spawning below Qualark,
3. fisheries removals between the 2 sites, and
4. on-route mortality from Mission to Qualark.

Adjusting effects from these factors (based on data from other estimators) may introduce additional error for the time series analysis between the 2 estimates. There may be, in the future, other means to better reconstruct stock or species specific Mission-projected Qualark estimates by precisely removing these effects for the so-called ‘apple-to-apple’ comparisons between the 2 estimates. In this report, we focus the analyses on the total salmon time series produced at the 2 sites without compensating any deviating factors.

Time unit of fish flux time series for the comparison analyses

Since salmon behaviour in the lower Fraser River are known to be affected by tidal influence (Levy and Cadenhead, 1995), daylight durations (John Holmes, personal communications), we chose hourly fish count as a basic unit for the fish flux time series analysis of total salmon estimate for the Qualark site but only hourly fish counts by the left-bank split-beam system at Mission as the Mission offshore flux produced by the mobile system can only offer a resolvable temporal scale of 24 hours. The hourly time unit ensures adequate, non-aliasing resolutions for semi-diurnal and diurnal events such as semi-diurnal tides and daylight durations. It also allows a resolution of fractions of a daily scale when estimating travel times of salmon upstream flux from Mission to Qualark.

Selected migration periods for the comparison time series analyses

We selected 2 time periods from the 2011 migration data for the comparison analyses:

1. The month of August when the migration was dominated by sockeye salmon with below-Qualark stocks (1,035,300) accounting for nearly 50% of the total sockeye past Mission (2,156,300), and
2. The month of September when the migration was dominated by pink salmon.

Due to the large divergence of below-Qualark stocks, the time series of the August salmon flux at the 2 sites diverted from each other significantly. The in-river fisheries removal also contributed to the deviation. We intend to use the August data to demonstrate that for scenarios similar to the 2011sockeye migration, it is very difficult to perform an 'apple-to-apple' type of comparison from the 2 estimates without introducing large uncertainty in the analysis due to test-fishing based stock identification error. On the contrary, pink salmon dominated the September migration and when reaching the Qualark site, pink migration remained numerically very strong in abundance. This means that the September data can be treated as mono-species time series at both sites, and that the much higher level of pink salmon abundance (than sockeye) tends to preserve the same temporal patterns at both sites when the in-river removal of pink salmon was negligible.

The temporal patterns of hourly salmon flux at two sites

Figures 10 and 11 show the hourly salmon flux observed at the 2 sites for the months of August and September (hourly flux of total salmon at Qualark vs. hourly flux of salmon abundance in the near-shore water off the left bank at Mission). Spectral and correlation analyses of the 2 time series led to the following conclusions:

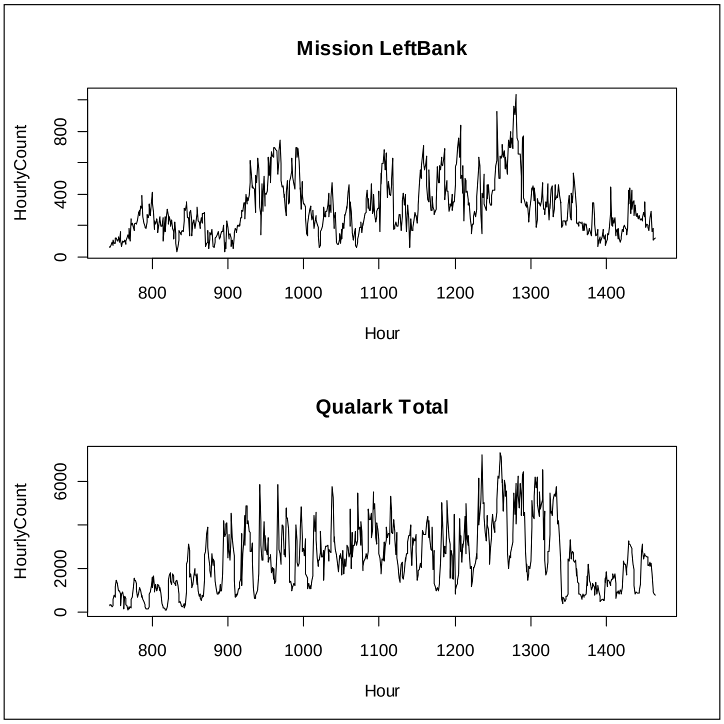

Figure 10. Hourly salmon flux time series observed at Mission and Qualark from August 1-31, 2011.

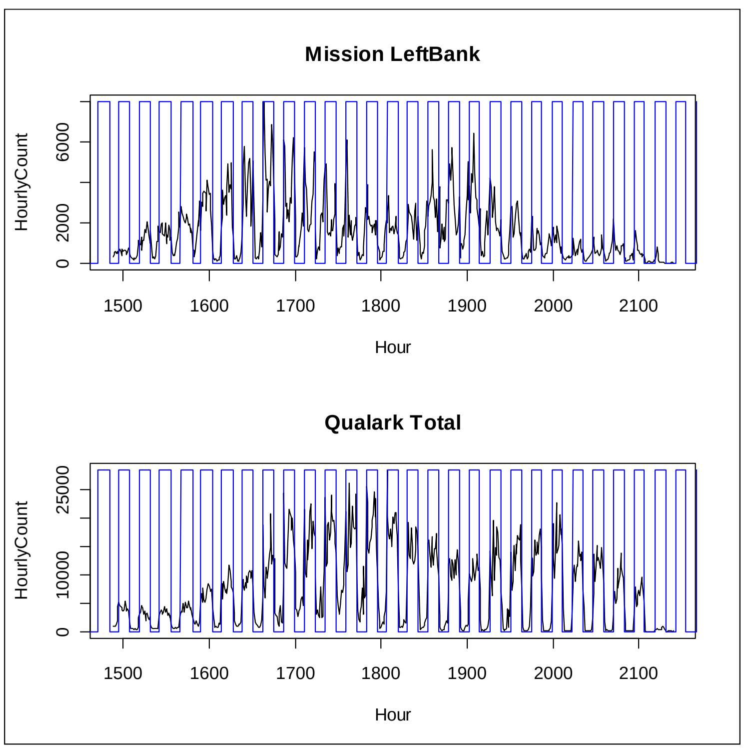

Figure 11. Hourly salmon flux time series observed at Mission and Qualark from September 1-28, 2011. Superimposed is the daylight-hour duration line (the blue line) for the month of September.

1. There is little similarity between the 2 time series for the month of August on the hourly scale; the maximum correlation coefficient of the 2 time series is merely 0.5. The similarity increases slightly with the coefficient increasing to 0.69 on a daily scale of 24 hours. The maximum correlation occurs at zero-lag for both cases indicating the temporal pattern of the salmon flux time series changed significantly by the time the fish arrived at Qualark.
2. The 2 time series displayed stronger similarities in September on both the hourly and daily scales with the maximum correlation coefficient reaching 0.65 for both time scales and occurring 3-4 days later relative to Mission timing (Figure. 13).
3. Daily peak migrations occurred during daylight hours at Qualark for both August sockeye period and September pink period (see Figure 12). While there was no obvious periodic pattern in the hourly time series for August at Mission, migration in September was correlated with and modulated by both the daylight durations and semi-diurnal tides (Figure 12).

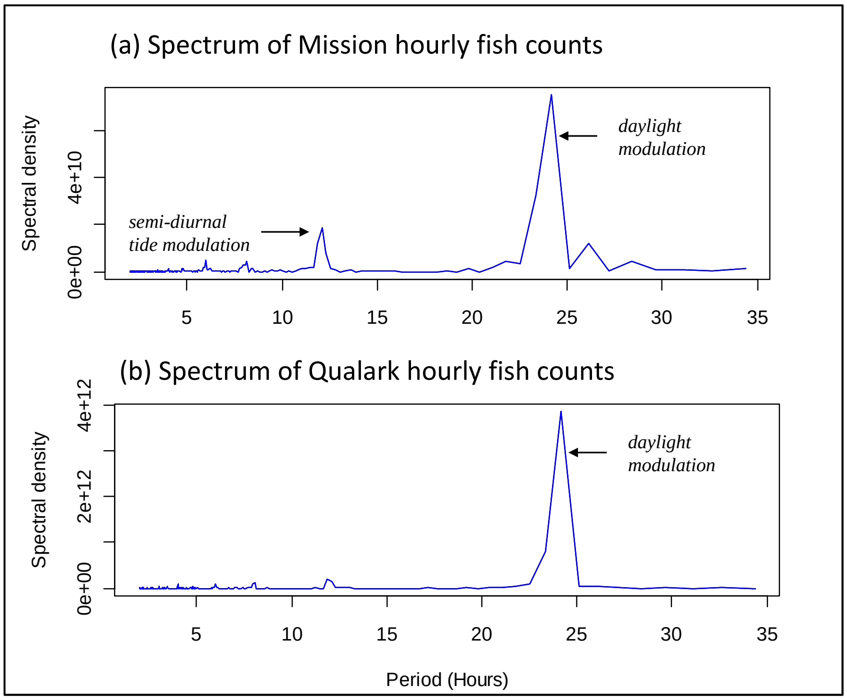

Figure 12. Spectrum density of September 2011 hourly salmon flux time series for (a) Mission left bank fish counts and (b) Qualark total fish counts. The spectra were estimated by a Fast Fourier Transformation (FFT) routine with 1024 hourly samples.

Estimated travel time from Mission to Qualark

The similarities between the salmon flux for the September period (Figure 11) allow us to perform cross-correlation analyses on the 2 time series to estimate travel times of pink salmon from Mission to Qualark. However, the migration profiles were heavily modulated at both sites by daylight effect at Qualark and daylight-and-tidal effects at Mission. A simple correlation of the 2 time series would be overwhelmed by the periodicities in the time series of diurnal and semi-diurnal patterns. To remove or minimize the influence on the analysis from the daylight and tidal modulations, we used a 4th order Butterworth filter to estimate the envelopes of the 2 time series. We consider the envelope signals to be the best estimates of migration profiles of salmon influx mainly determined by the migrating abundance that is free of daylight and tidal influences. Under this assumption, the phase difference between the 2 estimated migration profiles is solely caused by the delay of the arrival of the migration at Qualark due to the travel time from Mission to Qualark. Figure 13 shows the estimated migration profiles and the cross-correlation analysis of the 2 profiles.

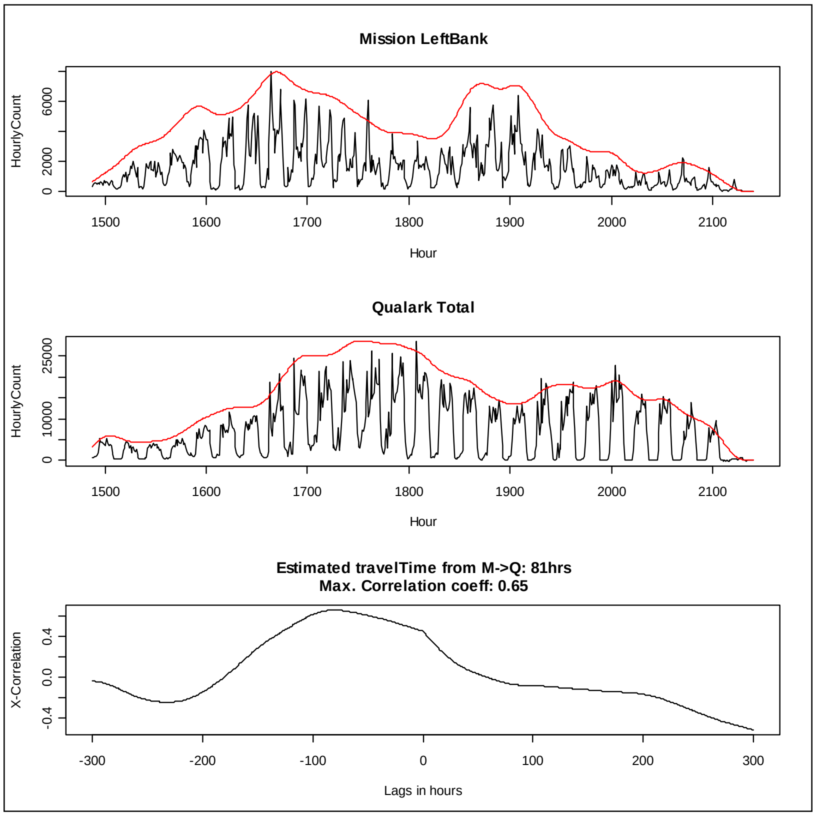

Figure 13. Estimated September 1-28, 2011 migration profiles (the red lines) at Mission (upper panel) and Qualark (middle panel) and the cross-correlation curve (bottom panel) which indicates the maximum coefficient of 0.65 at the lag of 81 hours or a travel speed of 28.1km/day for pink salmon.

The correlation analysis estimates an averaged travel time of 81 hours for fish (mainly pink salmon) in September 2011 to migrate from Mission to Qualark. This travel time corresponds to a daily migration speed of 28.1 km/day for pink salmon in this stretch of the river. For comparison purpose, we also performed the same analysis on the hourly flux time series from both sites for September 2010 when the migration was dominated by the late-run sockeye salmon. The results are presented in Figure 14.

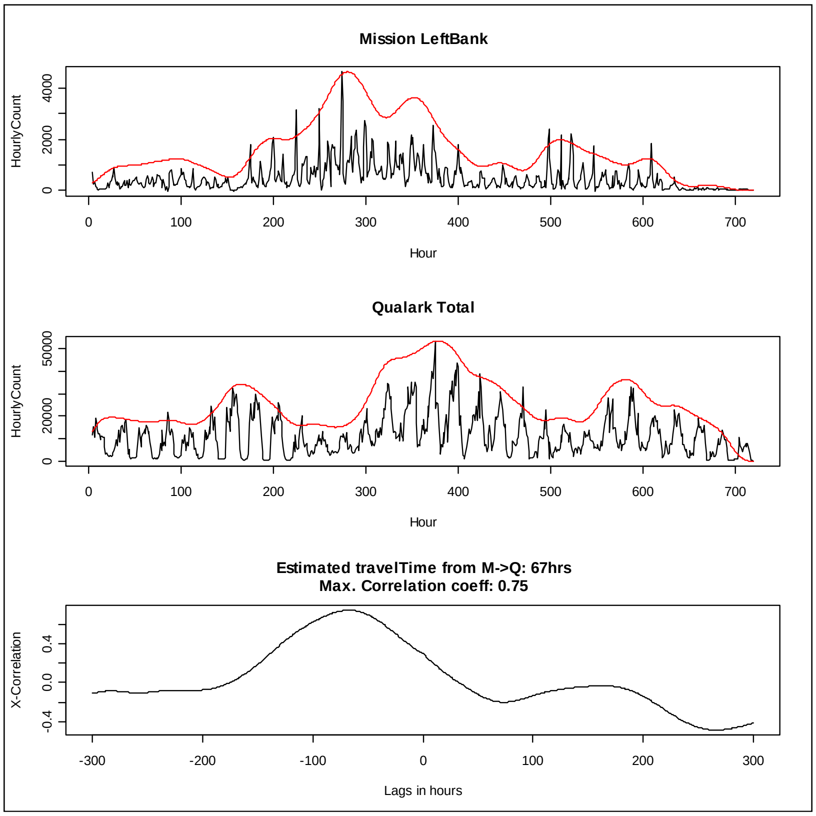

Figure 14. Estimated September 1-30, 2010 migration profiles (the red lines) at Mission (upper panel) and Qualark (middle panel) and the cross-correlation curve (bottom panel) which indicates the maximum coefficient of 0.75 at the lag of 67 hours or a travel speed of 34km/day for late-run sockeye.

The analysis estimates an averaged travel time of 67 hours for fish (mainly sockeye salmon) in September 2010 to migrate from Mission to Qualark. This travel time corresponds to a daily migration speed of 34 km/day for late-run sockeye salmon in this stretch of the river. According to LGL's tagging data for September 2010 (Karl English, personal communications), tagged fish took an average time of 94 hours to travel from Mission to Qualark at a migration speed of 24 km/day. It appears the tagged fish traveled at a significantly lower speed than the untagged fish. Also worth noting are the spectral analyses of the 2010 data which indicated that while the salmon migration at Qualark remained modulated by daylight durations as observed in other seasons and migration periods, the migration at Mission in September 2010 was mainly influenced by the semi-diurnal tides: migration peaked prior to and just after the occurrences of minimum flows.

Comparison of total daily salmon flux between Mission and Qualark

Since the strong pink salmon migration between the 2 sites were subjected to relatively little in-river fisheries removals, the 2011 daily total salmon profiles at the Mission and Qualark maintained similar temporal patterns due to the very large pink population returning to the lower river in September. Figure 15 shows the daily salmon flux profiles observed at the 2 sites for the month of August and September; the plotted Mission profile was estimated by the post-season estimator for the entire river. The 2 profiles yield a maximum correlation coefficient of nearly 0.9 at a lag of 4 days.

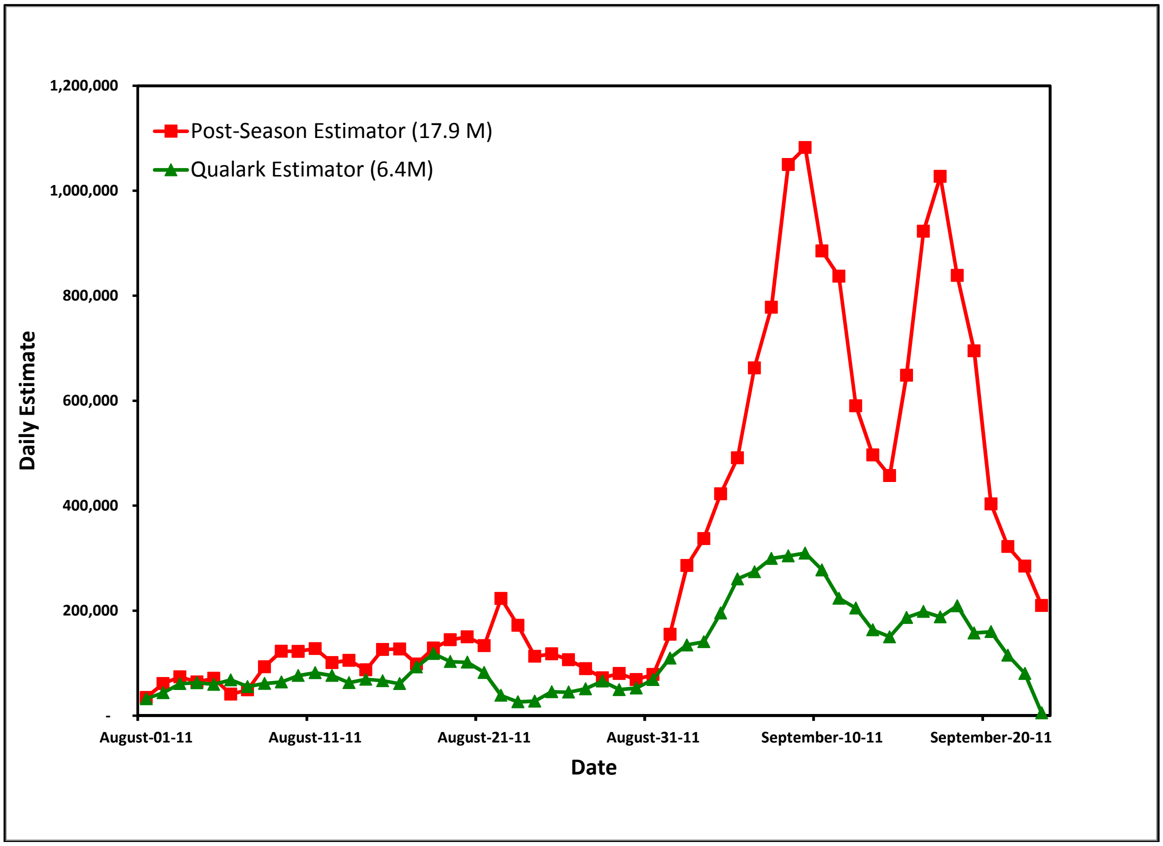

Figure15. Daily total salmon estimates at Mission and Qualark for August and September 2011. The Qualark profile has been shifted by 4 days to approximate the estimated delay of 81 hours due to travel times from Mission to Qualark.

While it is difficult to compare the 2 estimates for the 2011 sockeye stocks without introducing error due to stock identification uncertainty, it is relatively straightforward to assess Mission and Qualark escapements from the 2 estimates of pink salmon in September when pink salmon abundance overwhelmed other species. Table 9 presents a summary of hydroacoustically estimated total pink salmon run size and the distributions of pink salmon populations spawning between Mission and Qualark and above Qualark.

Table 9. Summary of the hydroacoustic based pink salmon run size for 2011 and spawning populations between Mission and Qualark and above Qualark.

Post-season estimated pink salmon past Mission	*Catch above Mission*	*Catch below Mission*	*Total run size*	*Net escapement above Mission*	*Qualark estimated pink*	*Percent of pink spawning below Qualark*
13,349,000	761,635	6,933,800	**20,282,800**	12,587,000	4,339,000	**66%**

The post-season estimator produced a total run size of 20,282,800 pink salmon for 2011 season which is about 2,000,000 higher than the Fraser River Panel approved 2011 pink salmon run of 18,300,000 based on the marine area test fishing catch data. With Qualark estimated pink passages, the 2 hydroacoustic estimates indicated 66% of the pink salmon spawned below Qualark, mainly in the Fraser main stem, Coquihala, Harrison and Chilliwack rivers.

CONCLUDING REMARKS

The findings and results presented in this report demonstrate:

1. The proposed estimator (the post-season estimator) is more effective than the current estimator in sampling near-shore salmon passage. When the migration is dominated by near-shore migrants such as pink salmon or late-run sockeye salmon, the proposed estimator captures a large portion of abundance migrating near both banks but undetected by the current estimator (Table 8 and Figs. 4 and 7).
2. When the migration is further offshore (during migrations of summer-run sockeye), the gain from the proposed estimator is moderate (see Figure 7 for differences between the 2 estimators in August).
3. The estimated cross-river fish distributions indicate more than 75% of the salmon flux occurs in the near-shore areas that can be directly sampled by the shore- or near-shore based stationary sonar systems, leaving only 25% of the flux (in the offshore area) to be estimated by the mobile sampling system (Figs. 8 and 9). At this time there is still no practical solution to the replacement of the mobile sampling system, but the proposed sampling method has enhanced the accuracy and precision of estimation for up to 75% of the total flux in near-shore waters. This has yielded the best gain for the SEF fund investments for the Mission hydroacoustic program improvement since 2008.
4. The proposed estimator produced a much more sensible estimate than the current estimator of total pink salmon flux past Mission (Figure 15). Combined with the Qualark estimate, not only the total run size can be derived from the Mission estimate but also the distributions of spawners above and below Qualark (Table 9).
5. When the abundance of below-Qualark stocks and in-river fisheries removals are relatively small to the total abundance (e.g. the late-run sockeye migration in 2010) or the migration is dominated by pink salmon (the September 2011 migration), the time series of hourly total salmon flux at Mission (left bank) and

Qualark maintain similar temporal patterns. Correlation analyses between the 2 time series (under these scenarios) can provide qualitative information on the occurrence of potential bias at Mission. The analyses also allow for estimation of travel times from Mission to Qualark (Figs. 13 and 14).

Based on these analyses and findings, we conclude that the proposed estimator is more robust than the current estimator and we recommend the implementation of this estimator for the PSC Mission hydroacoustic program.

There are 2 main costs associated with the implementation of the proposed estimator:

1. Capital cost of one DIDSON unit (including the rotator and cable) as a backup unit for in-season use. The estimated cost for this complete system is approximately $100,000 assuming we do not operate a left-bank offshore DIDSON system, and
2. A total salary cost for 2 in-season staff of about $20,000 over a 3-month field season to process DIDSON data.

ACKNOWLEDGEMENTS

This work was funded by the 2011 Southern Boundary Restoration and Enhancement Fund of the Pacific Salmon Commission. We are grateful to Hermann Enzenhofer and John Holmes of the Department of Fisheries and Oceans for providing us with the Qualark estimation data.

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FINANCIAL STATEMENT

Project Budget Form

SF-2011-I-12. Xie

Name of Projec Implementation of an offshore sub-sampling system with side-scan sonar for in-season use at the PSC Mission Hydroacoustics site

ELIGIBLE COSTS					TOTAL PROJECT BUDGET	OTHER FUNDING	PSC S. FUND GRANT AMOUNT	Actual Expenditure	Variance	% Var
Labour **Wages & Salaries**										
Position	# of crew	# of work days	hrs per day	rate per hour	Total (PSC + In-kind + cash)	In-Kind & Cash	PSC Amount	Actual PSC Exp.	Variance from PSC Amt	% Var
Technician(EG-5)	1	25	4	34.9	3,490	3,490				
Technician (EG-3)	1	25	3	30	2,250	2,250				
Biologist (BI-2)	1	25	3	38.2	2,865	2,865				
Scientist (RES-3)	1	25	3	52.6	3,945	3,945				
Support Staff	3	21	8	21.23	10,700		10,700	10,699.92	-	0%
Post-Season Processing	2	45	8	21.23	15,286		15,286	10,978.42	(4,307.18)	-28%
							-			
Person Days (# of crew x work days)		1,494		sub total	$ 38,535.52	$ 12,550.00	$ 25,985.52	21,678.34	(4,307.18)	-17%

Labour - Employer Costs (percent of wages subtotal amount)

	rate	12%	Seasonal				3,118	1,570.44	(1,547.82)	-50%
		25.00%	FullTime			3,138				
				sub total	$ 6,255.76	$ 3,137.50	$ 3,118.26	1,570.44	(1,547.82)	-50%

Subcontractors & Cc	# of crew	# of work days	hrs per day	rate per hour						
Software Support	1	19	7.5	70	9,975		9,975	3,674.00	(6,301.00)	-63%
					-					
					-					
Insurance if applicable	rate	0%								
				sub total	$ 9,975.00	$ -	$ 9,975.00	3,674.00	(6,301.00)	-63%

Volunteer Labour	# of crew	# of work days	hrs per day							
Skilled					-					
Un-skilled					-					
Insurance if applicable	rate	0%			-					
				sub total	-					
				Total Labour Costs	$ 54,766.28	$ 15,687.50	$ 39,078.78	$ 26,922.78	$ (12,156.00)	-31%

Site / Project Costs	Provide details in the space below (use an additional page if needed)					
Travel (do not include to & from work)		-		-			
Small Tools & Equipment		500	500				
Site Supplies & Materials		1,000		1,000	305.77	(694.23)	-69%
Equipment Rental	(DIDSON, Cables, Rotator Lease for 1 month plus S&H)	13,780		13,780	16,129.50	2,349.50	17%
Work & Safety Gear		500	500				
Repairs & Maintenace		2,000		2,000	925.80	(1,074.20)	-54%
Permits		-					
Other site costs	Generator Fuel, anchors, oil, misc	500		500	0.00	(500.00)	-100%
Technical Monitoring		-					
	Total Site / Project Costs	$ 18,280.00	$ 1,000.00	$ 17,280.00	17,361.07	81.07	0%

SF-2011-I-12. Xie

ELIGIBLE COSTS | **BUDGET** | **OTHER FUNDING** | **CONTRIBUTION FUNDING** | **Actual Expenditure** | **Variance**

Training (e.g Swiftwater, bear aware, electrofishing, etc).

Name of course	# of crew	# of days		Total (PSC + In-kind + cash)	In-Kind & Cash	PSC Amount	Actual PSC Exp.	Variance from PSC Amt	% Var
				-					
				-					
				-					
				-					
			Total Training Costs	$ -	$ -	$ -	0.00	-	n/a

Administrative Costs

	Total (PSC + In-kind + cash)	In-Kind & Cash	PSC Amount	Actual PSC Exp.	Variance from PSC Amt	% Var
Office space; including utilities, etc.	1,600	1,600				
Office supplies	600	600				
Telephone & Long Distance	1,000	1,000				
Photocopies & printing	60	60				
Insurance	100	100				
Indirect/overhead costs	3,335		3,335	3,335.00	-	0%
(If the PSC contribution to Indirect costs exceeds 20% of the total PSC grant	-					
you will be required to submit back-up documentation justifying the expense).	-					
Other overhead costs (PSC Office Support)	-					
Total Administrative Costs	6,695	$ 3,360.00	$ 3,335.00	3,335.00	-	0%

Capital Costs / Asset (use an additional page if needed)

Provide details in the space below

Assets are things of value that have an initial cost of $250 CAN or more and which can be readily misappropriated for personal use or gain or which are not, or will not be, fully consumed during the term of the project.

	Total (PSC + In-kind + cash)	In-Kind & Cash	PSC Amount	Actual PSC Exp.	Variance from PSC Amt	% Var
	-		-			
DIDSON	79,000		79,000	81,255.12	2,255.12	3%
Percent of Existing Acoustic Equipment (DIDSON, Sensors, CPU, Software, Cables, ADCP)	60,000	60,000				
Support Vessel	10,000	10,000				
	-					
Total Capital Costs	149,000	$ 70,000.00	$ 79,000.00	81,255.12	2,255.12	3%
Project Total Costs	$ 228,741.28	$ 90,047.50	$ 138,693.78	128,873.97	-$9,819.81	-7%

Revised 2010 Total Grant | 138,694.00 | CAN

Budget Summary
(PSC + in-kind + cash)

Total Labour Costs	$ 54,766.28
Total Site / Project Costs	$ 18,280.00
Total Training Costs	$ -
Total Overhead Costs	$ 6,695.00
Total Capital Costs	$149,000.00
Project Total	$228,741.28

Actual Advances

1st advance	126,935.00
2nd advance	-
3rd advance	-
Total advances	126,935.00
less actual $ spent	128,873.97
Difference	**1,938.97**
Amt due/(owed to PSC)	**1,938.97**

Pacific Salmon Commission

Implementation of an Offshore Sub-Sampling System with Side-Scan Sonar SF-2011-I-12

Statement of Receipts and Expenditures

As at: **March 28, 2012**

	ACTUAL	BUDGET	Variance
Receipts			
Project Grant	$ 126,935.00	$ 138,693.78	$ 11,758.78
Total receipts	$ 126,935.00	$ 138,693.78	$ 11,758.78
Expenditures			
Total Labour Costs	$ 26,922.78	$ 39,078.78	$ 12,156.00
Total Site/ Project Costs	$ 17,361.07	$ 17,280.00	$ (81.07)
Administration	3,335.00	3,335.00	-
Capital Costs	81,255.12	79,000.00	(2,255.12)
Total Expenditures	128,873.97	138,693.78	9,819.81
Balance	$ (1,938.97)	$ -	$ 1,938.97

I certify the information given above is, to the best of my knowledge, correct and complete

Date: March 28, 2012 Signature: [signature]

Bonnie Dalziel

Position: Accountant