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# **Hydroacoustics Review Technical Summary**

**Bob Conrad  
Aaron Dufault  
Mike Hawkshaw  
Ann-Marie Huang  
Erica Jenkins  
Cory Lagasse  
Mike Lapointe  
Marisa Litz  
Fiona Martens  
Catherine Michielsens  
Jamie Scroggie  
Mike Staley  
Timber Whitehouse  
Catarina Wor  
Yunbo Xie**

August 2019



**Pacific Salmon Commission  
Technical Report No. 41**

The Pacific Salmon Commission is charged with the implementation of the Pacific Salmon Treaty, which was signed by Canada and the United States in 1985. The focus of the agreement are salmon stocks that originate in one country and are subject to interception by the other country. The objectives of the Treaty are to 1) conserve the five species of Pacific salmon in order to achieve optimum production, and 2) to divide the harvests so each country reaps the benefits of its investment in salmon management.

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Pacific Salmon Commission  
600 - 1155 Robson Street  
Vancouver, B.C.V6E 1B5  
(604) 684-8081  
[www.psc.org](http://www.psc.org)



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Technical Report No. 41

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## Foreword

Lower Fraser in-river hydroacoustic methods play an important role for the in-season assessment of Fraser River sockeye stocks, and the quality of the abundance estimates generated by the hydroacoustic program at Mission has been the focus of inquiries beginning in the 1980's. Since 2008, an additional hydroacoustic program at Qualark has been able to provide independent estimates of total salmon abundances, and on some years, like 2010, these estimates differed substantially from the Mission total salmon abundance estimates. The expansion of the Mission program combined with the additional hydroacoustic program at Qualark has significantly increased the overall cost of hydroacoustic operations in the lower Fraser River. In 2013, the Pacific Salmon Commission formed the Fraser River Strategic Review Committee (FSRC) with the mandate to provide advice to the Commission regarding potential modifications to the hydroacoustic operations with the aim to reduce overall program costs while maintaining the necessary quality standards for in-season assessment. The report by an independent consultant in 2015 left many of the initial terms of reference (TOR) unaddressed, and as a result, the FSRC provided a bilateral group of technical experts with a revised list of tasks and timelines to address the TOR.

This PSC Technical Report documents the work of this group of bilateral experts. More specifically, it contains the Hydroacoustics Review Technical Summary, including the numerous appendices with technical details as well as the preface to this Technical Summary by the Fraser River Panel leadership. The technical evaluation of this work by Commissioner Dr. Brian Riddell, as well as the bilateral responses were provided in a memo to FSRC committee members as well as the Fraser River Panel and Technical Committee, August 6, 2019. Due to the lengthy nature of the hydroacoustic review progress (ongoing since 2013), this report also documents the technical work completed by both hydroacoustic programs (Mission and Qualark) since 2016, in response to some of the preliminary findings.

To ensure the transparency of the process, no changes have been made to the original documents that are part of this report, except for the following three changes. First, the cover letter to the Technical Summary provided by the Fraser River Panel leadership has been revised to ensure full support of the Fraser River Panel. The resulting changes that have been made are shown explicitly. Second, a few sentences have been added as introduction to each of the appendices of the Technical Summary to help the reader understand the information provided. And third, the reference to a non-existing table has been removed and an editorial note has been added to indicate this has been done. In addition, all the material provided in this report has undergone bilateral scrutiny except for the technical work by both hydroacoustic programs since 2016, including the species composition method that has been developed since then.

Overall, this report documents a substantial body of work regarding the Lower Fraser hydroacoustic programs at Mission and Qualark, which we hope will benefit both the Pacific Salmon Commission as well as other organisations who use similar methods for the assessment of their salmon stocks.

Fiona Martens and Catherine Michielsens  
Chiefs, Fisheries Management  
Pacific Salmon Commission

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## PART 1

# Cover Letter



## PACIFIC SALMON COMMISSION

ESTABLISHED BY TREATY BETWEEN CANADA  
AND THE UNITED STATES OF AMERICA  
MARCH 18, 1985

600 – 1155 ROBSON STREET  
VANCOUVER, B.C. V6E 1B5  
TELEPHONE: (604) 684-8081  
FAX: (604) 666-8707

Our File:

Your File:

August 15, 2019

Dear Members of the Fraser Strategic Review Committee,

### Re: Hydroacoustics Review

The attached document *Hydroacoustic Technical Review Summary* is presented for your consideration in the current review of the hydroacoustics programs in the Fraser River mainstem. This report summarizes work completed via the Fraser River Panel and Technical Committee as directed by the Fraser Strategic Review Committee (FSRC), and draws upon products of other component projects that formed part of the overall review to provide a synthesis of key findings and associated recommendations. The attached document has been reviewed by the bilateral Fraser River Panel and focuses on how the passage estimate differences (PEDs) between Mission and Qualark can affect assessments of run size and Total Allowable Catch (TAC) of Fraser sockeye. The technical review focused on evaluation of the likely contributing factors driving the PEDs during certain years, as well as whether adjustments to some elements of the current Mission hydroacoustics program are possible. The review does not cover other uses of the hydroacoustics estimates beyond in-season management decisions.

In conjunction with the hydroacoustics review a separate but related Southern Endowment Fund project titled "Improving Fraser River Test Fisheries and Run Size Estimates" was completed in March 2018 (Nelitz, M., A. Hall, C. Michielsens, B. Connors, M. Lapointe, K. Forrest, and E. Jenkins. 2018. Summary of a Review of Fraser River Test Fisheries. Pacific Salmon Comm. Tech. Rep. No. 40: 155 p.) Information and recommendations from this test fishery project were evaluated in relation to the hydroacoustics review as the test fisheries contribute data for assigning species and stock ID to the estimates of total fish passage generated by the hydroacoustics programs. In addition, the test fisheries are used to generate estimates of in-river sockeye escapement early and late in the season when the hydroacoustics programs are not operating due to financial constraints or are swamped by pink salmon passage.

Initial Panel recommendations in 2017 included continued operation of the Qualark hydroacoustic site through the 2018 Fraser sockeye season in order to conduct experiments at both Mission and Qualark to further our understanding of potential causes of passage estimate differences (PEDs) between Mission and Qualark, which have been most dramatic during Late Shuswap dominant cycle years of 2010 and 2014. Substantial efforts were made from 2016 to 2018 by both programs in the form of experiments to understand potential causes of PEDs. At Mission these experiments included an examination of offshore fish behaviour, potential biases in estimates using different sonar systems (split-beam vs. imaging sonar), the influence of fishing activity on cross-river fish distributions, left-bank river bottom reprofiling, and the impact of changes to sampling configurations (i.e. six aims vs. 10 aims). At Qualark, experiments



included an examination of near bottom blind zones, the vertical distribution of fish, and the presence of fish further offshore than the insonified area. The total PED in 2018 was 4.2% (207,100 sockeye), with the Mission projection being higher than Qualark.

After considering the technical evaluation contained in the attached document, including the additional work done by both hydroacoustic programs (Mission and Qualark) since 2016 and the non-technical experiential information from our years of serving on the Fraser River Panel, the Panel provided the following updated recommendations for the Fraser River mainstem hydroacoustics program:

1. Maintain the current hydroacoustics program at Mission that covers the entire cross-section of the river. (Within this recommendation, there is room to further investigate some small cost savings associated with sub-sampling the Mission mobile unit and potentially re-direct the funds to improving sample size of in-river test fisheries. However, there was no hydroacoustics gear configuration examined which would allow assessments to continue at both mainstem hydroacoustic sites for the cost of the current Mission program without severely compromising the data that is used by the Fraser River Panel.)
2. There may be a desire to further evaluate the continuation of Qualark in non-dominant Adams years pending available funding. As well, continuation of Qualark needs to be considered in the context of the overall sockeye assessment program and outcomes from the current test fishing review.
3. Longer term considerations for the continued operation of Qualark will need to incorporate the value of information generated by the site. At this time, Qualark data (both hydro-acoustic and test fishing data) are not formally utilized for in-season Panel management decisions. The value of these data was not evaluated in this technical review, which focussed on the use of hydroacoustics data used to calculate run size and TAC. In particular, the evaluation of the species and stock composition information used at Mission and Qualark as per deferred workplan items #11 & #12 may help quantify the value of the Qualark dataset during the times when species composition is highly uncertain due to the proportions of co-migrating Chinook and Pink salmon or when sample sizes at Whonnock and Cottonwood are small.
4. The Panel also supports the suggestions of additional work to further examine the impact of hydroacoustic estimate uncertainties on Management Adjustment (MA) models and the Run Size Adjustment (RSA) process.

The Fraser River Panel and Technical Committee are very willing to meet and discuss the findings to date and the recommendations provided above.

Sincerely,

  
Ms. Jennifer Nene, Chair

  
Ms. Lorraine Loomis, Vice-Chair

# Hydroacoustics Review Technical Summary

## Overview

### 1.1 Introduction

In response to concerns regarding increasing costs of hydroacoustic operations in the lower Fraser River, due to the addition of the Qualark hydroacoustics program in 2008 and the additions and modifications to the Mission hydroacoustics program in subsequent years, a document entitled 'Next Steps for Fraser River Acoustics' was presented to the Commissioners and the Fraser River Panel (FRP) by M. Lapointe in 2013 (Appendix 1). This document discussed the future of the hydroacoustic programs at Mission and Qualark and the related budgets. At the request of the Commissioners, the Fraser River Strategic Review Committee (FSRC) was formed with the mandate to provide advice to the Commission on potential modifications to hydroacoustic operations (Appendix 2 and Appendix 3) designed to reduce the total annual cost associated with two programs. The FRP developed a workplan to support the FSRC and an independent consultant was engaged (Appendix 4 and Appendix 5). With data and input from the FRP, hydroacoustics staff of the Pacific Salmon Commission (PSC) Secretariat, and Fisheries and Oceans Canada (DFO), the consultant produced a report and presented it to the FRP in the fall of 2015 (Appendix 6). The FSRC acknowledged the work of the consultant, but there was concern that the terms of reference (TOR) had not been fully addressed. The FSRC accepted input from the FRP and technical committee members and the FRP provided a revised list of tasks and timelines to comprehensively address the TOR and provide a recommendation for lower Fraser River hydroacoustics (Appendix 7). This report summarizes the technical work conducted as specified in the workplan with the intention of informing the FSRC.

### 1.2 How to “read” this document

This document has been designed to serve several purposes: first, the executive summary provides a high level summary of the hydroacoustics technical review; second, the executive summary points the reader to individual sections within the main body of the document which support the statements in the executive summary; finally, sections within the main body of the document also reference a suite of appendices (Part 1: Appendix 1-15).

## Acronyms

- ARIS – Adaptive Resolution Imaging Sonar
- DIDSON - Dual frequency IDentification SONar

- LB – left bank hydroacoustic system (can refer to either Mission or Qualark; left follows riverine convention, left bank of river when facing downstream)
- MA – management adjustment: MAs are added to the escapement goal when necessary to account for historic differences between Mission hydroacoustic estimates of fish passage (plus catch upstream of the hydroacoustic site) and spawning ground escapement estimates
- PEDs – Passage Estimate Differences (between Mission and Qualark, previously referred to as “DBEs”)
- RB – right bank hydroacoustic system (can refer to either Mission or Qualark)
- RSA – run size adjustment: post-season work to account for sockeye that are estimated to have died in-river (i.e., final run size = catch + escapement + RSA)
- TAC – total allowable catch
- TOR – terms of reference.

## Executive Summary

### 1. Conclusions:

- This review focused on evaluating the passage estimate differences (PEDs) between Mission and Qualark, potential causes of the PEDs, and how these differences could impact run size estimates and TAC calculations. To explore these questions, six alternate hydroacoustic gear configurations were examined using available information. The technical conclusions for each configuration are summarized below.
  - Mission only** – The review concludes that coverage of both banks and the mid-channel at Mission is the minimum gear configuration required to support in-season run size assessment and management (see 5.8.1):
    - All Fraser sockeye stocks, with the exception of Pitt, Widgeon, Alouette and Coquitlam migrate past the Mission site.
    - Mission provides estimates 2-3 days earlier than Qualark.
    - Mission has been the only method used to enumerate pink salmon returning to the Fraser River post-season, since the early 2000s. 2015 was the first year of getting in-season estimates of pink passage from the Mission program.
  - Qualark only** – Although the Qualark location is a more ideal site for hydroacoustic enumeration of salmon passage, with fewer potential sources of error than the Mission site, the review concludes that using Qualark by itself is not supported by the available information (see 5.8.2), because:
    - There are important sockeye stocks that are assessed by Mission but not assessed by Qualark (i.e., the Vedder/Chilliwack, and the Harrison/Birkenhead systems) which would require additional in-season assessment measures and associated resources.
    - Qualark provides estimates 2-3 days later than Mission, which may unacceptably delay in-season management decisions.
    - Qualark would not be able to provide estimates of total Fraser pink salmon escapements.
  - Mission and Qualark:** (see 5.8) Technical analysis of the PEDs suggests that continued long-term annual operation of both the Mission and Qualark hydroacoustic systems may not result in improved in-season sockeye estimates:

- With eight years of data from simultaneous operation, the review was unable to find any correlation between the occurrence of PEDs and a number of potential causal factors (see 4.6).
- In the two Adams-dominant years in the dataset (i.e., 2010 and 2014), 61 days with significant PEDs were identified in the 169 days examined (36% of the days). For comparison, during the other six years examined 48 days with significant PEDs were identified in the 258 days examined (19% of the days).
- In the two Adams-dominant years, the significant PEDs were large both numerically as well as percentage of the migration and went in opposite directions (Qualark larger than Mission in 2010 and vice versa in 2014). In addition, these PEDs may not be directly comparable, as the Mission configuration was not the same in these years. However, a retrospective analysis of the impact on the resulting in-season run size estimates and TACs were much smaller in magnitude than the PEDs themselves (see 4.5).
- The technical review supports the operation of Qualark in 2018 (an Adams-dominant year) but only if studies designed to further our understanding of the causes of passage estimate differences (PEDs) are included in a coordinated approach by both programs.
- For the longer term, an alternate recommendation to consider would be to run Qualark in addition to Mission only in years of expected high sockeye abundance (e.g., Adams-dominant and possibly sub-dominant years) with the same caveat as above that studies designed to further our understanding of the causes of PEDs are included in both programs. Note that logistical issues associated with not operating Qualark every year would need to be addressed (e.g., removing infrastructure during fallow years) so this may not be practical.
- It is important to note that there are other considerations that should inform a decision about the future of Qualark, including other uses for the hydroacoustics information beyond that of determining run size and TAC, such as its use to managers as a second reference point of fish passage estimates (see 5.7). As well, further investigation into the use of Qualark in informing sockeye estimates when there are large numbers of pink salmon in the lower river (as a relatively low proportion of pink salmon migrate past Qualark) may be helpful.

**iv. Mission without mobile** – is not supported by the available information (see 4.3.1.1).

- In the years examined (2010-2016), 20% to 40% of the total upstream migration past Mission was assessed by the mobile unit.
- The fixed percentage and regression-based estimation methods for replacing the Mission mobile estimates did not provide consistent and precise daily estimates of the number of salmon assessed by the mobile unit.
- The direction and magnitude of the differences between the Mission mobile assessment and estimates from the three methods varied considerably in-season which means they could differentially impact the assessment of different temporal segments of the run.
- Removing the mobile system would considerably increase the uncertainty in the Mission estimates of mid-channel salmon passage (i.e., the portion of the upstream migration not assessed by the bank-oriented hydroacoustic systems at Mission), which can be significant, as noted above.

**v. Mission without mobile in conjunction with Qualark** – is not supported by the available information (see 5.8.3)

- The Qualark data cannot be used to reliably estimate the portion of the migration assessed by the mobile unit.
- vi. If the objective is to reduce costs, one option is to operate the **Mission mobile unit using a systematic sub-sampling schedule** (see 4.3.1.2):
- Depending upon the sub-sampling schedule, cost-savings from \$22,000 to \$45,000 could be realized annually (see Appendix 8).
  - The every other day, every third day, or 3|4 (three days of sampling followed by four days of no sampling) sub-sampling schemes for Mission mobile present feasible alternatives with varying levels of cost savings.
  - Sub-sampling with the mobile system would increase the uncertainty in the Mission estimates of mid-channel salmon passage.
  - Sub-sampling would require developing a method for estimating the Mission mobile number on non-sample days prior to the next actual Mission mobile observation. Simple linear interpolation or other more complicated methods could be used to estimate Mission mobile once there are observations on either side of the non-sample days.
  - Sub-sampling schemes may be more appropriate in larger abundance years where the additional uncertainty would be unlikely to have substantive consequences to management.
- Note that logistical issues associated with subsampling at Mission would need to be addressed (e.g. securing and scheduling crew) and would vary among subsampling schemes.
- b. Suggested improvements:
- i. More evaluations of how in-river fisheries impact PEDs are needed, particularly during years of high abundance, as currently there are only two years of data (each with a different Mission hydroacoustics set up).
  - ii. Continued evaluation of blind zones at both hydroacoustic sites is recommended.
  - iii. Further examination of the effect of uncertainties on hydroacoustic estimates in-season and in other work (e.g., MA models and the RSA process) is needed.
  - iv. Qualark-specific stock identification and adjusted species composition estimates from Qualark test fisheries should be incorporated into the evaluation of PEDs.
  - v. An evaluation of species and stock composition at both Mission and Qualark will be important to improving overall in-season Fraser sockeye run size estimates is recommended, per post-poned workplan items #11-#12.
2. **Mission work items (workplan #1-10):** Potential issues in the Mission estimates were investigated under work items #1-10 using data and experiments from 2008-2015. No obvious problems were discovered, however, the available information suggests that the estimate of offshore salmon passage from the mobile hydroacoustic system is the most uncertain, and a near-shore blind zone on the left bank also contributes uncertainty to the Mission estimates. Modifications to the Mission sampling configuration and river profile in recent years were implemented to reduce these uncertainties (see 4.2.1).
3. **Qualark work items (workplan #13-14):** Potential issues in the Qualark estimates were investigated under work items #13-14 in 2015. No obvious problems were discovered during the period of investigation. However, additional explorations are planned (see 4.2.2).
4. **Assessment of replacing the Mission mobile system with a model-based estimate (Consultant report (Appendix 6) recommendation #1):** Three models to estimate offshore salmon passage were evaluated against the Mission mobile observations. None of the models provided consistently accurate estimates of the Mission mobile observations. For the best performing model, which used concurrent LB+RB estimates at Mission to estimate Mission mobile enumeration, the error introduced into the Mission counts by

removing the mobile system was greater than the sockeye PED between Mission and Qualark in 4 of the 7 years. Removing the Mission mobile system would therefore add considerable uncertainty into estimates generated by the Mission program for a cost savings of approximately \$70,000 annually. This would also impact the difference between Mission and spawning ground estimates dataset which is used by both the MA models and RSA process (see 4.3.1.1).

5. **In-season run size and TAC performance measures:** In general, in-season run size assessments are insensitive to errors in hydroacoustics (of the magnitude observed between Mission and Qualark) relative to other sources of uncertainty and bias in fitting the run size models. Based on the current PSC in-season run size model, the differences in estimates between Qualark- and Mission- based run size and TACs ranged from 2% to 16% (at 10 and 6 days after the peak of the Summer run, respectively) in the year of largest PEDs (2010 with a PED ranging from 25-30% with the Qualark estimates being larger). In the year with the next largest PEDs (2014), the PEDs between Mission and Qualark were smaller and in the opposite direction (Mission estimates larger) and differences in resulting run size estimates were generally minimal (see 4.5).
6. **Identify significant PEDs and when they occur:** A model that identified daily instances of significant differences in the hydroacoustic estimates by quantifying the minimum uncertainty associated with the estimates at each site found that out of 427 daily comparisons, there were 109 days when significant PEDs were identified from 2008-2015 (of which over half came from 2010 and 2014). This model has the potential to be useful in future years to incorporate estimates of uncertainty associated with Mission passage into MA models and the post-season RSA process, and could potentially be used in-season to assess whether observed PEDs are significant (see 4.6).
7. **PED correlations:** Using the current dataset and covariates identified, we are unlikely to build a predictive model to identify when a significant PED will occur. While more years of data might help with model fit, the true passage of Fraser sockeye in the river is unknown. Thus, the predictive model would not be able to identify which estimate (Mission or Qualark) is closer to the true value (see 4.6).
8. **Species composition at Mission and Qualark (workplan #11-12):** It was determined that these workplan items were outside the scope of the current project (see 4.2.3).

## Summary of Technical Analyses

### 1.3 Objective

FRP work item #18: *Identify a program design option from the risk assessment in 17 above that falls within the Mission budget. If this option does not adequately meet the defined fishery management objectives, explain why and identify a program design that would do so regardless of cost.*

The management objective focused on by the FRP in their analyses is to identify TAC for international sharing by the four Fraser sockeye management groups and Fraser pinks in a timely way such that fish are still available to fisheries in U.S. and Canadian marine waters.

## **1.4 Summary of Work: Evaluation of Individual Locations**

### **1.4.1 Work items #1-10: Potential sources of bias at Mission**

Work items #1-10 of the hydroacoustics work plan are focused on the Mission hydroacoustics program with the overall goal of compiling and reviewing data collected by the program and investigating potential sources of bias in the estimates of salmon passage. Work on these items was undertaken by PSC Secretariat staff throughout the Fall of 2015 and 2016 using data collected from 2009 to 2016 and has been summarized in detail in a technical report (Appendix 9).

There were several potential sources of bias in the Mission estimates identified in the consultant's report that were investigated under work items #1-10. These include: 1) a near-shore blind zone on the left bank of the site due to a convex bottom where fish passage cannot be observed directly but must be extrapolated from neighbouring areas; 2) an inflated cross-aim fish flux on the left bank due to the vertical movement of fish across multiple sampling areas; 3) using fish speed and upstream/downstream ratios from the left bank to predict offshore behavior; and 4) bias in target recognition by the mobile system leading to inaccurate estimates of offshore fish passage. These items were investigated by looking at experiments conducted and data collected from 2009 to 2016 by the Mission program. In some cases there was not enough information to conclusively determine the significance of the proposed bias, but there was also no clearly identifiable source of bias in the Mission estimates. Nonetheless, the available information suggests that the offshore portion of the passage estimate generated by the mobile hydroacoustic system is the most uncertain, and the extrapolation of passage on the LB also contributes some uncertainty to the Mission estimates. These uncertainties may be magnified during periods of very high salmon passage and when there is fishing activity through the Mission site. There have been improvements at the Mission site to reduce these uncertainties by installing additional shore-based systems on the right bank to reduce the sampling area of the mobile hydroacoustic system, and more recently by excavating the river bottom on the left bank to eliminate the blind zone.

The work completed for work items #1-10 has furthered our understanding of lower Fraser hydroacoustics and potential sources of bias in the Mission estimates. By assembling information and identifying potential biases, it also served as a foundation for investigations of PEDs between Mission and Qualark under work item #16.

### **1.4.2 Work items #13-14: Potential sources of bias at Qualark**

Two potential sources of negative bias were identified in the consultant's report (Appendix 6) at the Qualark site: fish migrating beyond the normal 29m ensonified zone and a potential blind zone due to the rolled configuration of the DIDSON beam. Investigatory work in 2015 revealed that these were likely low to negligible sources of bias in the estimates of passage at Qualark during the period examined

(Appendix 10). However, as 2015 was a year of low sockeye abundance as well as low water flows, further testing is planned.

### **1.4.3 Work items #11-12: Species composition at Mission and Qualark**

Mission and Qualark hydroacoustic sites estimate the total upstream salmon passage, however, species composition must also be estimated to determine the proportion of total passage attributed to each salmon species (e.g., sockeye, Chinook, pink). Methods for estimating species composition at Mission and Qualark differ, which makes comparing sockeye passage at each site much more uncertain during migration periods when sockeye do not dominate species composition. Thus, our analyses have tended to focus on even years or periods prior to mid-August on odd-years (when Fraser pink salmon are not present). Although the FRP acknowledges that species composition is an important line of investigation, it was determined to be outside the scope of the current project. The FRP and PSC staff are continuing to investigate improved methods of estimating species composition including following up on a methodology suggested in the consultant's report. There is also a Southern Endowment Fund project currently underway to investigate differences between species composition estimates produced by the fish wheel and the Adaptive Resolution Imaging Sonar (ARIS) length-based mixture model, and another project to undertake a review of test fisheries, which collect the samples used for species and stock composition.

## **1.5 Summary of Work: System Comparisons and Alternative Configurations**

### **1.5.1 Alternative hydroacoustic configurations and sampling schemes**

Table 1 is a summary table of alternative hydroacoustic configurations, including sampling schemes, considered for further quantitative evaluation. Evaluation of the configurations in the top portion of the table is contained in this document and appendices. The configurations at the bottom of the table were evaluated based on expert opinion and not pursued further due to minimal cost savings and/or impracticalities of implementation.

Table 1. Summary table of alternative hydroacoustic configurations considered for quantitative evaluation.

Hydroacoustic system configurations considered for further evaluation	
System configuration	Rationale for further evaluation
Mission LB + RB + mobile *	Full Mission program (see 5.8.1)
Qualark (LB + RB) *	Full Qualark program (see 5.8.2)
Mission LB + RB + mobile + Qualark	Full Mission + Qualark program. Provides the most information for management purposes, but is also the most expensive (see 5.8.4)



Mission LB + RB	Mission without a mobile system. Recommended for investigation in consultant's report and is feasible to implement (see 4.3.1.1)
Mission LB + RB + Qualark	Mission without a mobile system with full Qualark program. Provides some cost savings versus both full programs with possibility of producing adequate passage estimates at both sites assuming a model could be used to predict the mobile passage at Mission (see 5.8.3)
Mission LB + RB, Mobile <7d/week	Operating the mobile unit at Mission less than 7 days per week. While the cost savings are relatively small and there are some potential implementation issues to work through, this is the one portion of the existing Mission system where some cost savings might be found (see 4.3.1.2)
<b>Hydroacoustic system configurations not considered for further evaluation</b>	
<b>System configuration</b>	<b>Rationale for not evaluating further</b>
Mission LB + mobile	Mission without a RB site. Minimal cost savings versus full Mission program. Prior to 2011, considerable SEF funding was contributed towards developing the RB site at Mission and its benefits for improving the Mission estimate have been detailed in SEF reports.
Mission LB	Mission without a RB site or mobile. Minimal cost savings versus Mission LB + RB configuration and not likely to produce an accurate passage estimate.
Mission LB + Qualark	Minimal cost savings versus Mission LB + RB + Qualark.
Mission LB + mobile + Qualark	Minimal cost savings versus full Mission + Qualark program.
Qualark RB	Qualark without the LB site. Minimal cost savings compared to full Qualark program.
Qualark, no night	Qualark without any night operation and monitoring of passage. Someone must be at the Qualark site 24/7 for security purposes so an attendant would need to be hired which minimizes any cost savings.
Mission, no night	Minimal cost savings for same reason as Qualark site. Salmon passage at Mission is driven by tidal patterns and does not show a strong diurnal pattern as seen at Qualark, therefore night monitoring is necessary to accurately assess salmon passage.

\* configurations of primary interest

#### 1.5.1.1 Assessment of estimation methods for the Mission mobile count of salmon (Appendix 11)

This analysis was conducted to address the recommendation in the consultant's report to eliminate the Mission mobile system. Three alternative models were considered as substitutes for direct measurements of mobile passage: 1) assume mobile passage estimates are a fixed percentage of the daily total migration (the recommendation from the consultant's report); 2) predict mobile estimates from concurrent Mission LB+RB salmon estimates; and 3) predict mobile estimates from daily salmon estimates from Qualark (LB and RB) lagged to account for migration time. None of the models examined provided consistent and precise estimates of salmon counted by the mobile unit at Mission.

Removing the mobile system would increase the uncertainty in the Mission estimates. The best performing model (which used concurrent Mission LB+RB data) had a median annual absolute percent error of 10% across the seven years examined (2010-2016). In 4 of the 7 years, the total difference between the count by the mobile system and the model estimate for the assessment period was greater than the sockeye PED between Mission and Qualark for the same period. The fixed percentage model performed poorly compared to the other models with a 23% median annual absolute percent error, a smaller percentage of daily differences within  $\pm 10\%$ , and a greater tendency for a negative bias. The errors resulting from estimating mid-channel salmon passage without data from the mobile system were not random within a year; there were consistent periods of over- or under- estimation by each of the estimation models in most years. The largest differences often occurred later in the season, and would therefore differentially impact estimates for the run-timing groups.

These analyses only examined periods when there were estimates available at Mission from both the LB and RB systems, and when pink salmon were not abundant. Outside of these periods an alternative method that has not been evaluated would have to be used to estimate offshore salmon passage. Removing the mobile system would also affect the ability of Mission hydroacoustics to assess salmon during periods of high water levels (such as in early July 2012 and 2013), because during those periods, the shore-based systems cannot be installed and the mobile unit is the main system used for estimates.

#### *1.5.1.2 Assessment of sub-sampling with Mission mobile as an alternative to daily operation (Appendix 12)*

If an overall objective is to reduce the costs associated with the Mission hydroacoustic program, one option is to operate the Mission mobile unit using a systematic sub-sampling schedule. Cost savings from sub-sampling are not as great as those realized by completely eliminating the mobile unit and are dependent upon the sampling frequency throughout the season. The advantage of sub-sampling is that the Mission mobile unit is used to periodically estimate salmon passage and those estimates can be used as the basis for previous and subsequent days' estimates when there is no mobile sampling. This reduces the probability of extended periods of over- or under- estimation experienced by the estimation methods described in section 4.3.1.1.

Hypothetical systematic sampling schemes of every 2<sup>nd</sup>, 3<sup>rd</sup>, 4<sup>th</sup>, 5<sup>th</sup>, 6<sup>th</sup>, and 7<sup>th</sup> day were examined using the same Mission hydroacoustic data set used in the previous analysis (4.3.1.1). Because there are multiple starting dates possible for any scheme, 27 possible systematic schemes were evaluated. In addition, one sub-sampling scheme was examined where three consecutive days were sampled followed by four days with no sampling which resulted in a total of 30 different sub-sampling schemes being evaluated.

Of the sub-sampling schemes examined, the schemes based on sampling every 2<sup>nd</sup> or 3<sup>rd</sup> day or sampling 3 consecutive days then not sampling for 4 days generally performed better across all evaluation statistics than the other sub-sampling schemes. These three sub-sampling methods tracked daily mobile

estimates over each of the annual sockeye-dominant periods examined better than the model-based methods in 4.3.1.1 and had fewer extended stretches of days with consistent over- or under- estimates relative to the actual mobile estimate of salmon passage. These three sub-sampling methods present feasible alternatives with varying potential cost savings ranging from \$22,000 to \$45,000 annually (see Appendix 8). Sub-sampling with the mobile system would increase the uncertainty in the Mission estimates of mid-channel salmon passage. Ultimately the decision on whether a sub-sampling method could be applied to the operation of the Mission mobile hydroacoustic unit is a matter of risk tolerance by the managers. Sub-sampling will also require developing a method for estimating the Mission mobile number on non-sample days prior to the next actual Mission mobile observation. Simple linear interpolation or other more complicated methods could be used to estimate Mission mobile once there are observations on either side of the non-sample days. Sub-sampling schemes may be more appropriate in larger abundance years where the additional uncertainty would be unlikely to have substantive consequences to management. Logistical issues would need to be addressed (e.g. securing and scheduling crew) and would vary among subsampling schemes.

## **1.6 Summary of Work: Sockeye Stocks Assessed at Mission and Qualark (Appendix 13)**

All stocks of Fraser River sockeye migrate past Mission except the Pitt, Widgeon, Alouette and Coquitlam stocks. Several stocks spawn in tributaries which drain into the Fraser River downstream of Qualark but upstream of Mission: Chilliwack (Early Summers); Harrison (Summers); and Birkenhead, Big Silver, Weaver, and Cultus sockeye (Lates). The size of these stocks relative to the total Fraser sockeye return can vary greatly depending on the cycle year and variability in returns of each stock. From 2008 to 2015, the lowest annual proportion of Fraser sockeye potential spawning escapement assessed at Qualark was 63% (versus 99% at Mission), while the highest proportion was 94% (versus 100% at Mission), with an average proportion of 81% across years (versus 96% at Mission). This amounts to an average annual difference of 615,000 sockeye that migrate past Mission but do not migrate past Qualark (not including catches between the two sites). For detailed comparisons of the differences between years see Appendix 13.

Without hydroacoustic data, stock proportions and CPUE estimates from test fisheries could be used for in-season run size assessments and determining potential spawning escapement. Estimates based on test fishery data have historically been much more uncertain than hydroacoustic estimates, as demonstrated by challenges in estimating the run size of Pitt sockeye. For example, in 2013 the run size of Pitt sockeye based on test fisheries stock proportions was estimated at 203,000 while the escapement and catch totaled only 66,000, suggesting the run size was over-estimated in-season. Currently, test fishery-based estimates of run size for Pitt are added to the total estimated run size (Mission passage plus catch) despite its uncertainty, as it is the only estimate available for that stock. Without Mission or other system-specific hydroacoustic estimates, the same would be true for several lower river stocks that spawn in tributaries downstream of Qualark. While the Chilliwack/Vedder system is conducive to a system-specific DIDSON/ARIS enumeration program, due to physical characteristics of

the Pitt and Harrison River systems, with the exception of the Birkenhead, the stocks entering those systems (Pitt, Widgeon, Harrison, and Weaver) could not be hydroacoustically enumerated and would have to be assessed using test fisheries. This would significantly increase the uncertainty for estimated sockeye passage as well as the total run size.

## **1.7 Summary of Work: Management Implications – Run Size and TAC (Appendix 14)**

The impact of the PEDs on in-season run size estimates was quantitatively evaluated for the Early Summer- and Summer- runs (excluding Harrison) in 2010 and 2014, the years with the largest PEDs between Mission and Qualark for these two management groups. The results were conditional on the model used for the in-season assessment of run size and the 2010 data, which included test fishery, stock, and species identification data in addition to hydroacoustic data.

During the 10 days following the peak of the Summer-run in 2010, the difference in total run size estimates when using one of the two hydroacoustics sites ranged from 16% on August 20 to 2% on August 24. The 16% difference resulted in a difference in international TAC of 730,000 salmon out of a total international TAC of 10 million (2% represented 70,000 salmon out of 13 million). The directionality of the PEDs differed between and within years, therefore 2010 does not provide an indication of the overall directionality. The large PED in 2010 compared to other years was likely due to the fact that the 2010 Mission program was focused on research and development testing of more efficient sampling configurations, and the hydroacoustic system did not adequately sample the entire river width for the season as it has since 2011.

Differences in run size and TAC are small relative to the overall bias and uncertainty of in-season predictions of the 2010 and 2014 sockeye returns. Thus, improving the accuracy of hydroacoustic estimates would have little effect on the run-size assessments in these years of high abundance. Larger improvements to the run size estimates could potentially be obtained by improving the in-season stock assessment model. For example, the migration pattern of the runs in 2010 and 2014 was spread over a broader period than the model currently allows which caused the run-size models in those years to under-estimate the actual return regardless of which acoustic time series was used. Furthermore, due to improvements in the sampling configuration of the Mission site since 2010, it is less likely that a PED of the same magnitude as 2010 will occur in future years.

An important caveat to this analysis is that these results apply to the Early Summer and Summer-run (excluding Harrison) groups only. In-season estimates of run size for the Late-run group (where the largest PEDs occurred in both years) are not based on Mission hydroacoustics because a variable and unpredictable fraction of these stocks delay in the Strait of Georgia prior to migrating upstream. Similarly, Mission hydroacoustics are not used for in-season assessment of any delaying stocks and species (i.e., Harrison sockeye and Fraser pink salmon).

## 1.8 Summary of Work: Evaluation of Passage Estimate Differences (Appendix 15)

Identification of days with significant Passage Estimate Differences (PEDs) was based on 95% confidence intervals generated through stochastic simulation for both Mission and Qualark passage estimates. These confidence intervals are considered minimum estimates of the uncertainty associated with the estimates. Non-overlapping 95% confidence intervals for the matched Mission and Qualark passage estimates was used as the criteria to identify "significant" PEDs. Given that the variability in the estimates is being under-estimated, this standard was judged to be a good trade-off between identifying days with actual PEDs and minimizing the number of days where the PEDs might not be significantly different due to the under-estimate of uncertainty. There were 109 days out of a total of 427 days examined from 2008-2015 when significant daily PEDs were identified (>50% occurred in 2010 and 2014). The low sockeye abundance years of 2008, 2009, and 2015 had the smallest number of days with significant PEDs (7, 3, and 4 days, respectively) but the time-series length was also shorter in those years.

The technical group identified >20 potential causal factors for PEDs which were then tested to see if they covaried with significant PEDs. The covariates included: type of year (pink year, large sockeye abundance year); in-river fisheries (opening time, effort, location); river migration conditions (temperature, discharge); hydroacoustic gear configurations (mobile, blind zone extrapolation, offshore passage). A subset of covariates was selected for regression analysis using a combination of statistical methods and expert opinion.

In all, <10% of the presence/absence of PEDs could be explained by covariates, but >70% of the variation in the transformed (LN) size of the absolute value of the PEDs was explained by a regression model that included seven covariates. However, the direction of the PEDs could not be predicted by the model. Using the current dataset, it is highly unlikely that a predictive model could be developed from the current set of covariates to determine when or in which direction a significant PED would occur.

More years of data (current dataset contains 2 "high abundance years", 4 "pink" years, and 4 "non-pink" years) or improved data for the explanatory variables (e.g., better data on in-river fisheries) might improve the fit of the models. However, we do not have a method for determining the true number of fish migrating through the Fraser. Therefore, the models developed would only be informative about Mission-Qualark PEDs and not about which system more accurately represents true passage of sockeye salmon on a specific day.

## Synthesis of Findings

The evaluations, conclusions, and recommendations in this document are based on the goal of meeting the needs of current management and the data-collection systems currently used. The implications to management described in this section are considered within these constraints.

A persistent caveat to the work evaluating hydroacoustic estimates of sockeye passage in the Fraser is that we don't know what the true passage of sockeye is, so we cannot assess the accuracy or bias of either system and can only compare them to each other. There are also errors and uncertainties associated with estimates of the number of fish that leave the Fraser River mainstem between Mission and Qualark as well as with species and stock composition at both sites. These factors confound our ability to attribute PEDs to particular causes. Conversely, because the two sites are not assessing the same populations, comparisons of estimates of total salmon passage may mask important differences.

Table 2 and Table 3 show sources of uncertainty for both Mission and Qualark, as well as how the data from these two systems are used.

Table 2. List of inputs that are used to generate Mission passage estimates and list of outputs that use Mission passage estimates.

INPUTS used to generate Mission passage estimates	OUTPUTS that use Mission passage estimates
<ul style="list-style-type: none"> <li>hydroacoustic data (from LB, RB, mobile) <ul style="list-style-type: none"> <li>extrapolation methods (for blind zone and subsample counts within an hour)</li> <li>fish lengths for determining salmon / non-salmon in mixture model</li> </ul> </li> <li>species identification (from test fisheries and hydroacoustic lengths, models, and historical Chinook passage)</li> <li>stock identification (from test fisheries) <ul style="list-style-type: none"> <li>DNA analysis</li> </ul> </li> </ul>	<ul style="list-style-type: none"> <li>in-season test fish catchability estimates</li> <li>run size model* generates run size that feeds into: <ul style="list-style-type: none"> <li>numerical escapement goal</li> <li>TAC**</li> </ul> </li> <li>management adjustment models</li> <li>run size adjustment process (RSA) → S/R dataset <ul style="list-style-type: none"> <li>run size forecast</li> <li>escapement plan evaluation</li> </ul> </li> <li>Canada: in-river fisheries catch projections</li> </ul>

\* Note that the run size model does not always use hydroacoustic estimates (e.g., not used for Late run, Harrison or Pinks) and in addition to the hydroacoustic estimates, uses estimates of stock and species composition as well as forecasts of run size and timing, all of which have their own sources of uncertainty.

\*\* In addition to the uncertainties associated with the run size estimates noted above, TAC calculations also incorporate management adjustments.

Table 3. List of inputs that are used to generate Qualark passage estimates and list of outputs that use Qualark passage estimates.

INPUTS used to generate Qualark passage estimates	OUTPUTS that use Qualark passage estimates
<ul style="list-style-type: none"> <li>hydroacoustic data (from LB, RB) <ul style="list-style-type: none"> <li>extrapolation methods (subsample counts within an hour)</li> <li>fish lengths for determining salmon / non-salmon</li> </ul> </li> <li>species identification (from test fishery)</li> </ul>	<ul style="list-style-type: none"> <li>independent estimate of sockeye passage to compare to Mission through Qualark estimate, in-season</li> <li>can provide estimates of early-timed stocks when decisions are made to delay start of</li> </ul>

<ul style="list-style-type: none"> <li>• stock identification ( samples are collected in-season but analyzed post-season)</li> </ul>	other test fisheries or Mission due to conservation and/or financial reasons.
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## 1.9 Is there a clear cause for the significant PEDs?

Not that we could identify. We examined a number of potential causal factors (environmental, fishing, gear configurations) to determine if they covaried with the time, magnitude, or direction of the significant PEDs, and only found a relationship with magnitude. The cause of PEDs is likely from multiple sources and varies daily (and quite possibly hourly). It is possible that additional years of data could help elucidate potential factors.

## 1.10 What's the impact of the PEDs to management of fisheries?

Based on data from 2010, the maximum impact of the PEDs (30%) on run size is 16%, resulting in a difference in international TAC of 730,000 salmon out of a total international TAC of 10 million. The percent difference in run size based on the two different hydroacoustic time series can change substantially within a year (e.g., from 16% on 20 August 2010 to 2% four days later with a PED of 25%) and between years. Across years, there is no indication of a directional bias when using one hydro-acoustic time series versus the other. Even within a year, one system is not consistently higher or lower than the other.

A list of additional factors that are part of the management system and may be impacted by PEDs is summarized in Table 2.

## 1.11 When and why are statistically significant PEDs occurring?

Within a season, there is no clear pattern in the occurrence of significant PEDs. However, we observed that significant PEDs are much more likely to occur in high abundance years (2010 and 2014).

We were not able to identify a strong relationship between the occurrence of significant PEDs and any of the factors investigated. It is possible that factors impacting PEDs occur at a much finer scale than the scale of the data available for the explanatory variables.

## 1.12 Is there a way to predict when PEDs will occur?

There is no way to predict when a PED will occur with the current dataset and covariates examined. Additional years of data might alter this conclusion.

Note that without knowing the true number of sockeye migrating through the river, a predictive model would only be able to forecast when a PED would occur, not which site would provide the more accurate estimate on that day.

### **1.13 What do we need to consider regarding test fisheries?**

When it comes to generating run sizes, test fisheries and hydroacoustics are highly interdependent.

Test fisheries are used to support hydroacoustics in generating estimates of sockeye abundance by stock group (e.g., the Cottonwood, Whonnock, Qualark in-river test fisheries). Test fisheries are required to convert hydroacoustic estimates of fish passage into passage by stock and species used by management. Stock and species composition estimates become problematic during periods of low fish passage. Small test fish sample sizes that are not processed daily can result in several days of hydroacoustic estimates of salmon passage over- or under-estimating stocks or species.

Hydroacoustic estimates of sockeye by stock group are used to estimate catchability from the CPUE in other test fisheries (primarily marine, but also in river; especially Whonnock), and used to generate daily estimates of sockeye migration in the area represented by a test fishery (as input into run size models). There is approximately a 6-day migration time between the Juan de Fuca and Johnstone Strait test fisheries and Mission. If Qualark were the only hydroacoustic site, this lag time would increase to 8-9 days and delay run status updates by 2-3 days compared to the current system based on Mission data. Refer to 4.4 for additional test fishery considerations that would be associated with a Qualark-only hydroacoustic configuration.

Given the above, it is important to consider the configurations of the test fishery and hydroacoustic programs at the same time.

### **1.14 Is there a way to save money?**

Yes, but only at the cost of increasing the uncertainty in the assessment of the number of sockeye passing through the lower river. Qualitatively, this additional uncertainty ranges from medium to high levels. Other than the scenario where one site or the other is eliminated, the cost savings associated with the alternate gear configurations or sub-sampling schemes for the Mission mobile system that we examined in detail (Table 1) were insufficient to fund both programs for the cost of the current Mission program. However, incremental cost savings gained if Mission mobile sub-sampling program were to be implemented could be gainfully redirected at other Panel priorities such as improving test fish sample sizes in the river or increasing the number of stock ID samples processed in-season.



## 1.15 Additional things to consider that don't fall under "technical analysis"?

There are a number of additional factors to consider when making the decision about the future of hydroacoustic systems in the Fraser River that fall outside the technical expertise of the working group. These include, but are not limited to:

- i. The long-term financial costs of each gear configuration in its full implementation (including potential increases in test fishing or DNA sampling under the Qualark-only scenario).
- ii. The doubt experienced by decision makers when estimates of in-river passage cannot be verified in-season, given post-season adjustments to run sizes made in the past. The technical group has observed that at times of increased uncertainty associated with the Mission estimates (e.g., low sockeye abundance, high percentage of sockeye assessed by the mobile system, and/or transition periods when Chinook and pink proportions are high), some members within the Fraser Panel look for confirmation of Mission passage estimate numbers from the Qualark program.
- iii. Even though the true sockeye passage numbers are unknown, if the two systems are beginning to diverge, it is a signal for the in-season management system to look for potential issues at either site or for unusual fish migration behavior.
- iv. Non-bilateral uses of hydroacoustic information – e.g., in-river fisheries planning for lower Fraser First Nations fisheries often relies on Mission estimates to generate catch projections.
- v. The value of "dialing in" the TAC in the magnitude described in section 4.5 compared to the cost of operating a second hydroacoustic site.
- vi. The original impetus behind running the Qualark program was to be a data validation of the Mission program due to the growing concern about the uncertainty associated with the Mission estimates in the mid 2000s. In 2010-2011, recognizing the high cost of running both hydroacoustics programs, the goal of the Qualark program was changed to one of gathering information to help identify a method to "calibrate" the Mission estimates (e.g., based on environmental data, information on fisheries openings and effort, etc.). If we assume that the Qualark estimates better represent the true number of sockeye bound for spawning areas above Qualark, then this is still possible, but the following data limitations still exist: a) Fraser sockeye return in a four year cycle, which, when coupled with pink migration, results in the 2008-2015 dataset representing each cycle twice at best, b) Mission has been in its current gear configuration for 5 of the 7 years in the dataset, c) large sources of PEDs may be due to stock and species identification (i.e., representativeness of the fish caught in the test fisheries and small sample size issues) as opposed to hydroacoustics. This last data limitation is, however, unlikely to be the main cause of the 2010 and 2014 PEDs, as the discrepancies occurred during times of high sockeye abundance and were years when the majority of sockeye were through-Qualark stocks.
- vii. In addition to the more formal use of the hydroacoustics data as inputs into run size estimates and TAC calculations that were evaluated as part of this review, there are some informal quantitative uses of the Qualark data that were not evaluated (e.g., as an informal but quantitative verification of Mission sockeye passage estimates by PSC staff, particularly during times when the ability to differentiate sockeye from the other species of fish in the river are of concern).

## **1.16 Is there a recommendation from the technical group?**

Based on the current management needs of the Fraser Panel and the evaluation of the impacts of the PEDs on the estimates of run size and TAC in-season, the recommendation from the technical working group is to continue the Mission hydroacoustics program and discontinue Qualark. Based on the two years of largest PEDs from the eight years of simultaneous operation of the Mission and Qualark hydroacoustic systems, we were unable to show that Qualark demonstrably improved our in-season assessment of sockeye escapement and current bi-lateral FRP management.

However, the technical recommendation for the short term is to operate Qualark in 2018 but only if studies designed to further our understanding of the causes of PEDs are included in the program. The addition of the 2018 Qualark hydroacoustics and experimental data would be particularly useful from a technical perspective.

It is important to note that this technical recommendation is based on the following observations: 1. the largest magnitude of PEDs observed to date occurs on Adams dominant years and 2. the impact of the PEDs on run size and TAC in these years is relatively small. The considerations listed in 5.7 are not factored into this recommendation.

### **1.16.1 What if we only had Mission?**

The Mission hydroacoustic site has been used as the main estimate of sockeye passage in the lower Fraser River since 1977. However, it is a more challenging site than Qualark for hydroacoustic assessment of salmon passage due to tidal influence, an irregular bottom contour, and a much wider river channel (400m at Mission vs. 160m at Qualark).

The benefits of the location of the Mission site compared to the Qualark site are: a) all Fraser sockeye stocks, with the exception of Pitt and Widgeon, migrate past the Mission site; b) for the same group of fish, it can provide estimates 2-3 days earlier than Qualark; and c) it is currently the only method used to enumerate pink salmon returning to the Fraser. In addition to the benefits associated with the location of the Mission site, the Mission dataset is longer than the Qualark dataset and is used to develop MA and timing models and feeds into in-season run size models.

The implications to management of fisheries of this configuration: factors such as the irregular bottom contour and a large mid-channel area may contribute to the differences in hydroacoustic counts between Mission and Qualark. In the absence of upstream hydroacoustic counts at Qualark we would not have a second independent estimate of salmon passage to compare against Mission.

### **1.16.2 What if we only had Qualark?**

Generating estimates of salmon passage at the Qualark hydroacoustic site costs less than generating estimates at the Mission site and potentially provides a more accurate estimate of the abundance of

stocks spawning upstream of Qualark. However, if it were the only hydroacoustic site operating on the Fraser River mainstem, other methods would be needed to generate in-season estimates of the abundance of stocks that do not migrate past Qualark. In some years, these stocks can make up a large fraction of the total Fraser River sockeye return (e.g., Harrison, Weaver, and Birkenhead).

The benefits of the Qualark location is that it is a more ideal site for hydroacoustic enumeration of salmon passage, with fewer potential sources of error than the Mission site.

Although the Qualark hydroacoustic site costs less to operate than the Mission site, the capacity to generate comparable in-season estimates to the current Mission program would require a number of adjustments which would add to the financial cost of implementation of a Qualark only program. These include: a) in-season, real time estimates of stocks that leave the Fraser River mainstem downstream of Qualark; b) additional work on the representativeness of the species and stock composition estimates from the Qualark test fishery (see the Consultant's report Appendix 6); c) development and testing of new models to replace those that rely on the Mission dataset (e.g., MA, timing, and run size models); d) no post-season confirmation of in-season pink salmon run size would be available; and e) impacts to management decisions of having in-river hydroacoustic information 2-3 days later would need to be evaluated.

The assessment of fish assessed at Mission but not directly assessed at Qualark (i.e., Vedder/Chilliwack, and the Harrison/Birkenhead systems) would require additional in-season assessment. Assessment of these systems would likely result in the need to increase test fishery samples in lower river and/or in-season spawning ground assessment of fish passage. While the Vedder/Chilliwack system is conducive to a hydroacoustic-based in-season escapement estimate, the other systems are not. How those systems could be assessed in-season, or whether increasing test fishing samples would suffice would need to be evaluated.

The implications to management of fisheries of this configuration: increased uncertainty in the run size of stocks that spawn below Qualark would apply to in-season run size estimates as well as post-season assessments of run size that would carry over into the stock-recruit dataset that is used for pre-season run-size forecasts and evaluation of long-term escapement goals, among other things.

### **1.16.3 What if we had Mission (excluding mobile) and Qualark?**

Removing the mobile system adds a relatively large amount of uncertainty to the Mission estimate for a cost savings of approximately \$70,000 per year. The impact of discontinuing the mobile system at Mission would be the greatest on the front and tail ends of the Fraser sockeye run when abundance is low (i.e., during the migration of Early Stuart, early-timed Early Summers and Late-run stocks). Since in-season assessment of Late run does not rely on hydroacoustic estimates due to potential delay in Late-run migration when entering the Fraser River, the removal of the mobile system would impact the post-season run size estimate of Late-run but not the in-season estimate. Unfortunately, this is also the time period where other sources of uncertainty tend to be higher (e.g., species composition and stock

identification due to low test fishery samples). The early upstream migration of Late-run sockeye and associated periods of variable but sometimes high en-route mortality (confirmed by tagging studies), further complicates the ability of using alternate sources of data for post-season estimates of total return (e.g. spawning ground estimates may only provide estimates of the minimum number of fish entering the lower Fraser River).

The implications to management of fisheries of this configuration: using any of the estimation methods described in section 4.3.1.1 to replace the data supplied by the Mission mobile system would increase the uncertainty in the daily estimates at Mission and therefore to the management system.

#### **1.16.4 What if we had Mission (including mobile) and Qualark?**

While we acknowledge that this option is not feasible fiscally on an annual basis, it is the recommendation of the technical working group that both systems are operated in 2018 in order to further our understanding of in-river fish migration and so that additional evaluation of PEDs and their causes can be conducted.

The years of largest PEDs occurred in 2010 and 2014 (i.e., Adams dominant years). The value of having the Qualark site as an independent estimate of in-river passage stands out in these very large abundance years. However, we only have two years in the dataset and the directionality of the PEDs was different in both of these years.

With the exception of 2010, when Mission passage estimates were adjusted based on data from Qualark after July 30, Qualark estimates are not directly used for in-season calculations. However, the Qualark estimates have served as a useful validation check on the Mission passage estimates. The Qualark estimates have not been incorporated into the in-season run size models as the original purpose of the program was as a verification of in-river passage. The current timeline for in-season generation of passage estimates at Qualark also precludes its use in in-season run size models.

The operation of both systems, concomitant with studies designed to evaluate potential causes of bias and uncertainty at both sites, would assist with a better quantitative understanding of the assessment of fish passage as well as a decrease in the uncertainty that exists within the management system when there is a single site operating (see 5.8.6).

The implications to management of fisheries of this configuration: while this configuration is the most expensive, having two systems that are performing at optimal capacity is the best way to continue to evaluate potential causes of PEDs and increase the likelihood of identifying an in-season adjustment that may improve the Mission estimates in future years.

### **1.16.5 What if we had [insert alternative here]?**

We evaluated alternate gear configurations within the existing assessment framework. New and emerging technologies are not within the scope of this evaluation.

### **1.16.6 Future work**

Specific recommendations for further exploration in future years should both systems continue to operate include evaluations of blind zones at both Mission and Qualark sites and how in-river fisheries may impact PEDs. Regardless of the decision regarding the hydroacoustic gear configurations, it is recommended that future work investigate how uncertainties in hydroacoustic estimates are incorporated in-season and in other work (e.g., MA models, the RSA process).

As noted in section 4.2.3, accurate estimates of species composition are important at both sites, but was not examined as part of this evaluation. This work would include evaluation of the representativeness of stock and species identification of in-river test fisheries, and incorporation of the data (or adjusted data) into future PED comparisons.

## **1.17 Summary and Parting Thoughts**

Assessment of sockeye salmon passage in the Fraser River is subject to a wide range of uncertainties that can be traced back to the site configurations (e.g., blind zones), model assumptions (e.g., identification of stocks leaving the mainstem prior to hydroacoustic assessments), non-hydroacoustic assessments (e.g., catch estimates, stock and species identification), behavior of people (e.g., fisheries and vessel traffic), as well as to fish (e.g., variable migration times, variable distribution of fish within the water column and across the river channel and en-route mortality). Not all of these uncertainties can be quantified. However, analysis has shown that taking into account the uncertainties that we can quantify, the estimates of sockeye passage at Mission and Qualark were statistically similar 3 out of 4 days during the 2008-2015 period.

The directionality of the PEDs were not consistent between or even within years. Evaluation to date has been unable to identify any correlations between the presence of a PED and the potential causative factors examined by the technical working group. Despite not being able to identify a correlation to or causation of PEDs, we have gained a better understanding of the system and we believe that the technical evaluation described in this document and its appendices will prove to be foundational for future work.

# List of Appendices

## **Appendix 1 – PSC Secretariat Document 2013**

Document prepared by PSC secretariat staff for PSC Commissioners and the Fraser River Panel that was the impetus for the creation of the Fraser River Strategic Review Committee (FSRC). This committee was tasked to provide advice to the Commission regarding potential modifications to the hydroacoustic operations with the aim to reduce overall program costs while maintaining the necessary quality standards for in-season assessment.

## **Appendix 2 – Fraser Strategic Review Committee Terms Of Reference**

The terms of reference for the Fraser River Strategic Review Committee as provided by the Commissioners. The focus is on the clarification of fisheries management objectives for lower Fraser River in-river assessments as well as an evaluation of the hydroacoustic configurations at Mission and Qualark to ensure precise and timely information to satisfy Pacific Salmon Treaty obligations at an affordable cost.

## **Appendix 3 – Commission Instructions to Fraser River Panel**

This document is a request of information from the Fraser River Strategic Review Committee to the Fraser River Panel to inform the review of the hydroacoustic programs at Mission and Qualark.

## **Appendix 4 – Terms Of Reference for Consultant**

The terms of reference for an independent consultant to the Fraser River Strategic Review Committee. These echoed the FSRC TOR.

## **Appendix 5 - Fraser River Management Objective**

Document outlining the Fraser River Panel management and fiscal objectives related to Lower river hydroacoustic programs at Mission and Qualark.

## **Appendix 6 - Consultant's report**

Report from Dr. Carl Walters, the consultant that was engaged to review the hydroacoustic programs at Mission and Qualark.

## **Appendix 7 – Fraser River Panel Hydroacoustics Workplan**

Workplan for a bilateral group of technical experts that was established after the consultant's report left several TOR unanswered. The plan was developed by the Fraser River Panel and approved by the FSRC.

## **Appendix 8 – Hydroacoustics Operational Costs**

Overview document comparing the hydroacoustic operational costs at Mission and Qualark. The document also includes financial details regarding the potential cost savings following changes to the hydroacoustic programs.

## **Appendix 9 – Mission Technical Document**

Detailed summary of the work done by the PSC secretariat following the detailed workplan. The work presented in this document has been reviewed by the bilateral group of technical experts.

## **Appendix 10 – Qualark Technical Presentations**

Technical PowerPoint presentation documenting the work done by DFO staff following the detailed workplan. The work presented has been reviewed by the bilateral group of technical experts.

## **Appendix 11 – Assessment of Estimation Methods for the Mission Mobile Count of Salmon**

Document summarising the analyses that have been conducted to assess the feasibility of replacing the Mission Mobile estimate with an estimate from models that are based on data from the left bank and right bank hydroacoustic systems at Mission or from the Qualark hydroacoustic systems. The work presented in this document has been reviewed by the bilateral group of technical experts.

## **Appendix 12 - Sub-sampling with Mission Mobile as an Alternative to Daily Operation**

Further refinement of the work presented in Appendix 11, by examining the impact of subsampling (i.e., operating the mobile unit on alternating days) on mid-river abundance assessments. The work presented in this document has been reviewed by the bilateral group of technical experts.

## **Appendix 13 - Sockeye Stocks Assessed at Mission and Qualark**

Overview of the proportions of total Fraser sockeye abundance assessed at Mission and Qualark given that hydroacoustic programs are unable to assess those stocks that spawn below the hydroacoustic facility. These proportions can vary substantially from year to year given the large differences in stock composition on different cycle lines. The work presented in this document has been reviewed by the bilateral group of technical experts.

## **Appendix 14 – Management Implications for Run Size and Total Allowable Catch**

Comparison of the impact of the use of different hydroacoustic time series on in-season run size estimates derived through the standard run size models. The work presented in this document has been reviewed by the bilateral group of technical experts.

## **Appendix 15 – Fraser River Salmon Migration Model and Analysis of Hydroacoustic Data from Mission and Qualark Stations**

Report of the results of the statistical model used to produce confidence intervals associated with random errors around the Mission and Qualark sockeye passage estimates. This model identified periods where there is a significant passage estimate difference (PEDs) and evaluated the correlation of these PEDs with data on variables that might explain the PEDs.





# Appendix 1: PSC Secretariat document 2013

## Executive Summary

### Next Steps For Fraser River acoustics

#### Prepared by PSC Secretariat

January 14, 2013

**The purpose of the document is to stimulate discussions among Commissioners and the Fraser River Panel (*and Secretariat*) about the future plans for Fraser River acoustics.**

The cost of implementing the Secretariat's acoustics program at Mission has approximately doubled from about \$300,000 in 1994 to \$600,000 in 2012. In addition to the regular budget, the Southern Boundary Restoration and Enhancement Fund (SEF) supported the Secretariat's research at Mission in the amount of \$668,000 since 2004 including the purchase of three DIDSONs. The Qualark site was re-established in 2008 using DIDSON technology and has operated continuously through 2012. Adding Qualark, Mission, and SEF funds, more than \$1M was spent annually on lower river acoustics since 2008. The increased expenditures for program improvements at Mission and the initiation of work at Qualark have been driven largely by external pressures (formal public reviews into causes of discrepancies between Mission and upstream estimates).

## **II. Cost-Benefit Analysis**

The width of the Fraser River (400m), variation in fish behavior, and the need for 24 hours per day, 7 days per week coverage for 2-3 months drive program costs at Mission. The focus of research at Mission has been on improving accuracy of the estimates. Estimates from Qualark have been used to judge accuracy of Mission estimates, although it must be emphasised that both programs provide estimates of salmon abundance. The true number of fish passing Mission is unknown.

Three different programs linked to levels of abundance or species were evaluated:

- 1) Base program suitable for years of sockeye abundance up to about 4 million fish.
- 2) Enhanced program suitable for years of sockeye abundance up to about 14 million fish.
- 3) Supplementary program suitable for estimating pink salmon (up to 16 million pinks).

***Generally more abundant populations require more extensive and intensive shore-based sampling platforms to ensure accuracy.***

Each sampling program is illustrated schematically in figures and the incremental costs (both capital and operational) and benefits (effect on estimates) of each component are provided in tables. The quantification of "incremental" benefits needs a small refinement.

Major breakthroughs have occurred recently in the Secretariat staff's ability to estimate Fraser River Pink salmon<sup>1</sup>. We can generate credible acoustic estimates of pink salmon escapement which, coupled with catch estimates, can be used to generate estimates of total return that are independent of and much more precise than the traditional methods using test fisheries. However, these estimates come at a cost; approximately \$100,000 more than the sockeye program.

Our evaluation period is relatively short (5 years). Therefore conclusions about the programs, especially regarding a few specific components, are conditional on the circumstances observed and data collected thus far. Further testing would improve the robustness of conclusions and could be accomplished in the short term (2013, 2014). We are fairly confident that we have defined the maximum sockeye program needed, but less intensive sampling might be acceptable at intermediate levels of sockeye abundance which unfortunately were not observed in the evaluation period.

### **III. Potential future uses of the Qualark program**

The acoustic estimation of salmon is much less challenging at Qualark than at Mission. We reviewed four potential future uses of estimates from the Qualark site: (1) Calibration of Mission estimates (focus of ongoing SEF work), (2) In-season validation of Mission estimates, (3) Evaluation and improvement of sampling at Mission (focus thus far), and (4) Other (e.g. Planning in-river fisheries).

Despite the acoustic advantages of the Qualark site, the site poses three main challenges related to fisheries management. First, fish take 2-4 days to travel from Mission to Qualark and this creates time lags in the availability of run-size assessments. Typically, the Fraser River Panel does not update total return estimates until after the peak of the run has been observed at Mission. If Qualark estimates were used instead of Mission, run size updates would be delayed by a further 2-4 days. Second, some sockeye populations (e.g. Cultus, Harrison, Birkenhead, Chilliwack, Weaver Creek), and more than two-thirds of the Fraser River pink salmon populations spawn downstream of Qualark. Third, the long time series of Mission estimates is used to quantify in-season adjustments to escapement targets to compensate for natural, environmental and stock assessment factors. The long historical data set at Mission cannot easily be replaced with information from Qualark without a commitment to fund both sites for a significant time period. These challenges preclude consideration of Qualark as a replacement for Mission.

### **IV. Estimation of Species Composition**

Current acoustics applications have not typically been used to distinguish species. Thus, test fisheries are usually used to apportion acoustic targets to species. Test fisheries have provided biased estimates of species composition resulting in biased estimates of sockeye salmon at Mission in a few years (e.g. 2005). Sockeye estimates during the period when pink salmon predominate are of greatest concern. Species composition estimates at both Mission and Qualark are subject to test fishing biases.

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<sup>1</sup> The 1985 diplomatic note regarding implementation of the treaty calls for the Commission staff to estimate upriver escapements of sockeye and pink salmon for the Fraser River Panel.

Data gathered in recent years support development of stratified approach. Coupling test fishery sampling in different parts of the river with acoustic estimates for the same regions will provide more robust estimates of species composition. Hydro-acoustic based methods (e.g. fish length and tail beat frequency) are also being investigated.

## Pacific Salmon Commission

600 - 1155 Robson Street Vancouver, B.C.  
V6E 1B5  
(604)684-8081  
(604)666-8707 (fax)



To: Commissioners and Alternate Commissioners  
Our file: 63001

From: Mike Lapointe, Chief Biologist, Pacific Salmon Commission staff<sup>1</sup>  
cc: Fraser River Panel members, National Correspondents  
Date: January 14, 2013  
Re: Next steps for Fraser River Acoustics

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The purpose of this memo is to stimulate discussions among Commissioners, and the Fraser River Panel about the future plans for Fraser river acoustics. The memo is divided into four parts. The introduction provides the rationale for why a discussion is warranted. Next, we provide a cost-benefit analysis for the Mission program to support the development of a multi-year business plan. Third, we discuss the potential future uses for the Qualark program. Lastly, we discuss some challenges and potential budget implications related to the apportioning of acoustic targets to species.

### I. Introduction

Estimates of escapement are fundamental to the Fraser River Panel's fisheries management process<sup>2</sup>. Under the terms of the Pacific Salmon Treaty, the Panel is responsible for collecting data on upriver escapements through the conduct of a hydroacoustic program at Mission<sup>1</sup>. Beginning in 1992, five reviews<sup>2</sup> brought public attention and scientific scrutiny, leading to several specific recommendations about the Mission program that resulted in an ongoing research effort. Outdated technology (i.e. single beam) and an entirely vessel-based sampling program were identified as significant weaknesses leading to updated technology (split beam and DIDSON sonar) and shore based sampling platforms. In 2008, hydroacoustics staff completed a 5-Year Strategic Plan to guide program activities and research. Though research efforts were successful in increasing the accuracy of estimates, and a major breakthrough has occurred in pink salmon estimation in recent years, program improvements have had pragmatic consequences. First, program complexity has increased from 1 acoustic system to up to 7 systems. Second, program costs have approximately doubled from about \$300,000 in 1994 to \$600,000 in 2012. In addition to the regular budget, the Southern Boundary Restoration and Enhancement Fund (SEF) supported research in the amount of \$668,000 since 2004 including the purchase of three DIDSONs.

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<sup>1</sup> This document would not have been possible without significant help from Secretariat hydroacoustics staff. Kyle Adicks, Gary Graves, John Holmes, Barry Rosenberger, Larry Rutter, Mark Saunders, and Timber Whitehouse reviewed an earlier draft which improved this memo.

<sup>2</sup> See Appendix A for a detailed discussion of the purposes of lower Fraser acoustic monitoring ° See Part III. Potential future uses of the Qualark program.

Pearse<sup>2</sup> also recommended additional acoustic sites along the Fraser River to assist in regulating in-river fisheries. In response, DFO conducted a 5-year experimental program from 1993-1998 at Qualark Creek (95 km upstream from Mission) to design and test acoustic equipment for assessment of salmon migration. The Qualark site was reestablished in 2008 using DIDSON technology and results of both research phases have been applied to Mission. The Qualark site has a number of advantages for acoustic estimation of fish passage<sup>c</sup> which led PSC staff to advocate using

Qualark to validate Mission estimates<sup>3</sup> and supported the SEF committee's decision to fund the Qualark program in 2011 and 2012 at a cost of \$305,000/year. A main objective of the current Qualark SEF project is to integrate estimates for both sites and attempt to develop calibration factors<sup>4</sup>. The SEF also funded a second project related to improvements at Mission. The final reports for these projects will not be complete until mid-2013.

Adding Qualark, Mission, and SEF funds, more than \$1M was spent annually on lower river acoustics since 2008. The Cohen Commission recently recommended that both Mission and Qualark continue<sup>5</sup>. However, funding both Fraser river acoustics programs cannot be sustained indefinitely without either a significant increase in available resources or a reexamination of existing priorities. Therefore, a review of the current programs and a plan for the future is warranted. We hope that this review will assist with any short-term funding decisions needed prior to the completion of SEF technical reports next summer, but we acknowledge that these reports will also inform further discussions.

## **II. Cost/benefit analysis of Mission program**

There are two main challenges that shape the program used to estimate salmon passage at Mission. First, the Fraser River is 400m wide and fish are distributed throughout. Second, tides, river flow, boat noise from the transecting vessel, and river fisheries all affect fish behavior at the site.

To address these challenges the Commission's research has explored various sampling configurations using state-of-the-art technologies. From this experience, Secretariat staff have grouped sets of sampling tools into three proposed sampling schemes: (1) A base program; suitable for years of low sockeye abundance, (2) An enhanced sockeye program; suitable for years of high sockeye abundance and (3) A supplementary program suitable for assessing pink salmon. For each program, we provide a schematic of the sampling design (Figs. 1-3) and the total costs for our recommended program, but we also identify the incremental effects of removing specific sampling components on costs and risks (Tables 1-3).

The most significant operating costs of the Mission program are associated with the need for 24/7 sampling for a period of two to three months and the associated personnel costs for collecting (on the vessel) and processing the data. Baseline capital costs include two vessels (one for the transecting program, and a second to aid in the deployment of the left-bank weir and to provide access to the right bank), a trailer which houses staff on the left bank, a shed on the right bank and fence materials on both banks which prevent fish from migrating inshore of the acoustic equipment (fences are not shown in Figs 1-3 below). Split beam systems, DIDSONs, computers and other miscellaneous equipment represent significant incremental capital costs, but generally the incremental costs of deploying each piece of equipment is small relative to data processing and capital costs.

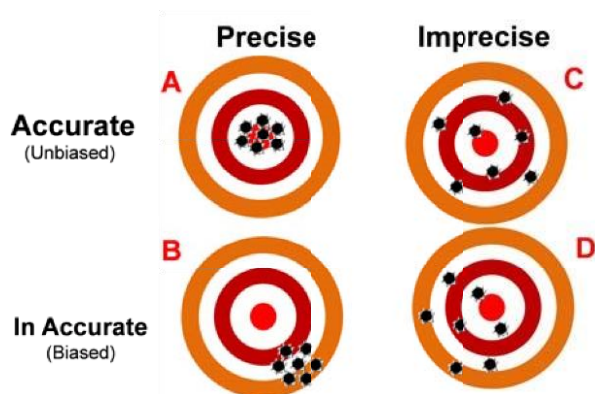
### **Accuracy and precision**

Benefits of assessment programs are typically quantified in terms of accuracy and precision as they impact the ability to achieve management objectives. These concepts are often misunderstood by layman and even

biologists. Below we use a target to help illustrate the differences between these concepts (Fig. A). An accurate and precise program would generate estimates that are both close to the bullseye and to each other as shown in panel A.

Alternately estimates may be very precise (repeated estimates similar to one another), but inaccurate (systematically far from the bullseye) as shown in Panel B. Panel B is important to understand because it demonstrates that very high precision does not by itself ensure high accuracy. For example, a hydroacoustic program might sample a consistent but incomplete fraction of the total area where fish migrate, thus repeated estimates would be similar, but would be underestimates (biased low). Often when managers or policy makers hear a scientist indicate his or her estimate has “tight confidence intervals”, they immediately assume the estimate is highly accurate. This is incorrect, confidence intervals refer to precision only. High precision comes from sampling large fractions of the population. To ensure high accuracy the data collection program must be designed carefully (e.g. completely sampling the area where fish are migrating). Absolute quantification of accuracy requires knowledge of the true value of what is being estimated. Panel D illustrates the inaccurate and imprecise situation. Lastly Panel C illustrates a situation where the *average* position of the estimates is close to the bulls eye, but there is scatter. Don’t worry if you are having trouble understanding how Panel C demonstrates accuracy, it is not critical to our discussions.

Figure. A. Schematic of concepts of Accuracy and precision.



The Mission program has always generated highly precise estimates. Even in the early years when single beam acoustics technology was deployed and estimates were based entirely on the transecting vessel (e.g. Fig 1 with the vessel only), statisticians showed that estimates of 200,000 fish had a precision of  $\pm 4\%$ <sup>6</sup> (example from paper; precision of daily estimates varies). Changes to technology and adding shore based platforms (e.g. Fig. 1). has not diminished the precision of the estimates. High precision comes from the large sampling effort – 24/7 temporal coverage and virtually complete spatial cover of the sampling area. Despite this high precision, elements of the program are subject to biases. For example, fish reach to the vessel and some avoid detection, especially in nearshore areas, hence the rationale for adding the shore-based systems (see Fig. 1). Thus, almost all of the Secretariat’s efforts have been directed toward moving the program from Panel B toward Panel A above; improving **accuracy** has been our focus. Consequently, we do not quantify precision as a measure of benefit in the below tables. However, if the Fraser River Panel would accept less precision than currently generated, we could reduce costs by physically counting a smaller fraction of the targets. Research is on-going to refine precision estimation methods.

In the Mission context, where is the bullseye? We don't know because the the true number of fish (sockeye or pink) passing Mission on any given day is unknown. Thus, we are forced to draw an indirect inference about accuracy by comparing Mission estimates to other *estimates* that we believe are more accurate and precise than the Mission estimates. For several reasons, we believe that the best estimates currently available for judging the accuracy of the Mission estimates are the Qualark estimates(see section III below). One important caveat is that these comparisons are most informative about accuracy when both programs are seeing the same populations(not all the fish travelling passed Mission migrate upstream to Qualark). Consequently, we quantify benefits below by noting the deviation between Mission<sup>1</sup> and Qualark estimates and we also note the directional biases associated with removing particular sampling components (Tables 1-3).

#### Base program (suitable for years of low sockeye abundance)

The base program was developed of the period from 2005-2007 and it has been the primary sampling program used for in-season estimates since 2010. The base program has been sufficient for estimating daily abundances up to 200,000 total salmon and years with up to about 3 million salmon for the season. The program consists of two DIDSONs and two split beam systems (Fig. 1). Estimates from the left bank and mobile split beam systems account for most of the annual estimate (Table 1, col 5, Annual %). The right bank DIDSON contributes only 11% to the annual estimate but can be a significant contributor on particular days (Table 1, col 5, Daily %, row 5). Note that both the vessel and shorebased systems sample the nearshore areas. But to ensure that total coverage by all systems adds to 100% the vessel contributions have been reduced to represent quantities of fish estimated in the areas not covered by the shore-based systems (Table 1; col 5 Annual %). Thus, the values in Table 1 (col 5, Annual%) do not represent incremental changes. In 2012, the estimate for the full base program (all systems in Fig. 1) was 8% larger than the estimate based on only the Left bank and mobile data. In other words, the right bank system detected 8% more sockeye that the vessel did in the common area sampled by both (i.e. blue triangle on right bank; Fig. 1). We can quantify these incremental effects for all systems and will include them in future tables. The left bank DIDSON has not typically been used for estimation on low abundance years because the split beam system adequately covers the same area (Fig. 1). However, the left bank DIDSON provides important diagnostic information used to verify targets (fish, debris), fish behavior, and fish size.

Two comparisons with Qualark are most relevant to the base program; 2008 and 2012. In 2012, the base program operated for most of August when the Mission projected Qualark number<sup>d</sup> was 2% less than the Qualark estimate (Table 1; col 6; row 2). During this period about 29% of the Mission estimate was associated with lower Fraser spawning tributaries downstream of Qualark (e.g. Chilliwack and Harrison); 71% of populations were bound for Qualark. In 2008, the Mission estimate did not include a right bank component. In that year, the Mission projected sockeye number was 9% larger than the Qualark estimate (Table 1; col 6, row 5). During this period, only 17% of the Mission estimate was associated with lower river tributaries; 83% of the populations were bound for Qualark. While the two programs did not assess identical populations in these years, comparable estimates provide some confidence in the estimates from both sites.

The cost of the base program is \$255,000/year. Incremental costs savings and risks associated with removing components are shown in Table 1. For example, the incremental cost savings for not operating the right bank

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<sup>1</sup> Mission estimate minus estimates for lower Fraser populations not bound for Qualark and any in-river catches between Mission and Qualark.

DIDSON (\$17,000, Table 1, row 6, col 3) are includes the costs of installing the right bank fence and shed, deploying and monitoring the DIDSON and counting the subsamples of each of the hourly DIDSON data file. Similarly, the incremental capital cost savings (\$13,000; Table 1, row 6 col 2) represents the total costs of the right bank fence, shed and DIDSON divided by the expected lifespan of these items. Most of the cost is associated with a DIDSON and the associated cables (total cost \$80,000, lifespan 8 years or \$10,000/year). The Right bank DIDSON offers potential costs savings but can contribute significantly to estimates on some days (Table 1, col 5, Daily %). The trailer and left bank fence are included as capital costs under the Left bank split beam system. The Left bank DIDSON offers less potential savings, and adds considerable robustness to the estimation. Investments in robustness are akin to buying insurance against atypical fish distributions and behaviors. Deviation related to atypical behaviors or distributions cannot be quantified without these systems being in place at the beginning of the season. Note that the costs of analyzing the vessel data (about \$3,000) were incorrectly included in the Left bank split beam row in Table 1 (col 3). If those costs are transferred the cost of the Left bank split beam and mobile components are comparable. Both components require 24/7 coverage and more temporary labor is deployed processing the higher density Left bank files.

#### Enhanced sockeye program (suitable for years of high sockeye abundance)

We have experienced two years (2006 and 2010) of high abundance that have suggested that the regular in-season Mission program was substantially biased low. In 2006, the in-season Mission estimates were approximately 1.5 million fish less than the sum of all spawning ground estimates plus in-river catch estimates for areas upstream of Mission<sup>7</sup>. In that year, the in-season estimates were based entirely on the left bank and mobile split beam systems (see Fig. 2). An experimental split beam system deployed on the right bank estimated an additional 340,000 sockeye post-season, but this additional amount still fell short of explaining the discrepancy. The left bank DIDSON data were not continuous enough for estimation. No offshore DIDSONs were deployed. Extremely low river flows were hypothesized to exacerbate fish avoiding detection by the transecting vessel.

In 2010, the in-season Mission estimates were based on the left bank and mobile split beam systems plus a DIDSON on the right bank. Again more fish were detected upstream both at Qualark and on the spawning grounds. The Qualark total salmon estimate exceeded Mission by about 2%, but this pattern of deviation is not consistent with the fact that 10% of the sockeye population was not bound for Qualark and there was harvest between the two sites. In-season projections of sockeye headed to Qualark were 20%(2.7M sockeye) less than the Qualark estimate. Post-season projections which included contributions from the left bank and right bank offshore DIDSONs reduced this discrepancy to 11% (Table 2; col 6; row 2). The deviations in these two years clearly demonstrate the need for an expanded sampling program at Mission in years of high abundance.

The Enhanced sockeye program should be sufficient for estimating daily abundances up to 600,000 total salmon and in years with up to about 14 million salmon for the season. The enhanced sockeye program builds on the base program by adding up to two DIDSON systems mounted offshore (Fig. 2) and by using the left bank system as part of the estimation. The potential benefits of the left bank offshore DIDSON cannot yet be quantified because it has only been deployed in 2011 and in that year its coverage area completely overlapped with the left bank split beam system. Estimates from the left bank and mobile systems account for 82% of the annual estimate (Table 2; col 5, Annual %; rows 3,4,6), but right bank systems also contribute about 18% on an annual basis (Table 2; col 5, Annual %; rows 5,7).



Both right bank DIDSONs can also represent significant fractions of the estimates on particular days (Table 2; col 5, Daily %; rows 5,7). The left bank DIDSON and split beam systems overlap in the first 20 meters (Fig. 2). Table 2 quantifies the annual contribution of the Left bank DIDSON (Table 2; col 5, Annual %; row 6), but we have reduced the contribution of the left bank split beam accordingly (Table 2; col 5, Annual %; row 3). It appears that the left bank DIDSON system detected more near-bottom targets than the left bank split beam in 2010, but a further evaluation in

2014 is desired. There is only one comparison with Qualark relevant to the enhanced sockeye program. For the period August 1<sup>st</sup> through September 10<sup>th</sup>, all systems shown in Fig. 2, except the left bank offshore DIDSON were operated continuously. During this period, the Mission projected Qualark number was 11% less than the Qualark estimate (Table 2; col 6; row 2). During the 2010 season only 10% of the Mission estimate was associated with lower Fraser tributaries downstream of Qualark (e.g. Weaver and Harrison); 90% of populations were bound for Qualark. We are confident that an enhanced program will improve accuracy, but we cannot be sure that the program will completely eliminate bias without testing continuous deployment of the sampling platforms shown in Fig. 2. Our next opportunity to test this configuration at high population levels will likely occur in 2014.

The total cost of the enhanced sockeye program is approximately \$360,000/year. Incremental costs savings and risks associated with removing components are shown in Table 2. Note that the estimates from the left bank and offshore DIDSONS were made post-season in 2010; in-season processing would result in a minor cost increase (<5%). The left bank offshore DIDSON may offer modest cost savings if future evaluation indicates it does not substantially contribute to estimates. Additional operational savings could result if the left bank DIDSON estimate could be substituted for the left bank split beam estimates in the first 20 meters from shore where spatial coverage of the two systems overlaps.

### Pink Salmon supplementary program

Until 2009, acoustic estimation of the upstream abundance of Fraser River pink salmon has not been possible because neither the single-beam (vessel based) nor the split beam systems are capable of effectively sampling the nearshore migration. A major breakthrough occurred in 2009 and 2011 when shore-based DIDSON systems were deployed on each bank. Although no independent escapement estimates exist for comparison (to judge accuracy), the resulting pink salmon escapement estimates were 16.1 and 13.4 million fish respectively. Adding catches to the escapements resulted in total return estimates that were comparable to independent total return estimates from marine purse seine test fisheries and other methods. The total return estimates were judged by the joint PSC-DFO Hydroacoustics Working Group (HAWG) to use more robust methodology than the purse seine test fishing estimates of abundance (used since 2003) and they have been formally adopted as the best estimates by the Fraser River Panel. The capacity to generate credible pink salmon estimates at Mission is particularly important given that no upstream escapement estimation program has been conducted since 2001 and because of the renewed interest in pink salmon harvest. The estimates in any particular year have minimal benefits to in-season management decisions in that year because most of the migration occurs too late relative to the typical timing of marine fisheries. If upstream migration is early relative to potential harvest opportunities, it is possible that the combination of escapement passed Mission to date plus any planned future in-river harvests, might be used to ensure that escapement targets have been reached. However, it would be very difficult to extrapolate the escapement to date and estimate total return. Thus, total return and harvest shares calculations would still depend on the marine test fishery data. Thus the incremental added in-season value of escapement estimates within any particular year is likely small. In future years, however, when combined with catch estimates, the

resulting total return estimates are independent of test fishery data. Thus, the expansion factors applied to test fisheries used for in-season run-size assessments in future years can be updated. Furthermore independent catch and escapement estimates would generate more accurate and precise estimates of exploitation rates than currently possible with the combination test fishery and catch data. The pink program has been sufficient for estimating daily abundances up to 1,800,000 total salmon and in years with up to about 18 million salmon for the season. This supplementary program would begin in mid-August of odd years only, and is incremental to the sockeye program. During the pink migration, 79% of the annual estimate comes from left bank split beam and DIDSON systems (Table 3; col 5, Annual %; rows 3 and 6). The right bank DIDSON and mobile split beam system contribute about 11% and 10% respectively (Table 3, col 5, Annual %; rows 4,5). The offshore right bank DIDSON contributed an immeasurable amount to the annual estimate (Table 3, col 5 Annual %, row 6). Comparisons with Qualark estimates are not possible, because only a fraction of the pink salmon (historically about one third<sup>7</sup>) spawn upstream of that site.

The cost of the supplementary program on pink salmon is approximately \$102,000/year. This represents the increased operation costs of extending the season about 6 weeks and the associated increased labor required to count the very high abundance DIDSON files. The increased costs of the supplementary program would be slightly smaller if the enhanced sockeye program preceded it because deploying the additional equipment would not be required. Capital costs are not included in this estimate, because the sockeye programs would already be in place. However, if offshore DIDSONs were required, those capital costs would be incremental to the \$102,000 supplement in years when offshore DIDSONs are not required for the sockeye program. Incremental costs savings and risks associated with removing components are shown in Table 3. Both offshore DIDSONs require further evaluation, though based only on 2011, the offshore right bank DIDSON is not cost effective.

### **Concluding comments on the Mission Cost-benefit analysis**

We have developed our three sampling programs from only five seasons of data gathered by an incomplete deployment of sampling components at Mission coupled with estimates from Qualark. The two offshore DIDSONs in particular (Figs. 2 and 3) require further testing in years with different pink and sockeye runs sizes for a more complete understanding of their potential benefit. We expect to evaluate the benefits of components for pink estimation again in 2013 without seeking additional funds from the Parties. However, we may need to approach the Parties for funds incremental to the regular program budget to evaluate the benefits of components for estimating large sockeye abundances in 2014. Alternately, funds may be available through SEF. So far, we have only been able to evaluate the enhanced sockeye program when the largest daily abundances were associated with late-run stocks. But we have observed different migration patterns in our acoustic data between periods dominated by summer-run versus late-run populations. Thus, we cannot be sure which sampling components will be most appropriate in years with large daily abundances of summer-run stocks. Similarly, we have observed an incomplete range of Mission sockeye estimates sizes during this 5 yr period with four relatively small escapements (up to about 4 million fish) and one (2010) extremely large abundance (>14 million fish). Thus, we do not know whether the base, enhanced or some immediate program is required to obtain accurate estimates when abundance estimates fall between 4 and 14 million sockeye. These intermediate abundance situations will require further evaluation. Consequently our conclusions about the potential benefits of the offshore DIDSONs (denoted by “ ? ” in Figs. 2 and 3) are conditional on the circumstances encountered and data

collected thus far. However, we are confident that the enhanced sockeye program likely represents the most intensive sampling program that will be needed.

We chose the 3 years to draw inferences about the accuracy of Mission estimates based on the fraction of sockeye common to both sites. Sockeye estimates in the other two recent years, 2009 and 2011, are confounded by the pink salmon passage later in the season due to the challenges of species composition<sup>1</sup> associated with the test fisheries at both sites. Some comparisons are possible for the period prior to significant upstream migration of pink salmon. For the period July 16-August 15 in 2009, about 75% of the sockeye passing Mission were estimated to be from stocks headed upstream to Qualark. During this period the Qualark estimate was 10% larger than the Mission estimate, but estimates at Mission in that year were based on the Left bank and mobile systems only (i.e. Fig. 1 without the right bank DIDSON). The complete base program was implemented in 2011. For the period July 21-Aug 17, less than 60% of the sockeye passing Mission are from stocks headed to Qualark, because of the large Harrison River run that year. During this period the Qualark estimate was 16% larger than the Mission estimate. Errors in the estimates of stocks bound for downstream of Qualark likely contribute to this difference; perhaps too many lower Fraser stocks were removed from the the Mission projection<sup>d</sup> used to compare with Qualark. Thus, we provide these comparisons for completeness, but caution readers about drawing strong inferences from them due to differences between the populations observed at both sites.

Tables 1-3 quantify capital costs as total costs divided by the expected life span of the equipment. This type of calculation is inconsistent with the current budget practices of asking for full capital replacement amounts in the year that equipment is due for life cycle replacement. We don't believe that the numbers shown in the Tables are misleading as the current practice may average out over time, but suggest that setting aside annual amounts is worthy of consideration in the future.

Decisions about potential reductions in number of sampling components from the three recommended programs we have outlined involve trade-offs between fishery management benefits (assessed through the Fraser River Panel) and program costs (assessed by the Commission's Finance and Administration Committee). Our intent is not to promote the full programs, but rather to provide objective information that can form the basis of discussion. Once this discussion is complete, we can explore the multi-year implications of various sampling programs in our business plan.

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<sup>1</sup> See section IV below.

## Base program – Suitable for years of relatively low sockeye abundance

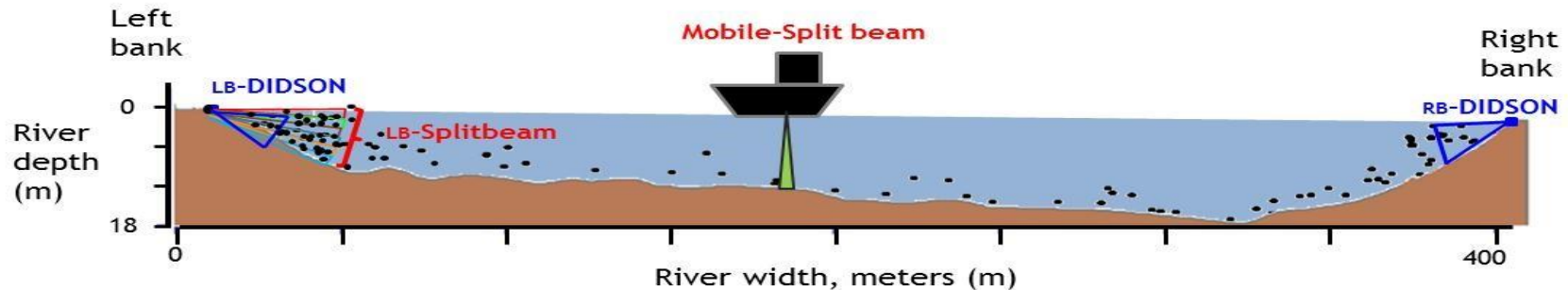


Figure 1. Schematic of base sampling program at Mission. Blue triangles denote approximate coverage of DIDSON sonar system on each bank. Multi-colored triangles on left bank denote multiple aims of split beam sonar system. The mobile split beam is denoted by the green triangle underneath the vessel. Black dots denote approximate cross river distribution of individual fish targets during periods of low daily abundance. Drawing is not to scale.

Table 1. Cost-benefit analysis of base program. For the base program, we list the Total Capital cost per year (Capital cost/expected equipment lifespan) and Total Operating costs. Costs for individual components are expressed as percentages of these totals. The spatial coverage is expressed as a fraction of the total river cross sectional area (i.e. blue shaded area in Figure 1 above). The proportion of the annual abundance and range in proportions of daily abundance estimates are expressed as fractions of the Mission estimates. The values in the Abundance columns are based on the August 6-24 period in 2012. The annual deviation with Qualark is calculated as (Mission projected sockeye to Qualark – Qualark sockeye)/Qualark sockeye) for the period when the Mission component systems were operating. Potential directional bias and other comments are provided as notes.

Component	Costs		Risks of removing components				Directional bias, and Other
	Capital per year (% of Total)	Operating (% of Total)	Spatial coverage (% of river cross section)	Abundance Coverage Annual %	Daily % Range	Deviation from Qualark Annual %	
Total cost	\$ 89,000	\$ 166,000				-2% (2012)	Note: Aug 6-24 when base program operated; +3% deviation for full season

Left Bank Split beam	39	40	10	66	32-79		Underestimation from boat due to avoidance; fish concentrated near left bank
Mobile Split beam	34	33	87	23	0-37		Underestimation due to fish distribution and large area
Right Bank DIDSON	13	17	3	11	4-47	9% (2008)	Underestimation from boat due to avoidance, Reduced capacity to verify targets (fish, debris), fish behavior and size
Left Bank DIDSON	14	9	3 (overlaps with split beam)	Not used for abundance on low years			Reduced capacity to verify targets (fish, debris), fish behavior and size

### Enhanced sockeye program – Suitable for years of relatively high sockeye abundance

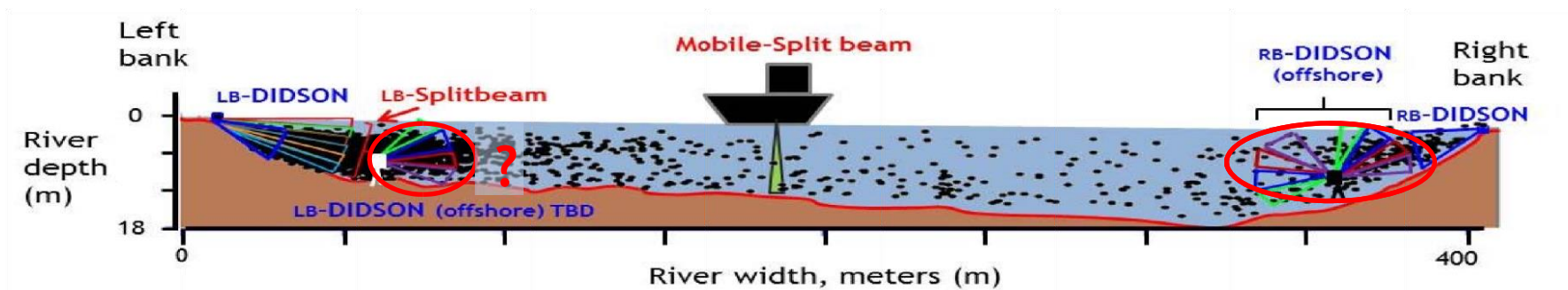


Figure 2. Schematic of enhanced sockeye sampling program. Same as Figure 1, except for two offshore DIDSON systems circled in red. Multi-colored triangles denote multiple aims of offshore DIDSON systems. The contribution of the left bank offshore DIDSON requires further evaluation. Black dots denote approximate cross river distribution of individual fish targets during periods of high daily sockeye abundance. Drawing is not to scale.

Table 2. Cost-benefit analysis of enhanced sockeye program. Same columns as Table 1. Calculations in Abundance coverage columns are based on August 1 through September 10 period of 2010. Offshore DIDSON systems have been added in last two rows.

	Costs		Risks of removing components				
Component	Capital per year (% of Total)	Operating (% of Total)	Spatial coverage (% of river cross section)	Abundance Coverage Annual %    Daily % Range		Deviation from Qualark Annual %	Directional bias, and Other
Total cost	\$ 113,000	\$ 247,000				-11% (2010)	Note: Aug 1-Sep 10 when all systems except Left bank offshore DIDSON were operating; -13% for full season
Left Bank Split beam	30	46	10	31	15-93		Underestimation from boat due to avoidance; fish concentrated near left bank
Mobile Split beam	27	31	69	31	19-57		Underestimation due to fish distribution and large area
Right Bank DIDSON	11	10	3	11	1-34		Underestimation from boat due to avoidance, Overestimation (same as below); Reduced capacity to identify small fish and debris
Left Bank DIDSON	11	9	3 (overlaps with split beam)	20	4-49		Underestimation from Left bank split beam if DIDSON detects more targets near bottom; Reduced capacity to identify small fish and debris
Right Bank Offshore DIDSON	11	2	9	7	7-40		Underestimation from boat due to avoidance
Left Bank Offshore DIDSON	11	2	9	TBD	TBD		TBD Need to compare relative to Left Bank split beam

# Supplementary program for assessing Pink salmon

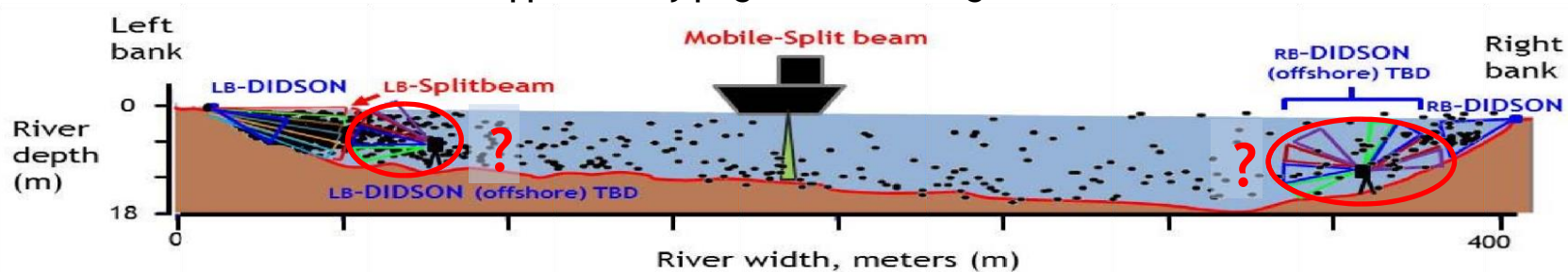


Figure 3. Schematic of pink salmon supplementary program. Same as Figure 1, except for two offshore DIDSON systems circled in red. Multi-colored triangles denote multiple aims of offshore DIDSON systems. The contribution of the both offshore DIDSON requires further evaluation. Black dots denote approximate cross river distribution of individual fish targets during periods of high daily pink abundance. Drawing is not to scale.

Table 3. Cost-benefit analysis of pink salmon supplementary program. Same columns as Table 1. Values in Abundance Coverage are based on the September period in 2011. Qualark deviations are not shown because of lack of comparability (see text). Offshore DIDSON systems have been added in last two rows.

Component	Costs		Risks of removing components			
	Capital per year (% of Total)	Operating (% of Total)	Spatial coverage (% of river cross section)	Abundance Coverage Annual %    Daily % Range		Directional bias, and Other
Total Cost	\$ 113,000	\$ 102,000				
Left Bank Split beam	30	38	10	21	14-92	Underestimation from boat due to avoidance; fish concentrated near left bank
Mobile Split beam	27	27	69	10	2-26	Underestimation due to fish distribution and large area
Right Bank DIDSON	11	11	3	11	4-27	Underestimation from boat due to avoidance, Overestimation (same as below); Reduced capacity to identify small fish and debris
Left Bank DIDSON	11	17	3 (overlaps with split beam)	58	47-80	Underestimation from Left bank split beam if DIDSON detects more targets near bottom ; Reduced capacity to identify small fish and debris

Right Bank Offshore DIDSON	11	6	9	<1%	0-1%	Likely a minor contributor; reconfirm in 2013
Left Bank Offshore DIDSON	11	6	9	TBD	TBD	TBD likely a minor contributor; confirm in 2013



### **III. Potential future uses of the Qualark program.**

The Qualark site offers a number of advantages for acoustic estimation of fish passage when compared to Mission. First, strong river currents concentrate fish within 20m of each bank which permits an entirely shore-based assessment using two DIDSONs. Second, there are no direct tidal impacts on fish behavior. Third, both river banks have been re-profiled and paved with sand bags, creating an environment that is optimal for acoustic sampling.

Despite Qualark's site advantages which permit much more robust estimates of fish passage, the site poses three significant disadvantages for fisheries management. First, fish take two to four days to travel between Mission and Qualark and this creates additional time lags between marine test fishery observations and subsequent acoustic validation. This time lag is consequential to in-season assessments and the achievement of Treaty objectives. Second, some sockeye populations (e.g. Cultus, Harrison, Birkenhead, Chilliwack, Weaver Creek; quantified above), and more than two-thirds of the Fraser River pink salmon spawn downstream of Qualark<sup>8</sup>. Third, the long historical data set at Mission cannot easily be replaced with information from Qualark without a commitment to fund both sites for a significant time period. These disadvantages preclude consideration of Qualark as a replacement for Mission.

Given this context, we review four potential future uses of estimates from the Qualark program below: (1) Calibration of Mission estimates, (2) In-season validation of Mission estimates, (3) Evaluate and improve sampling at Mission, (4) other (e.g. plan in-river fisheries).

#### **Calibration of Mission estimates**

The concept of calibration involves using a statistical model to relate deviations between Mission and Qualark to some measurable set of conditions (e.g. river flow, fishing effort patterns). Calibration factors could be estimated either using existing data from both sites or by augmenting these data with additional years. Following the overlapping data collection period, Qualark operations would be suspended, and conditions in future years would be used to predict the adjustments to Mission estimates.

Without prejudice to final SEF reports, discussions to date within the HAWG group have noted two significant challenges to this approach. These include: (1) Extended periods when the acoustic systems at each site are not estimating the same populations (as outline above). During these periods, relevant comparisons between estimates at the two sites require data such as species and stock composition from test fisheries and thus deviations between estimates cannot be attributed solely to acoustic sampling errors. (2) Deviations between estimates for short periods (e.g. one to several days) can result from variation in the time fish take to travel between the two sites (e.g. due to river flow, fishery or stock effects). These two sources of deviations complicate when and how comparisons can be used to develop calibration factors. Furthermore, we have only five years of comparisons, and it seems unlikely that the range of potential future environmental, fishery and relative abundance factors has been observed. Variation in the components used at Mission during this period further complicates the process. Therefore, if calibration is desired, it will likely require several more years of estimation at both sites.

#### **In-season validation of Mission estimate**

Under this scheme, Mission and Qualark would both operate together indefinitely. Daily comparisons of estimates from the two sites would be compared and Mission estimates could be adjusted during the season to reduce the pattern of deviations. This approach was used during the 2010 season, when estimates from Qualark were used to scale-up the Mission estimates because the latter appeared to be biased low. Alternately, Qualark and Mission could be combined to generate a more accurate and precise estimate. While continuous operation of both sites may provide the most robust lower Fraser River acoustic monitoring program, the challenges to calibration described above also add complexity to the in-season validation approach. For example, short term deviations might occur due to changes in travel time even though annual estimates might be very similar. Approaches that combine reduced Mission programs with in-season validation at Qualark would be less costly than operating both full programs, but they would be challenged by the same factors. An approach that uses Qualark to evaluate alternative sampling schemes at Mission would be more cost effective.

### **Evaluate and Improve sampling at Mission**

This approach compares Mission and Qualark estimates to determine which sampling schemes at Mission are required to provide the most robust estimates of salmon passage. In effect, the sampling scheme that minimizes deviations between Mission and Qualark estimates is deemed “best”. Secretariat staff have worked with HAWG to use Qualark for this purpose since 2008, and our work has informed the approaches shown in section II above. The Qualark program could further inform sampling improvements at Mission in future years, but such efforts should be carefully planned to target specific periods when both sites are estimating the same populations. We believe the next opportunity for a useful comparison is in 2014, when we anticipate the next very large sockeye migration. Unfortunately, we did not have sufficient DIDSON units in 2010 to implement the configuration shown in Figure 2 continuously through the season. An evaluation in 2014 would permit continuous evaluation of all components and help determine for example, whether a DIDSON anchored offshore of the left bank is needed. Thus, if funds can be found to implement Qualark in the future, 2014 would likely be the most informative year.

### **Other uses**

Lastly, estimates from Qualark could be used for other objectives such as: (1) estimating upper river populations of Fraser River sockeye, pink salmon, or other salmon species (2) planning in-river fisheries, and/or (3) estimating en-route losses between Mission and Qualark. An evaluation of the program’s potential to provide information related to these objectives is beyond the scope of this memo.

## **IV. Estimation of Species Composition.**

The Mission and Qualark acoustic programs currently provide estimates of the number of salmon sized targets migrating upstream. But fisheries management requires estimates for particular species (e.g. sockeye, pink) and stock-groups (e.g. Weaver). Currently acoustic estimates are apportioned to species using the relative abundance found in test fishery catches. When sockeye predominate (e.g. >90% of a test fishery catch), the impact of species composition errors is small. However, composition errors can have significant management consequences when sockeye salmon are not the dominant species migrating upstream. Two periods are the most challenging; (1) early in the season in years when sockeye abundance is low relative to chinook, and (2) after mid-August on pink years, when pink salmon migration begins and soon predominates

over sockeye. The early season issue is not new, and has minimal impact on bilateral management, because the main sockeye populations affected (Early Stuart, Chilliwack) are not the focus of commercial harvest opportunities.

The consequences of composition errors related to the later season problem has increased in recent odd years because the pink salmon migration has begun earlier (early August in some years) and overlapped with more of the Summer-run sockeye migration. The problem does not impact pink fisheries management decisions, because the effect of errors on the pink estimate is small and most of the pink migration occurs after most pink fisheries have concluded. The focus is on the impact on sockeye salmon estimates. For example, in 2005, in-season estimates of sockeye abundance passed Mission were decreased by about one third (from 8.4 to 5.6M), as a result of postseason adjustments for species composition errors<sup>9</sup>. The 2005 result triggered additional research that has expanded our knowledge of the problem. Below we briefly summarize ongoing efforts to address this issue.

Recent improvement to sampling schemes at Mission (e.g. Fig. 3) and observations from fish wheels and set nets anchored nearshore have reinforced our understanding that pink salmon migrate quite close to shore. This is especially true relative to sockeye salmon and explains why river test fisheries that sample the mid-channel areas catch disproportionately less pink salmon relative to their abundance. Conversely these test fisheries catch disproportionately more sockeye salmon. These observations dictate the need for a stratified approach that couples separate acoustic estimates of abundance for near-shore and offshore areas with separate estimates of species compositions in these regions.

We have gathered both acoustic and test fishery information in a stratified manner in recent years that can be used to evaluate alternative approaches. We have set net and fish wheel information for the nearshore areas and information from two drift net fisheries for the river channel. In addition to test fishing-based sampling, two acoustic based methods are being explored for species composition. PSC staff are exploring the use of lengths obtained from DIDSON images to distinguish species. DFO staff are testing a method that uses the fish's tail-beat frequency to distinguish species (again using DIDSON). Projects related to both methods have received funding from SEF, with the latter project entering its last year in 2013. While both of these methods are currently still in the experimental phase, both offer potential for more representative sampling than test fisheries which appear to be selective with respect to these species. The use of DIDSONs on each shore at Mission facilitates implementing either of these techniques for nearshore species composition in the future.

Depending on the details or provisions regarding the use of fish, test fishery-based species composition may be accomplished with little or no requirement for addition funding from the Parties but could impact the quantity of test fish deducted in determining harvest shares. If acoustic methods are employed, additional temporary personnel may be required for data processing. The magnitude of potential cost increases would likely be small (\$10,000-\$20,000/year) but they cannot be accurately estimated at this time.

- <sup>1</sup> Diplomatic note of August 13, 1985 regarding implementation of Article XV (paragraph 3) of the Pacific Salmon Treaty, paragraph A.1.c.
- <sup>2</sup> (1) Pearse, P. H. (1992). Managing salmon in the Fraser: Report to the Minister of Fisheries and Oceans on the Fraser River Salmon Investigation.: Department of Fisheries and Oceans. Ottawa.
- (2) Fraser River Sockeye Public Review Board. (1995). *Fraser River sockeye 1994: Problems and Discrepancies*. Public Works and Government Services Canada. Ottawa.
- (3) Macdonald, J. S., M.G.G. Foreman, T. Farrell, I.V. Williams, J. Grout, A. Cass, J.C. Woodey, H. Enzenhofer, W.C. Clarke, R. Houtman, E.M. Donaldson, and D. Barnes. (2000). The influence of extreme water temperatures on migrating Fraser River sockeye salmon (*Oncorhynchus nerka*) during the 1998 spawning season. Canadian Technical Report of Fisheries and Aquatic Sciences 2326, Minister of Public Works and Government Services. Ottawa.
- (4) External Review Committee. (2003). Review of the 2002 Fraser River Sockeye Fishery. Department of Fisheries and Oceans. Ottawa.
- (5) Williams, B. (2005). *2004 southern salmon fishery post-season review: Part I Fraser River sockeye Report*. Ottawa.
- <sup>3</sup> Lapointe, M. 2010. Uses and value of Qualark acoustics program. Memo to B. Rosenberger and L. Loomis. November 19, 2010.
- <sup>4</sup> Whitehouse, T. and R. Hope. 2012. 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. Detailed proposal to Southern Boundary Restoration and Enhancement fund. 8 p.
- <sup>5</sup> Recommendation 29 of 75 : “*The Department of Fisheries and Oceans should continue to provide sufficient funding to enable the Pacific Salmon Commission’s hydroacoustic facility at Mission and DFO’s hydroacoustic facility at Qualark to operate at the 2010 level.*” See Cohen Commission final report Vol. 3, p. 108.
- <sup>6</sup> Banneheka, S.G., R.D. Routledge, I.C. Guthrie and J.C. Woodey. 1995. Estimation of in-river fish passage using a combination of transect and stationary hydroacoustic sampling. Can. J. Fish. Aquat. Sci. 52: 335-343.
- <sup>7</sup> Pacific Salmon Commission 2011. Report of the Fraser River Panel to the Pacific Salmon Commission on the 2006 Fraser River sockeye and pink salmon season. (see Appendix I. p. 50)
- <sup>8</sup> Average proportion of major population spawning below Qualark 1957-1985 is 69%; range 41-93%.
- <sup>9</sup> Pacific Salmon Commission 2009. Report of the Fraser River Panel to the Pacific Salmon Commission on the 2005 Fraser River sockeye and pink salmon season. (see Appendix J. p. 62).

## Appendix A Purposes of acoustic monitoring

The principal uses of lower river escapement data include:

- (1) ***Achievement of conservation objectives:*** The highest priority management objective for the Fraser River Panel is to “obtain spawning escapement goals by stock or stock grouping”<sup>6</sup>. During inseason management, the Fraser River Panel actively monitors progress toward “gross” escapement goals to ensure that sufficient fish are passing upstream for the combination of spawning escapement, management adjustments (see (2) below) and any in-river catch requirements.
- (2) ***Estimation of management adjustments:*** Management adjustments are increments to spawning escapement targets that are added to compensate for either systematic assessment errors, or enroute losses that cause upper river escapement estimates to be less than lower river estimates. The Fraser River Panel adopts these adjustments to increase the likelihood that escapement targets are achieved.<sup>2</sup> Compensation for systematic differences observed in Early Stuart and Early Summer run sockeye estimates began in 1995. An extensive post-season review following the 1998 season(see MacDonald et al. 2000; endnote 2(3) in main document) recommended that PSC and DFO staff develop models to predict needed adjustments to escapement targets in response to adverse river conditions (high temperatures, high flows). These “Environmental” Management Adjustment (EMA) models were first used to predict expected differences based on in-season forecasts of river flow and temperatures in 2001 and they have been integrated as part of in-season management every year since. In 2012, nearly 400,000 fish were added to the escapement targets of Early Stuart, Early Summer and Summer-run sockeye to compensate for expected differences. Given the increased frequency of warm river temperatures observed in the last 15 years and future predictions from climate change models, management adjustments are likely to become increasingly important for ensuring the long term sustainability of the stocks.
- (3) ***Estimation of Run-size:*** Run-size estimates are critical for the achievement of conservation and allocation objectives defined in the Treaty<sup>3</sup> and both in-season and post-season estimates of total Fraser sockeye returns rely heavily on Mission estimates. Without acoustics, in-season run size estimates would be much more uncertain as daily abundances from test fisheries are 5 to 10 times more variable than abundances estimates obtained from acoustics. For most of the historical time series, post-season estimates of the total Fraser sockeye return were based on summing the catches in all areas with the spawning escapements. However in the last 20 years lower river escapement estimates (instead of spawning escapement plus in-river catches) have been used to estimate returns for several stocks and years to better account for in-river losses. Conservation actions taken in response to en-route losses and other sources of declining productivity of Fraser River sockeye salmon have included in-

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<sup>1</sup> Pacific Salmon Treaty, Annex IV, Chapter 4, paragraph10.

<sup>2</sup> Pacific Salmon Treaty, Annex IV, Chapter 4, paragraph 3b

<sup>3</sup> e.g. Pacific Salmon Treaty, Annex IV, Chapter 4, paragraphs 3, 10, 13

season reductions in allowable catches and also have increased the importance of escapement estimates in total return calculations.

# Appendix 2: FSRC TOR

## Terms of Reference for the Fraser Strategic Review Committee on In-River Assessment of Fraser River Sockeye and Pink

### (Hydroacoustics)

February 14, 2013

### Background

Located approximately 80 km upstream of the mouth of the Fraser River, the Pacific Salmon Commission's (PSC) Mission hydroacoustic station has been operational since 1977, serving as a daily in-season enumeration reference, assessing the upstream passage of Fraser River sockeye and pink salmon.

The Diplomatic Note of August 13, 1985 (paragraph A.1.c) states that the Commission shall

*conduct test fishing on Fraser River sockeye and pink salmon; collect data on upriver escapements by observation at Hell's Gate and through the conduct of a hydroacoustic program at Mission Bridge.*

Staff and funding requirements to support the Fraser River Panel have grown and the enumeration capacity at Mission has increased relative to the earlier period when the 1985

Diplomatic Note was signed. Given these developments, a review by the Pacific Salmon Commission of the in-river assessment programs for Fraser River sockeye and Pink salmon is timely.

### Mandate

The purpose of the Fraser Strategic Review Committee (FSRC) is to provide advice to the Commission on potential modifications to the hydroacoustic operations in the lower Fraser River based on the following:

- Clarification of in-river assessment objectives.
- Review of technological options (alternative or complementary) for providing accurate, precise and timely information to satisfy obligations under the *Pacific Salmon Treaty*.
- Effectiveness and affordability related to levels of risk tolerance and objectives.

### Scope of the Review

To this end, the FSRC shall examine alternative hydroacoustic monitoring configurations for the Mission Bridge and Qualark Creek stations – both as independent and as complementary operations, as well as other assessment methodologies. The FSRC will be supported by the PSC Secretariat, Fisheries and Oceans Canada staff and others as required. The examination should include:

- a) Clarification of the fisheries management objectives for lower Fraser River in-river assessment. Objectives may include (but are not limited to):
  - species priorities,
  - level of accuracy required to inform fisheries management decisions, ○ reliability and timeliness of data; (in-season versus post-season/in season timing versus location),
  - robustness of the enumeration system to unpredictable variations in fish behaviour, and river conditions (e.g. discharge, temperature);
- b) Evaluation of existing hydroacoustics station configuration, as well as new alternatives or additions, in terms of whether they meet fisheries management objectives, value for money, bilateral management application, and the appropriate distribution of funding responsibilities as may be applicable.

Based on the assessment the FSRC shall provide recommendations for the next five-to-ten years.

### **Membership**

The Fraser Strategic Review Committee shall be comprised of up to three (3) Commissioners from each party. Each party will designate one member to serve as a co-chair.

Committee members shall be appointed for the duration of the work associated with the strategic review, which is anticipated to be approximately two years.

### **Meetings**

Meetings of the FSRC will be held when determined by the co-chairs to be necessary to carry out the business of the FSRC. Scheduling shall be done to minimize costs and travel, and to the extent possible, so as to not to interfere with the normal course of business of meetings of the Commission or the Fraser River Panel. The co-chairs of the FSRC shall communicate regularly with the chair and vice-chair of the Fraser River Panel to identify issues and the need, if any, for joint meetings of FSRC and the Fraser River Panel.

The co-chairs of the FSRC may invite other subject-matter experts (e.g. Fraser River Panel and Technical Committee members, Secretariat staff, and other national section advisors) and/or outside experts to attend and/or participate in FSRC meetings.

FSRC meeting reports will be prepared by the co-chairs and presented to the Commission at its regularly scheduled meetings. The FSRC shall strive to deliver a final report for presentation to the Commission during the 2015 Annual Meeting.



# Appendix 3: Commission Instructions to FRP

## Fraser River Hydro-Acoustics Strategic Review – Instructions to Fraser River Panel

- 1) Considering fisheries management objectives for Fraser River sockeye and pink salmon as defined in Chapter 4 of the Pacific Salmon Treaty, the Fraser River Panel is to inform a review of the current Hydro-acoustics programs at Mission and Qualark.
- 2) This review would address questions such as (but not limited to) the following:
  - a. What data/information from Mission and Qualark is critical to informing decisions such that agreed-upon fisheries management objectives can be met?
  - b. What additional considerations are there with respect to providing this data/information to inform fisheries management decisions (e.g. precision, accuracy, timeliness etc.)?
  - c. What are the most cost-effective ways of collecting the required information without incurring unacceptable impacts on data quality and timeliness?
  - d. Are there other opportunities or potential sources of data that could improve the quality and/or timeliness of data/information to inform fisheries management decisions that should be considered as part of the overall program to obtain data regarding fish numbers, species, etc.?
  - e. Are there alternate approaches to managing and administering the hydroacoustics program(s), and data from these programs, that would reduce overall costs (e.g. an integrated approach managed by the PSC)?
  - f. Considering the risks of NOT having some/all of the data components from the Mission and Qualark hydro-acoustics program, what are the recommendations for the overall program?
- 3) The Fraser Panel is awaiting instructions on timelines and procedures for completing this work in cooperation with the Strategic Review Committee.

# Appendix 4: Terms of Reference for Consultant



DRAFT

Terms of Reference for an independent consultant to the Fraser Strategic Review Committee (FSRC)

July 2, 2015

## Background

The Pacific Salmon Commission established the FSRC in February 2013 to provide advice on the optimal hydroacoustic sampling program for the lower Fraser River. The Committee includes two senior members from each National Section<sup>7</sup> and has the following terms of reference:

*“...the FSRC shall examine alternative hydroacoustic monitoring configurations for the Mission Bridge and Qualark Creek stations – both as independent and as complementary operations, as well as other assessment methodologies. The FSRC will be supported by the PSC Secretariat, Fisheries and Oceans Canada staff and others as required. The examination should include:*

- a) Clarification of the fisheries management objectives for lower Fraser River in-river assessment. Objectives may include (but are not limited to):*
  - species priorities,*
  - level of accuracy required to inform fisheries management decisions,*
  - reliability and timeliness of data; (in-season versus post-season/in-season timing versus location),*
  - robustness of the enumeration system to unpredictable variations in fish behaviour, and river conditions (e.g. discharge, temperature);*
- b) Evaluation of existing hydroacoustics station configuration, as well as new alternatives or additions, in terms of whether they meet fisheries management objectives, value for money, bilateral management application, and the appropriate distribution of funding responsibilities as may be applicable.”*

The FSRC has engaged with the Fraser River Panel (Panel) on objective (a) above, and this work is ongoing. In February 2015, the FSRC, the Panel, and the Secretariat concluded that a third party should

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<sup>7</sup> Brian Riddell, Paul Sprout (Canada); Ron Allen, Kyle Adicks (U.S.)

be engaged to assist with objective (b). In particular, the participants decided that an appropriate expert (the consultant) should be retained to quantify and evaluate deviations in fish passage estimates generated at the Qualark and Mission sites. Using this evaluation, the consultant would recommend a suite of program design options that would deliver cost-effective and robust estimates that meet Panel objectives under various riverine conditions for fish passage and fiscal scenarios.

### Terms of reference

The consultant shall analyze all relevant data provided by the FSRC, Fraser River Panel, PSC Secretariat, and Fisheries and Oceans Canada on hydroacoustic estimation of Fraser River stocks of sockeye and pink salmon at the Mission and Qualark sites. This analysis shall lead the consultant, with input from the Fraser River Hydroacoustic Oversight<sup>8</sup> and Technical<sup>9</sup> Teams, to:

1. Identify and describe the circumstances associated with observed deviations in estimates generated at the Mission and Qualark sites under the respective sampling designs and assumptions for unbiased enumeration.
2. Define and calculate performance measures for alternative program designs and scenarios. This calculation should:
  - a. Consider the range of fish densities encountered (non-dominant sockeye run years, dominant sockeye run years, and pink + sockeye years), river conditions (e.g., tides, flow, water clarity, etc.), and other factors; and
  - b. Compare the robustness and testability of assumptions in enumeration methods
3. Assess how well each program element meets defined fishery management objectives. (Refer to attached: “Fraser River Panel Management Objectives related to the Sockeye and Pink Salmon Hydro-acoustic Assessment Program Review”).
4. Combine information from performance assessments and information provided on cost of each program element in a risk assessment framework that includes defined fishery management and funding constraints.
5. Given the potential PSC need to limit total program costs to those for the Mission site only, identify a program design option from the risk assessment in paragraph 4 that falls within that budget. If this option does not adequately meet the defined fishery management objectives, explain why and identify a program design that would do so regardless of cost.
6. Identify key information gaps and options to address same.

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<sup>1</sup> Brian Riddell, Paul Sprout (Canada); Ron Allen, Kyle Adicks (U.S.)

<sup>2</sup> U.S.: Lorraine Loomis, Kirt Hughes, Kyle Adicks, Tim Tynan, Robert Conrad. Canada: Jennifer Nener, Les Jantz, Mike Staley, Timber Whitehouse.

<sup>3</sup> Timber Whitehouse, Fiona Martens

### Deliverables and timeline

- Regular (e.g. bi-weekly) updates/check-ins with the oversight team (or subset thereof) .... (include written summary?)
- September 15, 2015: Consultant delivers an interim report to the FSRC, the Oversight Team, and Technical Team for review
- October 15, 2015: Oversight Team, Technical Team, and FSRC complete their review of interim report and prepare an update for the Commission at 2015 Fall Meeting (October 26-30, 2015). Following the Executive session, these groups provide comments to consultant for future work.
- June 15, 2016: Consultant delivers final version of report based on input above and consultation with Oversight Team/Technical Team. Consultant also delivers key findings to Fraser River Panel at pre-season meeting.
- September 1, 2016: Oversight Team uses June 2016 report from consultant to develop final package of recommendations for FSRC. FSRC uses these recommendations as the basis for a final presentation to the Commission at the 2016 Fall Meeting.

# **Appendix 5: Fraser River Management Objective**

## **Fraser River Panel Management Objectives related to the Sockeye and Pink Salmon Hydro-acoustic Assessment Program Review**

The purpose of this document is to outline the management and fiscal objectives, performance measures and linkages to be considered in designing the most cost effective hydro-acoustic program in the Fraser River.

For the past several years hydro-acoustic programs have been conducted at both Mission and Qualark in the Fraser River to assess the abundance of the sockeye and pink salmon returning to the Fraser River.

As a result of a funding shortfall required to conduct both programs, the Fraser River Panel (FRP) has been directed by the Fraser Strategic Review Committee to evaluate both the Mission and Qualark programs in an effort to develop the most efficient and cost effective hydro-acoustic program for the Fraser River.

Recently a workplan for the review of the hydro-acoustics programs has been developed by the FRP and key staff from the Pacific Salmon Commission and DFO. One of the tasks (#4) was for the FRP and its Technical Committee to define the objectives required from a lower Fraser Assessment program and the linkages to other in-season information.

### **Fisheries Management and Fiscal Objectives**

1. The primary purpose of the lower Fraser River hydro-acoustic program(s) is to provide accurate and timely daily escapement estimates of Fraser sockeye and pink salmon in the most cost effective manner. In future years it is anticipated that the only funding available for Mission and/or Qualark will be the annual amount available to run the Mission program, at current level. As such it is essential that the best suite of hydro-acoustic components and associated assessment activities of the Mission and Qualark programs be identified that can be operated within the available budget.
2. For sockeye, daily escapement estimates are required to be identified at the stock level (stock ID samples from associated test fisheries) to assist in meeting the management objectives for the four run-timing groups in the Fraser. Information at this level is required primarily to achieve identified escapement objectives for the run-timing groups as well as inclusion in the post season determination of the differences between the estimates otherwise known as the Management Adjustment.
3. This information must be available to the Fraser Panel in a timely manner in order to inform the decisions made regarding fisheries in marine and freshwater areas.

In order to develop the most efficient and cost effective hydro-acoustic program going forward, a thorough evaluation which explores all of the component parts of each existing program at Mission and Qualark is required. The relative contribution of each piece of equipment needs to be identified in order to assess the risk associated with not using that particular piece of equipment in future years.

Among other elements this work should explore whether there are biases associated with the gillnet test fisheries used for stock and species composition that may be affecting the relative accuracies from the Mission and Qualark sites.

Work Plan Item #4:

1. Define objectives required from a lower Fraser Assessment program, including linkages between lower River assessments and other in-season information (e.g. run size estimation, management adjustments).	The FRP and its Technical Committee to define management objectives.	List of fisheries management and fiscal objectives, performance measures, and linkages to be considered in evaluation. Identify keys risks that would require some evaluation.
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Fisheries Management Objectives: Canada and US are able to identify TAC available for international sharing, for:

- A) E Stuart,
- B) E Summer,
- C) Summers,
- D) Lates,
- and
- E) Pinks,

in a timely way such that fish are still available to fisheries in US and Canadian marine waters.

# Appendix 6: Consultant's Report

Walters Report October 10, 2015

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Comparison of Mission and Qualark hydroacoustic facilities for providing escapement information for management of Fraser River sockeye and pink fisheries

Carl Walters  
Professor Emeritus, Fisheries Centre  
University of British Columbia

October 10, 2015

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## Introduction

Two hydroacoustic counting systems are now used in the Fraser River to provide inseason information on escapements of sockeye and pink salmon past commercial fisheries. Information from these facilities has been considered vital for inseason management, and there are basic questions now about whether both facilities should continue to be operated in view of budget constraints and whether counting systems at other locations might better serve management needs. The Mission facility has been operated since the late 1970s, and discrepancies between its estimates and upstream escapement estimates have led to various improvements in its operation over the years (see Appendix J in English et al. 2011), by moving from single beam mobile counting to fixed split-beam counting and use of DIDSON acoustic cameras. The Qualark facility using DIDSON cameras has been in full operation since 2010; it is much cheaper to operate than the full Mission system, but provides estimates 2-3 days later than Mission and does not provide escapement information for important stocks spawning downstream of Hope.

This report examines differences in estimates from the Mission and Qualark facilities, with the aim of determining why the estimates from them sometimes differ substantially. In order to evaluate management risks associated with either system and with differences between them, the report first reviews how the estimates are now used in inseason management, to point out that even exact escapement numbers would be of only limited value for management and how current use of the estimates may now be creating serious management risks that have apparently not been fully appreciated. It then examines the differences in a somewhat different way than has been previously presented in comparisons by PSC and DFO staff, with emphasis on deviations in the cumulative escapement patterns rather than day-to-day differences, since it is mainly the cumulative patterns (by run timing group) that drive management decisions. Examination of these cumulative patterns shows that neither system is clearly superior in terms of providing escapement estimates, the next report section examines ways to reduce cost and ways to provide more timely information particularly for late-run sockeye stocks that are at particular risk of overharvest while they delay migration at the Fraser River mouth. A final section reviews pros and cons of operating the two systems, and concludes that priority should be given to the Mission system despite any concerns about its accuracy and higher cost, because of the broader range of management needs that it can serve (pink stock assessment and management of First Nation fisheries), and to development of other systems for capturing better information along the ocean migration routes.

The main finding of this report is that operation of the Mission facility should be continued at a reduced level (without mobile sampling and sampling during night or falling tide hours), and savings from this reduction should be put toward operating the side-scan system tested at Chatham point in 2007. It would be much cheaper to just operate Qualark, but that would result in serious loss of information about pink escapements, and loss of useful inseason data for management of FN fisheries upstream of Mission. Operation of Qualark should be continued at least in years of high late runs (2018, 2022, etc) to determine whether Mission will continue to provide unreliable estimates in those years despite any ongoing efforts to improve its operation.



### Importance of acoustic escapement estimates for inseason management

Fraser sockeye and pinks are harvested in a gauntlet of fisheries that extend from Queen Charlotte Sound to well upriver of Hope (Figure 1). Commercial harvesting begins to impact the stocks about 8-12 migration days before fish reach the first acoustic facility at Mission.

Through most of the 20<sup>th</sup> century, this complex gauntlet was managed by a relatively simple strategy that led to stable and high exploitation rates largely independent of stock sizes, achieved by taking the commercial harvest in a large number of short time-area fishery openings. Because fishing fleets were large, each opening took a high proportion of the fish present in and entering the fishing area during the opening but were each limited in overall impact because each of those high removal proportions was a small proportion of the overall run. Over most of that management history (before 1990) that was evidently quite successful because both catches and stock sizes grew dramatically, IPSFC did not have either good run size forecasts or the “benefit” of Mission hydroacoustic data to complement in-season updating of run size estimates based on catches in the various fishery openings.

Management has been greatly complicated in recent years by (1) introduction of stock-size dependent exploitation rate goals (Total allowable mortality or TAM rules by run timing group); (2) increased priority on achieving allocation goals to growing First Nations (FN) fisheries; and (3) management of the northern seine and troll fisheries through quotas, which removes the safety afforded by short time-area openings along with the ability to use catches from such openings for overall stock size estimation (so-called “purse seine models”). Today, management action at any point in the season is not about how many fish have already arrived and been caught or escaped, but rather about how many more are coming and could/should be harvested.

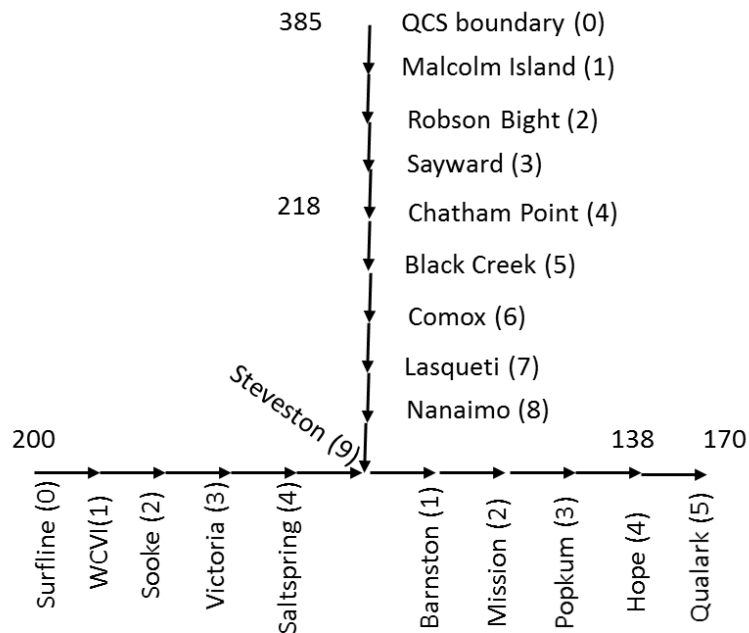


Figure 1. Movement of Fraser River sockeye. Named landmarks show roughly where fish are each day after entering the two gauntlet fisheries (Johnstone and Juan de Fuca Straits)

There are five basic risks in the management of salmon gauntlet fisheries: (1) overfishing (measured as failure to achieve escapement goals); (2) underfishing (allowing more fish to escape than “needed” for maximum future production; for the major Fraser sockeye stocks, the total excess of escapement over MSY-based escapement goals since 1996 has been about 24 million fish (Fig. 2), representing an economic loss to industry of at least \$300 million); (3) failure to achieve allocation goals between the US and Canada and among the Canadian fishing interests (seine, GN, troll, FN); (4) erosion in stock structure caused by overfishing of some substocks; and (5) “tail-end loading”, i.e. distortion in exploitation rates suffered by early versus later running fish such that there is selection against later run timing. Most debate about how to improve Fraser River management has been about how to reduce risks (1)-(4), and the tail-end loading risk has largely been ignored despite many warnings over the years about its potential importance for long term sustainability.

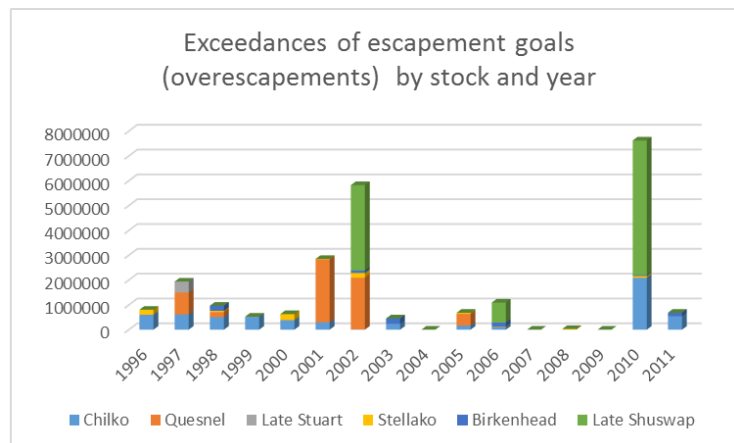


Figure 2. Exceedances of DFO estimates of optimum escapement (to maximize long term average yield) for major Fraser River sockeye stocks in recent years.

Improved inseason run size estimation would help to reduce at least the first three risks. Unfortunately, even knowing escapements exactly would be of only minor value in improving the inseason estimation. The main cause of inseason estimation errors is not inaccuracies in estimates of catch and escapement to date, rather it is uncertainty about the proportion of each total run represented by these estimates to date (Adkison et al. 2015). To see why this is, consider how the inseason estimates are constructed: the estimate for each date is basically equal to the estimated run to date, divided by the proportion of the run that these fish represent. In the Fraser case, estimated total run sizes  $\hat{N}$  are given by

$$\hat{N} = (C_t + E_t + T_t)/P_t \quad (1)$$

where  $\hat{N}$  is the run size estimate (by stock timing group) based upon data up to day or week  $t$  of the season,  $C_t$  is the cumulative catch as of time  $t$ ,  $E_t$  is cumulative escapement as of time  $t$ ,  $T_t$  is the estimated number of fish currently in transit (en-route) from the outside end of the Gauntlet (Fig. 1) to the escapement monitoring point, and  $P_t$  is the estimated proportion of the total run that has arrived at the outside end of the gauntlet to date. Note that when  $P_t$  is small, e.g. 0.2, dividing the catch+escapement+transit number by it means multiplying by  $1/P_t$ , e.g. expanding the data by 5x when  $P_t=0.2$ . Such expansion factors are obviously suspect. Further, in the Fraser case the only information currently available about  $T_t$  is from outside catches and quite variable test fisheries, yet  $T_t$  can be large; for a typical run timing pattern, at the time when 20% of the fish have reached Mission roughly 50% of the run has entered the northern fishing areas, i.e. 30% of the total run is in the  $T_t$  in-transit category (and at risk to harvesting). The  $T_t$  in-transit situation is much worse for late run stocks that hold off the Fraser River mouth, such that as much as 90% of the fish that have survived the outside fisheries may be at risk to river-mouth fisheries without there being any sound inseason estimate of the number of holding fish (a good example was 2014, where estimates of the number of fish holding off the river mouth ranged from as low as 2 million to over 6 million; see Appendix D for a possible way around this problem). But even if there were no uncertainty about  $T_t$ , there is major interannual variation in the  $P_t$

pattern that makes any inseason estimate highly suspect for  $P_t < 0.5$ , i.e. before 50% of the run has entered the fishing areas (Fig. 3).

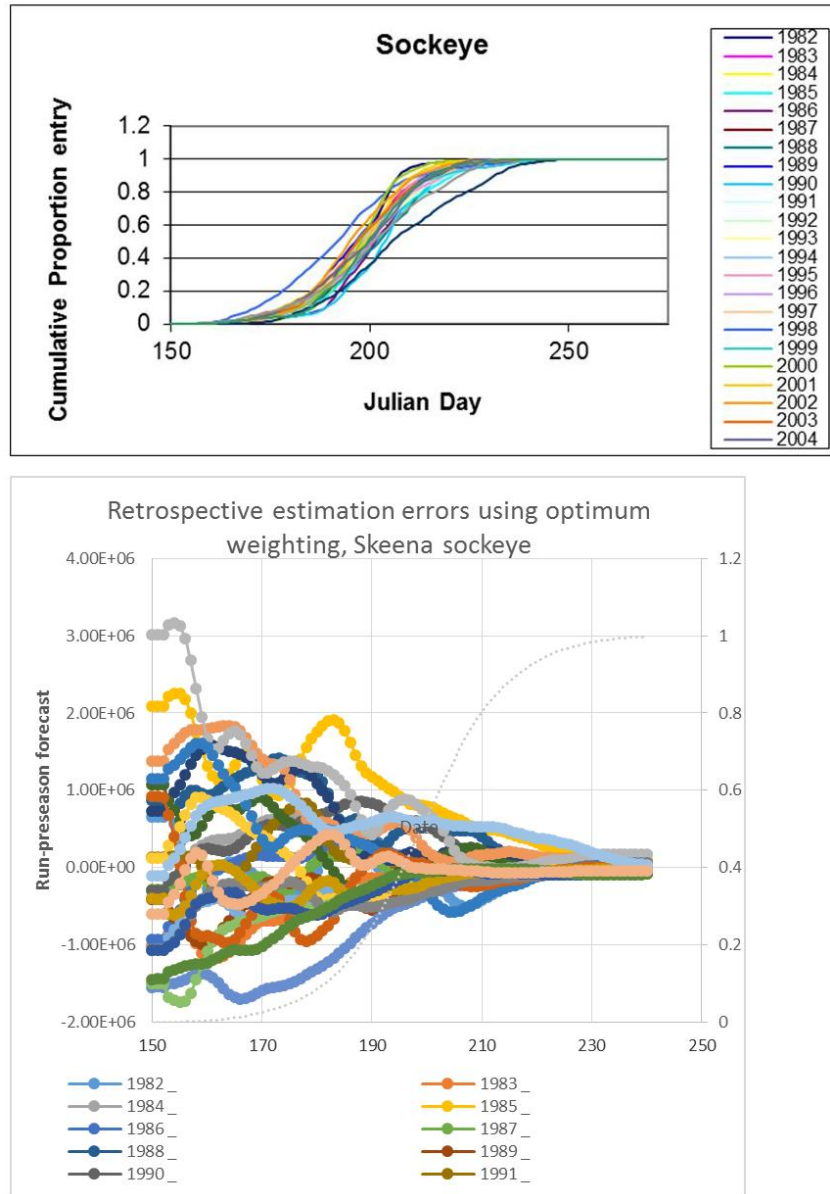


Figure 3. There is high interannual variation in run timing of sockeye salmon, as measured by the proportion  $P_t$  of the run that has entered fishing areas as of any date (top panel), and this causes large retrospective errors in inseason run size estimates (bottom panel). Note how estimation errors are large before Julian day 200, when  $P_t=0.5$  on average. Example data shown here are for recent reconstructions of sockeye entry patterns for the Skeena River, where entry patterns are easier to reconstruct than for Fraser stocks due to simpler migration patterns (Hawkshaw, ms in prep.).

There is apparently a belief in DFO that it is possible to still use the historical management strategy of the IPSFC of taking large catches in outside (Johnstone Strait) fisheries, then using inside (river mouth and upstream) "clean up" fisheries to fine tune the allowable harvest so as to avoid large exceedance of escapement goals. But particularly for late run stocks, that historical strategy relied heavily on abundance estimates from purse seine models to assess the likely numbers of fish holding off the river mouth, and even those estimates were not always reliable (e.g. in 1994 when slowing of migration through the Johnstone Strait apparently led to higher purse seine exploitation rates than expected, and dangerous overestimation of the run size escaping to the river mouth).

In addition to overall run size estimation that is perilous before at least half the fish have been seen, the cumulative acoustic data can be used at any time during the season for short term trend projection of the number of fish likely to arrive at acoustic monitoring sites over the next few days, for early and summer runs. After correction for harvest effects, these projected arrivals represent the current number of fish moving through fishing areas near the river mouth, and these estimates can be very helpful particularly for achieving US/Canada allocation objectives since the US fisheries are all within a few migration days of the Mission acoustic facility. The sea-ward test fisheries (areas 20, 12, and 13) also provide information that is crucial to making estimates and projections of incoming abundance, but at present these test fisheries are highly variable due to low sample sizes and have quite uncertain catchability coefficients (expansion factors). It must be emphasized again that these projections are not reliable for late run fish pooled at the river mouth and liable to move upstream in quite unpredictable patterns.

Three additional and important uses of acoustic data from Mission are for (1) direct confirmation (or not) of run sizes indicated about one week earlier by test fisheries, (2) providing direct estimates of the numbers of fish entering the important FN and recreational fisheries downstream of Hope, hence offering assurances of progress toward escapement goals and options for improved management of these in-river fisheries that may become more important in future management; (3) providing direct escapement estimates for pink salmon, for which escapement estimation using mark-recapture methods is difficult or impossible (pinks use a wide variety of spawning habitats and may shift spawning distributions unpredictably from year to year); and (4) improving stock-recruitment estimates by providing en-route mortality estimates (as differences between acoustic estimates at Mission or Qualark and spawning ground spawner estimates) as a component of total recruitment for some stocks in recent years (the majority of stock-recruitment data pairs for most stocks are from before 1990, and are spawning ground estimates of spawners and recruitments estimated as spawners plus catch; these data pairs do not depend at all on the acoustic information).

It appears to be an assumption in DFO harvest management planning that the overall objective "conservation first" implies achievement of numerical escapement goals as a top priority, and this

assumption creates a strong demand for both inseason escapement tracking and the earliest possible improvement in run size estimates. But the assumption is actually not correct; ecological sustainability requires only that exploitation rates remain below the maximum sustainable rate at low stock size. As they are calculated from spawner and recruitment data, numerical escapement targets (optimum spawning numbers predicted from stock recruitment equations) are in fact intended to achieve the economic objective of maximum long term yield. This is questionable as an objective in the first place, because it ignores social and economic hardship implied by high interannual variation in harvests (Hawkshaw and Walters 2015). Thus it would be quite possible to move from emphasis on achieving escapement goals, which implies in-season emphasis on acoustic data as measures of achievement, to emphasis on limitation of exploitation rates which was historically and still can be achieved by time-area closure management without any estimation of numerical stock size at all.

Two management practices are now contributing to “tail-end loading” (in the Skeena as well the Fraser sockeye fisheries), i.e. higher exploitation rates on the later-arriving fish of some stocks, except in years like 2013 when overall exploitation rates have been very low (Appendix A). The first is the policy of setting initial quotas for the ITQ fishery to low, “safe” values while planning to release additional quota as inseason stock estimates improve. As shown Table 1, typical overall exploitation rate goals of around 60% cannot be met at all unless first-half exploitation rates of at least 30% are allowed, and even relatively modest precautionary first half exploitation rates of say 40% result in having to double (to 80%) the exploitation rates on the second half of those runs.

Table 1. Effect of conservative exploitation rate choices for the first half of runs on exploitation rates needed on the second half of runs to meet a 60% overall harvest rate objective. Note how severe the difference in second-half rates needs to be when first half rates are very conservative.

Exploitation rate allowed on first half	Exploitation rate required on second half to meet 60% overall rate objective
0%	120%
10%	110%
20%	100%
30%	90%
40%	80%
50%	70%
60%	60%
70%	50%
80%	40%

The second practice that could cause tail-end loading is “escapement-based triggering” of fishery openings as part of the precautionary approach, where cumulative escapement estimates are watched closely and fishery openings are avoided until it appears reasonably likely that escapement objectives will be met.

Tail-end loading is an extremely dangerous practice from the standpoint of ecological sustainability, and can in fact be far more deleterious over the long term than regular failure to meet numerical escapement goals. Run timing patterns are highly heritable, and increasing mortality rate of later-arriving fish acts to select for earlier run timing (Adkison and Cunningham 2015; Quinn et al. 2007). This is especially dangerous in the Fraser system, since persistent warming of the river driven by climate change is very likely, and one of the most likely adaptive responses to this warming will be (absent selective fishing effects) a shift to later run timing.

There is a hopeful point about how to avoid tail-end loading: relatively simple spreadsheet models (Uplanner demo provided) can be used to do pre-season planning of fishery opening patterns (time-area openings) that would result in relatively predictable overall exploitation rates distributed evenly over the run timing patterns of the major stock groupings. These pre-season opening plans can then be modified during the season, but will generally only need to be if there are large deviations from preseason predicted run sizes or realized exploitation rates in some openings. Currently, preseason planning does use a spreadsheet model that may be unnecessarily complex, and appears to focus mainly on achievement of escapement and allocation goals; it does not appear that such detailed planning of openings is being done with any commitment to the planned openings, and this leads to opportunity for arbitrary risk management decisions by fishery managers (“let’s wait another week until we are more sure of the run”); with detailed pre-season plans, such decisions would be open to scrutiny to determine whether extra caution is really needed.

Another advantage of earlier fisheries to avoid tail-end loading is that these fisheries can provide useful information about run sizes well before fish reach Mission, without causing high risk of overall overfishing. Conditions for participation in these fisheries might include detailed (space/time) catch reporting and use of particular gears and fishing locations. If these fisheries are intense and localized, they will take a high proportion of the run at risk to them, each catch then being a direct estimate of the number of fish in the exposed run segment or “boxcars” fished. This is basically why the “purse seine models” were useful for providing earlier run size estimates in historical fisheries management, especially to estimate the number of late run fish escaping them and likely pooling at the Fraser River mouth.

What if there were a reversal in the philosophy of management, to “front end load” the fisheries by always allowing early, pre-planned fishery openings while concentrating corrective actions after better inseason estimates become available? This would certainly reduce the probability of achieving numerical escapement goals for years when returns are smaller than expected based on pre-season forecasts. But assuming that good inseason estimates become available when about 50% of each run has passed, the maximum possible overall exploitation rate on each run would then also be on order 50% (i.e. if all fish from the first half of the run were harvested). It is easy to demonstrate using models like the FRSSI simulator that putting such a 50% lower bound on annual exploitation rates would not in fact endanger any of the major sockeye stocks, and would only result in a 10-15% loss of long-term yield compared that attainable if escapement goals were reached every year. This is a small price to pay for predictable fishing opportunities and reduction in genetic impacts and wastage of surplus production now being caused by tail-end loading.

The risk of high exploitation rates when early openings are allowed but run sizes are much lower than expected (like 2009, 2015) is not actually all that high, because of how fishermen behave. When

abundances are low, a high proportion of fishermen cannot achieve catch rates high enough to cover operating costs, i.e. fishing effort and exploitation rates decrease as a “bioeconomic response”, and they simply do not go fishing. This response is mainly helpful for achieving stock-dependent exploitation rate goals in situations where overall exploitation rates are also limited by taking harvests mainly in short, spatially restricted fishery openings.

Most of the complexities of current inseason management, with attendant need for escapement estimates from the acoustic facilities, could be avoided by simply moving back to management based on fixed exploitation rates that can be achieved by limited time-area openings independent of stock sizes. Simulation studies comparing fixed exploitation rate to fixed escapement harvest control rules (and to other TAM rules) typically show relatively low loss in long term yield due to the regular occurrence of below-optimum escapements when exploitation rates are high even in low abundance years (e.g. Pestal et al. 2011). Table 2 shows mean annual yields from 200 year simulations of alternative harvest control rules for 10 of the Fraser sockeye stocks, with stock-recruitment parameters estimated from the data provided for Cohen Commission analyses. These simulations show that there would be large loss in yields from using conservative escapement goals calculated using the Ricker model, for those stocks that have cyclic dominance patterns better described by the Larkin model (which predicts much lower optimum escapements for the cyclic stocks, basically to prevent strong negative effects on productivity of cycle line interactions). Importantly, the Larkin model predicts considerable negative effect of exploitation rate caps currently included in TAM rules (FRSSI working group, 2014), and better performance from simply fishing at 65% annual rates than from setting conservative escapement goals using the Ricker model.

Table 2. Predictions of mean annual yield (millions of fish) from 200 year simulations of alternative harvest control rules for 10 Fraser sockeye stocks (early Stuart, late Stuart, Stellako, Bowron, Raft, Quesnel, Chilko, Seymour, late Shuswap, and Birkenhead). Recent TAM rules are close to the “Larkin S target” row with 65% cap, but escapements actually achieved have been closer to the “Ricker S target” row.

	No TAM cap	65% TAM cap
<b>Ricker S targets</b>	3.83	3.23
<b>Larkin S targets</b>	6.76	5.14
<b>Fixed 65% HR</b>	4.99	4.99

There is a very disturbing possibility that delayed density dependent effects in combination with highly precautionary harvest rates have already resulted in the Fraser sockeye system as a whole moving back to the abundance pattern that it exhibited before 1900, i.e. only one very strong year out of every four followed by three very low years. If this pattern continues, there will only be significant commercial fisheries, with attendant need for improved inseason management, only when there are dominant late run years. But if there is a decision to try to break up this emerging dominance pattern, a basic requirement will be to fish much harder in the dominant return years so as to reduce escapements enough to weaken delayed density dependence effects and allow rebuilding of off-cycle lines. Much improved inseason assessment information, especially for abundance of late run fish reaching the Fraser River mouth, would be needed in order to meet that



requirement for higher exploitation rates on dominant lines without high risk of severely overfishing those lines. As noted in the next section, the Mission facility as currently operated cannot be trusted to meet that need; its estimates for high late run years continue to be unreliable.

It has long been asserted that Fraser River sockeye are managed by run timing groups (early Stuart, early summer, summer, late) with different target exploitation rates and escapements for each group (e.g. Woodey 1987). But in reality, run timings except for the early Stuart have so much overlap that it is not possible to manage the early summer, summer, and late runs for substantially different exploitation rates. Rates have long been reduced (since the mid-1980s) for the early Stuart, but have covaried strongly and have been within 10% or so of each other for the other timing groups. This raises considerable doubt about the value of having good inseason escapement estimates by timing group (and hopefully major stocks within each group) at Mission or Qualark.

### Analysis of Differences Between Estimates (DBEs) at Mission and Qualark

This section examines broad patterns that have been found in DBEs, and comments on possible causes for these differences. Data used in this section are described in Appendix B, where there are also instructions for accessing powerpoint presentations by PSC and DFO that describe the basic operation of the facilities and how that operation has changed in recent years. The basic findings of this section are that (1) large DBEs are associated mainly with large late runs, for which the Mission and Qualark escapement information is of limited value except for management of FN fisheries, and (2) larger DBEs may have been caused by “blind spots” in acoustic coverage at both sites. Two other possible causes of DBEs were evaluated (errors in estimation of escapement and catch between Mission and Qualark, “beam saturation” at one or the other sites during times of high migration rates), but these do not appear to have caused large cumulative DBEs except that there could have been beam saturation at Mission in 2010 during the very large late run that year.

#### Patterns in DBEs, 2008-14: the main issue is estimation of late run escapement

Proponents of the two acoustic systems insist that each is giving accurate estimates of sockeye passage, except perhaps later in the season in pink return years. Estimates of total DBEs for 2008-2014 prepared by PSC staff (Table 3) show that the estimates are indeed broadly comparable, in years ranging from very low (2009) to massive (2010) sockeye runs.

Table 3. Summary of DBEs for Mission and Qualark, compiled by PSC staff. Note that the Mission estimate for each year is corrected for estimated escapement of stocks spawning below Qualark and for FN catches. Potential causes identified by PSC staff for years of larger percentage differences shown in red.

Year	2008-2014	2008	2009	2010	2011	2012	2013	2014
Mission	26,258,000	990,000	610,000	12,248,000	1,100,000	984,000	1,657,000	8,553,000
Qualark	26,392,000	916,000	572,000	14,044,000	1,333,000	953,000	1,605,000	6,966,000
%DBE	-0.5%	7.5%	6.2%	-15%	-21%	3%	3%	19%
<i>p</i> -value (paired)	0.8439	0.2106	0.4752	< 0.0001	0.0427	0.6720	0.2933	0.0016
Remarks	Identical	Similar	Similar	Different (M<Q)	Different (M<Q)	Similar	Similar	Different (M>Q)
Potential Causes				Inadequate sampling of RB late-run fish passage at Mission after Sept 13	50% total sockeye run below Qualark: lower-river stock ID error could have larger impact on projection			1. In-river fisheries; 2. Extremely low discharge (esp late-run peaks) challenged sampling conditions at either or both sites.

In comparing estimates from the two locations, it is important to recognize that neither site gives a complete count of fish passing the site. Each estimate of hourly or daily passage consists of a sum of actual counts  $CD_h$  by device and hour  $h$ , with each count multiplied by expansion factors  $ED_h$  representing the estimated (or assumed based on sampled area/time) proportion of fish represented by that count:

$$N_h = \sum_n CD_h ED_h \quad (2)$$

Statistical variation in these  $N_h$  estimates (due to fine scale space-time variation in fish movement) has been examined empirically (Xie et al. 2012; Xie and Martens, 2014), and this variation has been found to have coefficients of variation CV on order 0.05-0.1 depending on ED. For Qualark, the sum in eq. (2) is over the DIDSONs at the two banks, and the image sampling protocol typically involves cross-validated counts for 20 min/hour so that  $ED_h$  is around 3 (Timber Whitehorse, pers. Comm.). For Mission, the sum is over nearshore estimates for DIDSONs and split-beam counters (and counting slices) that see directional movement of individual fish, and also a mobile single beam count of densities across mid-river that requires an ED expansion factor representing fish movement speed and direction and possibly corrections for avoidance of the sampling vessel by fish (Xie et al. 2008). For Mission, there is also expansion of estimates to correct for acoustic blind spots near the inshore river bottom.

It should be noted that incomplete counting and the random statistical variation that it causes in hourly abundance estimates is not a significant cause of imprecision in estimates over longer time periods (days, cumulative numbers over multiple days). The CVs of such cumulative estimates are much lower than the CVs of the individual counts. For a cumulative estimate that sums over  $n$  counts with proportions  $p_n$  of the total estimate in each count, the cumulative estimate has CV equal to the hourly estimate CV times the square root of the sum of squares of the  $n$   $p_n$  values. This root sum factor typically has values less than 0.1 even for daily counts, and on order 0.03 for whole season sums.

In other words, all of the daily and seasonal estimates presented for both sites are extremely precise in terms of random statistical counting effects, and in fact are grossly more precise than is actually needed

for effective management advice. Any substantial difference between the sites must be due to noise caused by relatively small stock composition samples (see Appendix C), errors in catch estimates, and statistical bias (inaccuracy) caused by use of incorrect (or incomplete) expansion factors EDh.

In order to compare estimates (expanded counts) from the two sites, it is necessary to (1) account for the time required for fish to move from Mission to Qualark (2-3 days), and (2) loss of fish during that movement, due to escapement to lower river stocks (mainly Harrison, Weaver, and Birkenhead) and to FN catches upstream of Mission. Estimation of losses by PSC staff has been done by using stock composition estimates at Mission. So if the total Mission passage estimate for a day is  $N_d$ , it has been assumed that  $N_d(1 - P_{lower}) - FN_{catch}$  should have reached Qualark 2-3 days later, where  $P_{lower}$  is the estimated stock composition proportion of lower river stocks for day d. Some fine scale patterns in the day-to-day DBEs (autocorrelated deviations with persistence times of a few days) are almost certainly due to statistical errors in the Plower composition estimates. There are likely also errors in the FN catch estimates, and at least some unaccounted en-route mortality especially at times of high river temperatures.

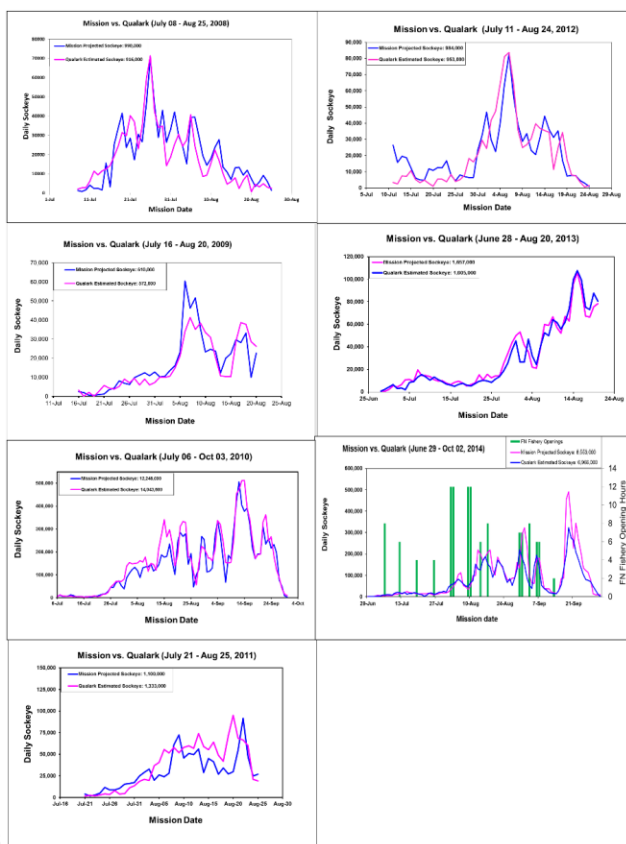


Figure 5.

Figure 4. Estimates prepared by PSC staff of daily sockeye escapements at Qualark compared to predicted numbers for the same days from Mission daily total escapement two days earlier, corrected for estimated escapement to lower river stocks and FN catches. Note large scale differences for these graphs between years of low (2009) versus very high (2010, 2014) total abundance.

Note that while the differences between the sites in daily estimates appear visually to be largest for 2011 (when about 50% of the Mission total estimate was assigned to lower river), the total difference for that year was not large because the total run was small (Table 3).

More detailed comparison of daily estimates from the two sites (Fig. 4) indicates differences between the sites that sometimes persist for periods of several days or weeks in most years. But when the data are plotted instead as cumulative escapement trends, i.e. in the main format used for inseason abundance estimation and management decision making, a very different picture of DBEs emerges (Fig. 5). Very large cumulative DBEs are evident only for 2010, when the corrected Mission estimate was much lower than Qualark, and for 2014 when the Mission estimate was much higher. Both of these

large discrepancies mainly represent late run (Shuswap) fish. Most of the negative DBE for 2010 is due to a very high estimate of lower system escapement for that year (1.4 million fish), when the DFO estimate of lower system escapement was much lower (around 0.5 million).

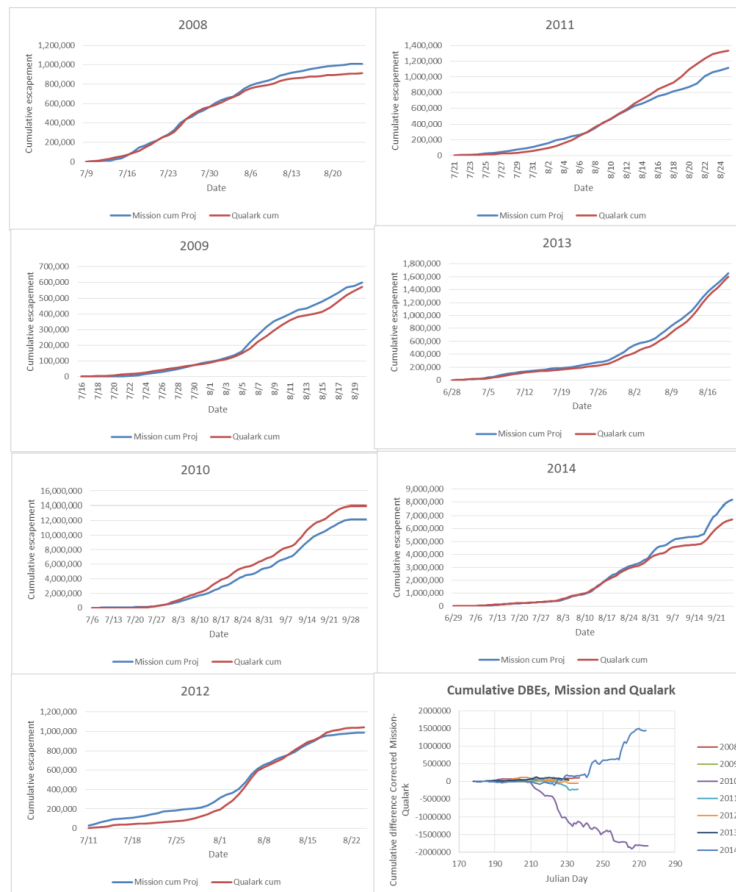


Figure 5. Plots of the same data as in Figure 4, but as cumulative rather than daily escapements. Such cumulative estimates are much more important for management. Lower right panel shows cumulative DBEs, indicating severe deviations in estimated total numbers only for 2010 and 2014.

The most pronounced DBE over the 2008-14 period occurred over the period Sept. 21-30, 2014. The Mission prediction of Qualark passage over this period was 2.72 million, and the DBE was 0.87 million. The estimated Bin 1 (inshore, high frequency DIDSON 4-9 m range) passage at Qualark was 1.57 million, and there is only reason to suspect fish were missed in the outside (8-9 m) part of this bin range (see Fig. 7). After correcting the Mission predicted passage for this inshore estimate, the Mission prediction of

passage through the Qualark Bin 1 8-9 m segment and Bins 2-3 (low frequency DIDSON 9-19 and 19-29 m ranges), where PSC staff have argue that fish could have been missed, was 1.15 million. But the reported Qualark passage for the offshore bins was only 0.3 million. So if the Mission prediction were actually the true Qualark offshore passage over the period, about 3.9 sockeye must have passed the last two meters of Bin 1 and Bins 2-3 for each fish actually estimated to have passed those bins. This is a much higher error rate than indicated by any known weakness in the Qualark counting system. So either the Mission estimate was high for some reason, or if not then there must have been serious en-route mortality between Mission and Qualark.

Another indication of possible overestimation of escapement by the Mission site in late 2014 is from comparison of Mission, Qualark, and near-final DFO estimates of escapement for the late Shuswap stock complex (Figure 6). The Qualark estimate was very close to the DFO estimate, while the Mission estimate was considerably higher and would imply considerable enroute or prespawning mortality if both Mission and DFO estimates are assumed to be correct. But note in Fig. 6 that the close agreement between Qualark and spawning ground estimates implies practically no mortality during migration if the Qualark estimate was indeed accurate, and that also does not seem likely hence suggesting that the Qualark estimate was at least somewhat low.

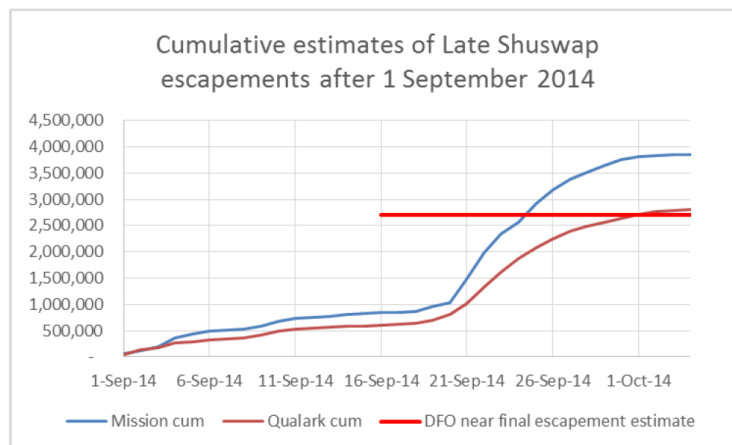
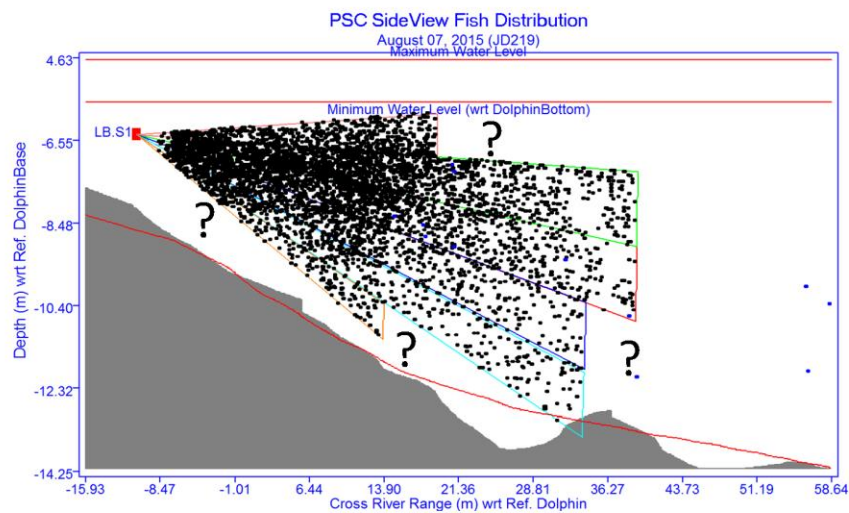


Figure 6. Comparison of cumulative estimates of late Shuswap sockeye escapement after September 1 (fish most likely to spawn successfully) from Mission prediction of Qualark passage, Qualark estimates, and DFO's near final escapement estimate for the late Shuswap complex.

#### Acoustic blind spots as possible causes of DBEs

While there is little reason to doubt the precision or accuracy of counts for well-ensofied sampling strata at either site, both sites have acoustic blind spots for which there are no direct observations under at least some flow conditions (Fig. 7). At Mission, the split-beam data are collected for pie-shaped slices extending offshore; for slices representing steeper beam angles, the estimates are deliberately cut off using "range-gating" of the signals; this is done because the more distant signals from these slices are contaminated with noise representing back-scatter from the bottom and things like gas bubbles

A statistical expansion procedure is used at Mission to account for fish moving through the blind spots. The data are partitioned into 1 m deep x 5 m spatial grid cells, then a 2-D nearest neighbor extrapolation method is used to calculate abundances for each unsampled grid cell from abundances in the adjacent onshore and shallower cells. For one example provided by Yunbo Xie, August 7, 2015, this led to a left-bank total flux estimate of 1900 fish where the observed number in sampled bins was 1235, i.e. the expansion was quite large. This expansion procedure can obviously cause both imprecision and bias in the overall daily estimates. For example, the expanded estimates could be low during periods when some fish or stock tend to move nearshore and hug the bottom, so as to give low density estimates in adjacent sampled bins; movement of fish higher in the water column could give densities in adjacent sampled bins much higher than numbers actually moving close to the bottom.



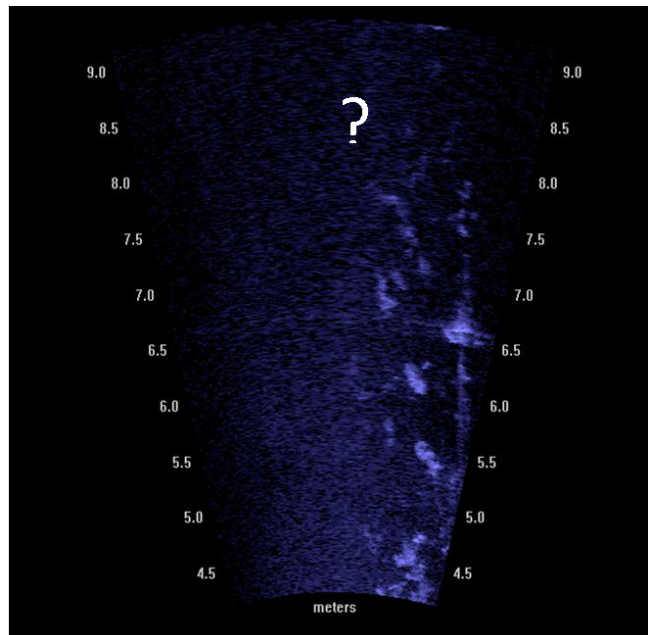


Figure 7. There are acoustic “blind spots” at both Mission and Qualark, indicated by question marks in these pictures. At Mission (top panel), “range-gating” (offshore cutoff) of the deeper split-beam counting slices causes a part of the cross-sectional area to be invisible to the gear. At Qualark (bottom panel), the near shore (high frequency 5-9 m offshore) imaging does not reach the bottom near the outside margin of the bin (the equipment rail on the bottom becomes invisible, particularly at low flows) so fish could move below the effective DIDSON beam area and not be included at all in the overall estimates. Split beam example image provided by Yunbo Xie, DIDSON image provided by Timber Whitehorse. Whitehorse points out that the Qualark image as shown could be misleading, since counting technicians can adjust gain in the images to see features like the rail in more detail when there is suspicion that images from any one gain might cause fish to be missed.

At Qualark during 2014, the two periods of high positive DBEs (Sept 1, 21-30) were associated with a strong shift in the distribution of counts across counting bins, with a much higher proportion of the counts occurring in the more offshore (bin 2, 9-19 m offshore and bin 3, 19-29 m offshore) counting bins (Fig. 8). It is the inshore bin for which PSC staff have argued that using the DIDSON rotation during low flow periods is most likely to cause fish moving near the bottom to be missed (bottom features are visible for the offshore bins 2-3, but it is not clear whether all fish moving through these bins are actually visible even higher in the water column even when technicians adjust image gains to avoid apparent blind spots evidenced by not seeing the rail at standard gain settings). There were also pronounced shifts toward deeper water at times earlier in the year, but these did not result in substantial DBEs possibly because flows were higher.



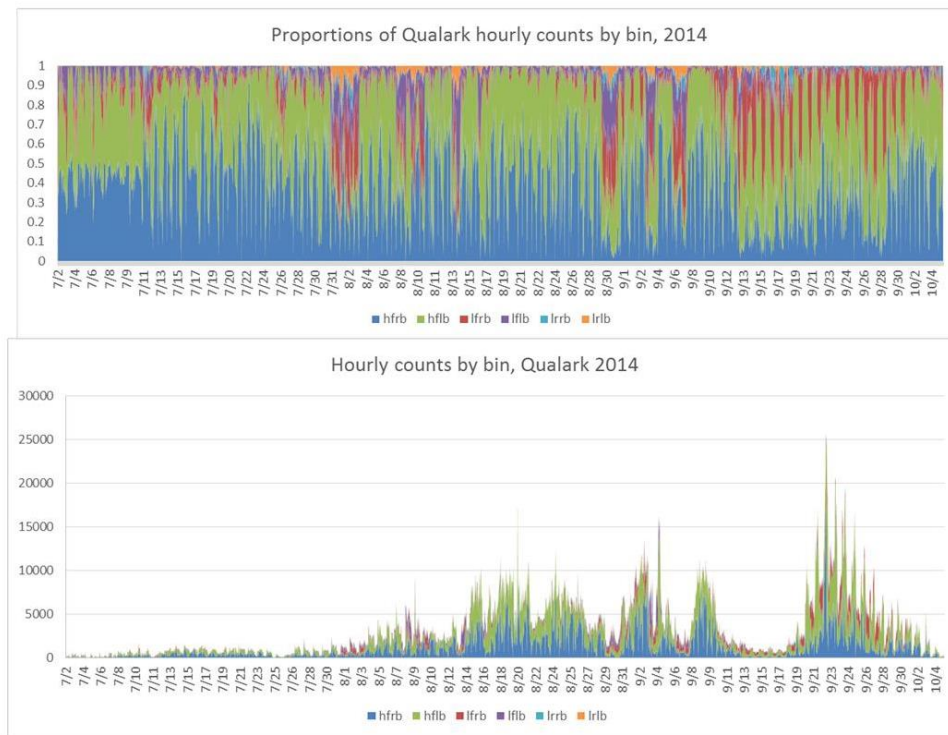


Figure 8. Hourly proportions and totals of Qualark DIDSON sockeye estimates by counting bin and river side, 2014. Typically most of the fish are seen in the hf (bin 1 high frequency 4-9 m) and lf (bin 2, low frequency 9-19 m offshore) bins, with very few fish in the lr (long range, 19-29 m offshore) bins. But during spikes of late run fish around September 1 and 22-26, there was a strong shift into the deeper water bins (5-9 m, 9-30 m) indicating high proportions of bin 1 fish near the outer edge of that bin where there could be a counting blind spot (and there may also be counting blind spots in the deeper bins). Note also that sharp daily drops in left bank proportions occur at 0700 and 1900, coincident with test gillnet fishing drifts and likely caused by net avoidance behaviors.

An interesting question is whether problems with extrapolation to blind spots could have caused the persistent pattern of apparent underestimation at Mission that started early in 2010 and became cumulatively worse throughout the migration (Fig. 5). In order for the extrapolation method to have underestimated abundances, densities of fish moving in the blind spots (hugging the bottom near shore) would have to have been much higher than in adjacent inshore and shallower counting bins. There was no definite onshore shift in Mission counts for most of 2010 as evidenced by the proportion of the daily estimates from offshore mobile vs inshore split beam counts (Fig 9), in contrast to 2014 when both of the periods of high positive DBEs were associated with dramatic decreases in the proportion of daily

estimates from the mobile gear. The 2010 DBEs first appear in early August, coincident with the start of operation of the Mission right bank DIDSON system (Fig. 10).

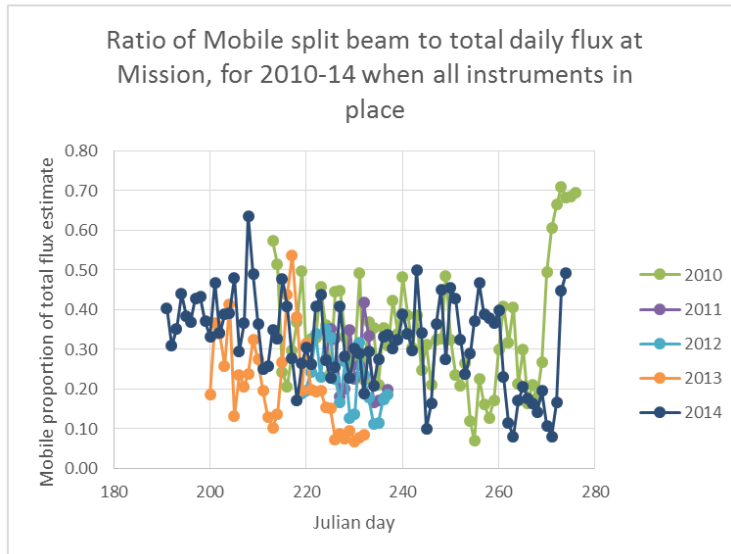


Figure 9. Proportions of daily total flux estimates from the mobile single beam counts at Mission, for years with fully operational nearshore sampling.

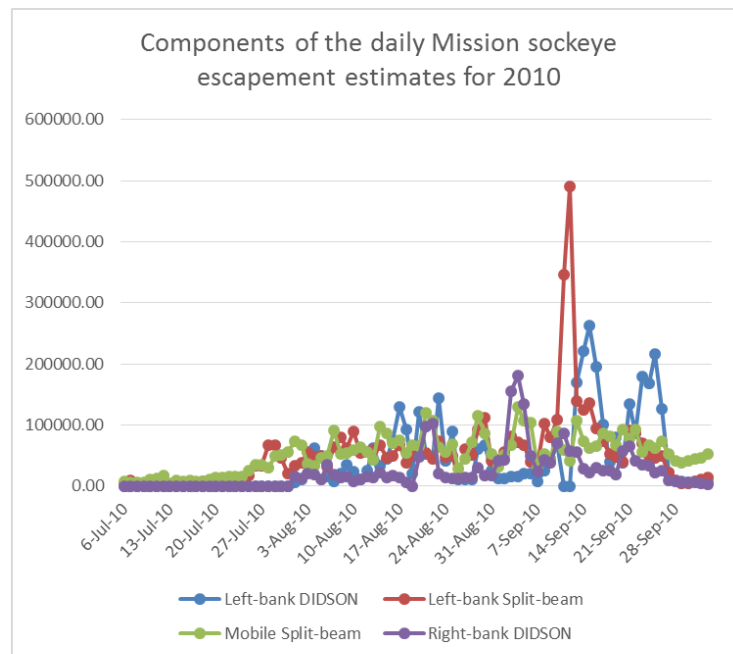


Figure 10. Daily Mission estimates by sample stratum for 2010; note right bank DIDSON started operation August 1, near the time when negative DBEs started to appear.

Another indication that expansion factors for Mission might be variable enough to cause considerable estimation error, especially at the level of stocks or run-timing groups, is the correlation between estimates of lower river escapements (Harrison, Weaver, Cultus, Birkenhead, and Chilliwack) at Mission, versus DFO estimates of spawning ground numbers (Fig. 11). There was one year (2009) when spawning ground estimates even exceeded the Mission estimates, though this difference was small enough to possibly be due to statistical variability of the DFO escapement estimates. Also, the observed slope of the relationship (1.61) implies an average en-route or prespawning mortality rate of almost 40%, which seems high for these lower system, late-run stocks.

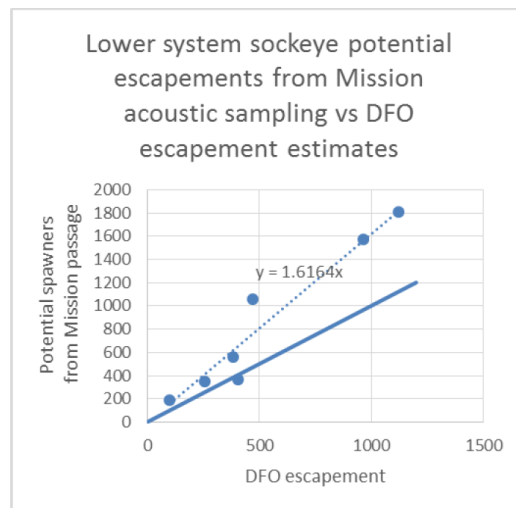


Figure 11. Comparison of estimates of DFO lower system (Harrison, Chilliwack, Cultus, Birkenhead, Weaver) spawning ground escapements with lower system escapements estimated at Mission. Solid line shows 1:1 relationship.

#### Concerns about tidal effects on Mission estimates

Water flow velocities at the Mission site are impacted by tides, and these velocities affect upstream movement rates of fish so as to affect estimates of the net flux of fish (since flux is cross-sectional density of fish times upstream movement speed). When Mission was operated with only single-beam mobile gear, the gear gave only cross-sectional density estimates and net upstream movement speeds had to be inferred from other data. But as the Mission system is currently operated, movement speeds and upstream-downstream movement directions of individual fish near the banks are estimated directly from the split-beam and Didson data so as to directly account for tidal effects, and cross-validation checks show that these stationary gears give very similar hourly flux estimates, i.e. counts of the moving “dots” from the split-beam gear do not differ substantially from the direct observations of fish shapes from the Didson gear. These flux estimates vary strongly with tides, and are much lower during periods of rapidly falling tides. Tidal variation in movement speeds for targets from the single beam mobile system are estimated from (assumed to be the same as) movement speeds directly observed in the split-beam samples.

So if any tidal effects are causing bias in the Mission estimates, these effects must be attributed to the mobile gear (offshore) component of the hourly flux estimates. As noted above, that mobile component is not a large component of the estimates at most times (Fig. 9). It is very unlikely that tidal effects are a major cause of DBEs, particularly the persistent cumulative DBEs that occurred in 2010 and 2014.

#### Options to reduce operating costs

Before examining the question of whether to operate only one of the two acoustic systems, it is worth asking whether operating costs at each site can be reduced enough to make closure of either site

unnecessary. The rich data set (hourly, multiple sampling strata) for 2010-2014 (Appendix B) can be used to ask what would have happened if the data from various strata and times had not been collected, with estimates of fish missed during those strata/times obtained instead by expansion of estimates from the remaining strata/times. One immediate result from examining the spatial stratum (bin) data is that it would be unwise to eliminate either of the near-shore acoustic devices for either location (i.e. unwise to sample passage only near one or the other river bank); as shown in Fig. 8 for Qualark and Fig. 10 for Mission, there are complex and persistent shifts in the bank to bank proportions of the daily estimates, which could lead to spatial expansions being wrong for time periods of up to one month.

One option at Mission that would save at least \$80,000 per year in labor costs during years of full operation (late runs, pinks present), and possibly as much as \$100,000, would be to discontinue the mobile single beam sampling and apply a simple expansion factor to the data from the nearshore split beam and DIDSON systems. As shown in Fig. 9, the proportion of the daily run estimate from mobile sampling is typically quite low (averaging around 30%) and highly variable from day to day, with only occasional shifts for longer times. When cumulative escapements patterns are estimated by replacing the mobile sample stratum data with a simple 30% expansion of the shore data, the cumulative escapement trends most useful for management decision making are only modestly affected (Fig. 12).

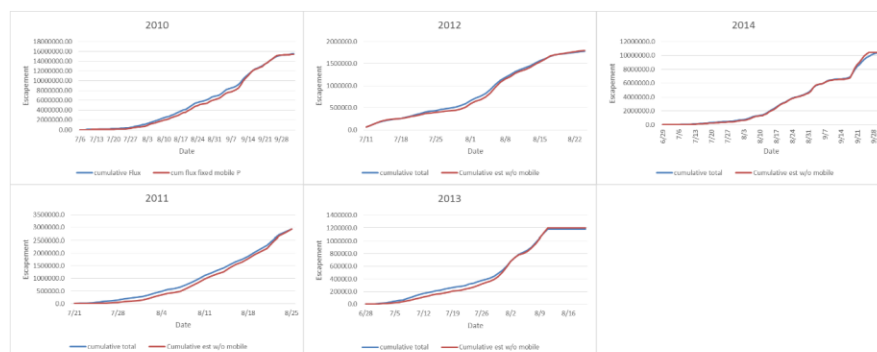


Figure 12. Effect on cumulative sockeye escapements at Mission of replacing the mobile single beam estimates for each day with a single 30% expansion factor on the near shore stratum estimates

A second option for reducing costs at both Mission and Qualark would be to shut down operations from 8PM-4AM, recognizing that fish movement is typically concentrated in daylight hours (modified by tidal effects at Mission). For Mission, this would result in savings in labor costs of roughly \$75,000 per year. For Qualark, the savings would be less, around \$50,000 per year. As shown in Fig. 13, replacement of the Mission nighttime (8PM-4AM) data with a constant expansion factor (based on assuming 73% on average of the daily run occurs during the daytime hours) would result in very similar cumulative escapement trend for much of each season, with some modest diversion later. As shown in the lower right panel of Fig. 13, the diversions would be due to a clear 2-year pattern in the daytime run proportions, with higher daytime proportions (near 80%) in odd years and lower (near 65%) in even years.



Figure 13. Effect on cumulative sockeye escapements at Mission of replacing the nighttime (8PM-4AM) estimates with a constant expansion factor based on the average (73%) daily proportion of the estimates occurring in daytime hours. Lower right panel shows interannual variation in the daytime proportions, showing that deviations in the cumulative estimates are due to odd-even year variation in the daytime proportion.

One might suspect that the two year even-odd variation at Mission is due somehow to pink salmon effects, but in fact the deviations in estimates begin developing well before any pinks arrive; a more likely explanation is that there is a 2-year periodicity in the timing of the rising tides that favor upstream movement.

Daytime (4AM-8PM) run proportions at Qualark are less variable than at Mission, on both a daily and annual basis, with on average 80% of the movement during day hours (Fig. 14). Interestingly, there is a trend toward a higher daytime proportion later in the year except in years of high late run abundance (2010, 2014), and a weak even-odd variation with the same pattern as at Mission.

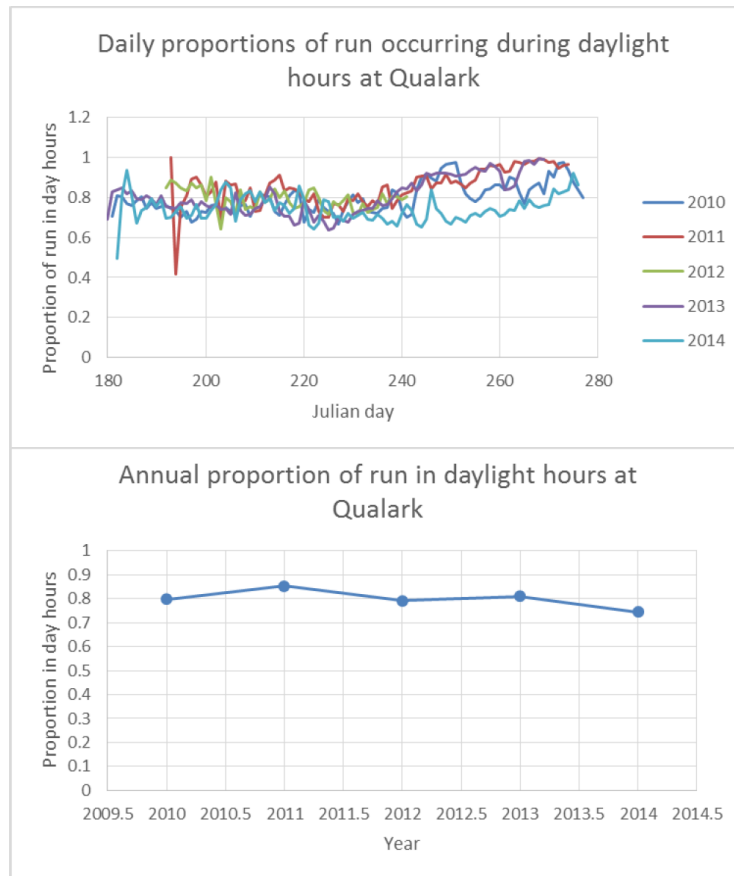


Figure 14. Daily and annual proportions of Qualark sockeye estimates occurring during daylight (4AM-8PM) hours.

The combination of eliminating mobile sampling and sampling only during daylight hours would reduce annual labor costs for Mission by roughly \$155,000, and for Qualark by only \$50,000 (DFO staff insist that there would be no savings at all), and neither cost-saving measure would substantially degrade performance of the systems at estimation of cumulative escapement. It should be noted that these savings are not large compared to the annual full-season (late run and/or pink year) operating costs, which PSC staff have estimated to be near \$750,000 for Mission and \$335,000 for Qualark.

### Options to obtain more timely abundance estimates

There are a number of options for using acoustic methods, along with improved catch monitoring, to provide earlier information on run sizes, so as to provide up to 10 days earlier updating of in-season abundance estimates. These rely on the idea that earlier assessment of abundances of fish entering the

system, particularly the Johnstone Strait, would provide both better information for management of quota fisheries along with estimates of escapement to the Georgia Strait, a critical issue particularly in large late-run years where the fish will be holding off the river mouth.

One simple option would be to use essentially the same approach as for the mobile sampling at Mission, using either a moving single-beam system or drifting dual beam systems to sample densities of migrating fish along a transect at the northern end of the Johnstone Strait (and possibly the outer Juan de Fuca, but that may be unnecessary if climate change continues to drive high northern diversion rates). These would be much longer transects than at Mission, hence less frequent passes with associated higher variances of cross-sectional density estimates (but probably much lower variances than are now seen in the seine and gillnet sampling that covers only tiny spatial area per set). There would also be severe problems separating migrating sockeye and pinks from the variety of other abundant fishes; for dual-beam sampling, this would be less of a problem since the combination of target strength and movement direction/speed would allow counting of only those fish likely to actually be migrating salmon.

To complement transect acoustic systems near the Strait entrance(s) and also existing net test fishing, it would be really helpful to have accurately geo-referenced data for each set from the purse seine quota fishery. Surely it is not unreasonable to ask those who profit from the ITQ system to provide GPS bearings and catches for each set that they make. Simply mapping the distribution of sets, let alone catches per set, would very likely give good estimates of spatial (and temporal) variation in fish distributions within the Straits, since it is quite certain that skippers are good at targeting fish (and avoiding areas of low density) and hence will find and move their sets with movements of the fish. These data along with the test fishing sets should be usable with spatial statistics models (geo-statistical models) to provide far less variable estimates of mean spatial catch rates (relative abundances) than is possible with the test fishing data alone. To assure that the spatial set information is provided in a timely way, vessels should be equipped with simple electronic logbook systems with regular cell phone reporting (as Ron Goruk and others have been testing with troll fishermen). A few years of spatial set distribution information might well demonstrate that the acoustic transects and be concentrated or located in zones of consistently high migrating fish abundance, hence allowing more transects and therefore more precise density estimates. Accurate geo-referencing of seine catches would also improve post-season reconstructions of run timing, by allowing more accurate assignment of seine catches to migration "boxcar" segments.

It might also be possible to capture acoustic data collected by seine vessels while searching for set locations, and combine these data with both catch and acoustic surveys in spatial statistics models. This approach is being used for Atlantic herring assessment (Claytor, 2000; Surette, et al. 2015)

Acoustic sampling transects could also be used in other locations to provide far larger spatial area coverage and sample sizes for relative abundance indices than is possible with test fishing gear. For example, multiple daily transects off the river mouth might provide much more useful information than the existing troll test fishery, particularly in years of high late-run abundance when the troll catch per effort exhibits hyperstability due to gear saturation. However, tests of this approach have also encountered hyperstability of the acoustic estimates due to beam saturation (Keiser, PSC tech. rep.).

The most promising acoustic option now available is the fixed split-beam system tested at Chatham point in 2007 (Vagle, et al. 2008). This system looked out into the Johnstone Strait from two backscatter



sonars mounted on a fixed underwater tripod, powered from the Chatham Point lighthouse and capable of being remotely controlled and sending timely information via the internet (i.e. at low field labor costs). Part of the project involved development of sophisticated software for identification and counting of migrating fish against the very noisy acoustic background near the site, and the test resulted in quite credible estimates of total sockeye run size despite obviously high variance in the day-to-day migration rate estimates. With two additional years of testing and refinement of this system in 2016-7, it very likely would be capable of providing a much better estimate of late run escapement to the Georgia Strait in 2018 than will otherwise be possible, and hence far safer management of fisheries near the river mouth for holding fish. There is also promise for distinguishing between sockeye and pinks (both even and odd year stocks pass that location) by using differences in spatial movement patterns (pinks migrate closer to shore, may show other distinguishing features given more data). After refinement, the Chatham point system would allow improvement in in-season abundance estimates about one week earlier than is possible using escapement data from Mission. If the equipment is still available for use in 2016-8, annual labor costs for operating the system would not likely be much more than the \$144,000 budgeted from PSC for the 2007 test. The overall budget for that test was much higher, but mainly due to labor costs associated with test fishing, which is already being supported.

### Mission or Qualark or both: which system should have priority given limited funding?

Table 4 reviews some basic pros and cons of Mission versus Qualark if funding limitations allow operation of only one of the systems. This table was developed in recognition that statistical accuracy of the estimates is only one, actually relatively minor concern in relation to use of the data for management. The table points out that comparison of the two systems is in fact one of those “doing the right thing versus doing the thing right” issues, where Mission provides information to address a wider range of sockeye and pink management concerns while Qualark may be more accurate but is much more limited in possible use.

A key objective for developing the Qualark system in the first place, despite its placement at a less useful location for management decision making, was to provide an independent check on suspect estimates from the Mission facility. It has met that objective to some degree, demonstrating that both facilities give very similar estimates for at least the early part of the annual escapement. But because of possible blind spot problems at both facilities along with uncertainties about stock composition and FN catches, Qualark has not provided an absolutely solid baseline against which to judge Mission, particularly in years of high late runs. So on balance, the strongest justifications for continuing operation of the Qualark facility would be its lower cost and potential to assist in correction of the blind spot problems at Mission. But dealing with the blind spot problems at Mission will require various direct measurements at the site (as has been done to cross-validate split beam estimates using DIDSON cameras), so this leaves only reduced cost as justification for continuing Qualark operations except as a means to check whether corrections made at Mission have in fact been effective. Proponents of continued operation of Qualark certainly cannot be faulted for being suspicious of any claim to having finally “got it right” at Mission. Note that it is not an argument against the Qualark-only option that it does not directly measure escapements of lower river sockeye stocks; in fact, it can in fact be used to estimate those escapements as its upriver escapement estimates times the Whonnock test fishery composition

estimates of the ratio of lower river to upriver abundance (the same ratio as used in calculation of predicted Qualark arrivals from total Mission passage).

Another hope for Qualark has been to provide post-season estimates on enroute mortality of upriver stocks, by comparison of the Qualark estimates with later DFO escapement estimates. This is a perilous approach to mortality estimation, due to statistical variation and possible bias in mark-recapture and other escapement estimation methods (e.g. expansion of partial DIDSON counts). A far more effective approach to the study of enroute mortality might be routine tagging programs used as in recent years to directly measure the timing and location of mortality by counting tagged fish passing multiple acoustic or radio tag receiver sites. This option would not of course preclude operation of Qualark by DFO to meet other objectives, such as cross-validation and monitoring of escapement estimation procedures and management of upper river fisheries.

Instead of closing one or the other system, another possible option is to use savings from reduced operations (daytime operation only at both sites, no mobile at Mission) to continue operating an integrated system with both facilities, perhaps increasing operations in years of large late run abundances when DBEs have been most severe (though the value of escapement information for late run abundance estimation and management is not that great). Unfortunately, it is not yet clear what the advantages of this integrated choice would be, besides making biologists more comfortable about counting acoustic returns that look like fish instead of counting moving dots and providing warnings of large, unmonitored disappearance of fish between the two sites. When discrepancies between the two components of the integrated system did occur, it would still be impossible (as it has been from data collected over the last five years) to decide which of the two component estimates (or required correction factors for lower system escapements and FN catches) was at fault. One could always argue from a scientific and risk averse management perspective that more years of comparative data from both sites are needed to fully evaluate possible estimation problems, especially at the Mission site.

Still another and apparently attractive option is to operate the Qualark facility only in years of large late runs when the Mission estimates are most suspect, and use savings from this (along with savings from reduced Mission operation) to operate a system at Chatham Point that would provide more timely inseason abundance estimates, especially for late run escapement to the Georgia Strait and river mouth. Combined with continued operation of the Mission facility, this option would avoid loss of inseason information about escapements of pink salmon to the major spawning areas between Mission and Qualark. As noted above, if the Chatham Point facility were operated beginning in 2016, there would be a two year evaluation and calibration period before it would be really needed for the next large late run in 2018.

It should be noted that a serious weakness in all acoustic system options is difficulty in estimating species and stock composition of the abundance estimates (Appendix C), i.e. separating pinks and sockeye and possibly also sockeye stocks. The current practice of obtaining species/stock ratios from net sampling is apparently not completely effective, especially for obtaining sockeye:pink ratios. But there is some promise for improving estimates of sockeye:pink ratios by statistical analysis of fine-scale differences in hydroacoustic spatial distribution and movement data (Vagle et al. 2008); in particular, pinks tend to concentrate near shore and to exhibit more sharply defined diurnal movement patterns, and may also swim a bit more slowly. There is also promise for improving the estimation of sockeye and pink proportions of the Qualark count by fitting the catch per effort test fishing data so as to provide

differential catchability coefficient estimates and an associated correction equation for observed versus actual proportions of the counts (Appendix E).

### Overall recommendations

There is a clear need to provide more timely and rather than more accurate and precise in-season abundance estimates from some combination of hydroacoustic and other sampling methods. To this end, the general recommendations of this report are:

1. Continue operation of the Mission facility with reduced sampling effort (without mobile and nighttime or falling tide sampling).
2. Use the savings from reduced Mission operation to help fund the following initiatives:
  - a. Testing and operation of the side-scan acoustic system at Chatham Point
  - b. Development of by-set, georeferenced catch reporting for the SN and GN fisheries in the approach areas (Johnstone and Juan de Fuca Straits), with attendant data capture (electronic logbook) and spatial data analysis software development to permit mapping of catch rate distributions and timing
  - c. Development and testing of systems for capturing acoustic data from fishing vessels while these vessels are searching for set sites, again in the approach areas
  - d. Testing alternative sampling methods and acoustic data analysis protocols for providing more accurate species composition (pinks vs sockeye) estimates.
3. Operate the Qualark facility, perhaps at a reduced level (not at night) and only in periods when information is needed by DFO for monitoring and management of in-river FN fisheries and for checking the efficacy of measures taken at Mission to reduce its bias, particularly once every four years when large late runs are expected and there is high risk of divergence between Mission and Qualark estimates.
4. If funding cuts force a choice to operate either Qualark at its current funding level or Mission at a much reduced level, and if pink stock assessment is not a priority, then only the Qualark facility should be operated.
5. Continued operation of Qualark should be contingent on careful tests of its possible blind spots, in particular by operating test Didson cameras in a way that is sure not to have blind spots along the river bottom and offshore, and Didson cameras should be operated offshore at times to provide reassurance that there are not many fish moving along the bottom at distances more than 30m offshore.

Beyond these specific recommendations, there is also a clear need to carefully review the overall harvest management strategy for Fraser sockeye, and the current policy of shifting to quota managed fisheries that have much higher information requirements than the historical practice of limiting exploitation rates mainly through short time-area fishery openings. The current “escapement first” policies are causing unnecessarily high variability in fishing opportunities for all user groups and may well be leading to more severe interannual variation in run sizes (only one big run every four years) with attendant loss of portfolio effects that helped to stabilize catches during the latter part of the last century.



Table 4. Pros and cons of operating Mission versus Qualark acoustic facilities.

	MISSION	QUALARK
PROS	<ol style="list-style-type: none"> <li>1. Pink escapement monitoring</li> <li>2. Earlier inseason information (slightly, 2-3 days)</li> <li>3. Timely data to improve management of growing FN fisheries below Hope along with upriver FN fisheries given timely catch information from the fisheries below Hope</li> </ol>	<ol style="list-style-type: none"> <li>1. Probably more accurate estimates, especially if operations changed to remove blind spots</li> <li>2. 50% Lower cost</li> <li>3. Less serious “interference” problem with pinks</li> <li>4. Escapement information for interior chinook, coho</li> <li>5. Cross-check information for annual escapement estimates</li> <li>6. Data for management of upriver FN fisheries</li> </ol>
CONS	<ol style="list-style-type: none"> <li>1. Probably less accurate due to tide effects, wide river, bottom shape where migrating fish concentrate</li> <li>2. Twice as costly</li> <li>3. Possible severe under- and over-estimation for late runs</li> <li>4. Requires extrapolation for acoustic blind spots</li> </ol>	<ol style="list-style-type: none"> <li>1. Later inseason information (3 days)</li> <li>2. Limited upstream calibration check options</li> </ol>

## References

- Adkison, M.D., and Cunningham, C.J. 2015. The effects of salmon abundance and run timing on the performance of management by emergency order. Can. J. Fish. Aquat. Sci. Published on the web 15 June 2015, 10.1139/cjfas-2015-0174.
- Claytor, R.R. 2000. Fishery acoustic indices for assessing Atlantic herring populations. Doctoral dissertation, University of British Columbia. 307 p.
- English, K.K., T.C. Edgell, R.C. Bocking, M. Link and S. Raborn. 2011. Fraser River sockeye fisheries and fisheries management and comparison with Bristol Bay sockeye fisheries. LGL Ltd. Cohen Commission Tech. Rept. 7: 190p & appendices. Vancouver, B.C. [www.cohencommission.ca](http://www.cohencommission.ca).

- FRSSI working group. 2014. A brief history of Fraser sockeye harvest planning (2003-2013). Fraser sockeye sockeye 2014 planning workshop, handout 1.
- Hawkshaw, M., and C. Walters. 2015. Harvest control rules for mixed-stock fisheries coping with autocorrelated recruitment variation, conservation of weak stocks, and economic well-being. *Can. J. Fish. Aquat. Sci.* 72:759-766. <http://dx.doi.org/10.1139/cjfas-2014-0212>.
- Pestal, G., Huang, A.-M., Cass, A., and the FRSSI Working Group. 2011. Updated methods for assessing harvest rules for Fraser River sockeye salmon (*Oncorhynchus nerka*). Fisheries and Oceans Canada, CSAS Research Document 2011/133 (<http://www.dfo-mpo.gc.ca/csas-sccs>).
- Quinn, T.P., Hodgson, S., Flynn, L., Hilborn, R., and Rogers, D.E. 2007. Directional selection by fisheries and the timing of sockeye salmon (*Oncorhynchus nerka*) migrations. *Ecological Applications* 17(3): 731-739.
- Surette, T., LeBlanc, C.H., Claytor, R.R., and Loots, C. 2015. Using inshore fishery acoustic data on Atlantic herring (*Clupea harengus*) spawning aggregations to derive annual stock abundance indices. *Fisheries Research* 164:266-277.
- Vagle, S., Ding, L., Boesen, M., Cronkite, G., and Xie, Y. 2008. A study to determine the feasibility of hydroacoustic monitoring of migrating sockeye and pink salmon in the marine area. Southern Boundary Restoration and Enhancement Fund Project Final Report, Pacific Salmon Commission. 44 p.
- Woodey, J.C. 1987. In-season management of Fraser River sockeye salmon (*Oncorhynchus nerka*): meeting multiple objectives. *Can. Spec. Pub. Fish. Aquat. Sci.* 96:367-374.
- Xie, Y., Michielsens, C.G.J., Gray, A.P., Martens, F.J., and Boffey, J.L. 2008. Observations of avoidance reactions of migrating salmon to a mobile survey vessel in a riverine environment. *Can. J. Fish. Aquat. Sci.* 65:2178-2190.
- Xie, Y., Michielsens, C. G. J., and Martens, F. J. 2012. Classification of fish and non-fish acoustic tracks using discriminant function analysis. – *ICES Journal of Marine Science*, doi:10.1093/icesjms/fsr198.
- Xie, Y., and F.J. Martens. 2014. An empirical approach for estimating the precision of hydroacoustic fish counts by systematic hourly sampling. *N. Am. J. Fish. Manag.* 34: 535–545.

## Appendix A. Evidence of tail-end loading of Fraser sockeye exploitation rates in recent years

A basic recommendation for salmon management over the years has been to avoid differentially high or low exploitation rates on different parts of the run timing pattern for a given stock or run timing group (Fig. A1), except as necessary in response to inseason information indicating a much lower stock size than expected.

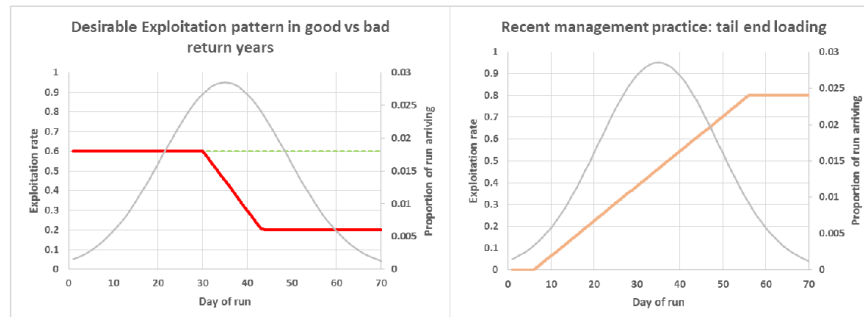


Figure A1. Exploitation rate patterns under alternative inseason management practices. Left hand panel shows desirable pattern with equal exploitation rate on all timing segments (green dotted line) except when run size is found during the season to be much lower than expected (red line). Right hand panel shows pattern that occurs when early openings are avoided as a precautionary practice.

PSC staff do annual run reconstructions for Fraser River sockeye, where for each entry timing date for each stock they estimate the catches and escapements of fish that entered the outside fisheries on that date. This is done by simply shifting catches and estimated Mission/Qualark escapements occurring on various dates to the estimated date when those fish entered the system, in a spreadsheet layout. Using these reconstructions, it is simple to estimate the overall exploitation rate suffered by fish that entered the system on any date, simply by dividing the total catch for the entry date by the estimated number of fish entering (catch plus escapement). The result of this estimation for stock data aggregated to the main timing groups (similar results are obtained on a by-stock basis) is a very clear demonstration that later arriving fish within each major run timing group have suffered higher exploitation rates in all but a few cases since 2010 (Fig. A2). The fishery was apparently shut down early in 2013 so the pattern is not evident for that year, and also for late runs in 2014.

The late run estimates shown in Fig. A2 must be interpreted with caution, since it is not clear that escapement timing dates for fish that hold at the river mouth correspond in any close way to the dates when those fish entered the outside fishing areas.

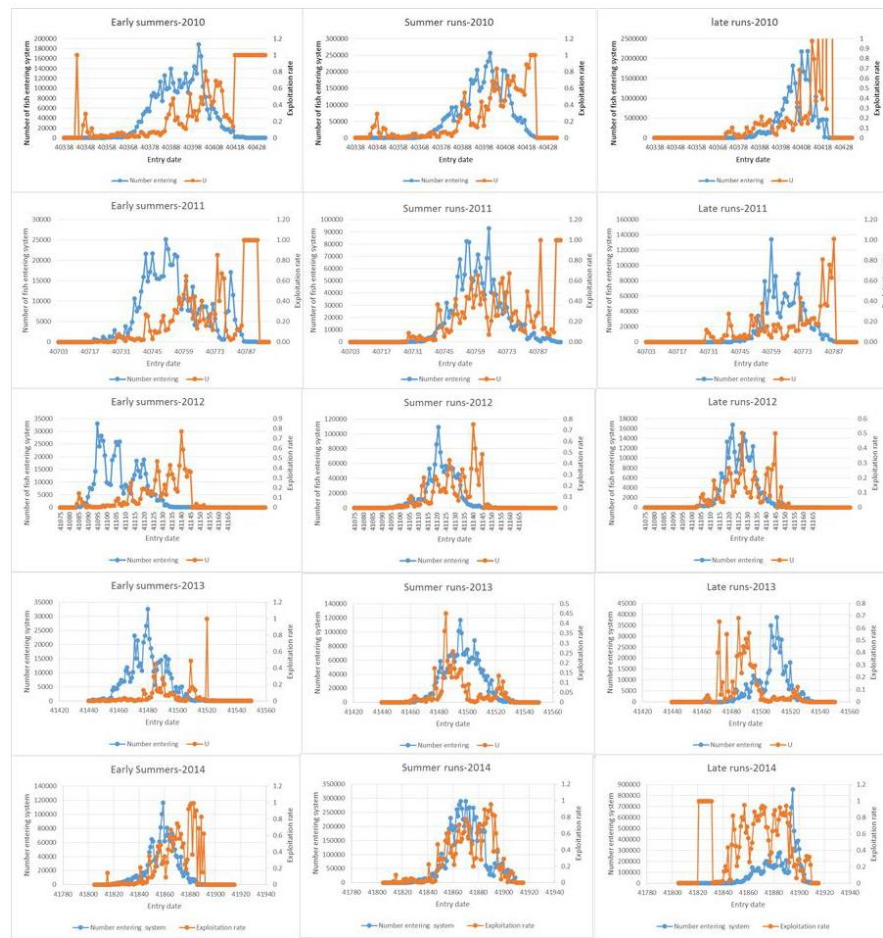


Figure A2. Estimates of daily number of fish entering approach areas by run timing group, and estimated cumulative exploitation rates suffered by each of these daily entry “boxcars”. Data from PSC run reconstruction spreadsheets provided by M. LaPointe and Catherine Michelsens, PSC. Exploitation rate (U) for each day (orange lines) is not the exploitation rate for fisheries occurring on that day, rather the rate suffered by fish that entered that day, on later days during their migration.



## Appendix B. Data sets used in analysis of DBEs

The analyses of hydroacoustic data presented in this report were based mainly on a set of powerpoint presentations and spreadsheets provided by PSC and DFO staff. Copies of these presentations and spreadsheets with calculations added to them for plots presented in the report are available from the Author, at the following Dropbox public link:

<https://dl.dropboxusercontent.com/u/51142274/Walters%20Report.zip>

These presentations and spreadsheets were

- 1) Detailed descriptions of operational characteristics of the Mission and Qualark sites, provided for Mission by PSC staff (mainly Yunbo Xie, ForCarlWalters\_July07,2015\_PSC.pptx) and for Qualark by DFO staff (mainly Timber Whitehorse, Attachment5\_HAWG june 2015\_JK.pptx).
- 2) Estimates of daily number of sockeye passing Mission and Qualark for 2008-2014, along with estimates by PSC staff based on stock composition sampling at Mission of the number of fish at Mission headed for spawning areas downstream of Qualark (DailyMissionSockeyeProjectionVsQualarkSockeyeEstimates2008-2014.xlsx). This was the core dataset used to estimate both daily and cumulative DBEs.
- 3) Hourly Qualark sockeye estimates for 2008-2014 (Qualark Hourly Counts\_2008-2014 v30Jul15.xls). Only the 2010-2014 data (with counts from both banks) were used in analysis of possible reductions in sampling effort and cost. Data are separated by bank (left, right) and counting bin (one high frequency inshore bin, two low frequency offshore bins)
- 4) Hourly Mission sockeye estimates for 2008-2014 (MissionHourlyCounts2008-2014.xlsx), used mainly to examine options for reduced sampling effort by omitting night-time counting.
- 5) Daily Mission total salmon estimates 2008-2014 separated by instrument (Didsons, split-beam, mobile) (CrossRiverDistOfMissionTotalSalmonEstimates2008-2014.xlsx). Used to assess impact of removing components from the system, particularly the mobile gear.
- 6) Cost accounting data for operation of Mission and Qualark, divided into personnel, site, and data processing cost components and with cost differentials for longer operation in some years (5\_final Acoustic Costing template FRSC.xlsx).
- 7) Tidal data used to verify spreadsheets provided by Yunbo Xie (TidalEffectsAtMission.ppt) that Mission hourly counts show peaks more closely related to tide (lower counts on falling tides) than to day-night cycles and that there is no systematic variation in Mission counts with the semi-lunar tidal cycle (data from <http://www.isdm-gdsi.gc.ca/isdm-gdsi/twl-mne/inventory-inventaire/interval-intervalle-eng.asp?user=isdms-gdsi&region=PAC&tst=1&no=7654&ref=maps-cartes>)
- 8) Estimates of daily Mission passage of lower river stocks, harvests of these stocks, and DFO escapement estimates from the NUSEDs database, prepared by I. Guthrie, PSC (SpawnerAbund\_v\_MissionPass\_Miss-Qual-stcks\_Walters\_2015-09-10.xlsx).
- 9) Daily estimates of total salmon passage at Qualark for 2008-2015, and daily total test fish catches by species, used in Appendix E to provide corrected sockeye and pink escapement estimates (data from multiple by-year spreadsheets provided by Timber Whitehorse summarized in the single spreadsheet "multiyear sockeye pink estimation at Qualark.xlsx).

### Appendix C. Variability in escapement estimates for individual stocks due to stock composition sampling

Even if the acoustic system(s) give precise and accurate estimates of daily and cumulative total sockeye escapements, there can be considerable variability in the estimates for individual stocks (or run timing aggregates) due to binomial sampling variation in stock proportions from the relatively small daily DNA samples. The daily DNA sample size target at each acoustic site is 50 fish, but even that relatively small number is difficult to achieve with gill net sampling when total abundance is low (Mike LaPointe, PSC, pers. Comm.). It is quite simple to simulate the effect of this binomial sampling variation on daily and cumulative escapement estimates for a given stock, for various assumptions about sample sizes and the proportion that the stock makes up of total daily escapement ("variability due to composition sampling.xlsxm" spreadsheet provided to PSC staff).

An example simulation of the binomial sampling variability for a single stock that represents 10% of the total run over the main days of its migration, with daily sample size 50 fish for DNA, is shown in Fig. B1. This basic message from this example is that fishery managers should expect considerable day-to-day variation in stock-specific escapement estimates, for any stock(s) that are low (<20%) proportions of total escapement.

Variation in cumulative escapement estimates across multiple (20) replicate samples for this simulated stock is shown in Fig. B2. Here the basic message is that composition sampling can cause quite high variation even in total escapement estimates for smaller stocks, and that the CV of the estimated cumulative escapement to date is quite high until at least 20% of the stock has escaped. This means that projections (expansions) of individual stock total escapements are expected to be quite poor even if there is no "process error" variation in the actual run timing curve away from a normal curve.

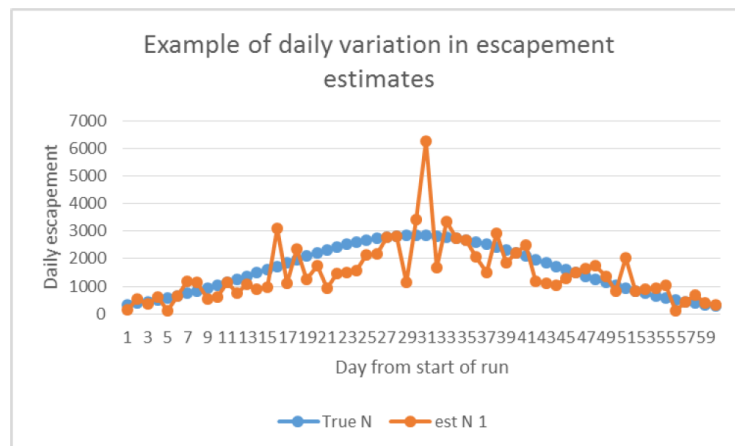


Figure B1. Example of simulated versus true daily escapements for a stock that makes up 10% of total escapement on average, with 50 fish collected for DNA each day. Accurate stock assignment based on the DNA data assumed.

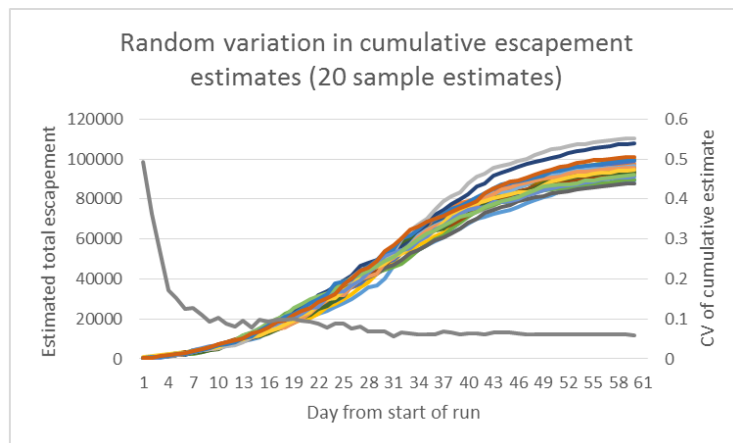


Figure B2. Variation in cumulative escapement estimates across 20 binomial sampling trials, for the stock shown in Fig. 1 (10% of total escapement, 50 fish/day). Note that CV of the cumulative estimate decreases over time but levels out at near the day of peak migration (30) for the stock.

Unfortunately, the relative high variability in estimates due to composition sampling shown in Fig. B2 cannot be readily reduced just by increasing daily DNA sample sizes. As shown in Table B1, the CV of final abundance estimates would not be substantially reduced, especially for smaller stocks, even by doubling the daily DNA sample size to 100. Much larger sample sizes of order 500/day might eventually be achieved at nearly the same cost as existing sampling by using new DNA sampling methods (B. Riddell, PSF, pers. Comm.), and that would certainly reduce uncertainty due to DNA sampling considerably.

Table B1. Effect of daily DNA sample size and stock proportion of total run on the CV of estimates of total escapement. Note that the CV of estimates are high for stocks that make up less than 5% of total escapement, even if DNA sample size were doubled.

		Stock Proportion			
		0.01	0.05	0.1	0.2
Sample Size	20	0.26	0.11	0.09	0.07
	40	0.20	0.11	0.06	0.05
	60	0.22	0.09	0.07	0.03
	100	0.20	0.06	0.04	0.02
	500	0.05	0.02	0.02	0.01

## Appendix D: using stock composition sampling and Mission escapements of summer run sockeye to estimate the number of late run sockeye holding at the Fraser River mouth

One of the more serious problems in Fraser River sockeye management is the accumulation of large numbers of late run fish off the Fraser mouth in years of dominant late Shuswap returns. This accumulation is highly vulnerable to seine and gillnet fisheries, but the number of fish still at risk to harvest is highly uncertain because the fish are not counted at Mission or Qualark until well after they enter the accumulation. Outside test fisheries and catches provide some indication of the number of late run fish that have entered the system, but estimates based on such data are not considered reliable.

PSC staff are currently using two methods to improve estimation of late run abundance (C. Michelsens, PSC, pers. Comm.). The first is to use in-season estimates of test fishing catchability of summer run fish (from summer run c.p.u.e., catch, and Mission escapement data) to improve estimates of test fishing catchability for late run fish in the approach areas, giving daily late run abundance estimates as test c.p.u.e. divided by catchability. This method avoids having to use pre-season estimates of late run test fishing catchability in expanding the test fishing c.p.u.e. data. The second method is to use estimates of the ratio of early summer Thompson smolts to late run Thompson smolts, along with Mission estimates of early summer escapement, to expand the early summer escapements into late run estimates, well before the late run fish arrive at Mission.

Fortunately, there may be a third way to estimate the daily number of late run fish arriving at the accumulation area, by using stock composition sampling in the Johnstone Strait in conjunction with estimates of daily arrivals of early summer and summer fish at Mission. Suppose the stock composition sampling on a given day  $t$  shows a ratio  $R_t$  of late run to early summer plus summer sockeye in the Johnstone Strait, and that the estimated number of early summer plus summer run fish passing Mission or caught in in-river fisheries below Mission about 10 days later is  $ES_{t+10}$ . Then an estimate for two days earlier of the number of late run fish arriving at the River mouth is just  $L_{t+8} = R_t ES_{t+10}$ . Accumulating these daily  $L_t$  estimates over time while subtracting estimated number of late run fish moving upstream to Mission gives a running estimate of the number of fish still holding off the Fraser River mouth.

Note that this method depends on the summer and late run fish having the same migration patterns between the Johnstone Strait and the river mouth, i.e. having the same northern diversion rates and suffering the same exploitation rates in outside fisheries. There is reason to doubt at least the equal vulnerability assumption, because of anecdotal evidence that late run fish may sometimes slow their migration in the Johnstone Strait so as to be more vulnerable to fisheries there (e.g. 1994). Note also that the method will begin to fail later in the season, as summer run entry numbers fall off and the  $R_t$  ratio increases without bound.

It should be further noted that the expansion factor  $R_t$  can have high sample variation (Fig. D1) if it is based on small (50-100 fish) daily genetic samples. The variance can be reduced somewhat by using Kalman filtering techniques to combine  $R_t$  estimates over days, assuming the true  $R_t$  do not change rapidly. But as shown in Fig. D1, even with such filtering the  $R_t$  ratios may become dangerously large ( $>5.0$ ) after more than 50% of the late run has entered the Johnstone Strait.

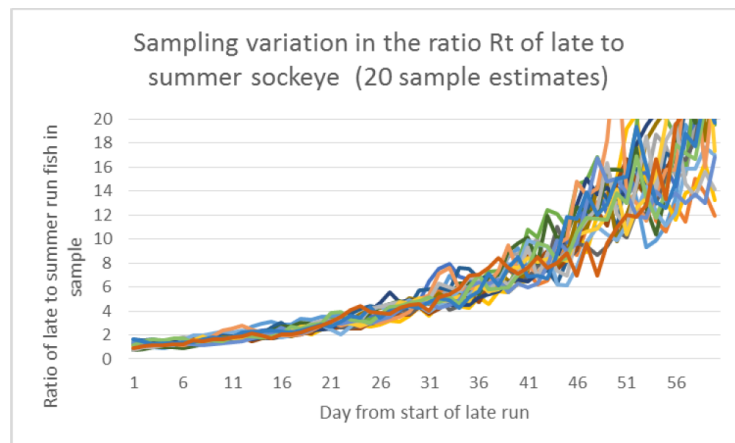


Figure D1. Sample variation in  $R_t$  estimates for years when the late run is about four times higher than the combined early and summer run, and when only 50 fish are collected each day in the approach test fisheries for composition estimation.

It would be relatively simple for PSC staff to test the method using historical  $R_t$ ,  $ES_t$  data, comparing the resulting  $L_t$  cumulative estimates to total river mouth catches plus escapements to Mission or Qualark. This would show whether the method works at all, and whether applying it early in the season (when  $R_t$  ratios are not huge) leads to early cumulative  $L_t$  patterns that predict (using normal models) later arrivals.

#### Appendix E. Estimation of pink and sockeye abundances using hydroacoustic estimates of total abundance along with test fishing estimates of species composition

The Mission and Qualark hydroacoustic facilities now provide daily estimates of total numbers of salmon passing the facilities. Sockeye and pinks dominate these total numbers at most times. Gillnet test fisheries provide ratios of catch per effort (cpue) for the two species at each site, i.e. proportions of total gillnet c.p.u.e. attributable to each species. Unfortunately, these proportions are not unbiased estimates of the proportion of the daily run that should be attributed to each species, if the species have different gillnet catchability coefficients due to body size differences along with differences in spatial distribution patterns (pinks tend to swim nearer shore). Fortunately, it is possible using the total abundance and c.p.u.e. data to estimate by-species catchability coefficients (and corrections for gear saturation effects), that make use of data from times when one or the other species is nearly absent (pinks are absent in even years, and earlier in the migration season in all years).

A basic model for how catch rates vary in the presence of possible gear saturation is the “multispecies disc equation” that predicts c.p.u.e. for species  $i$  in day  $t$  of a season as

$$Y(i,t) = q(i)N(i,t)/[1+h\sum_j q(j)N(j,t)] \quad (E1)$$

where  $Y(i,t)$  is the predicted c.p.u.e. for species  $i$ , day  $t$ ,  $q(i)$  is a base catchability coefficient for species  $i$  when overall abundance is low,  $h$  represents gear saturation (“handling time”) per fish encountered, and

the sum in the denominator represents combined saturation effects (loss of effective “searching time”) over all species encountered by the gear. Suppose there are two  $i$ ’s,  $i=s$  for sockeye and  $i=p$  for pink; in that case, eq. (1) predicts that the observed sockeye proportion in the test fishery catch will vary as

$$PO(s,t) = Y(s,t)/[Y(s,t)+Y(p,t)] = q(s)N(s,t)/[q(s)N(s,t)+q(p)N(p,t)] \quad (E2).$$

That is, the observed sockeye proportion  $PO(s,t)$  of the total c.p.u.e is predicted to be independent of the gear saturation effect represented by the denominator of eq. (E1), since the same denominator term appears in both  $Y(s,t)$  predictions and hence cancels in the ratio calculation. This is important, since it tells us that the c.p.u.e. ratios should not be affected by gear saturation.

Suppose now that we reparameterize eq. 2 by expressing it in terms of  $q(s)$ , the relative catchability ratio for pinks  $R=q(p)/q(s)$ , and the true sockeye proportion of  $N$ ,  $P(s,t)=N(s,t)/[N(s,t)+N(p,t)]$ . Equation (E2) then becomes

$$\begin{aligned} PO(s,t) &= q(s)P(s,t)N(t)/[q(s)P(s,t)N(t)+q(s)R(1-P(s,t))N] \\ &= q(s)P(s,t)/[q(s)(P(s,t)+R(1-P(s,t)))] \end{aligned} \quad (E3).$$

Here,  $N(t)$  is the observed total estimate of salmon numbers passing the facility. This equation can then be solved for the true sockeye proportion  $P(s,t)$  in terms of the observed proportion  $PO(s,t)$ . Noting that  $q(s)$  cancels in the numerator and denominator of eq. (3), the solution for  $P(s,t)$  becomes simply:

$$P(s,t) = PO(s,t)R/[1-PO(s,t)(1-R)] \quad (E4).$$

This the critical correction equation; it says that even if the species  $q$ ’s are unknown, we can correctly estimate (on average) the sockeye proportion of the daily total  $N(t)$  knowing only the observed proportion  $PO(s,t)$  of sockeye in the total test fishery c.p.u.e. and the ratio  $R$  of pink to sockeye catchabilities.

It is possible to develop equations analogous to eq. E4 for multiple species, in particular for the three-species case where chinook salmon are included. In this case, the estimation seeks to obtain  $P(c,t)$ , the corrected chinook proportion, using information on  $PO(c,t)$  the observed chinook test fishing proportion. Instead of a single  $R$  for the relative vulnerability of pinks, the three species case has two relative vulnerability parameters,  $R(p)$  for pinks and  $R(c)$  for chinooks. Equation E4 is replaced by a rather messy solution to three linear equations constrained to sum to 1.0:

$$P(s,t) = [1-PO(p,t)/\{PO(p,t)+R(p)/R(c)PO(c,t)\}]/[1+PO(c,t)/(PO(s,t)*R(c))-PO(p,t)/\{PO(p,t)+R(p)/R(c)*PO(c,t)\}] \quad (E5)$$

$$P(p,t) = PO(p,t)*[1-P(s,t)]/[PO(p,t)+R(p)/R(c)*PO(c,t)] \quad (E6)$$

$$P(c,t) = 1-P(s,t)-P(p,t) \quad (E7).$$

Note that these equations fail in spreadsheet layouts when  $P(s,t)=1.0$  (only sockeye present), and need to be replaced by eq. E4 for cases (days  $t$ ) when  $P(c,t)$  is zero. Note further that it may be reasonable to include coho and chums also, by assuming that coho catchability is similar to either pinks or sockeye and that chum catchability is similar to chinooks (based on body size arguments); to do this, the  $PO(i,t)$  simply need to include coho observed proportions in the  $PO(s,t)$  or  $PO(p,t)$  data, and chum proportions

in the  $PO(c,t)$ , and the species are split after applying eqs. E5-E7 by using ratios of the observed proportions (e.g.,  $PO(\text{coho},t)/[PO(\text{coho},t)+PO(s,t)]$  if coho are assumed similar to sockeye).

Given historical  $Y(s,t)$ ,  $Y(p,t)$ , and  $N(t)$  data, the problem then becomes to estimate the catchability ratio  $R$ . This cannot be done just by looking at  $c.p.u.e./N$  ratios for times when only one or the other species is dominant in the daily run, since such ratios are strongly affected by gear saturation (effects of the  $h$  parameter in eq. (E1)). Instead, we need to fit the  $Y(s,t)$  and  $Y(p,t)$  data so as to obtain estimates of  $q(s)$ ,  $q(p)$  or more simply  $R$ , and the gear saturation parameter  $h$ . This estimation can be carried out easily in a spreadsheet format, given columns for the observed  $Y$ 's and  $N(t)$ . First, calculate a column of the observed  $PO(s,t)$  from the  $c.p.u.e.$  columns (ratio of sockeye to total  $c.p.u.e.$ ). Then calculate a column of  $P(s,t)$  corrected sockeye proportions using eq. (4), and use these proportions to calculate columns of corrected sockeye and pink numbers  $N(s,t)=P(s,t)N(t)$  and  $N(p,t)=N(t)-N(s,t)$ . Using these estimates of the  $N(i,t)$ , calculate predicted  $c.p.u.e.$ 's for each species each day using eq. (1), with trial values for  $h$ ,  $q(s)$ , and  $q(p)=Rq(s)$ . Finally use Solver in Excel to vary the three parameters  $h$ ,  $q(s)$ , and  $R$  so as to obtain best fits to the observed  $c.p.u.e.$  time series.

Figures E1 and E2 show the  $c.p.u.e.$  fitting results from applying this estimation approach to the 2008-2015 Qualark data so as to estimate a common or year-independent average  $q(s)$  and  $R$  for all years except 2010. As expected, the estimated  $R$  was low (0.51) implying pink catchability about half of sockeye catchability, the sockeye  $q(s)$  (0.0018) was quite reasonable, as was the gear saturation parameter  $h$  (0.0063 implying a maximum average  $c.p.u.e.$  of around 150 sockeye per day at very high sockeye abundances). Including the 2010 sockeye data result in parameter estimates that do not make sense. For some reason, the sockeye test  $c.p.u.e.$  in 2010 was very low and the test fishing  $c.p.u.e.$  did not track abundance changes;  $c.p.u.e.$  rarely exceeded 60 fish per day (summed over all test net sets), whereas  $c.p.u.e.$ 's exceeding 100 sockeye/day were common in other years of lower sockeye abundance.

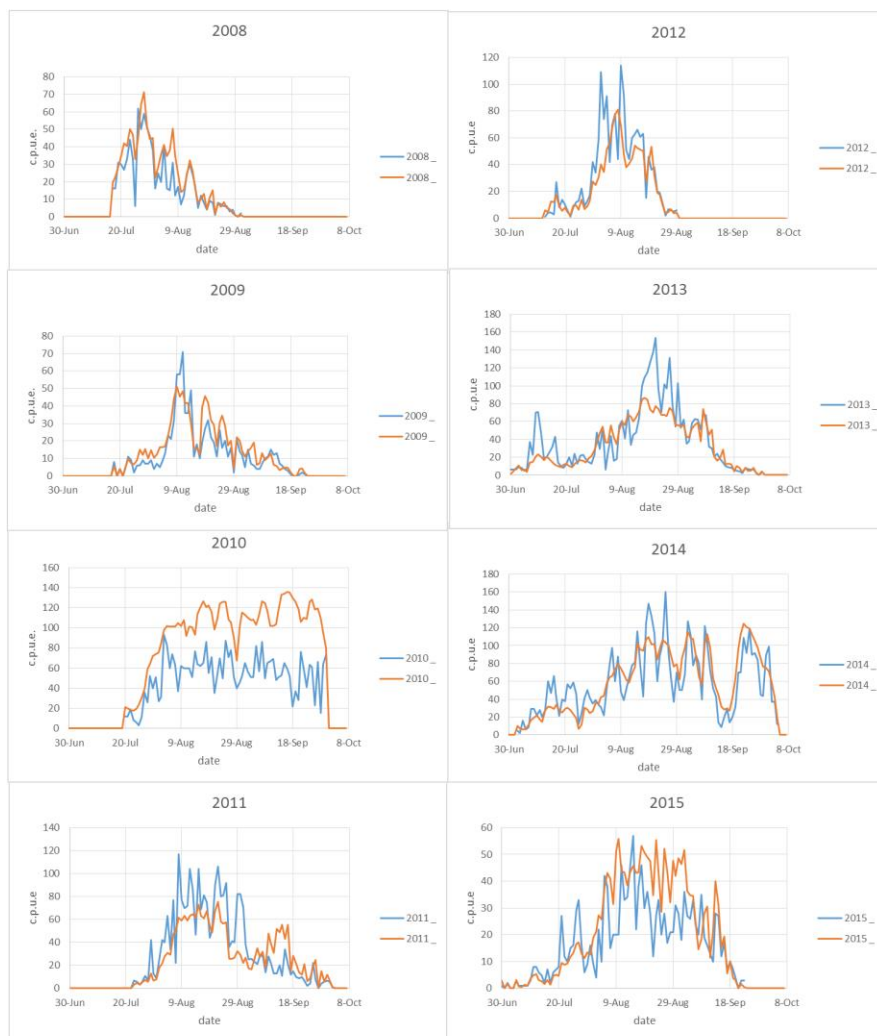


Figure E1. Comparison of observed and predicted daily sockeye catch per effort at the Qualark site. Predicted daily test fishing catch is from the multispecies disc equation (eq. E1). Note that 2010 data were not used in the parameter estimation, since catch per efforts were much lower throughout that year than predicted from the very high abundances.



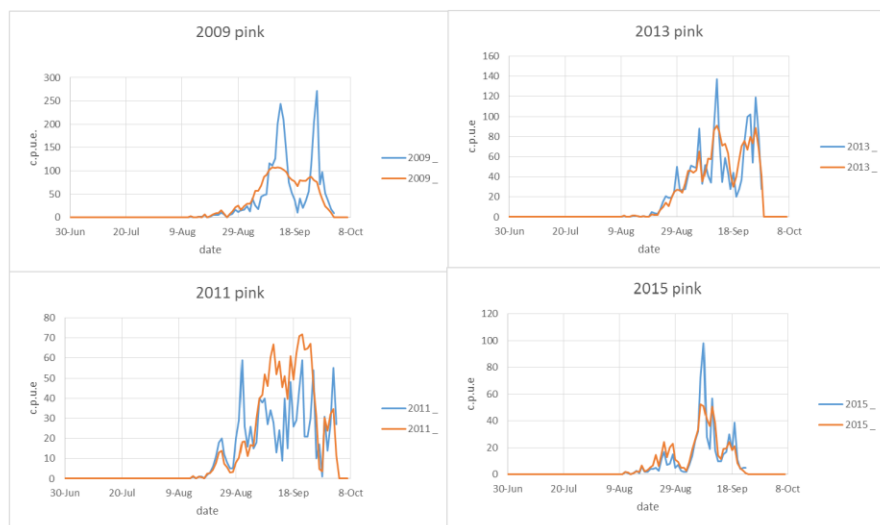


Figure E2. Comparison of observed and predicted daily pink catch per effort at the Qualark site, again using the multispecies disc equation (E1).

Plots of observed daily c.p.u.e versus corrected daily abundances show definite evidence of hyperstability ( $h > 0$ , Fig. E3), though these plots must be interpreted with caution due to the statistical errors-in-variables effect of measurement errors in the daily abundance (X-axis of relationship) due to sampling variation in the c.p.u.e. ratios for the pink estimates (sockeye data are shown only for years when pinks were absent). There are also indications from these plots that c.p.u.e. may saturate differently for pinks than for sockeye.

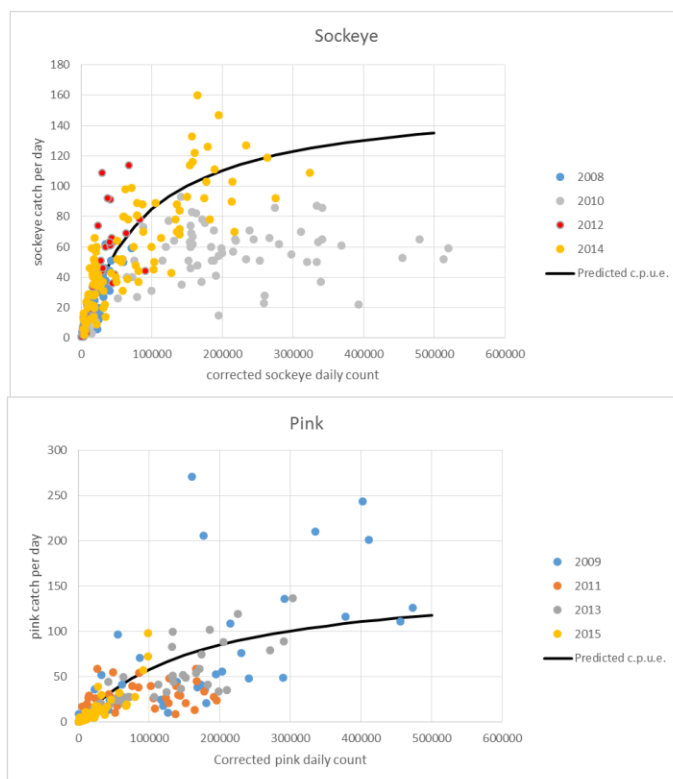


Figure E3. Modeled and observed relationships between daily c.p.u.e. and corrected daily abundance, for periods when one or the other species dominated the catch. Solid lines show the multispecies disc equation prediction of c.p.u.e. using the fitted  $RR$ ,  $q(s)$ , and  $h$  parameter estimates. Note that the sockeye data for 2010 were not used in the model fitting.

Additional work needs to be done on this estimation method, in particular to allow for inclusion of at least Chinook and possibly also coho in the approach and to explain some indications of interannual variation in  $q(s)$  (e.g. 2010, 2011) and in  $R$  (e.g. 2009). Also, it might be better to use time-smoothed estimates of the c.p.u.e.'s and the corrected species proportions  $P(s,t)$ , to remove some of the statistical noise caused by small test fishery sample sizes. But overall the approach definitely appears to give more realistic sockeye abundance estimates than use of uncorrected c.p.u.e. ratios.

Table E1 shows uncorrected (c.p.u.e. ratio) versus corrected sockeye and pink total escapement estimates. The correction method results in sockeye estimates ranging from 250,000 to 700,000 fish lower than the uncorrected estimates, i.e. estimates 15-20% lower. Use of these corrected estimates will have substantial impact on estimates of enroute mortality of sockeye for recent odd years.

Table E1. Comparison of uncorrected (c.p.u.e. ratio) estimates of sockeye and pink escapements at Qualark to estimates from the correction equation E4.

	Sockeye		Pink	
	Uncorrected	Corrected	Uncorrected	Corrected
2008	871,743	871,743	0	0
2009	1,187,367	922,131	5,999,924	6,265,160
2010	14,260,769	14,260,769	0	0
2011	2,883,881	2,296,298	2,702,514	3,290,097
2012	1,048,783	1,048,783	0	0
2013	3,976,922	3,275,061	4,047,222	4,749,083
2014	7,461,899	7,461,899	0	0
2015	1,820,595	1,549,590	894,340	1,165,346

The differences in estimates shown in Table E1 indicate a clear need to revisit any estimates of en-route mortality for sockeye that has been estimated by comparing Qualark escapements to spawning ground escapements. The corrected Qualark estimates will result in lower estimates of en-route mortality for later timed sockeye stocks in odd years, hence lower recruitment estimates (since total recruitment for a year is estimated as catch plus final escapement plus estimated en-route mortality).

# Appendix 7: Fraser River Panel Hydroacoustics

## Workplan February 2017

Detailed list of work tasks with status – Feb 7, 2017

Terms of Reference	Work Item	Targeted Completion Date	Status (Feb. 7, 2017)
	<b>Mission work items</b>		
2b	1. Bibliography (technical reports & publications)	January 31, 2016	Complete
1 & 3	2. Systems used to produce daily total salmon & total sockeye estimate at Mission. (2008-2015; odd years for sockeye time period only)	January 31, 2016	Complete
1	3. Amount in daily estimate from direct sampling vs. amount derived from extrapolation. (2008-2015; odd years for sockeye time period only)	February 29, 2016	Completed for 5 of the 8 common operation seasons: 2008, 2010, 2012, 2014, 2015.
1	4. Fisheries removal of through Qualark stocks between Mission and Qualark. (2008-2015; odd years for sockeye time period only)	Complete	Complete
1	5. Mission projected Qualark estimate. (2008-2015; odd years for sockeye time period only)	Complete	Complete
1 & 2b	6. Cross aim fish flux due to vertical fish movements in the left-bank split-beam sampling areas. a. Do we want to repeat analysis for other years? (ie. 2010 & 2014 if data available) If available, analysis completion March 31, 2016.	Completed Analysis showing no bias from split-beam fish counts (PSC Tech Report #16, for 2004 data comparison; SEF project)	Completed with 36hrs of data (No data was collected for this testing purpose after 2004).
1 & 2b	7. Bias or randomness of the extrapolated left-bank fish flux a. Do we want to repeat analysis for other years? (ie. 2010 & 2014 if data available) If available, analysis completion March 31, 2016.	Completed Analysis showing no bias from split-beam fish counts (PSC Tech Report #16, for 2005 data comparison; SEF project)	Completed with direct counting comparisons from 18 hrs of fish count data from 2005 season and 30 days flux comparison from July 2014 (No data was collected for direct counting comparison)

Terms of Reference	Work Item	Targeted Completion Date	Status (Feb. 7, 2017)
			purpose after 2005 season.)
1 & 2b	8. Bias in the offshore fish flux estimates by the mobile system as fish start shifting offshore due to fishing or tidal influences. a. Comparing the fish behaviour (speed & downstream ratio) between the left-bank split-beam and the vessel based DIDSON.(Years available: 2014, 2015)	February 29, 2016	Completed with 10 days of 2015 data & 6 days of 2014 data.
1 & 2b	9. Bias in target recognition by the mobile system. a. Qualitative comparison between mobile split-beam flux and the vessel based DIDSON flux. (Years available: 2014, 2015)	February 29, 2016	Cannot be done with existing data
1	10. Inventory of when discrepancies between Mission & Qualark occurred. a. Based on relative difference to present the statistical description of the difference by providing various probability intervals for the outliers. Reader can look at table to examine DBE events of their choice according to the statistical description table.	February 29, 2016	Completed with detailed analyses for 2010 and 2014 DBE data.
1	11. Species Composition work	Longer term	No set start and end time.
	<b>Qualark work items</b>		
	12. Species Composition work	Longer term	No set start and end time
1 & 2b	13. Report out to Fraser Panel of results of September 2015 evaluations with ARIS looking beyond 30m	January 11, 2016	Complete
1 & 2b	14. Report out to Fraser Panel on results of September 2015 evaluations comparing DIDSON at 35 roll and with ARIS (with no roll and 1 aim) Note: PSC staff has suggested that a subset of recorded files be counted to quantify impacts of size threshold cutoff (30cm in DIDSON), recognizing that impact is likely small and PSC staff have been able to replicated 2010 DIDSON counts using threshold. Feb 8 proposed deadline would not be expected to include this comparison.	February 8, 2016	Complete
	<b>Analysis steps (mainly by DFO staff )</b>		
1	15. Exploratory analyses by DFO staff a. PSC staff to provide Mission data i. Daily fish passage estimates produced with and without key pieces of equipment (i.e. without boat, without right bank, etc...) ii. Daily spp composition estimates used to with i. to get daily estimates of sockeye passage (with description of method(s) used and estimates of variability) iii. Daily stock ID estimates used with ii. For in season run size estimation (with	a-b May 31, 2016         c-e June 9, 2017	15 a. b complete

Terms of Reference	Work Item	Targeted Completion Date	Status (Feb. 7, 2017)
	<p>description of method used and estimates of variability)</p> <p>b. DFO staff to provide Qualark data</p> <p>i. Daily fish passage estimates produced with and without key pieces of equipment (i.e. without beyond zone 3 without other bank, etc...)</p> <p>ii. Daily spp composition estimates used to with i. to get daily estimates of sockeye passage (with description of method used and estimates of variability)</p> <p>iii. Note: PSC staff suggest important to note when DIDSONS are moved down the ramp or quantify protocol used to move equipment as % in each Bin can vary with position of DIDSONs.</p> <p>c. Compare estimates of stock passage derived from Mission and Qualark estimates</p> <p>i. Quantify periods in data when proportions of the estimate coming from various estimation components at Mission tend to repeat (e.g. 30% of estimate from mobile for a period of X days in a row).</p> <p>ii. Quantify periods in the data when proportions of the migration associated with various proportions of the cross river distribution are repeated (e.g. X% beyond 50m at Mission), or (X% in Bin 3 @ Qualark).</p> <p>d. Evaluate patterns found in c above relative to total daily abundance (e.g. periods of high or low abundance?),</p> <p>i. timing during the year, water level, water temperature, tidal cycle, human (e.g. fishing) activity, etc. Are these patterns predictable??</p> <p>e. Compare estimates of total run size derived from Mission and Qualark estimates of fish passage. Are deviations between estimates from the two sites; 1) statistically significant, and 2) associated with periods of repeat patterns within the data at each site significant</p>		<p>Sampling variation associated with the estimates at both sites is being quantified and work is nearing completion. This will provide context for both intra and inter annual comparisons of estimates obtained from both sites. (e.g. are the differences in passage estimates more or less than expected given the sampling variation at each site). Movement model under development to explore mechanisms for differences. Predictive models not yet developed, but planned.</p>
	<b>Panel Work Items</b>		
2	<p>16. Develop qualitative (and where possible quantitative) performance measures for alternative program designs and scenarios, considering the range of fish densities encountered, river conditions and other factors</p>	June 9, 2017	<p>Identified in-season run size as one of the PMs in May 2016. Additional performance measures being</p>

<b>Terms of Reference</b>	<b>Work Item</b>	<b>Targeted Completion Date</b>	<b>Status (Feb. 7, 2017)</b>
			discuss with Fraser Panel in Feb. 2017.

<b>Terms of Reference</b>	<b>Work item</b>	<b>Targeted Completion Date</b>	<b>Status (Feb. 7, 2017)</b>
2, 4	17. Assess how well each program element meets management objectives (e.g. timeliness, precision, accuracy, cost-effectiveness, etc.).	September 2017	Completed impact analyses on in-season run size for 2010 & 2014 using Mission vs. Qualark estimates.  The Panel envisions a Table that summarized the results of quantitative evaluations related to these objectives and where those are not available, a qualitative summary will be provided.
5.	18. Identify a program design option from the risk assessment in 17 above that falls within the Mission budget. If this option does not adequately meet the defined fishery management objectives, explain why and identify a program design that would do so regardless of cost.	September, 2017	Work not commenced yet, pending on complete outcomes under Work Item 17

## Appendix 8: Hydroacoustics Operational Costs

### **Lower Fraser Operational Acoustic Program Costing (excluding capital infrastructure investments)**

The values presented here summarize the program costs for the Mission and Qualark hydroacoustics programs on the Lower Fraser River. There are two annual program costs provided for Qualark. The base cost consists of a shorter field season with approximately two months of hydroacoustic monitoring, which would be used in years where there are no pink salmon or few Late run sockeye, such as 2016. The enhanced cost represents a longer field season with approximately three months of hydroacoustics monitoring including periods of pink salmon or Late run sockeye migrations in September. For Mission, there are three costs provided: a base cost, covering a similar time period to the Qualark base program; an enhanced cost, consisting of a program to assess delaying Late run sockeye; and a pink salmon cost, including the additional costs of assessing pink salmon into September.

Since the Mission site is administered by the PSC and the Qualark site is administered by DFO there are some differences in the cost components of each program. Mission hydroacoustics has 4 indeterminate staff (2 technicians, a manager, and a hydroacoustics scientist) that oversee the operation of the site and provide daily estimates of salmon passage. When the site is not operational, indeterminate staff work on research and program development, scientific publications, administration, as well as supporting Fraser River Panel activities. These costs for indeterminate staff at Mission are included in the “Other” category, and as part of the total cost.

The total cost for each program also includes DNA processing costs from in-river test fisheries. For Mission, DNA costs include analysis of samples from both Whonnock and Cottonwood test fisheries in the lower Fraser River. In the absence of a Mission hydroacoustics program, some DNA analysis would still be required to estimate escapement of stocks spawning below Qualark. The Qualark program costs include DNA sampling and analysis from the Qualark test fishery.



## Lower Fraser Operational Acoustic Program Costing (excluding capital infrastructure investments)

	Qualark "Base" Year (no dominant Late Run or Pinks)	Qualark "Enhanced" Year (with Late Run or on a Pink Year)	Mission Base 2014	Mission Enhanced 2014	Mission Pinks (Odd years)	Consideration of changes in requirement
	(increment over Base) Set Up/De-mob = 11 days ; Ops = 64 days ; Total Field Time = 75 days	(increment over Base and Enhanced) Set Up/De-mob = 11 days ; Ops = 93 days ; Total Field Time = 104 days		(increment over Base)	(increment over Base and Enhanced)	Add comments/information if available
<b>Personnel</b>						
<i>Planning, logistics and management oversight</i>						
Indeterminate staff	\$7,500	\$0	\$52,584	\$0	\$0	
<i>Mobilization &amp; Operations (for Qualark, L and R bank at Mission)</i>						
Indeterminate staff	\$1,875	\$0	\$70,029	\$27,078	\$0	
Overtime	\$0	\$0	\$18,352	\$7,096	\$0	
DFO Seasonal staff (EBP inc)	\$38,625	\$14,935	\$69,300	\$26,796	\$0	
YFN Technical Staff	\$60,775	\$27,115	na	na	\$0	
DFO Seasonal staff overtime	\$7,817	\$3,542	\$12,117	\$4,685	\$0	
<b>SubTotal</b>	<b>\$109,092</b>	<b>\$45,592</b>	<b>\$169,798</b>	<b>\$65,655</b>	<b>\$0</b>	
<i>Mobilization &amp; Operations (Mobile split-beam)</i>						
Indeterminate staff	na	na	\$ 17,507	\$ 6,769	\$0	
Overtime	na	na	\$ 4,588	\$ 1,774	\$0	
Seasonal staff	na	na	\$ 34,650	\$ 13,398	\$0	
Seasonal staff overtime	na	na	\$ 6,058	\$ 2,343	\$0	
<b>SubTotal</b>	<b>\$0</b>	<b>\$0</b>	<b>\$62,804</b>	<b>\$24,284</b>	<b>\$0</b>	
<i>Post Season analysis and reporting (for Qualark, L and R bank at Mission)</i>						
Indeterminate staff	\$3,750	\$0	\$20,773	\$14,838	\$9,561	
Overtime	\$0	\$0	\$0	\$0	\$0	
DFO Seasonal staff (EBP inc)	\$15,330	\$0	\$0	\$5,524	\$3,386	
Seasonal staff overtime	\$0	\$0	\$0	\$0	\$0	
<b>SubTotal</b>	<b>\$19,080</b>	<b>\$0</b>	<b>\$20,773</b>	<b>\$20,362</b>	<b>\$12,946</b>	
<i>Post Season analysis and reporting (Mobile equipment)</i>						
Indeterminate staff	na	na	0	0	0	
Overtime	na	na	0	0	0	
Seasonal staff	na	na	0	0	0	
Seasonal staff overtime	na	na	0	0	0	
<b>SubTotal</b>	<b>\$0</b>	<b>\$0</b>	<b>\$0</b>	<b>\$0</b>	<b>\$0</b>	
<i>Other (specify, add lines as necessary)</i>						
Indeterminate staff	na	na	\$147,730	-\$48,685	-\$9,561	A high proportion of indeterminate wages is associated with this role. He is largely focused on writing technical reports, scientific publications, and data analysis. He is only partially involved in the field program.
Overtime	na	na	\$0	\$0	\$0	
Seasonal staff	na	na	\$0	\$4,455	\$0	
Seasonal staff overtime	na	na	\$0	\$0	\$0	
<b>SubTotal</b>	<b>\$0</b>	<b>\$0</b>	<b>\$147,730</b>	<b>-\$44,230</b>	<b>-\$9,561</b>	
<b>Acoustic Site Costs</b>						
Staff travel & Field Camp operation	\$18,880	\$8,555	\$10,417	\$4,028	\$0	
Access Lease	\$6,000	\$0	\$8,625	\$0	\$0	
Vehicle rental	\$4,065	\$1,355	\$0	\$0	\$0	
Vehicle fuel	\$600	\$200	\$3,317	\$1,283	\$0	
Vehicle maintenance	\$0	\$0	\$429	\$166	\$0	
Vessel Fuel	\$375	\$125	\$6,130	\$2,370	\$0	
Vessel maintenance	\$0	\$0	\$5,661	\$2,189	\$0	
Moorage and Towing	\$0	\$0	\$900	\$0	\$0	
Weir materials and maintenance	\$1,725	\$0	\$361	\$139	\$0	
Technical supplies	\$4,000	\$0	\$0	\$0	\$0	
Materials	\$1,200	\$0	\$938	\$363	\$0	
Equipment rental	\$800	\$0	\$876	\$12,839	\$0	
Equipment Maintenance	\$2,880	\$0	\$5,800	\$1,700	\$0	
Data storage	\$900	\$0	\$3,389	\$1,311	\$0	
Hydro/Telephone/Sanitation	\$1,060	\$0	\$5,265	\$2,036	\$0	
Technical contracts	\$1,200	\$0	\$3,287	\$0	\$0	
Shipping/postage/office supplies	\$810	\$0	\$950	\$367	\$0	
Other (Prof Services HE)	\$10,880	\$0	\$1,440.00	\$0	\$0	
Other(Prof Services- Software)	na	na	\$11,842.86	\$4,737	\$0	
<b>SubTotal</b>	<b>\$55,375</b>	<b>\$10,235</b>	<b>\$69,628</b>	<b>\$33,527</b>	<b>\$0</b>	
<b>Data Processing &amp; analysis</b>						
DNA processing	\$60,800	\$27,550	\$63,679	\$63,679	\$0	Most of Mission samples are processed in-season, which has resulted in a higher proportion of samples being processed in 2014 than usual due to the strange and protracted nature of the program.
Data analysis and reporting	--	--	\$0	\$0	\$0	
Post Season data processing	--	--	\$0	\$0	\$0	
Other (specify, add lines as necessary)	--	--	\$0	\$0	\$0	
<b>SubTotal</b>	<b>\$60,800</b>	<b>\$27,550</b>	<b>\$63,679</b>	<b>\$63,679</b>	<b>\$0</b>	
<b>Total Cost</b>	<b>\$251,847</b>	<b>\$335,224</b>	<b>\$586,995</b>	<b>\$750,272</b>	<b>\$753,657</b>	
<b>Total Incremental Increase</b>		<b>\$83,377</b>		<b>\$163,276</b>	<b>\$3,386</b>	
<b>LESS OTHER PERSONNEL</b>	<b>\$251,847</b>	<b>\$335,224</b>	<b>\$439,265</b>	<b>\$602,541</b>	<b>\$605,927</b>	

## Mission mobile sub-sampling cost savings

The costs presented here summarize the potential savings from a reduced sampling program of the Mission mobile system, as detailed in Appendix 12. The costs are based on field site operations in 2014, 2015 and 2016. The field season in 2016 was shorter because there is no assessment of pink salmon or delaying late-run sockeye, so costs in that year are lowest.

### Annual maintenance and capital savings

Annual maintenance and boat capital costs (average 2014-2016)	\$12,000
Assumed proportion of maintenance costs saved	50%
<b>Annual savings in maintenance and capital</b>	<b>\$6,000</b>

### Daily cost of operating mobile system

Boat operator	\$25/hr * 24 hours	\$600
Fuel costs		\$100
<b>Total daily cost</b>		<b>\$700</b>

### Savings from reduced daily operation, sampling every 2nd day

includes savings from daily operating costs and annual savings in maintenance and capital

2014 (43 days not sampled)	\$36,100
2015 (34 days not sampled, includes sub-sampling Pink period)	\$29,400
2016 (24 days not sampled)	\$22,800
<b>Average savings, sampling every 2nd day</b>	<b>\$29,433</b>

### Savings from reduced daily operation, sampling every 3rd day

2014 (57 days not sampled)	\$45,900
2015 (45 days not sampled, includes sub-sampling Pink period)	\$37,500
2016 (31 days not sampled)	\$27,700
<b>Average savings, sampling every 3rd day</b>	<b>\$37,033</b>

# Appendix 9: Mission Technical Document

## Summary of PSC Work Items for the Fraser River Strategic Review Committee (FSRC)

Pacific Salmon Commission, Vancouver, British Columbia, Canada

October 18, 2016

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## Introduction

After reviewing Dr. Carl Walters' report on lower Fraser hydroacoustics programs in July 2015, the Fraser River Panel (the Panel) and the Fraser Strategic Review Committee (FSRC) decided additional analyses were required before making recommendations on a long-term program design to the Commission. Accordingly, the Panel and relevant staff developed a work plan to guide these analyses (Appendix A). The FSRC reviewed and approved that plan in February 2016, with a request for regular progress reports.

This summary document was prepared by Secretariat staff and reviewed by a technical oversight team from the Fraser River Panel and Technical Committee. It summarizes results from the ten work items related to Mission acoustics. It is important to note that a substantial amount of investigative work relevant to the ten work items has been conducted either jointly with Department of Fisheries and Oceans staff (Applied Technology Division, Pacific Biological Station) or independently by PSC hydroacoustics staff since as early as 1995 in responses to recommendations by the 1994 Fraser River Sockeye Public Review Board (see reference R0 for details). Thus, this report summarizes work completed since October 2015 and over the past twenty years.

Work item 1 provides a bibliography referenced in subsequent work items. Work items 2, 3, 6, 7, 8, and 9 describe equipment, methodologies, and potential biases in the collection and processing of Mission data. Items 4 and 5 document methods used to generate the projection of sockeye expected to reach the Qualark site from Mission data. Item 10 provides an inventory of periods of discrepancies between Mission projections and Qualark estimates and summarizes the correlation of daily discrepancies during discrete periods of the 2010 and 2014 season to other factors (e.g. river conditions, fisheries, component of the estimates, etc.). This work sets the foundation for many of the tasks listed in work item 15.

This document is organized by work item, and was developed to provide readers with a summary of the key findings for each work item along with references to supplemental files with more detailed results and underlying analyses. Each work item is bookmarked in the pdf file to permit easier navigation to work item summaries. The supplemental files are organized into sub-folders for each work item and can be accessed on the secure site. A memory stick containing all files will also be provided to each of the four FSRC members, and key members of the Panel's Oversight and Technical teams.

The first fifteen work items outlined in Appendix A are of technical nature and designed to help explain discrepancies between Mission projections and Qualark estimates. This information should serve as the foundation for pending policy discussions in the Panel and

the FSRC over alternative hydroacoustic regimes. The Secretariat has provided one analysis as a performance measure to help guide those policy discussions in the FSRC and the Panel (under Work Item 17). Secretariat staff retrospectively compared the impact of using: (1) Mission estimated sockeye escapement, (2) reconstructed Mission sockeye escapement (backward) from Qualark sockeye estimate and in-river catch or (3) combination of (1) and (2) for the 2010 and 2014 sockeye returns, and demonstrated that all three methodologies would have performed equally well in reproducing in-season run size estimates. The results of this analysis are summarized in the supplemental pdf file [Item 17- AlternativeHydroAcousticEstimatesForRunSizeAssessment.pdf](#)

## Item 01: Bibliography (technical reports & publications)

### ***Objective***

1. To provide the FSRC with relevant references and background materials on the Mission hydroacoustics program.

### ***Key outputs and conclusions***

1. A total of twenty-one publications are identified for their relevance to the ten work items identified by the Fraser River Panel for the FSRC review.
2. A brief summary is provided of the objectives and findings of each publication as they relate to the other work items.

All the publications can be downloaded as PDF files from the [Item1.Biblio](#) sub-folder. Each publication is labelled sequentially R0... R20 and these labels are used to reference documents later in the summary. The publications of technical nature present essential research and development outcomes guiding major transitions and advancements in sonar technologies and sampling methods for the Mission hydroacoustic program since 1995. Chronological records of hydroacoustic systems implemented for in-season sockeye periods are summarized below (with relevant references):

1. 1977-2003 (*M* system): A vessel-based mobile single-beam system acquiring fish density information by transecting the river and migration speed information by stationary sampling. The daily passage was estimated through a duration-in-beam model which assumes all fish swim upstream and do not avoid the transecting vessel (**R1, R2, R7, R8**).
2. 2004-2009 (*L+M* system): A left-bank fixed-location split-beam system to enumerate fish passage up to 50m from the left bank; A vessel-based split-beam system acquiring fish density information by transecting the river. The offshore passage beyond 50m from the left bank was estimated by a fish flux model that assumes fish beyond 50m from the left bank maintain the same swimming behavior as fish detected by the left-bank split-beam system (**R3, R5, R6, R9, R12, R16**).
3. 2010 (a testing *D1+L+M +D3+D2* system): This was primarily a testing season to assess performance of DIDSON technology for the Mission program. A left-bank DIDSON (*D1*) was tested to enumerate fish passage up to 20m from the left bank; a left-bank split-beam system enumerated fish passage from 20-50m; a vessel-based split-beam system acquiring fish density information from 50-350m; a tripod mounted DIDSON off the bottom (*D3*) enumerated fish passage from 350-370m; a

right-bank DIDSON (*D2*) enumerated fish passage up to 30m from the right bank (**R10, R13**).

4. 2011-2015 (primarily *L+M+R* system): A left-bank fixed-location split-beam system to enumerate fish passage up to 50m from the left bank; a vessel-based split-beam system acquiring fish density information from 50-370m; a right-bank DIDSON (*D2*) enumerated fish passage up to 30m from the right bank (**R15-20**).

The full list of publications can be found in the Reference section at the end of this document. The objectives and key findings of each publication are briefly summarized here:

- **R0** (1995) provides comprehensive records of investigations into the “disappearance” of 1.3 million sockeye that were projected by PSC to reach the spawning terminal areas in 1994. The 1994 review board appointed four technical working groups to conduct detailed critiques and examinations of methods and data used for the estimation of (1) sockeye escapement at Mission (produced by Mission Hydroacoustics Facility), (2) in-river catch, (3) en-route mortality, and (4) spawning escapement. The factors leading up to the 1994 review may provide some context relative to the current FSRC process.
- **R1** (1994) provides technical assessment of the mobile survey method PSC employed since late 1970s to estimate salmon escapement at Mission using a single-beam echosounder system. This is a technical report produced by the Mission Hydroacoustics Working Group. Members of the group, comprising DFO and PSC science and technology experts in acoustics and fisheries, were appointed by the 1994 Fraser River Sockeye Review Board. Key findings are: the single-beam sounding system was executed by PSC staff in a consistent manner since 1977 at Mission site; the system performed well under normal fish behavior scenarios but it is not robust for abnormal fish behavior (milling, holding); the system is less effective in detecting fish passage in nearshore shallow waters due to (a) fish may avoid the sounding vessel when it navigates over the shallow water and (b) the near-bottom blind zone of a downward looking sound-beam due to the finite pulse-width (0.4 msec) of projected acoustic pings.
- **R2** (1995) refined the duration-in-beam model PSC had adopted for deriving estimates of salmon abundance from the single-beam data. The key results and findings are as follows: provision of a correct mathematic model for the duration-in-beam estimator; using example data to demonstrate that the single-beam estimator is highly precise with a CV less than 5% for a daily abundance level around 300,000; it also hypothesizes that the CV would vary with abundance.
- **R3** (1997) documents for the first time key findings of fish behavior at Mission site based on a joint research effort between PSC and DFO in the 1995 field season using a side-looking split-beam system.



- **R4** (1998) provides the algorithms for the development of two-dimensional nearest neighborhood extrapolations of fish passage into the acoustic blind zone on the left-bank.
- **R5** (1998) demonstrates that an elliptically shaped sound beam with a zero-degree roll angle is more effective than a circular beam in detecting and counting fish migrating near the river bottom.
- **R6** (2000) describes a fish tracking algorithm for a riverine environment with a key finding that the probability of acoustic detection of fish targets diminishes with range in either the lower Fraser River or Thompson River.
- **R7** (2002) uses data collected over 4 field seasons (1995-1998) by a split-beam system at Mission to assess potential sources of bias in Mission estimates by a single-beam mobile sounding system.
- **R8** (2004) provides an optimal sampling scheme for river-transect samplings of spatial density of fish migration.
- **R9** (2005) provides comprehensive summaries and analyses on the comparisons of both fish counts and behavior statistics estimates produced by the split-beam system and DIDSON from data collected in 2004 and 2005 seasons. The presented results verify that the split-beam system produced unbiased estimates for salmon abundance and behavior in comparisons to the DIDSON.
- **R10** (2007) presents a detailed study of the differences in fish behavior measured at points located across the river channel based on 16 days of data acquired in the 2006 season at Mission. The results quantify how migration behavior varies across the river width. The study concluded that using the left-bank fish behavior statistics, the mobile flux model could lead to a significant bias in estimating fish passage near the right bank. A more robust sampling configuration using fixed sonar on the right banks was proposed for counting fish near the right bank.
- **R11** (2008) describes a pilot project using both mid-range (~100 m) and long-range (1-2 km) sonar systems to estimate salmon passages in southern Johnstone Strait (off Chatham Point). The preliminary results demonstrate the feasibility of using these systems for estimating salmon in Johnstone Strait.
- **R12** (2008) quantifies avoidance behavior of fish in response to an approaching mobile sounding vessel based on DIDSON imaging data. The study concludes that fish take laterally evasive actions when present within a 4-m radius from the propeller of the vessel. Therefore, the mobile sounding method is not appropriate for estimating fish passage in near-shore waters.
- **R13** (2010) summarizes a field test (in 2008 and 2009 seasons) of offshore sampling methods using stationary sonar systems launched from an anchored vessel. The major achievements and findings from this study are:
  1. Estimation models and extrapolation methods were developed to estimate offshore fish passage with spatially sub-sampled fish counts, but

2. The data collected from an anchored vessel were too noisy to extract reliable fish targets, and
  3. The frequent navigational use of this stretch of the river by other commercial, recreational and fishing vessels made it impossible to conduct consistent and safe operations of data collection from an anchored vessel in offshore water especially in the middle of the channel.
- **R14** (2010) is a user manual for operating Qualark counting site. It documents the design and counting methods developed at Qualark by DFO using DIDSON technology.
  - **R15** (2012) proposed a basic sampling configuration for Mission site. This configuration is the foundation of the sampling method implemented at Mission since 2011 season. The key results from this report include:
    1. the design of a combined sampling system consisting of two shore-based sonar systems and a mobile sounding system (left-bank split-beam, mobile and right-bank DIDSON, often abbreviated as LMR);
    2. Spectral analysis of left-bank hourly fish passage data at Mission, which displays a temporal pattern clearly modulated by a semi-diurnal tidal forcing.
    3. Spectral analysis of hourly fish passage data at Qualark, which displays a strong diurnal pattern synchronized with daylight hours.
    4. Correlation analysis of hourly passage data at two sites from September 2010 data to show sockeye salmon take 67 hours to travel from Mission to Qualark (93 riverine kilometers).
    5. Correlation analysis of hourly passage data at two sites from September 2011 data to show pink salmon take 81 hours to travel from Mission to Qualark.
    6. Using DIDSON fish count data from DIDSON systems deployed in near-shore waters, in combination with offshore split-beam fish counts, to produce hydroacoustics based pink salmon escapement estimate for 2011 season.
  - **R16** (2012) presents a discriminant function analyzer to separate fish and non-fish acoustic tracks generated by a split-beam sounder system. This DFA analyzer has been proven to be effective for Mission split-beam data prior to the arrival of the bulk part of pink salmon.
  - **R17** (2013) summarizes a 2-year study on using a combination of two shore-based sonar systems and a mobile sounding system (LMR) to produce Mission estimates. The key results from this report include:
    1. Comparisons of Mission projected sockeye escapement and Qualark estimated sockeye escapement. The comparison was done for 2010, 2011 and 2012 seasons.

2. Incremental cost analyses of Mission program (if assume Qualark is correct).
  3. Precision of Mission estimates using systematic sampling
- **R18** (2014) demonstrates that a vertically rotational DIDSON is more effective than split-beam sonar in counting fish passages over a concave river bottom on the right bank.
  - **R19** (2014) presents an empirical method for estimating the precision of systematic sampling of fish passage.
  - **R20** (2015) presents working models and formulas for estimating the precision of total salmon, sockeye salmon and pink salmon estimates based on sampling configurations at Mission site. It also presents a mathematical framework (with numerical examples) for estimating precision of Mission-based projection of sockeye escapement at Qualark.

## **Item 02: Systems used to produce daily total salmon estimates at Mission**

### ***Objectives***

1. Present detailed information on the hydroacoustics systems used to produce daily total salmon estimates throughout the 2008-2015 field seasons at Mission
2. Provide the Mission cross-river sampling ranges covered by the individual systems for 2008-2015
3. Describe the rationale for the deployment and selection of the hydroacoustics systems to produce the daily total salmon estimates
4. Quantify the annual proportions of total salmon passage (excluding pink salmon dominated migration periods for odd years) estimated by the shore-based systems and offshore system (the downward-looking vessel-based sounding system).

### ***Key outputs and conclusions***

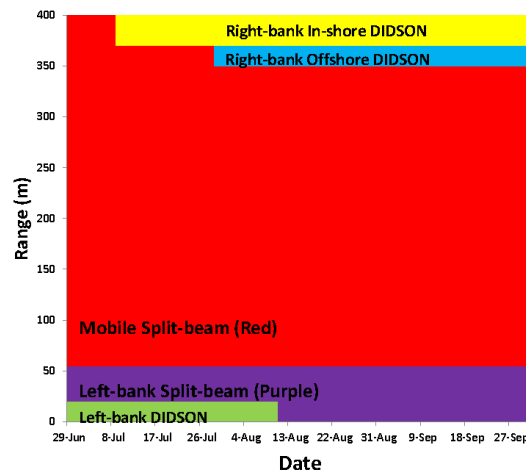
1. A complete time series is provided of the daily estimate and the cross-river range of each hydroacoustics system from 2008 through 2015 within the excel file [Item2.SystemsforDailyEst\RangeBinnedDailySalmonEstimate2008-2015.xlsx](#)
2. The results demonstrate the evolution of the Mission program from a simplistic L+M sampling configuration (left-bank plus the mobile sounding systems) used in 2008 and 2009 seasons (with 2010 season primarily engaged in R&D field testing)

to a more robust LMR sampling configuration comprising the left-bank, mobile and right-bank sounding systems from 2011-2015 seasons. The implementation of shore-based sonar systems (including both the split-beam and DIDSON imaging sonar) has improved counting accuracy of fish passage in nearshore waters by reducing the use of mobile data to eliminate biases due to vessel-avoidance behavior and target recognition ambiguity inherent in the mobile data. There has been a significant reduction in the proportion of estimated flux by the mobile system after the 2010 season, as a result of increased sampling of total fish passage by the shore-based systems.

3. In addition to producing more robust estimation of sockeye escapement, the LMR configuration together with more effective counting capacity for nearshore fish targets by imaging sonar (DIDSON) has greatly enhanced the Mission hydroacoustics facility for estimating pink salmon escapement in the lower river.

The hydroacoustics systems used to produce the daily total salmon estimate are shown using time-space plots with stacked colours representing the use of estimation data from individual systems over the corresponding sampling range bins (widths of colour coded areas along y-axis). Plots for all years from 2008-2015 can be found in the supplemental powerpoint [Item2.SystemsforDailyEst\Systems used in estimation 2008-2015.pptx](#). As an example, we present the following plot to show the time-space record of selected estimation data from five systems over the cross-river range bins for the 2014 season.

## 2014 Estimation Systems



**Figure 1.** Time-space record of selected estimation data from 5 systems over the cross-river range bins for the 2014 season.

For any cross-river range bin, we selected the estimation data from individual systems based on two criteria: (1) the availability of individual systems for fish counting in that range bin, and (2) if more than one system samples the same range bin, selecting the data from the system with the greatest effectiveness in fish counting for that range bin under various riverine conditions, stock or species specific fish behavior. The second criterion was established through system testing and data comparisons through multiple seasons under several SEF funded projects (References R9-10, R12-13 and R14-19). For instance, the mobile system sampled the near-shore fish passage which was also sampled by the left bank systems. But we chose fish counts from the left-bank systems to estimate the nearshore fish passage to eliminate the bias due to vessel-avoidance behavior in nearshore shallow water.

The rationale for the selection of estimation data in each season is explained in the [Mission Equipment Deployment 2008-2015.docx](#) file. As an example, the rationale for system selection in the 2014 season is summarized as follows:

- The crew deployed three key systems (left-bank (LB) DIDSON, left-bank split-beam and mobile split-beam) to generate the first official estimate on June 29. The estimates between June 29 and July 08 were produced using data from LB DIDSON (sampling 0-20m from left bank), LB split-beam (20-55m) and mobile split-beam (55m-400m, i.e., the rest of the channel). LB DIDSON data was chosen for this earlier period of the season because the system was sampling an inshore area free of convex bottom features (see descriptions in Item03).
- The right-bank (RB) inshore DIDSON was deployed on July 08. Estimates between July 09 and July 28 were produced using data from LB DIDSON (0-20m), LB split-beam (20-55m), mobile split-beam (55m-370m) and RB inshore DIDSON (370m-400m). RB inshore DIDSON data was chosen for estimation due to its high accuracy (free of vessel avoidance effect) in counting fish passage near the right bank compared to the use of mobile split-beam data.
- The right-bank offshore DIDSON was deployed on July 28. Estimates between July 29 and Aug 10 were produced using data from LB DIDSON (0-20m), LB split-beam (20-55m), mobile split-beam (55m-350m), RB offshore DIDSON (350-370m) and RB inshore DIDSON (370m-400m). RB offshore and inshore DIDSON data was chosen for estimation due to its more accurate counting of fish passage near the right bank in comparison to the mobile data in the same range bin of 350-400m. In other words, we further reduced the use of the mobile data for the estimation of total salmon.

- As the water level receded (down to 3000 CMS at Hope, BC), the crew had to move the left-bank systems to a deeper water location on Aug 05. This relocation put the left-bank systems approximately 15m further offshore from their original location on June 29 (the beginning date of the program). At this updated offshore location, it was found (after 5 days of operation from Aug 06-10) that the LB DIDSON's 15° vertical beam was severely shadowed by the convex bottom features in the 5-20m sampling range bin. As a result of the shadowing effect, the DIDSON data over this range bin was biased low and unsuitable for the use of estimation (for detailed analysis of the DIDSON data see the supplemental file [Item2.SystemsforDailyEst\2b. Assessment of left-bank DIDSON systems at Mission.pptx](#)). In contrast to the DIDSON beam-width, the LB split-beam transducer had a much narrower vertical beam-width of 2° making the split-beam data (especially from the upper aims) over the same range bin less affected by the shadowing effect. In conjunction with the extrapolation method for the blind zones (see Item03 for details), the split-beam data was selected for the estimation of fish passage over the range bin of 0-20m. Estimates between Aug 11 – Oct 01 were produced using data from LB split-beam (0-55m), mobile split-beam (55m-350m), RB offshore DIDSON (350-370m) and RB inshore DIDSON (370m-400m).

Summarized in Table 1 are the proportions of seasonal total salmon for 2008-2015 seasons (excluding pink salmon dominated migration periods for odd years) estimated with the data from the left-bank system, the offshore mobile system, and the right-bank system.

Table 1. Proportions of seasonal total salmon passage estimated from the left-bank, mobile and right-bank systems (excluding pink salmon dominated periods for odd years). Values in parentheses are estimated sockeye distributions for 2015 season, which are unavailable for other seasons (see footnote 1 below).

Year (Period)	Total Salmon	Total Sockeye <sup>1</sup>	Proportion 1 (LB.Systems)	Proportion 2 (Offshore.Mobile.System)	Proportion 3 (RB.Systems)
2008	1.7M	1.4M	32%	68%	NA

<sup>1</sup> For non-pink salmon years, we assume that sockeye distributions have the same distributions as that of total salmon as we are unable to separate sockeye from other species in each of the three areas presented in Table 1 due to the lack of cross-river stratified species information for chinook, coho and chum. For 2009 and 2011, species information (marine test fishing data, etc) for pink salmon during early part of the migration does not have the cross-river resolution either. Stratified pink salmon distribution data was available for the 2013 season, but only after Aug 20 which is outside the sockeye data analysis range for this report. Only the 2015 data analyzed for this work item contains range stratified pink salmon distribution from Aug 02 – Aug 26, which allows for the estimation of sockeye distributions across the river by separating them from pink salmon by range bins. Since most of the data analyzed excluded data from pink salmon dominated periods, sockeye were expected to exhibit cross-river distributions very similar to that of total salmon for the periods presented in Table 1.

(July 09 - Aug 24)					
2009 (July 16 - Aug 20)	1.1M	0.8M	40%	60%	NA
2010 (July 06 - Oct 03)	15.5M	14.3M	56%	29%	15%
2011 (July 21 - Aug 25)	3.0M	2.1M	62%	31%	7%
2012 (July 11 - Aug 24)	1.8M	1.6M	67%	23%	11%
2013 (June 28 - Aug 20)	2.2M	1.9M	72%	20%	8%
2014 (June 29 - Oct 02)	10.4M	10.1M	61%	26%	13%
2015 (July 11 - Aug 26)	2.1M	1.5M	60% (55%)	32% (37%)	8% (7%)

**Item 03: Amount in daily estimate from direct sampling vs. amount derived from extrapolation (2008-2015; odd years for sockeye time period only)**

***Objectives***

1. Explain why there are acoustic blind zones at the Mission hydroacoustics site;
2. Describe how fish flux in the blind zone is estimated;
3. Quantify the proportion of fish flux extrapolated in the blind zone relative to the total flux for various migration periods across multiple seasons.

***Key outputs and conclusions***

1. The blind zone was first identified in 2002 and affects the flux estimate on the left bank near-shore only due to the shape of the river-bottom in this area. Fish flux in the blind zone is estimated using a nearest neighbor algorithm that extrapolates the flux from neighbouring, observable regions
2. The excel file [MissionFluxBySystem&Extrapolation.xlsx](#) is provided containing the daily proportion of extrapolated flux relative to the total daily salmon estimate for 2008, 2010, 2012, 2014, and 2015. The percent of total salmon flux extrapolated for each season varies from 10-23% (Table 2).

Mission daily estimates of total salmon escapement comprise two components:

- C1: direct measured fish flux in the non-obstructed zone, and
- C2: extrapolated fish flux in the acoustic blind zones near the river surface and bottom areas.

The process and methodology for identifying and accounting for the blind-zone using extrapolation are detailed in several of the references provided under work item 1. The key points are summarized as follows:

- The mechanisms of acoustic blind zones for a side-looking split-beam system deployed on the left bank at Mission site were identified in 2002 through a joint research between DFO and PSC. Readers are referred to Fig. 24 and associated descriptions on page 30 in R7. This research pointed at a potential solution to estimating fish passage in these blind zones by stating (2nd paragraph from the bottom of page 30 of R7):

*“We feel confident that we can measure and correct for these two biases. The bias from the blind zones can be taken into account when estimating the total flux. .... At the very least, the flux can be estimated for the blind zones from the measured fluxes in the bordering areas.”*

- Following the recommendation from the joint research (R1), a two-dimensional nearest neighborhood algorithm was tested and implemented in a software program to estimate fish passage in the blind zone by extrapolating the measured passages from the areas bordering the blind zone. Readers are referred to Page 9 of R9 (2nd paragraph on page 9):

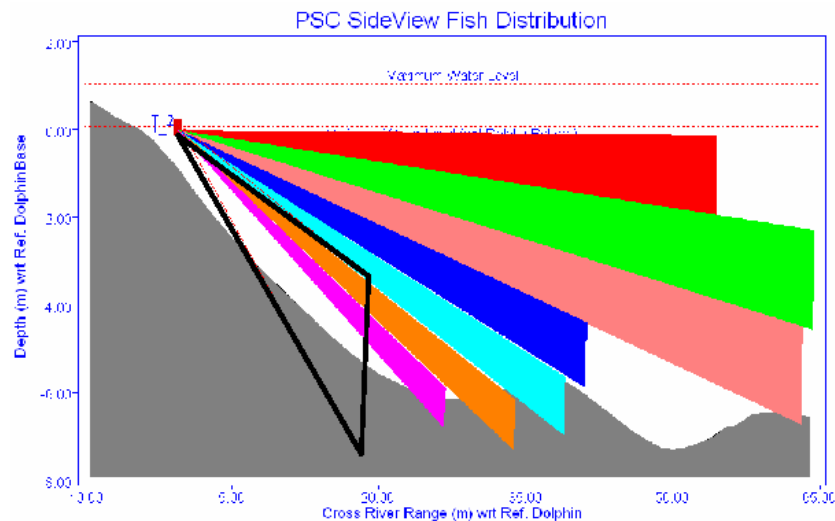
*“However, the total number of net upstream fish passing through the entire left-bank area should also include an amount of flux passing through the area that is not directly sampled by the left-bank system (i.e. in blind zones near the surface and bottom; see Figure 5). This amount of flux, denoted as  $M_0$ , is estimated by extrapolating estimated flux in the sampled area to the un-sampled area using a geo-statistical model.”*

Readers are also referred to Fig. 15 on Page 24 of R9 and associated descriptions (page 24 of R9):

*“The uneven profile of the river-bottom (as shown in Figure 8) prevents the split-beam sonar from grazing along the bottom to insonify the bottom-oriented fish for long ranges. The bottom features block the probing sound-beam at a certain range causing it to be*



ineffective in detecting targets beyond that range. The range limitation by the bottom is critically dependent upon the aiming angle of the beam and transducer distance off the bottom. Thus, the near-bottom area, shadowed from acoustic insonification by the split-beam transducers is the split-beam blind zone. Figure 15 shows an example of the cross-section of a blind zone near the left bank.



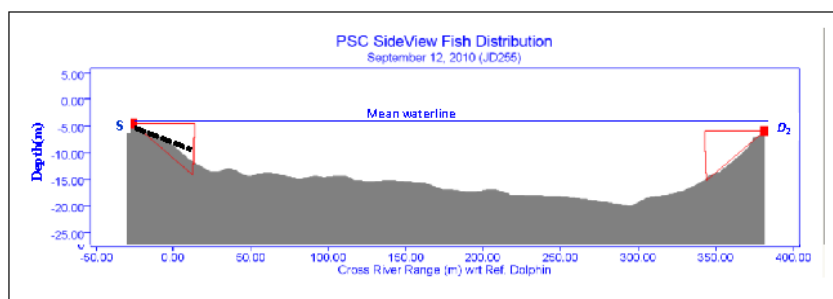
**Figure R9-15.** Example of a split-beam blind zone: the area under the pink-coloured beam-coverage area is not sampled by the  $2^\circ \times 10^\circ$  split-beam transducer due to interferences of bottom features (not shown by the smoothed profile). The heavy lines outline a geometrical sampling area by the 12-degree DIDSON-beam aimed at  $-16^\circ$  relative to the river-surface. The area highlighted with the checker pattern is a partial blind zone over which DIDSON data were used to assess the split-beam fish-flux extrapolated from the sampled areas above the blind zone.

The current split-beam model estimates fish-flux in the blind zone by extrapolating the flux estimates from the insonified area using a nearest-neighbour model (Bowman and Azzalini, 1997). The extrapolated flux needs to be assessed for its accuracy with direct measurements of the flux in the blind zone through other means.”

Note that in the example shown in Fig. R9-15, the near surface blind zone is minimal (i.e. vast majority of near surface estimate is being directly sampled by the aim denoted in red).

- The imaging sonar DIDSON was implemented for near-shore fish counting on both banks after the 2010 field testing. The bottom over the inshore area of the right bank followed a generally concave profile. It was found that a 15-deg DIDSON vertical

beam could acoustically illuminate the entire inshore cross-section from a single aim with little obstructions from the river bottom or surface making the right-bank DIDSON a robust counter for nearshore fish passage on the right bank. On the contrary, while the inshore portion of the bottom profile of the left bank followed a smooth linear slope, the profile took a sudden dip at around 20m range with a steeper slope (see Fig. R9-15 and Fig. R18-1). This sudden dip of the profile created a convex bottom over the nearshore area of the left bank. The convexity prevents the probing sound from wide beam sonar (such as the DIDSON) from detecting fish beyond the convex point by shadowing the fish. An SEF funded study with the 2013 seasonal data revealed that the convex bottom profile created a near-bottom blind zone with a more adverse effect on acoustic sampling of fish passage than previously thought. Readers are referred to Fig. 1 on page 3 of R18 and associated discussions for more detailed information on this issue:



**Figure R18-1.** The shadowing of the sound-beam by the convex bottom profile of the left bank. The beam area beneath the dark dashed line is shadowed by the bottom. On the contrary, the concaved bottom profile of the right bank allows the 14° DIDSON beam ( $D_2$ ) to fit perfectly to the entire cross-section of the water column for sampling the near-shore fish on the right bank.

- Fish migrating in both near-surface and near-bottom blind zones of the left bank are estimated using spatial extrapolation. However, the magnitude of the near surface extrapolation is minimal because only a small fraction of the fish migrating near the surface areas is outside the sampling area by the upper most aim of the sound beam (e.g. red triangle in Fig. R9-15 above). While the bottom blind zone is caused by the convexity of the bottom profile, the near-surface blind zone is caused by entrained air bubbles caused by boat wakes and/or weather events. The bubbles or bubble plumes can severely limit the effective sounding range of the sound beam at upper aims.

- The acoustic blind zone and corresponding passage extrapolation only affect a portion of the left-bank passage. Estimates of fish passage in the offshore (estimated by the mobile system) and nearshore areas of the right bank (estimated by the right-bank DIDSON system) are based on measurements of fish passage with no spatial extrapolations.

Seasonal proportions of fish flux extrapolations relative to the left-bank total passage and cross-river total passage are summarized in Table 2. Daily time series of proportions of extrapolated passage relative to total cross-river passage and total left-bank passage for 2008, 2010, 2012, 2014 and 2015 seasons can be found in the file [Item3. DirectSamplingvs.Extrapolation\MissionFluxBySystem&Extrapolation.xlsx](#). Note: due to time constraints, we were unable to complete a similar analysis for the 2009, 2011 and 2013 data in this report. We believe the results from the selected 5 seasons are representative for most migration scenarios encountered at Mission site.

Table 2. Proportions of extrapolated salmon flux relative to the total cross-river flux and the left-bank total flux for the 2008, 2010, 2012, 2014 and 2015 seasons.

Year (Period)	Mission Daily Total Salmon	Left-bank (LB) Total Salmon	Extrapolated Salmon	Percent of Extrapolation wrt Daily Total Salmon	Percent of Extrapolation wrt LB Total Salmon
2008 (July 09 - Aug 24)	1.7M	0.54M	0.17M	10%	31%
2010 (July 06 - Oct 03)	15.5M	8.64M	2.38M	15%	28%
2012 (July 11 - Aug 24)	1.8M	1.17M	0.41M	23%	35%
2014 (June 29 - Oct 02)	10.4M	6.33M	2.05M	20%	33%
2015 (July 11 - Aug 26)	2.1M	1.26M	0.35M	17%	28%

#### **Item 04: Fisheries removal of through-Qualark stocks between Mission and Qualark. (2008-2015; odd years for sockeye time period only)**

##### ***Objective***

1. Describe the methodology for projecting sockeye from Mission to Qualark, as well as estimating catches of sockeye between Mission and Qualark for stocks that migrate through Qualark
2. Quantify the exploitation rate of sockeye between Mission and Qualark

### ***Key outputs and conclusions***

1. The complete time series of daily catches of sockeye between Mission and Qualark for 2008-2015 is provided in the excel file [Item4&5.FisheriesRemovals&MissionProjectionsQualark\DailyMissionSockeyeProjectionVsQualarkSockeyeEstimates2008-2015.xlsx](#).
2. Fisheries removals between Mission and Qualark are generally a small proportion of total sockeye passage, with exploitation rate over the entire season ranging from a low of 1% to a high of 9%. However, fisheries removals do contribute to uncertainty in projecting sockeye from Mission to Qualark on certain years, especially when combined with other factors described in item 5.

The estimate of fisheries removals of through-Qualark stocks is based on two key data sources: 1) catch reports between Mission and Sawmill Creek by DFO; and 2) the estimated proportion of through-Qualark stocks migrating above Mission based on stock ID information from PSC lower river test-fishing catches. The level of temporal resolution of the catch reports varies over the period of comparisons. In the earlier years (e.g. 2008) catch estimates were generally provided by openings which in the lower Fraser typically occurred on weekend (i.e 2-3 days). These catch estimates were typically spread over the days of the opening assuming equal distribution of the catch across the days open. Beginning in 2009, total catch for the opening was assigned to days based on the relative number of open hours associated with each day. More recently, daily catch for an opening is estimated from either the number of open hours or effort estimates or a combination of effort and hours where available.

For the purposes of calculating catch removals, the Fraser River upstream of Mission is divided into three reaches that correspond to the level of resolution of the catch reporting: (1) from Mission upstream to the Harrison River confluence with the Fraser, (2) from the Harrison confluence to Hope, and (3) From Hope to Sawmill Creek. It is assumed to take sockeye one day to travel between each reach. Because the Qualark site is located within the third reach, it is necessary to partition the catch in this reach to areas upstream and downstream of Qualark. The confluence of Emory creek with the Fraser, just downstream of Qualark is used as the boundary and based on advice of DFO staff, about half of the catch in this reach occurs in areas downstream of Emory Creek (i.e. downstream of Qualark). This fraction may vary inter and intra annually, but typically the same fraction (e.g. 50%) is applied to each day of any given year to estimate the portion of that day's catch that occurs downstream of Qualark.

While unique catch reports are typically not available for individual days, the sockeye stock proportions are estimated for each day. However, the stock proportions are not based on samples obtained from the catches in the fishery. They are based primarily on daily

samples obtained from lower river test fisheries at Whonnock and Cottonwood. Two or more days samples from these test fisheries may occasionally be pooled, especially early and late in the season when the daily test fishery catches are particularly low. Seaward test fisheries can also contribute to stock identifications at Mission, particularly early in the season.

The daily proportions that are applied to individual river reaches are the same as those used to estimate the daily escapement at Mission with two exceptions: (1) the proportions are adjusted for the removal of stocks from catches in reaches downstream, and (2) the proportions are adjusted for stocks bound for tributaries that are downstream of Qualark. The application of the stock proportions from the lower river gillnet test fisheries which both use variable mesh gillnets, presumes that stocks are equally vulnerable to the gear used in fisheries upstream (largely drift or set gillnets with single mesh sizes). The daily removals of through-Qualark stocks were then derived by multiplying the estimated daily proportions of through-Qualark stocks from the test-fishing data to daily catch estimates in each reach (i.e. a forward reconstruction).

The estimation model for catch removals assumes that no fish bound for tributaries downstream of a particular Fraser river reach are caught in fisheries located upstream of where their tributaries enter the Fraser. However, this assumption is likely violated in two ways. First, we have evidence from samples collected in the main-stem Fraser upstream of where tributaries exit that fish population can “overshoot” their tributaries. For example, Harrison sockeye proportions have been estimated in samples taken from the test fishery at Qualark. This violation leads to an underestimate of the catch of these populations and over-projection of the fish bound for Qualark based on Mission. Second, we are limited by the location of boundaries associated with particular catch areas. Fortunately, one of those boundaries is the Harrison River (the Mission to Harrison reach), but the Vedder River enters the Fraser downstream of the Harrison and fish entering the Vedder (i.e. Chilliwack and Cultus) are assumed to be vulnerable to harvest in the entire Mission to Harrison reach. Violation of this assumption could lead to an overestimate of the catch of Chilliwack and Cultus and under projection of the fish bound for Qualark based on Mission. We do not have data to suggest that either of these two violations is a source of significant error, but there has been very limited samples obtained and analyzed from catches between Mission and Qualark. All populations bound for tributaries that enter the Fraser upstream of Mission and downstream of Qualark could be subject to these violations (i.e. Birkenhead, Big Silver, Harrison River, Weaver Creek and Channel, Chilliwack, Cultus, and miscellaneous streams tributary to the Harrison-Lillooet drainage).

Given the various assumptions used to generate projections of through-Qualark stocks from Mission acoustics data, it is noteworthy that the daily comparisons with Qualark match

quite well most of the time (e.g. see Figs. 2-4). However, it is also important to note that daily discrepancies between Mission projections and Qualark estimates during particular periods may be caused by violations of the assumptions used to remove catches that occur between the Mission and Qualark sites. Thus, deviations between Mission projections and Qualark estimates may occur for reasons that are unrelated to hydroacoustics sampling at either site. Table 3 provides a tabulated summary of seasonal estimates of proportion and catch of through-Qualark stocks above Mission for the eight seasons. Also listed in Table 3 are estimates of Harrison sockeye escapement past Mission and the exploitation rate (ER) of sockeye between Mission and Qualark defined as:  $ER = \text{Catch} / (\text{Mission Sockeye})$ . For detailed daily time series of estimated removal data, readers can review spreadsheet provided:

[Item4&5.FisheriesRemovals&MissionProjectionsQualark\DailyMissionSockeyeProjectionsVsQualarkSockeyeEstimates2008-2015.xlsx](#)

Table 3. Summary of annual estimates of proportion of through-Qualark stocks above Mission (excluding pink salmon dominated periods for odd years). Also listed for references are estimates of Harrison sockeye escapement past Mission and the exploitation rate (ER) of sockeye between Mission and Qualark for the comparison periods.

Year (Analysis Period)	Mission Total Sockeye	Harrison Sockeye past Mission	Percent of ThruQualark Stocks at Mission	Sockeye Catch btwn Mission and Qualark	Qualark Estimated Sockeye	ER of Sockeye btwn Mission and Qualark
2008 (July 09- Aug 24)	1.4M	36,000	82.3%	142.0K	0.91M	10%
2009 ( July 16-Aug 20)	0.8M	148,000	75.4%	9.5K	0.57M	1%
2010 (July 06 - Oct 03)	14.3M	1,055,000	89.9%	669.2K	14.0M	5%
2011 (July 21 - Aug 25)	2.1M	675,000	58.9%	174.0K	1.33M	8%
2012 (July 11 - Aug 24)	1.6M	140,000	69.0%	140.2K	1.04M	9%
2013 (June 28 -Aug 20)	1.9M	166,000	79.1%	40.3K	1.60M	2%
2014 (June 29 - Oct 02)	10.1M	995,000	88.6%	550.4K	6.97M	5%
2015 (July 11 - Aug 26)	1.5M	145,000	83.8%	21.6K	1.10M	1%

## **Item 05: Mission projected Qualark estimate (2008-2015; odd years for sockeye time period only)**

### ***Objectives***

1. Describe the methodology for projecting sockeye from Mission to Qualark (as in item 4 above) and other potential sources of uncertainty not related to hydroacoustics.
2. Quantify the daily difference between estimates (DBE) for Qualark and the Mission projected Qualark estimate.

### ***Key outputs and conclusions***

1. The complete time series of the Mission projected Qualark estimate for 2008-2015, along with catch removals and daily abundance of sockeye that spawn below Qualark, is provided in the excel file: [Item4&5.FisheriesRemovals&MissionProjectionsQualark\DailyMissionSockeyeProjectionVsQualarkSockeyeEstimates2008-2015.xlsx](#) (same file as described in item 4).
2. From these time series, we conclude that for dominant cycle years (2010 and 2014), DBE contributed by errors in stock ID estimate is likely very small as 90% of through-Mission stocks were heading for Qualark. Even for off cycle years 2008, 2013, and 2015 (excluding species bias periods by pink salmon in odd years), over 80% of stocks estimated to pass Mission were bound for areas upstream of Qualark.
3. For off cycle years 2009, 2011 and 2012, 25% to 40% of the stocks passing Mission were estimated to be bound for tributaries that leave the Fraser main-stem downstream of Qualark. For these years, DBEs cannot be solely attributed to hydroacoustic sources.
4. When estimates from 2008-2015 are pooled together (about 450 parallel observations), the daily DBE between Mission and Qualark is not statistically significant. However, the daily DBE is statistically significant for 2010, 2014 and 2015 when these years are examined individually (see Tables 4 and 6). The DBE can fluctuate throughout a season, and temporal DBE patterns are examined further in item 10.

The projection of sockeye daily escapement at Qualark is based on estimates of the following variables:

1. Mission daily total sockeye escapement.
2. Estimated proportions of through-Qualark stocks based on Mission stock ID from PSC test fisheries catches. The projection model assumes that there is no escapement of below-Qualark stocks (Harrison, Chilliwack, etc.) that stray through Qualark site. This assumption is not always valid but we did not assess the associated error on the DBE in this report.
3. Estimated fisheries removals of through-Qualark stocks between Mission and Qualark (see Item 04 for details).
4. Mean sockeye migration time from Mission to Qualark (95km of river distance). Historically, PSC assumes a 2-day travel time for Early Summer-run and Summer-run groups and a 3-day time for Late-run groups or pink salmon. However, time series analysis between Mission left-bank hourly fish count and Qualark hourly total passage count showed a mean travel time of 67 hours for Late-run sockeye and 81 hours for pink salmon (see page 20-22 of R15). The true travel time for sockeye stocks is likely between 2 and 3 days and varying within a season depending upon river conditions. Even if we can estimate the travel time down to hourly scales, we cannot use the finer scale travel time than daily for the projection model at its current form because most of the model inputs (Catch and stock ID data) are limited to (at the best) daily scale. We performed various numerical tests on the sensitivity of the model to travel time variations and we found that the difference in weekly projection is negligible using 2 or 3-day lag. For this analysis, we use a 2-day lag for the non-dominant years (2008, 2009, 2011, 2013, 2015) and 3-day lag for dominant years of 2010 and 2014.
5. An assumption of no en-route mortality between Mission and Qualark. Due to the lack of tagging data to quantify the mortality rate, the projection of Qualark escapement assumes there is no en-route loss and that all removals are accounted for in fisheries catch estimates and escapement to watersheds below Qualark (Harrison, Chilliwack, etc.).

The daily projection of through-Qualark stocks follows the same methodology described in item 4 above. The assumptions regarding migration time are required to permit daily comparison of the time series of estimates from each site. Readers can find the daily time series of projected escapement at Qualark for 2008-2015 within the excel file: [Item4&5.FisheriesRemovals&MissionProjectionsQualark\DailyMissionSockeyeProjectionVsQualarkSockeyeEstimates2008-2015.xlsx](#)

Table 4 provides a tabulated summary of seasonal projections of Qualark sockeye and Qualark estimated sockeye escapement for the eight seasons. Also listed in the table are the key estimates that PSC adopted for generating the projections.



Table 4. Summary of seasonal projections of Qualark sockeye and Qualark estimated sockeye (excluding pink salmon dominated periods for odd years). Also listed are the key estimates used in generating the projection, and *p*-values from parried tests of daily estimates. *p*-values listed in red indicate significant DBE for the corresponding season.

Year (Analysis Period)	Mission Total Salmon	Mission Sockeye	Percent of ThruQualark Stocks	Catch	ER	Projected Sockeye	Qualark Sockeye	% Diff	<i>p</i> -value (daily parried test)
2008 (July 09- Aug 24)	1.7M	1.4M	82.3%	142.0K	10%	1.0M	0.91M	10%	0.1730
2009 ( July 16-Aug 20)	1.1M	0.8M	75.4%	9.5K	1%	0.6M	0.57M	5%	0.5974
2010 (July 17 - Oct 03)	15.4M	14.2M	89.9%	669.2K	5%	12.1M	14.0M	(15%)	<b>0.0001</b>
2011 (July 21 - Aug 25)	3.0M	2.1M	58.9%	174.0K	8%	1.12M	1.33M	(19%)	0.0586
2012 (July 11 - Aug 24)	1.8M	1.6M	69%	140.2K	9%	0.99M	1.04M	(5%)	0.4976
2013 (June 28 -Aug 20)	2.2M	1.9M	79.1%	40.3K	2%	1.66M	1.60M	4%	0.3573
2014 (June 29 - Oct 02)	10.4M	10.1M	88.6%	550.4K	5%	8.41M	6.97M	17%	<b>0.0038</b>
2015 (July 11 - Aug 26)	2.1M	1.5M	83.8%	21.6K	1%	1.30M	1.10M	15%	<b>0.0028</b>
All Years (437 pairs of data)	38M	34M	85%	1.75M	5%	27.3M	27.5M	(0.7%)	0.6430

Based on the assessment of numerical contributions to the projected Qualark daily sockeye escapement, qualitative descriptions of likely sources of projection error is summarized in Table 5 for individual years. The rationale for the descriptions was solely based on observed (over the eight seasons) relative numerical impacts on the projection from four variables: hydroacoustic fish counts, stock ID, catch estimate, and species composition. While some of the rationale may be debatable for their significance from biological point of view, it is very likely from the observed numerical values that hydroacoustic fish counts had the highest impacts on the projections for 2010 and 2014 seasons as numerical impacts from either stock ID or catch estimates were very limited in their magnitudes. Also noticed is that for migration scenarios similar to 2011 season (very low run size coupled with low through-Qualark stocks and relatively high exploitation rates), both stock ID and/or catch estimation errors can significantly impact the projection accuracy.

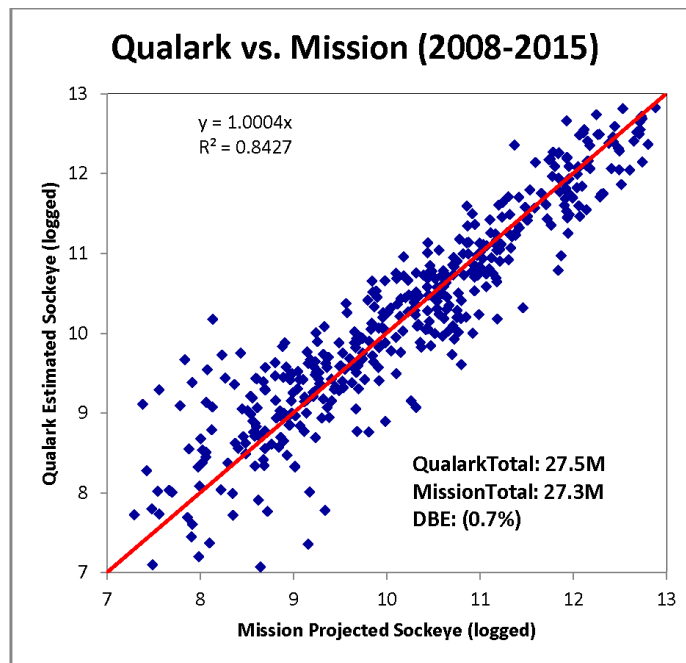
Table 5. Summary of factors likely having large numeric impacts on the projection of Qualark daily sockeye escapement. Bold-faced factors are considered to be highly probable causes for the DBE. Also presented is the rationale proposed for the likelihood.

Year (Analysis Period)	% Diff	%Thru-Qualark Stocks at Mission	Exploit. rate btwn Mission and Qualark	Factors with likely large impacts on projection	Rationale
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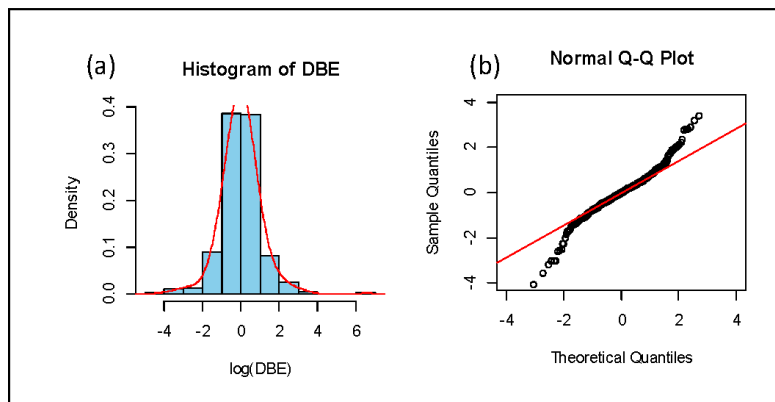
2008 (July 09- Aug 24)	10%	82.3%	10%	Catch	Small run w/ high exploitation rate between Mission and Qualark
2009 ( July 16-Aug 20)	5%	75.4%	1%	Stock ID	Small run w/ 25% Mission stocks estimated as below-Qualark
2010 (July 06 - Oct 03)	(15%)	89.9%	5%	<b>Hydroacoustics fish count</b>	Large run w/ low ER and high % of thru-Qualark stocks
2011 (July 21 - Aug 25)	(19%)	58.9%	8%	Stock ID & Catch	Small run w/ 40% Mission stocks as below-Qualark & high ER
2012 (July 11 - Aug 24)	(5%)	69%	9%	Stock ID & Catch	Small run w/ 30% Mission stocks as below-Qualark & high ER
2013 (June 28 -Aug 20)	4%	79.1%	2%	Species estimate error for pink salmon	Small run but pink salmon may impact sockeye estimate in Aug
2014 (June 29 - Oct 02)	17%	88.6%	5%	<b>Hydroacoustics fish count</b>	Large run w/ low ER and high % of thru-Qualark stocks
2015 (July 11 - Aug 26)	15%	83.8%	1%	Species estimate error for pink salmon	Small run but pink salmon likely impacted sockeye estimate in Aug

Over the 2008-2015 seasons, 437 (out of 448) pairs of estimates of Qualark sockeye daily escapement were produced from the Mission and Qualark data series for comparisons. The key statistical descriptions of the two estimates are summarized as follows:

1. The two estimates are statistically identical (paired  $t$ -test yields a  $p$ -value of 0.643);
2. The variances of the two estimates are statistically equal ( $F$ -test yields a  $p$ -value of 0.764);
3. The two estimates are highly correlated with a significant relation (Fig. 2);
4. DBE over the eight seasons follows a near-perfect normal distribution (in log space) as shown in Fig. 3. This is consistent with the hypothesis that error between the two estimates originated mainly from non-directional random sources.



**Figure 2.** Qualark estimated vs. Mission projected daily Qualark sockeye abundance from 2008-2015 seasons (excluding pink salmon dominated periods for odd years). The slope of the fit is highly significant with a virtually zero  $p$ -value (i.e., reject  $H_0$ : slope = 0).



**Figure 3.** (a). Histogram of DBE (2008-2015), and (b) Quantile plot of the DBE relative to a normal model. Points falling along the red diagonal line are consistent with expectations from a normal distribution.

However, DBE differs among individual seasons with DBE's in some years showing statistically significant differences between the two estimates while in other years the differences are negligible. Table 6 is a summary of statistical testing results on DBE for individual years.

Table 6. Summary of testing results on Mission vs. Qualark daily sockeye estimates for 2008-2015 (excluding pink salmon dominated periods for odd years).

Year	DBE(%)	<i>p</i> -value (paired test)	Remarks
2008	10%	0.1730	similar
2009	5%	0.5974	similar
2010	(15%)	0.0001	Mission is lower
2011	(19%)	0.0586	marginally similar
2012	(5%)	0.4976	similar
2013	4%	0.3573	similar
2014	17%	0.0038	Mission is higher
2015	15%	0.0028	Mission is higher
2008-2015	(0.7%)	0.6430	identical

Even within a season, the DBE displays non-uniform temporal patterns as shown in Figure 4.

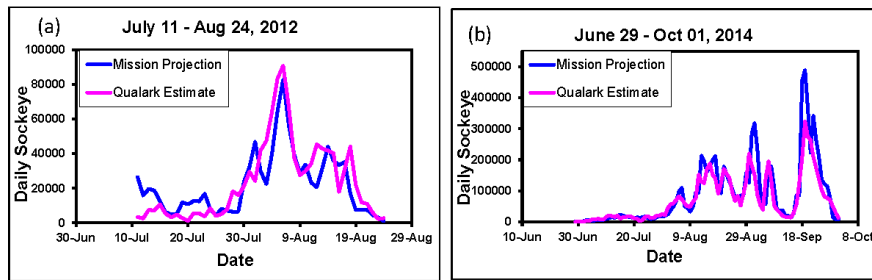


Figure 4. Time series of Mission projected and Qualark estimated daily sockeye passage at Qualark: (a) 2012 season (0.99M vs 1.04M) and (b) 2014 season (8.41M vs 6.97 M).

Detailed analysis of DBE's within-season temporal patterns is provided in [Item10](#), which quantifies factors that are correlated with the observed episodically temporal patterns in DBEs for individual seasons.

## **Item 06: Cross aim fish flux due to vertical fish movements in the left-bank split-beam sampling areas**

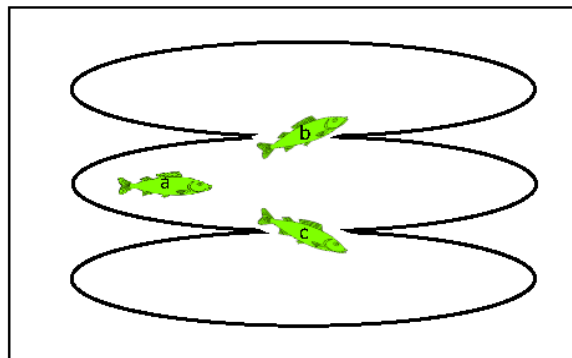
### ***Objectives***

1. Describe the mechanism through which cross aim fish flux could bias estimates generated by the left bank split-beam;
2. Assess whether cross aim fish flux is a significant source of bias.

### ***Key outputs and conclusions***

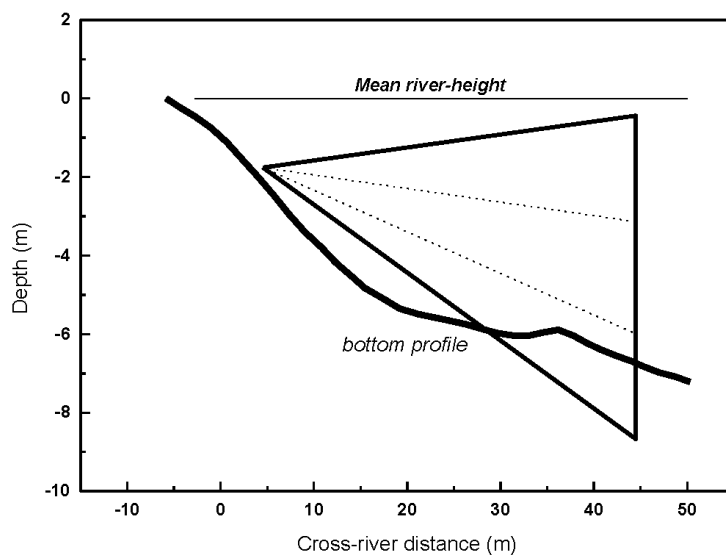
1. A 36-hour experiment conducted in 2004 comparing split-beam estimated passage with DIDSON estimated passage revealed no bias due to cross aim fish flux.
2. Examining the vertical swimming angle of 5000 salmon on September 19, 2014 suggested no systematic vertical movements, and therefore no bias due to cross aim fish flux.
3. Though experiments have only been performed during limited time periods, there is thus far little evidence to suggest that cross aim fish flux is a significant source of bias in estimating fish passage at Mission.

PSC employed a vertically stratified sampling scheme to estimate left-bank fish passage through the entire water column using narrow-beam transducers of 2 to 4-deg beam-width (Figure R9-15). Concerns have been raised that if fish exhibit systematic vertical movements, estimates of passage rates based on such stratified fish counts would be inflated due to the crossing of the same flux of fish into multiple sampling strata as shown in Figure 5.

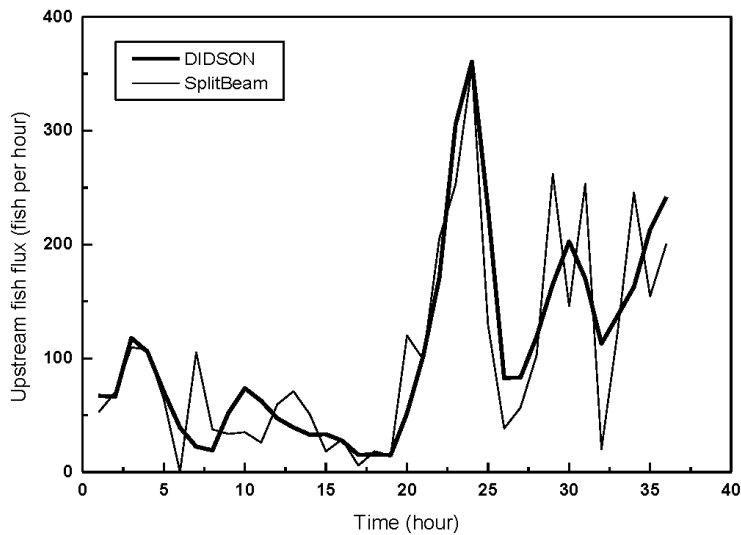


**Figure 5.** A schematic illustration of three distinctive fish flux orientations intercepted by the three vertically stratified sampling volumes. Orientation of fish flux represented by fish (a) does not bias the estimate produced by the stratified sampling while flux orientations represented by fish (b) or (c) would inflate the estimate by this sampling method.

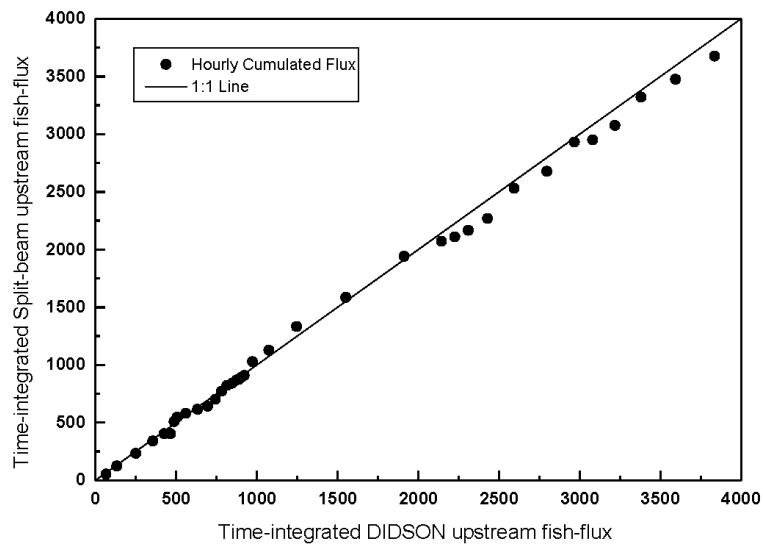
A direct approach to assess the accuracy of the estimate by this stratified sampling method is to compare the estimate with a non-stratified fish count by a wide-beam system over the same area. In the 2004 field season when the DIDSON technology was first tested for Mission sonar work, we designed and implemented an experiment on the left bank where a split-beam system and a standard DIDSON unit were deployed at the same location to sample the same area of fish passage. Detailed descriptions of the experiment are provided in R9. For the convenience of readers, we cite three key figures from R9 here.



**Figure R9-8.** The commonly sampled area by the DIDSON beam aimed at  $-4^\circ$  and the two split-beam transducers. Also shown are 3 sub-triangle areas (separated by the two dotted lines) sampled by a  $4^\circ \times 10^\circ$  split-beam transducer at 3 aims with 6-minute sampling at each aim. The 3 aims of samplings were followed by 7 aims of samplings by a  $2^\circ \times 10^\circ$  transducer (not shown in the figure).



**Figure R9-10.** Hourly net upstream fish-flux for the 36-hour time period starting at 00:00 Aug 22, and ending at 13:00 Aug 23, 2004. The two time-series are significantly correlated ( $r = 0.86$ ).

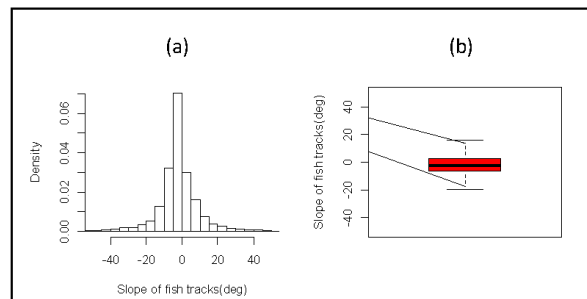


**Figure R9-11.** Time cumulative net upstream fish-flux estimates by the two estimators. The cumulated totals at the end of the 36-hour time period are 3835, and 3674 for the DIDSON and the split-beam sonar, respectively. The means of the two hourly estimates are 106, and 102, respectively, which are statistically similar ( $p = 0.828$ ).

The results of tech report R9 and their relevance to this work item are summarized as follows:

- PSC conducted a 36-hour test in the 2004 season to compare estimates from the vertically stratified split-beam fish count with the non-stratified DIDSON fish count over a common area off the left bank.
- The comparison based on this 36-hour duration of fish counts showed that the estimates from the two systems (one with stratified sampling; the other non-stratified sampling) were statistically identical. Therefore, fish migrating during this testing period would not have had significant vertical movements.
- We recognize that this result was based on a limited dataset and may not reflect fish behavior during all the scenarios encountered over the 2008-2015 seasons. Unfortunately left-bank DIDSON data collected after the 2004 field testing were not spatially synchronized with the left-bank split-beam data. As a result, we were unable to repeat the same comparison analysis with additional data.

Based on our fisheries sonar work since 1995, we have observed little evidence that adult returning salmon exhibit systematic vertical movements at this site. To show this, we selected approximately 5000 fish targets tracked by the left-bank split-beam system on September 19, 2014 when more than half a million sockeye were estimated to have migrated past Mission. Since the split-beam system measured the vertical fish movements, we were able to evaluate the vertical slopes of swimming trajectories of the fish as they moved through the sound-beam. Figure 6 shows the measured distribution of the slopes for the 5000 detected fish targets.

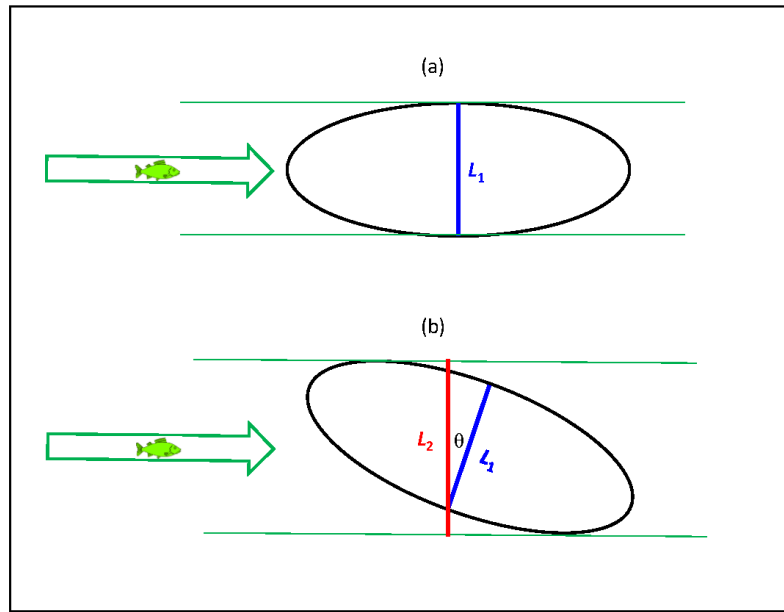


**Figure 6.** Distribution of vertical slope of swimming trajectories of 5000 fish targets measured by the left-bank split-beam system on September 19, 2014. (a) observed probability density function of the slope; (b) boxplot of the distribution.



The observed slopes and their distribution indicated no systematic vertical movements by these fish. The median and mean were both around  $-2^\circ$ , which is consistent with the roll angle of the transducer deployed for the sampling. The very tight 1st-to-3rd quantile width  $[-4^\circ, 4^\circ]$  as shown in the boxplot indicates that the majority of the fish were swimming consistently upstream in a horizontal orientation.

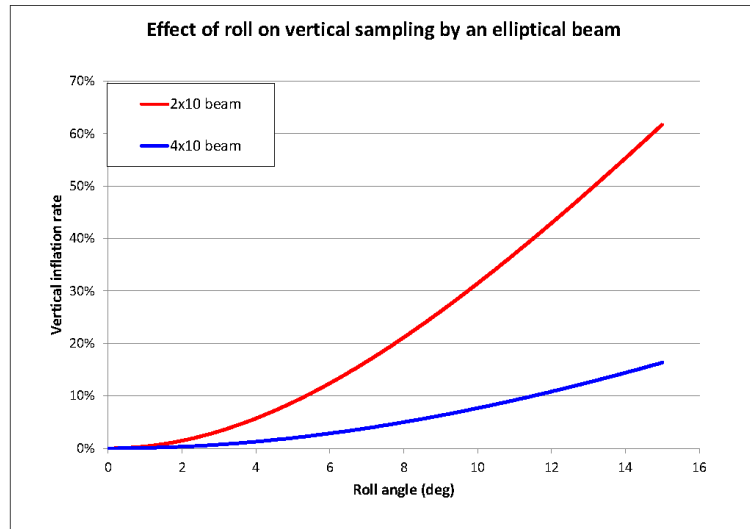
Though we cannot completely rule out the possibility of inflations of the total fish count by a small percentage of fish that might have crossed more than one sampling stratum, the likelihood of such random error appears to be very slim to cause noticeable directional high bias in the total fish count. For a transducer with an elliptical beam-pattern, we can assess the inflation of fish counts by the transducer deployed with a roll angle of  $\theta$  (see Appendix of R6 for detailed derivations). Figure 6B schematically illustrates the acoustic footprint of an elliptical sound beam for intercepting a horizontally oriented fish flux with a perfectly leveled deployment and a deployment with a roll angle of  $\theta$ .



**Figure 6B.** Acoustic footprint of an elliptical sound beam for intercepting a horizontally oriented fish flux with (a) a perfectly leveled deployment which yields a vertical intercepting dimension of  $L_1$ , and (b) a deployment with a roll angle of  $\theta$  which results in an increased intercepting dimension of  $L_2$ .

The roll of the transducer beam causes an increase in the vertical intercepting dimension from  $L_1$  to  $L_2$ . Based on this geometric model, we can estimate the counting inflation rate

due to this increase. The metric to measure the inflation rate is:  $(L_2 - L_1)/L_1$ . Figure 6C is the response of  $(L_2 - L_1)/L_1$  to roll angle  $\theta$ .



**Figure 6C.** Vertical inflation rate vs. roll angle for elliptical beam transducers.

It is evident that the greater the asymmetry of a beam pattern the more susceptible the system is to the inflation error (compare the response of a  $2^\circ \times 10^\circ$  transducer to a  $4^\circ \times 10^\circ$  unit). From this model, we see a roll angle of  $2^\circ$  causes an inflation rate of 1.5% for the  $2^\circ \times 10^\circ$  transducer.

## **Item 07: Bias or randomness of the extrapolated left-bank fish flux**

### ***Objectives***

1. Assess whether the extrapolation method for estimating fish flux in the left bank blind zone may introduce significant bias or error into the daily total salmon estimate

### ***Key output and conclusions***

1. An experiment was conducted in 2005 comparing split-beam counts with extrapolation to DIDSON counts without extrapolation and including the blind-zone. Eighteen hours of fish count were compared with a difference in total counts of 9%, which does not suggest a significant bias from the extrapolation method. However, the comparison relies on several assumptions outlined in further detail within this work item.
2. Examination of the dataset described in Item 3 suggests that the daily proportion extrapolated fluctuates within and among seasons. There is some evidence of a relationship between total salmon abundance and proportion extrapolated in 2012 and 2014, but not for 2008, 2010, and 2015. Item 10 will further examine any relationship between the proportion extrapolated and DBE between Mission and Qualark.

As described in Item 03, fish flux in the bottom acoustic blind zone on the left bank was extrapolated from measured split-beam fish counts in the neighboring areas using a two-dimensional nearest neighborhood method. To assess the accuracy of extrapolated fish counts, we designed and conducted an experiment on the left bank in September 2005 to use DIDSON fish counts over the same range bin (6-20m) sampled by the split-beam to compare the estimates between the two systems. The sampling geometry over this comparison range bin is shown in *Figure R9-15*. There were two major difficulties that imposed challenges for this comparison study:

1. The DIDSON beam was too wide to fit exclusively into the blind zone where the fish count was extrapolated by the observed split-beam data, and
2. Because the DIDSON was aimed at a steep angle to include the bottom blind zone, the sonar insonified many small non-salmon species such as northern pike minnows (*Ptychocheilus oregonensis*, see photo in Figure 7) which were seen hovering right above the bottom and moving upstream.



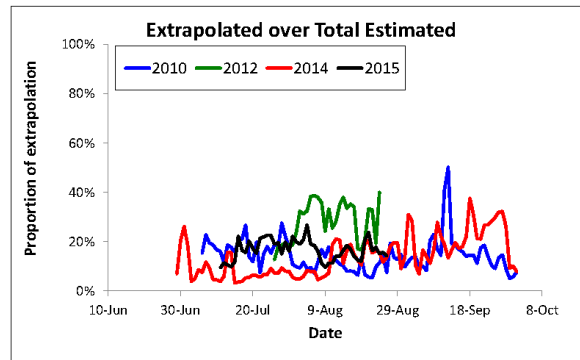
**Figure 7.** A northern pike minnow (15 cm in body length) caught by a beach seine net on the left bank of Mission site in the summer of 2009.

The obtained DIDSON fish counts comprised fish passages from (a) commonly insonified zone by the split-beam, (b) the split-beam blind zone, and (c) small sized non-salmon species hovering above the bottom. DIDSON counts of salmon-sized targets were extracted from the total fish count using a length-based mixture model. The DIDSON fish count was then compared with the split-beam fish counts from both the split-beam's sampled and blind zones. Detailed descriptions of the experiment and analysis are provided on pages 24-27 in R9.

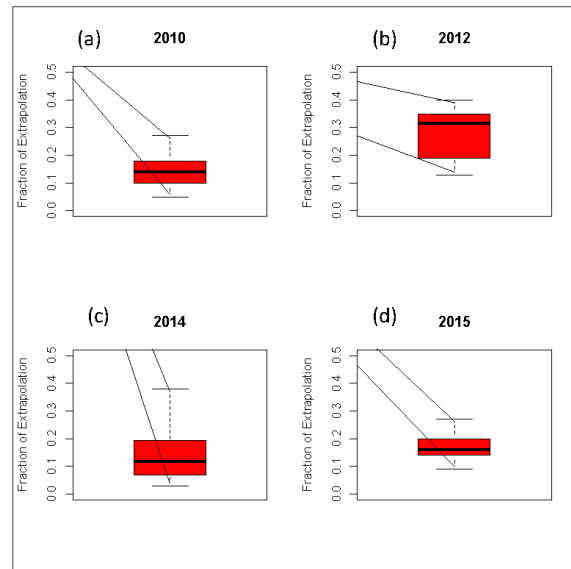
The key results from R9 as they relate to this work item are summarized as follows:

- Due to the sampling limitation by the two-dimensional DIDSON with a wide ( $12^{\circ}$ - $17^{\circ}$ ) vertical beam, DIDSON could only acquire total fish count data from both the split-beam's sampling zone and blind zone.
- A total of 18 hours of fish counts were obtained from the DIDSON and the split-beam system for the comparison range bin between September 22 and 24. The overall comparison yielded a 9% difference between the two estimates while during the peak migration period between 1500 and 1700 hours, the difference was 6%.
- While the DIDSON data from this study was unable to provide a direct assessment on the accuracy of the extrapolation method for the blind zone, it did provide an assessment of fish passage estimates in the entire water column produced by the split-beam and its associated extrapolation method. The result, though limited by the amount of data for this study, did not indicate a significant bias from the extrapolation method.

Examining the data from more recent years, as described in Item 3, reveals that the extrapolation accounts for 17% of the total salmon estimate on average (see Table 2). This varies from 10 to 23 % with a standard deviation of 5%. However, this proportion of extrapolation fluctuates within the season, as shown in Figure 8.



**Figure 8.** Time series of proportion of extrapolated amount of estimate relative to the total amount of daily estimate for 2010, 2012, 2014, and 2015 seasons.



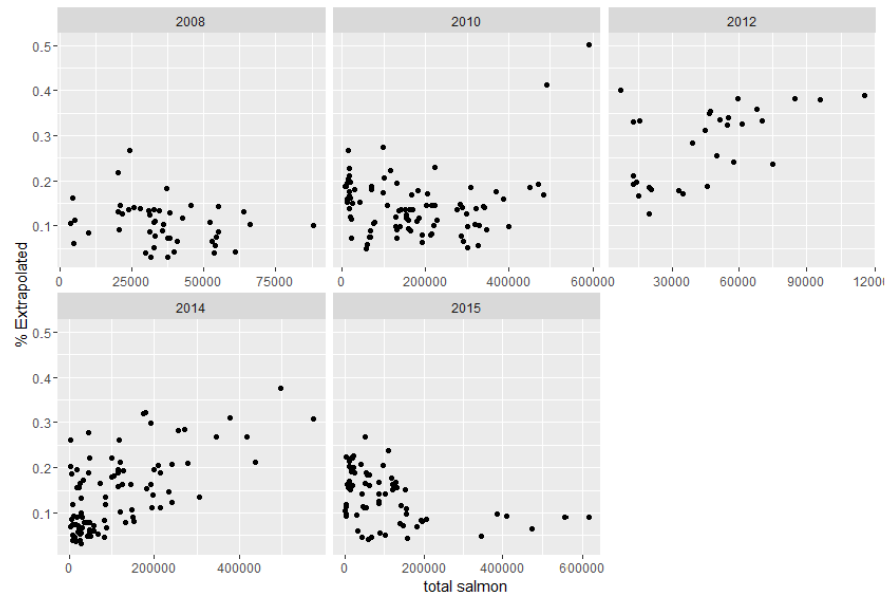
**Figure 9.** Boxplots of distributions of fraction of daily extrapolated amount of estimate for (a) 2010, (b) 2012, (c) 2014, and (d) 2015 seasons.

Table 7. Summary of key statistics of fraction of daily extrapolated amount of estimate.

Year	1st quantile	Median	3rd quantile	Standard deviation
2010	10%	14%	18%	6.8%
2012	13%	32%	35%	8.3%
2014	7%	12%	20%	8.3%
2015	14%	16%	20%	4.3%

While the percentage of extrapolation shows generally random patterns against daily total abundance for 2008, 2010, 2015, this percentage appears to exhibit a trend with the abundance for 2012 and 2014 (see Figure 9B).

Except for the 2012 season, the medians of daily fraction of extrapolation fall within 12-16% with 2015 having the smallest variation while 2012 and 2014 the highest variations (see quantile widths in Fig. 9). The correlation between the proportion extrapolated and the DBE is assessed in Item 10.



**Figure 9B.** Percent of daily estimate from extrapolation vs. total daily salmon estimate for 2008, 2010, 2012, 2014 and 2015 seasons.

The most effective approach to reduce the extrapolation impact on the estimation is to re-profile the left-bank nearshore bottom with a smooth linear slope so that a sound beam can sample the entire water column without being shadowed by obstructions on the bottom. Permits are being obtained from the Province of BC to do this work in the near future.

### **Item 08: Bias in the offshore fish passage estimates by the mobile system as fish change migratory behavior due to fishing or tidal influences**

#### ***Objectives***

1. Describe the potential impact of differences in fish behavior (i.e. speed and swimming direction) between offshore and nearshore fish on the daily total salmon estimate;
2. Assess potential biases as a result of differences in fish behavior between the left bank and mid-channel.

#### ***Key Outputs and Conclusions***

1. Typically fish speed and direction is measured from the left bank near-shore, and we apply these behavioural statistics to fish observed by the mobile system in the mid-channel. Experiments were conducted over 16 days in 2014 and 2015 to measure fish speed and direction at offshore locations and examine whether applying these direct measurements of offshore behavior would significantly affect the total fish passage estimate. The total difference in salmon flux estimates over the entire 16 days was less than 1%, with most days confined to  $\pm 3\%$ , suggesting that our assumption of using left-bank fish behavior for offshore fish does not significantly bias the estimate of total fish passage.
2. Downstream swimming events were observed offshore under certain conditions, such as when driftnet fishing occurred through the Mission site. These did not have a large influence on the daily total salmon estimate during the days examined, but we cannot rule out their potential influence during time periods outside of the experiment.

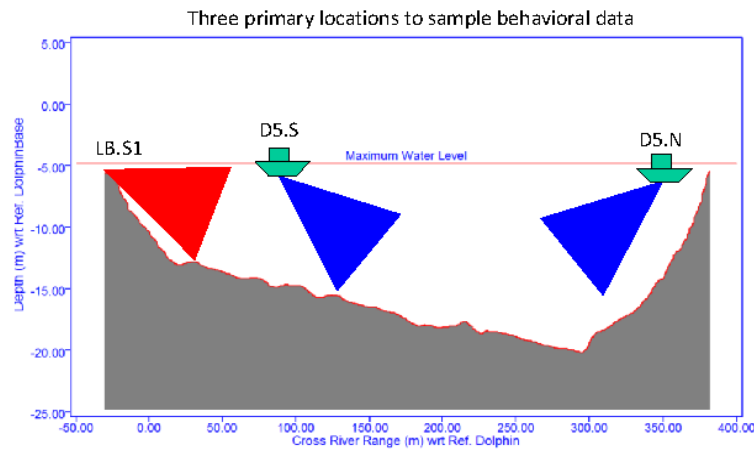
Daily escapement of salmon migrating in offshore area is determined by three variables: (1) spatial density of fish present in the river, (2) speed of travel of the fish, and (3) direction of travel of the fish. Estimation errors in any of the three variables can bias the estimate of offshore salmon passage. Work under Item08 quantifies impacts on accuracy due to estimation errors in speed of travel and direction of travel, the two behavioral variables.

Work under Item9 qualitatively assesses impacts from estimation error in fish density measurements by the mobile sounding system.

It is very difficult, if not impossible, to accurately measure the true moving speed and direction of travel of fish by a vessel-based moving transducer (see Item 09 for the main adverse factors) whereas these behavioral variables can readily be measured by a stationary split-beam transducer. Due to the lack of reliable data on fish behavior from the mobile sounding system on the transecting vessel, fish passage in the mid-channel area (i.e., beyond the sounding ranges from either bank by the shore-based systems) was estimated by a flux model. The model takes the fish density data acquired from the mobile sounding system and behavioral statistics (fish speed and downstream ratio) measured near the left bank by the shore-based system to derive the passage rate. Basic principles and detailed descriptions of the model are given in R2, R8 and R9 (see pages 56-57 of R9 for the derivation). Estimation accuracy of offshore fish passage hinges on the assumption of uniform fish behavior across the river. A field study in the 2006 season showed differential fish speeds and downstream ratios across the river (see R10 for detailed descriptions and key findings from the study).

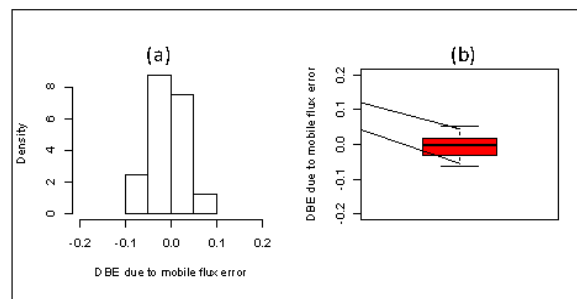
The objective under this work item is to provide readers with an idea about the impact of differential fish speeds and downstream ratios of offshore fish relative to nearshore fish on the total fish estimate. For this purpose, we re-generated a total of 16 days of mobile estimates for the 2014 and 2015 seasons using fish speeds and downstream ratios measured at the two offshore locations by a DIDSON launched from the echo sounding vessel during its stationary sounding hours (on average, 3 hours of sampling per location per day). The areas sampled by the vessel-based DIDSON are schematically shown in Figure 10. The regenerated estimates, denoted as *alternative estimates* hereafter, were compared to the in-season estimates to assess the magnitude of DBE from this source of error. Readers can download the detailed results and data used from the sub-folder [Item8. Fish Behaviour](#)





**Figure 10.** Locations and sampling areas for behavioral data (fish speed and downstream ratio) at the three primary locations for estimating offshore fish passage with the mobile sounding data. Behavioral data from left-bank split-beam (LB.S1) was used for in-season estimate; data from vessel-based DIDSON at the south (D5.S) and north (D5.N) stationary sounding locations was used to generate estimates to assess the DBE due to non-uniform fish behavior between the left bank and offshore areas.

Table 8 tabulates the DBE's between in-season daily estimates and estimates using the behavioural data from the two offshore locations for the 16 days. The distribution of the DBEs are shown in Figure 11.



**Figure 11.** Distribution of daily DBE between in-season estimates and the alternative estimates. (a) Histogram of the DBE, and (b) boxplot of the DBE distribution which shows a median of 0.3% with a quantile range from -2.8% to 1.2%. Note: the DBE is calculated from the formulae:  $(\text{in-season} - \text{alternative})/\text{in-season}$ . A percent difference of zero indicated no bias.

Table 8. Summary of comparisons between in-season daily estimates and alternative estimates using offshore fish behavior data. Also listed are the in-season mobile portions of the estimates, which are indicators of the weights of mobile estimates on the total estimates.

Date	In-season w/LB.S1 behavioral data		Alternative w/D5.S and D5.N behavioral data	
	Estimate	Mobile Portion	Estimate	DBE
2014-08-06	151,715	26%	155,441	-2.5%
2014-08-15	191,274	28%	200,345	-4.7%
2014-08-31	306,469	34%	290,257	5.3%
2014-09-18	495,594	11%	499,209	-0.7%
2014-09-19	571,226	8%	585,014	-2.4%
2014-09-21	279,277	21%	289,476	-3.7%
2015-08-08	54,074	51%	51,528	4.7%
2015-08-22	120,537	29%	115,516	4.2%
2015-08-23	117,437	25%	118,144	-0.6%
2015-08-29	154,740	26%	164,295	-6.2%
2015-08-30	128,214	19%	135,118	-5.4%
2015-09-05	614,640	4%	598,174	2.7%
2015-09-06	557,446	6%	556,856	0.1%
2015-09-07	409,544	8%	406,827	0.7%
2015-09-10	142,738	14%	142,781	0.0%
2015-09-11	193,208	10%	191,769	0.7%

The key results and findings under this work item are summarized as follows:

- Using the left-bank fish behavioral data to estimate the offshore fish passage resulted in an overall DBE (relative to using the alternative behavioral data) of less than 1% for the 16 days of total estimate;
- The vast majority of the daily DBE's are confined to  $\pm 3\%$  (see Fig. 11). For periods dominated by sockeye migrations (the 2014 data and 2015 data up to the end of August), the overall DBE is 1.3%.

- Use of left-bank behavioral data does not cause significant bias in the estimation of total fish passage by the current sampling configuration for all the migration scenarios examined for the investigated periods.
- The mobile flux model is most sensitive to variations in upstream swim speed  $v$  and downstream ratio,  $R_d$ . The model takes a product form of  $v \times (1 - 2R_d)$  (see Eqn. (A5) in R9, and Eqn. (11) in R10). Our study showed that offshore fish tend to maintain higher swimming speed but also exhibit higher downstream ratio than fish nearshore, which leads to an increased  $v$  but a decreased  $(1 - 2R_d)$  in comparison to nearshore values. Because of the differences in opposite directions, the difference between the alternative and in-season estimates of offshore fish passage can be much less than perceived from the variations in  $v$  or  $R_d$  alone.
- Large downstream fish movements were observed between 2200-2300 hours on Aug 31, 2014 at the south location. Fish appeared to be startled by some local events. By carefully reviewing the imaging file, it was found that a few sturgeons were foraging on the fish at this location causing the otherwise normally upstream migrating fish to take rapid evasive reactions. A clip of the image file showing this abnormal behavior can be downloaded from the Power-point file [2014Assessment of Estimation Error Using Leftbank Fish Behaviour.pptx](#) (note: clip had to be removed from secure site due to large file size, but can be provided upon request). The large downstream movements observed offshore resulted in a  $R_d$  of 12% which was 4 times the downstream ratio of 3% observed on the left bank. The alternative offshore estimate was 97,400 which was 14% lower than the in-season offshore estimate of 113,600 on this date. Since the offshore passage accounted for only about one-third of the total migration, the difference between the alternative and in-season offshore estimates resulted in only a 5.3% difference in the estimates of total fish passage by the two methods.
- Large downstream fish movements were also observed at 11am on September 05, 2015 by the vessel-based DIDSON when it started a 45-min sounding at the north location. Similar downstream movements were also observed for the same period of time by the right-bank offshore DIDSON. Image clips of these systematic downstream movements are provided in the [2015Assessment of Estimation Error Using Leftbank Fish Behaviour.pptx](#) file (note: clip had to be removed from secure site due to large file size, but can be provided upon request). The abnormal behavior coincided with the commencement of the 12-hour opening of drift-net fishing. Though there is a fishery exclusion boundary around the site, drift net activity was documented to occur past the systems on both shores and through the normal transecting path taken by the vessel. Increased downstream migration is

consistent with fish reacting to drift fishing activity. The large downstream movements observed in the offshore water resulted in a downstream ratio of 40% which was 5 times the  $R_d$  of 8% observed off the left bank by the left-bank system. As a result of this high  $R_d$ , the alternative offshore estimate was only a quarter of the in-season offshore estimate for this date (5,000 vs. 20,000). But, the impact of this seemingly very large error on the total estimate is negligibly small with a DBE of 2.7% (Table 8). This outcome was primarily due to the fact that over 95% of the fish (mostly pink salmon) were migrating in nearshore waters sampled by the shore-based systems. Therefore, errors in the offshore estimation had little impact on the total estimate.

## **Item 09: Bias in target recognition by the mobile system**

### ***Objectives***

1. Describe potential biases that may exist due to challenges in recognizing fish targets using the mobile hydroacoustics system;
2. Determine the potential impact of these biases by comparing passage estimates using the mobile split-beam data currently used to an offshore DIDSON unit.

### ***Key outputs and conclusions***

1. The mobile estimation system has undergone improvements since 2004, yet potential biases still exist and the offshore flux is likely the least accurate component of the daily estimate.
2. A direct comparison between the mobile split-beam data and offshore DIDSON is not possible with data currently available and is likely not feasible to collect due to differences in how the systems are deployed and the areas covered by the different beam types.

Spatial density of fish at Mission was measured by the mobile sounding system through the metric of average number of fish per transect. Accurate recognition of fish targets from the mobile data remains a challenge for the program. Main factors affecting recognition of fish targets from the mobile data are summarized as follows.

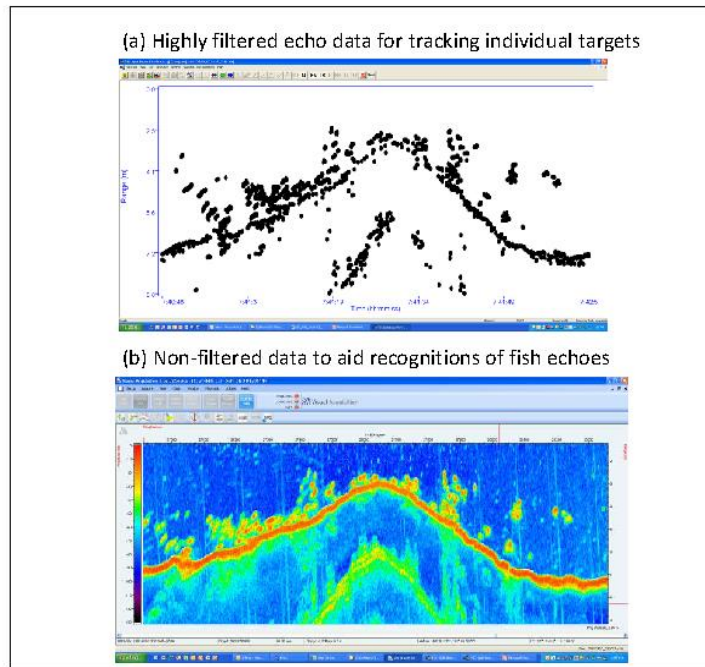
- A. Fish traces detected by the moving transducer are significantly shorter in durations than detected by a stationary transducer, which reduces the amount of the echo information for ascertaining individual targets;

- B. The moving transducer towed by the vessel is subjected to a noisier and more variable sound field than a stationary transducer due to an unsteady platform caused by various surface wave actions;
- C. A large amount of acoustic noise is present in offshore area from debris moving downstream through the mid-channel (especially in early season or after severe weather events).

These factors can bias recognition of fish targets by either classifying noise as fish (type I error) or fish as noise (type II error). We found in the 2004 field season that there is an increased likelihood of classifying noise as fish early in the season when abundance is low (e.g., during Early Stuart migration) but noise level is high (large amounts of debris in June and early July). Because the mobile flux model is proportional to fish density estimated from the mobile data, (see Eqn. (A5) in R9, and Eqn. (11) in R10), errors in target recognition from the mobile data can severely bias the estimation of offshore fish passage.

We took three major steps to address the target-recognition challenge after the 2004 season.

1. Using the principles of discriminant function analysis, we developed and implemented a statistical software tool to help remove noise from the mobile data (see R15 for detailed descriptions).
2. Implemented a Biosonics DT-X split-beam sounder for mobile sounding in the 2011 season. This system is superior to the HTI Model 241 system in that it readily provides users with both the highly filtered echo data for tracking fish and unfiltered echo data. The unfiltered data contains a lot more information than the filtered data allowing users to see the full spectrum of the acoustic events detected by the mobile system (see Figure 12). This helps users reduce the ambiguity in recognizing fish targets. The detailed description of this is provided in R15.
3. We deployed a DIDSON off the vessel during periods when the vessel was anchored (see Figure 10). The DIDSON images collected from the vessel were particularly helpful in verifying presence or absence of fish targets in offshore water and semi-quantitatively (due to spatial and temporal limits of the data) verifying offshore fish passage estimated from the mobile split-beam system.



**Figure 12.** DT-X split-beam data acquired from the transecting vessel at Mission on September 10, 2011. (a) Data after the single-target filtering (for tracking individual fish), and (b) Unfiltered echo data where colors represent target strength (TS) values of detected echoes. The (red colored echo traces correspond to higher TS targets; the continuous red-colored line is the bottom of the river.

Under the current sampling configuration, an effective approach to minimize the error associated with the mobile estimate on the total fish estimate is to extend the counting ranges of the shore-based systems from both banks toward the mid-channel so that we can further reduce the use of mobile data for the estimation. However, the fundamental solution to obtaining accurate estimates of offshore fish passage is to replace the mobile sounding method with fixed location systems that are capable of sampling fish migrating in the mid-channel. Unfortunately, such systems have not been developed for Mission site yet. Until such systems are available, it is imperative that actions be taken to minimize the impact of potential errors in the mobile system on the estimate. These include minimizing the disturbance of fish migration at the Mission site. Such disturbances can increase the fraction of fish in the offshore areas and cause fish behavior in offshore areas to differ from that in nearshore areas.

## Item 10: Inventory of when discrepancies between Mission and Qualark occurred

### **Objectives**

1. Quantitatively and qualitatively describe periods of time when significant DBEs are observed between the Qualark estimate and the Mission-projected estimate.
2. Analyze the relationship between daily DBE and potential influential variables to determine what factors may explain large DBE value.

### **Key outputs and conclusions**

1. Twelve variables that are potentially influential to DBE are identified. These variables relate to fisheries activity, fish behavior, acoustic blind zones, stock ID and river conditions.
2. A correlation analysis was completed for five different time periods within 2010 and four periods within 2014 season to determine which variables are associated with DBE events. The strength of the correlation with DBE varies among time periods, but fisheries opening hours at Mission is among one of the most highly correlated variables with DBE. Fisheries openings are also correlated with higher offshore fish passage at Mission. This suggests a possible mechanism for some of the DBE events in 2010 whereby fisheries openings forced fish into off-shore areas, which were then underestimated by the mobile sampling system at Mission.
3. Apart from the variables directly implicated by the correlations analysis with DBE as likely causes, other likely causes were also presented that were based on the knowledge of spatial sampling effort (2010) and covariations among the influential variables (2014) for the investigated time periods.

Seasonal DBE's between Mission projections and Qualark estimates have been characterized by the analyses presented under [Item05](#) (see Table 6). The focus of this section is to examine within-season temporal patterns of DBE's for individual years. The objective is to identify possible causes for the observed DBE patterns so that we can predict DBE's in the future when similar causes arise, and/or to identify potential actions that might be taken to minimize these differences in the future. Since DBE's are caused by multiple sources of errors, we use a method of multi-variate analysis as described below to evaluate potential sources of errors that may contribute to the observed DBE.

We consider the magnitude of daily DBE as a *response variable* which is hypothesized as a function of a set of *influential variables* that may potentially cause the DBE. These variables fall into five categories: (1) fisheries activity at the hydroacoustics sites and

interception (catches) of sockeye migrating upstream from Mission to Qualark, (2) abnormal fish behavior, (3) effect of acoustic blind zones, (4) estimates of the proportion of stocks passing both acoustics sites, and (5) environmental river conditions (e.g. river temperature and discharge). We have identified below twelve influential variables for the analysis.

*M.Set*: Mission set-net opening hour (fisheries variable);  
*M.Drf*: Mission drift-net opening hour (fisheries variable);  
*M.Off*: Mission % of offshore passage to total passage, i.e., % of total passage estimated by the mobile system (behavioral variable);  
*Ext.LB*: % of extrapolation to Mission left-bank total passage (acoustic blind-zone effect);  
*Ext.TT*: % of extrapolation to Mission total passage (acoustic blind-zone effect);  
*Q.Set*: Qualark set-net opening hour (fisheries variable);  
*Q.Drf*: Qualark drift-net opening hour (fisheries variable);  
*Q.Off*: Qualark % of offshore passage (estimated in Bins 2&3 via DIDSON sampling at low frequency ) to total (behavioral variable);  
*ThrQ%*: percent of through-Qualark stocks to total through-Mission stocks (stock proportion variable);  
*Catch*: Sockeye catch between Mission and Qualark (fisheries variable);  
*Dischg*: River discharge measured at Hope, BC (environmental variable);  
*Temp*: River temperature measured at Qualark Creek (environmental variable);

Observed or estimated values for all the influential variables are available in a spreadsheet in the **Item10** sub-folder that have been uploaded. Note: estimates for *Ext.LB* and *Ext.TT* have not been produced for 2009, 2011, and 2013 due to the time constraints for this work, and estimates for *Q.Off* are unavailable for 2008 due to different methodologies that were used in that year.

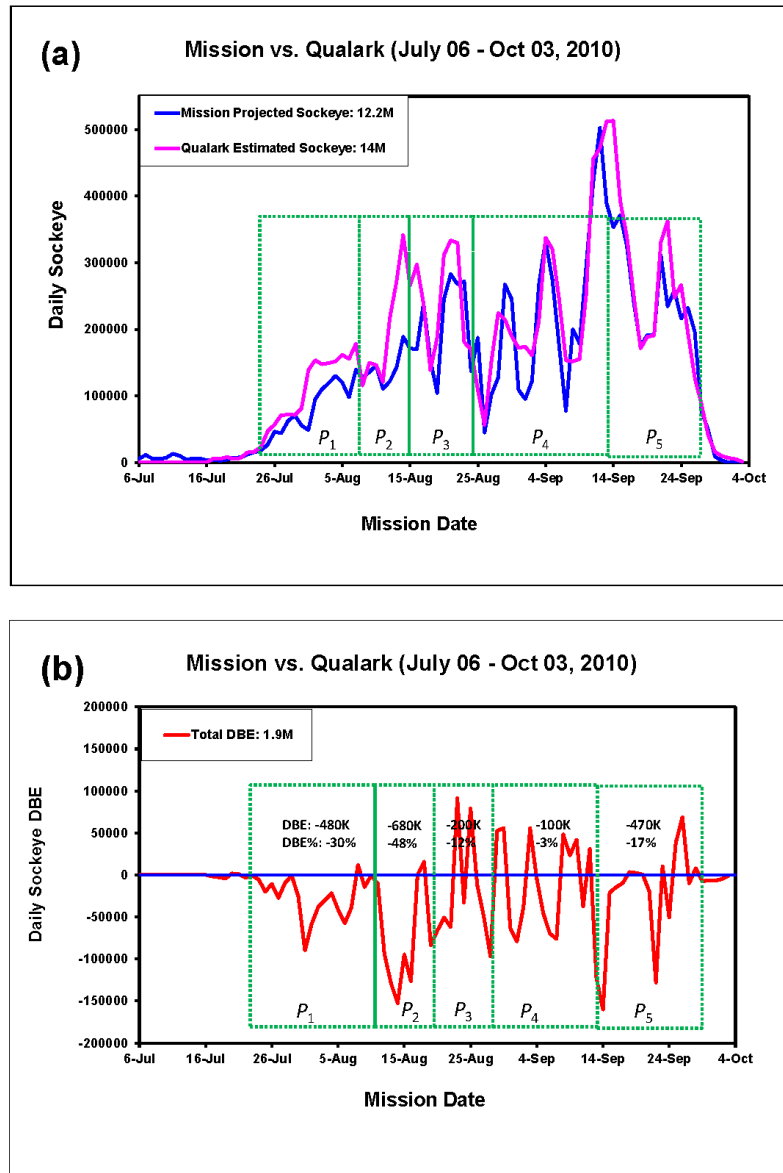
For this report we limit the covariance analysis to the twelve variables listed, but more could be added for subsequent analyses. It is important to note that this analysis is looking for factors associated with the DBE, but does not by itself establish causation. Furthermore, some of the influential variables may interact with each other in addition to impacting the DBE. However, we believe this type of exploratory analysis is an important first step which should provide a foundation for more sophisticated analyses.

### ***Analysis of 2010 DBE pattern***

Figure 13 shows time series of daily sockeye estimates produced by Mission and Qualark and their DBE for the 2010 season. The DBE time series is divided into five periods for the covariance analysis. We chose the periods based on information related to (1) the relative abundance of sockeye run-timing groups, (2) fishing activities, (3) riverine



conditions (discharge and temperature), (4) distinct patterns in the DBE time series, and (5) some DBE episodes that caused management concerns or actions while in-season. We acknowledge that alternative DBE periods could be chosen. It is important that when assessing DBE patterns from the DBE time series (Fig. 13 b), we gain a comprehensive view of episodes related to DBE patterns by examining the two estimation time series (Fig. 13a).



**Figure 13.** (a). Times series of Mission projected estimate and Qualark estimated daily sockeye abundance in 2010. (b) Time series of daily DBE between the two estimates. The DBE time series is divided into five periods (denoted as  $P_1$  to  $P_5$ ) for the covariance analysis. Also shown in (b) are difference and percent difference for each period.

Table 9 is a correlation matrix among the DBE and the twelve variables for Period 1 of 2010. It provides not only the correlations between the DBE and the influential variables but also the correlation between these influential variables.

Table 9. Correlation matrix among DBE and the twelve influential variables for Period 1 of the 2010 season (July 23-Aug 10, 2010). Values in red are correlation coefficients with respect to the DBE with  $p$ -values  $< 0.05$  under the null hypothesis test; values in blue are correlations ( $p$ -values  $< 0.05$ ) between influential variables.

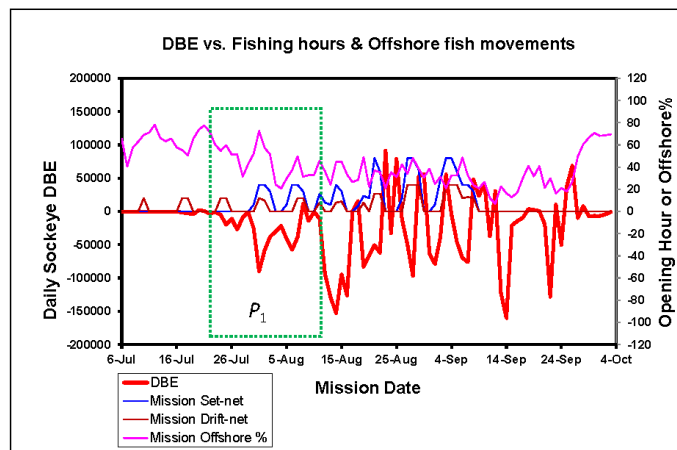
	DBE	M.Set	M.Drf	M.Off	Ext.LB	Ext.TT	Q.Set	Q.Drf	Q.Off	ThrQ%	Catch	Dischg	Temp
DBE	1.00	0.77	0.31	0.34	-0.19	-0.66	0.05	-0.16	-0.37	0.20	0.50	-0.20	0.61
M.Set	0.77	1.00	0.48	0.30	-0.13	-0.56	-0.21	-0.07	-0.44	0.28	0.51	-0.36	0.29
M.Drf	0.31	0.48	1.00	0.48	0.32	-0.12	-0.22	-0.35	-0.42	-0.15	0.00	0.16	-0.45
M.Off	0.34	0.30	0.48	1.00	0.71	-0.01	-0.38	-0.38	-0.48	-0.66	-0.12	0.66	-0.05
Ext.LB	-0.19	-0.13	0.32	0.71	1.00	0.68	-0.14	-0.24	-0.01	-0.81	-0.37	0.77	-0.33
Ext.TT	-0.66	-0.56	-0.12	-0.01	0.68	1.00	0.17	0.03	0.51	-0.48	-0.43	0.42	-0.42
Q.Set	0.05	-0.21	-0.22	-0.38	-0.14	0.17	1.00	0.19	0.63	-0.02	-0.19	0.08	0.29
Q.Drf	-0.16	-0.07	-0.35	-0.38	-0.24	0.03	0.19	1.00	0.48	0.03	0.02	-0.15	-0.01
Q.Off	-0.37	-0.44	-0.42	-0.48	-0.01	0.51	0.63	0.48	1.00	-0.03	-0.07	-0.02	-0.02
ThrQ%	0.20	0.28	-0.15	-0.66	-0.81	-0.48	-0.02	0.03	-0.03	1.00	0.57	-0.93	0.22
Catch	0.50	0.51	0.00	-0.12	-0.37	-0.43	-0.19	0.02	-0.07	0.57	1.00	-0.70	0.41
Dischg	-0.20	-0.36	0.16	0.66	0.77	0.42	0.08	-0.15	-0.02	-0.93	-0.70	1.00	-0.25
Temp	0.61	0.29	-0.45	-0.05	-0.33	-0.42	0.29	-0.01	-0.02	0.22	0.41	-0.25	1.00

Key outputs from the covariance analysis for Period 1 of 2010 DBE are summarized as follows:

- The DBE is correlated with fisheries openings at Mission, especially with the set-net opening with a coefficient  $r$  of 0.77.
- Fisheries openings appear to cause fish migration offshore at both Mission and Qualark. The covariance coefficients (the blue values in Table 9) suggest that when there are fisheries openings at Mission a greater proportion of fish are observed offshore by the mobile system. This hypothesis is consistent with observations of fish distribution before and after fishing activity at both sites.
- The DBE is moderately correlated with increased offshore fish passage at Mission. The offshore passage accounted for 40% of the total passage in this period.
- Sockeye catch between Mission and Qualark co-varies with set-net openings at Mission. As a result, the DBE correlation with catch is likely due to fishing activities in the lower river.

- The DBE is negatively correlated ( $r = -0.66$ ) with relative abundance estimated by extrapolation at Mission to the total abundance. The median of the extrapolation for this period is 15% with a 1st-to-3rd quantile range of 10-18%.
- The DBE is correlated ( $r = 0.61$ ) with river temperature. However, this correlation cannot be further investigated or quantified as there were no estimates of en-route mortality between the two sites. The median temperature for this period is 18.7°C with a minimum-to-maximum range of 18.1-19.1 °C. Given that the temperature range during this period is only one degree Celsius, it is possible this correlation is spurious. Alternately, the relationship may suggest some sort of impact on the migration related to a temperature threshold.

Figure 14 shows the Period 1 temporal patterns of the 2010 DBE and the top three co-varying variables (with relatively higher correlation coefficients than other variables). Two of the variables are related to fishing activity and the other to offshore fish movements observed at Mission. All three variables co-vary with magnitude of the DBE.



**Figure 14.** Temporal patterns of 2010 DBE in Period  $P_1$  (within dashed green box) vs. temporal patterns of three top ranking co-varying variables: Mission set-net opening hour, Mission drift-net opening hour, and percent of Mission passage attributed to offshore areas.

Similar analyses were performed for all five periods of 2010 DBE. Covariance matrices will be made available for download from the **Item10** sub-folder at a future date. Key features of the DBE and likely causes in Periods 1-5 DBE inventories are summarized in Tables 10 and 11.

Table 10. DBE patterns and likely causes for Periods 1-3 (Early Summer & Summer runs dominated migrations) in 2010 season. Note: not all the proposed likely causes listed in the table are revealed by the correlation analysis with the DBE.

Year	Period	DBE Pattern & Managers Concerns/Actions	Ranking of correlations between potential influential variables (fishing activity, acoustics and stock proportion) and DBE & Comments	Ranking of correlations between potential influential variables (environmental variables) and DBE & Comments	Leading hypotheses for correlations & Comments
2010	P <sub>1</sub> : July 23 - Aug 10	<p><u>DBE Pattern:</u></p> <ol style="list-style-type: none"> <li>1. Mission consistently lower than Qualark.</li> <li>2. Mission projected: 1.6M</li> <li>3. Qualark estimated: 2.1M</li> <li>4. DBE: 30%.</li> </ol> <p><u>Managers Concerns &amp; Actions:</u></p> <ol style="list-style-type: none"> <li>1. Mission might have underestimated sockeye escapement.</li> <li>2. Instructed field program staff to double check sampling systems and data. But no major errors were identifiable from the field program at Mission.</li> </ol>	<p><u>Correlations w/ DBE:</u></p> <ol style="list-style-type: none"> <li>1. Mission Set-net (<math>r=0.77</math>);</li> <li>2. Mission Offshore (<math>r=0.34</math>);</li> <li>3. Mission Drift-net (<math>r=0.31</math>);</li> </ol> <p><u>Comments:</u></p> <ol style="list-style-type: none"> <li>1. Mission offshore passage accounted for 40% of total passage, and was correlated with drift-net (<math>r=0.48</math>) &amp; set-net (<math>r=0.30</math>) fishery duration (open hours).</li> <li>2. Qualark offshore passage accounted for 30% of total passage, and was also correlated with set-net (<math>r=0.68</math>) &amp; drift-net (<math>r=0.48</math>) fishery duration.</li> </ol>	<p><u>Correlations w/ DBE:</u></p> <p>River Temperature (<math>r=0.61</math>);</p> <p><u>Comments:</u></p> <ol style="list-style-type: none"> <li>1. Mean temperature: 18.7°C;</li> <li>2. Mean discharge: 3100 m<sup>3</sup>/sec</li> <li>3. The Fraser river was warm but no estimates of en-route mortality are available to quantify the potential effect of temperature on DBE.</li> </ol>	<ol style="list-style-type: none"> <li>1. As much as 73% of the total passage was derived from offshore sampling of fish passage at Mission. The peak offshore percentage (73% of the total) occurred on July 31<sup>st</sup> and was associated with both set-net and drift-net fishing activity in the areas near the Mission site.</li> <li>2. The mobile system underestimated the offshore passage at Mission. But note, no independent data are available at Mission to verify this possibility.</li> </ol>
	P <sub>2</sub> : Aug 11 - Aug 19	<p><u>DBE Pattern:</u></p> <ol style="list-style-type: none"> <li>1. Mission consistently lower than Qualark.</li> <li>2. Mission projected: 1.4M</li> <li>3. Qualark estimated: 2.1M</li> <li>4. DBE: 48%.</li> </ol> <p><u>Managers Concerns &amp; Actions:</u></p> <ol style="list-style-type: none"> <li>1. Mission underestimated sockeye passage.</li> <li>2. On Aug 19, managers adopted a Mission escapement that was scaled to Qualark retrospectively starting on Aug 01.</li> <li>3. Mission program after Aug 19 focused on research and development work rather than in-season estimation under the SEF project for the remainder of the season. This impacted where and when sampling equipment was deployed at Mission.</li> </ol>	<p><u>Correlations w/ DBE:</u></p> <ol style="list-style-type: none"> <li>1. Mission Set-net (<math>r=0.31</math>);</li> <li>2. Mission Offshore (<math>r=0.17</math>);</li> <li>3. Mission Extrapolate (<math>r=0.13</math>);</li> </ol> <p><u>Comments:</u></p> <ol style="list-style-type: none"> <li>1. The analysis did not identify any influential variable that were highly correlated with DBE.</li> <li>2. Mission offshore passage accounted for 36% of the total passage, and it was highly correlated with the duration of drift-net (<math>r=0.92</math>) &amp; set-net (<math>r=0.82</math>) fisheries (open hours).</li> <li>3. Qualark offshore passage accounted for 23% of total passage, and it was also highly correlated with both set-net (<math>r=0.92</math>) &amp; drift-net (<math>r=0.83</math>) fisheries duration.</li> </ol>	<p><u>Correlations w/ DBE:</u></p> <p>River Temperature (<math>r=0.48</math>);</p> <p><u>Comments:</u></p> <ol style="list-style-type: none"> <li>1. Mean temperature: 18.6°C;</li> <li>2. Mean discharge: 2600 m<sup>3</sup>/sec</li> <li>3. The Fraser river was warm but there are no estimates of en-route mortality available to quantify the temperature effect on DBE.</li> </ol>	<ol style="list-style-type: none"> <li>1. No variables were identified that were highly correlated with the DBE.</li> <li>2. There was a strong correlation between fisheries openings and offshore fish distribution at both sites.</li> <li>3. The mobile system underestimated the offshore passage at Mission. But there is no independent data at Mission to verify this.</li> </ol>

	P3: Aug 20 - Aug 28	<u>DBE Pattern:</u> Somewhat oscillatory pattern. Mission projected: 1.7M Qualark estimated: 1.9M DBE: 12% (much smaller DBE than Periods 1&2).	<u>Correlations w/ DBE:</u> 1. Mission Drift-net ( $r=0.22$ ); 2. Mission Extrapolate ( $r=0.21$ );  <u>Comments:</u> 1. The analysis did not identify any influential variables that were highly correlated with DBE. 2. Mission offshore passage accounted for 32% of total passage, and it was correlated with drift-net ( $r=0.55$ ) & set-net ( $r=0.55$ ) fisheries (open hours). 3. Qualark offshore passage accounted for 22% of total passage, and it was highly correlated with set-net ( $r=0.97$ ) & drift-net ( $r=0.99$ ) fisheries duration.	<u>Correlations w/ DBE:</u> No apparent covariance w/ DBE from either temperature or discharge;  <u>Comments:</u> Mean temperature: 17 °C; (near average for time of year) Mean discharge: 2100 m <sup>3</sup> /sec (low flow for time of year).	1. No variables were identified that were highly correlated with the DBE. 2. There was a strong correlation between fisheries openings and offshore fish distribution at Qualark. 3. No leading hypotheses for causes of DBE can be identified.
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Table 11. DBE patterns and likely causes for Periods 4&5 (Late-run dominated migrations) in 2010 season. Note: not all the proposed likely causes listed in the table are revealed by the correlation analysis with the DBE.

Year	Period	DBE Pattern & Managers Concerns/ Actions	Ranking of covarying fishery, behavior, acoustic, stock ID variables with DBE & Comments	Ranking of covarying environmental variables with DBE & Comments	Likely Causes of DBE & Comments
2010	P4: Aug 29 - Sept 12	<u>DBE Pattern:</u> 1. Oscillatory pattern. 2. Mission projected: 3.6M 3. Qualark estimated: 3.7M 4. DBE: 3%. 5. The two estimates are statistically identical (paired testing $p = 0.6156$ ; two-sample testing $p = 0.866$ )	<u>Correlations w/ DBE:</u> 1. Qualark Offshore% ( $r=0.48$ ); 2. Qualark set-net ( $r=0.46$ );  <u>Comments:</u> 1. Qualark offshore passage accounts for 34% of total passage, and was strongly correlated with set-net ( $r=0.96$ ) & drift-net ( $r=0.9$ ) fisheries duration.	<u>Correlations w/ DBE:</u> Discharge ( $r=0.46$ );  <u>Comments:</u> Mean temperature: 15.4 °C; (Near average for time of year) Mean discharge: 1900 m <sup>3</sup> /sec. Discharge trending to lower than average for the time of year.	1. As many as 83% of the total passage was attributable to offshore sampling at Qualark. The peak percentage offshore occurred at Qualark on Sept 04 (Qualark timing) and was associated with drift net fishing in the area. 2. There was a strong correlation between the duration of fisheries openings and offshore fish distribution at Qualark. 3. Overall magnitude of DBE was small and did not trigger managers' concerns.
	P5: Sept 13 - Sept 22	<u>DBE Pattern:</u> 1. Mission consistently lower than Qualark. 2. Mission projected: 2.8M 3. Qualark estimated: 3.3M 4. DBE: 17%.	<u>Comments:</u> 1. This period corresponded to the peak migration of late-run stocks in the lower river. 2. Set-net and drift-net fisheries were closed at both sites for this period.	<u>Comments:</u> Mean temperature: 13.7 °C; Near average temperature for the time of year Mean discharge: 1750 m <sup>3</sup> /sec  Discharge was trending to low values for the time of year;	Right-bank inshore DIDSON removed on Sept 13; passage within 30m from the right bank was likely underestimated by the mobile system.

Summary of DBE analysis for the 2010 season:

1. Of the five DBE inventory periods, the analysis attributes prominent DBEs from three periods to the following leading hypotheses:
  - Period 1 (July 23-Aug10; DBE% = 30%) Underestimation of offshore passage by the mobile system when a large fraction (up to 73%) of fish were forced into offshore by drift-net and set-net fishing activities at/near the site.
  - Period 2 (Aug11-Aug19; DBE% = 48%) Underestimation of offshore passage by the mobile system when a large fraction of fish (up to 50%) were forced into offshore by drift-net and set-net fishing activity at/near the site.
  - Period 5 (Sept 13-Sept 22; DBE% = 17%) Under-sampling of fish passage on the right bank due to the removal of the right-bank inshore DIDSON which was being deployed elsewhere in support of the SEF project.
2. Over these three periods, Mission projected a total of 5.8M while Qualark estimated 7.4M sockeye resulting in a DBE of 1.6M fish. This DBE accounts for 84% of the seasonal DBE of 1.9M between the two programs for the 2010 season.
3. The analysis cannot identify leading hypotheses for the causes of DBEs for Period 3 (Aug 20-Aug 28) when Mission projected 1.7M and Qualark estimated 1.9M (DBE%=12%).
4. Similarly, no leading hypotheses were identified for sources of bias for Period 4 (Aug 29-Sept12) when the two estimates are statistically identical (3.6M vs. 3.7M;  $p\_value = 0.866$ ). However, the analysis did reveal a higher proportion (34%) of the estimates attributed to bins 2&3 at Qualark during this period.
5. In general, large portions of fish move offshore when fishing commences at or near either site. Such offshore movements are highly correlated with the set-net openings at Qualark ( $r > 0.8$ ; see Figs. 15&16) and with drift-net openings at Mission.

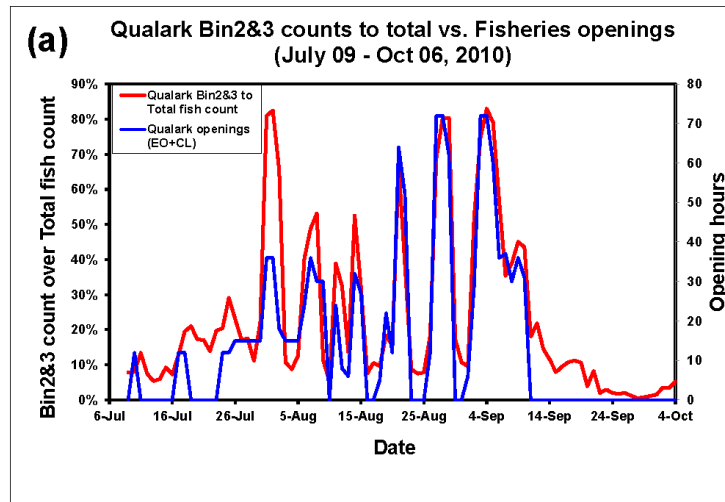


Figure 15. Qualark Bin2&3 fish counts over total fish counts vs. opening hours for EO (economic opportunity) and CL (communal licensed) fisheries. Over the regular opening period from July 20 – September 10 Qualark estimated a total of 8.3M sockeye 31% of which were seen migrating in range bins 10-30m. The percentage of Bin2&3 fish count (to total) is found highly correlated with the opening duration ( $r=0.86$ ).

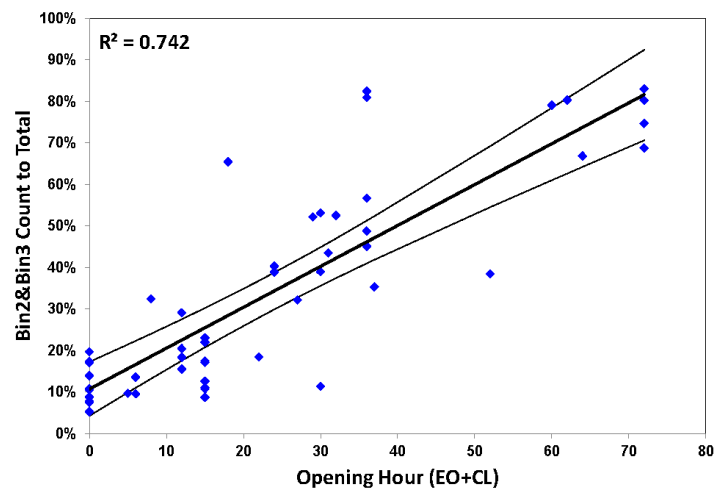


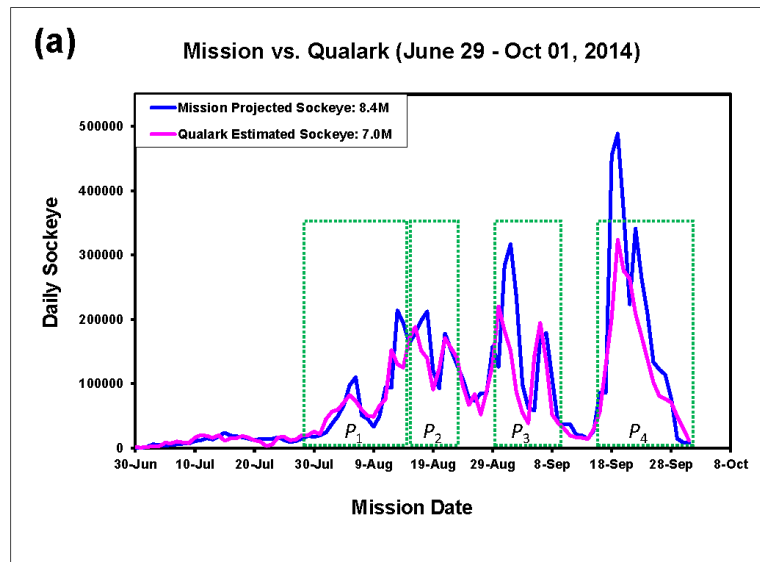
Figure 16. Regression plot of Qualark Bin2&3 fish count (to total) vs. opening hours for EO and CL fisheries from July 20 – September 10, 2010. The opening duration accounts for 74% of the variability in the relative Bin2&3 fish count to the total. The two thin lines are the upper and lower



bounds of the 95% confidence interval of the regression line (the bolded line) which is highly significant ( $p < 10^{-16}$  under the null hypothesis test).

### ***Analysis of 2014 DBE pattern***

A robust sampling configuration was implemented at Mission site for the 2014 season. This configuration, the result of research and development effort since the 2010 season, provided adequate spatial sampling of fish passage across the river throughout the season at the site as shown in Figure 1. There was much less variation in the sampling configuration than that used in the 2010 season for the R&D testing. Therefore, the observed DBE pattern in the 2014 season was much less influenced by the variation of in-season sampling configurations in the 2014 season compared to 2010. Figure 17 shows time series of daily sockeye estimates produced by Mission and Qualark and their DBE for the 2014 season. The 2014 DBE displayed a very different temporal pattern than the 2010 DBE (compare Fig. 17b with Fig. 13b). Accordingly, the 2014 DBE time series is divided into four periods for the covariance analysis as shown in Figure 17.



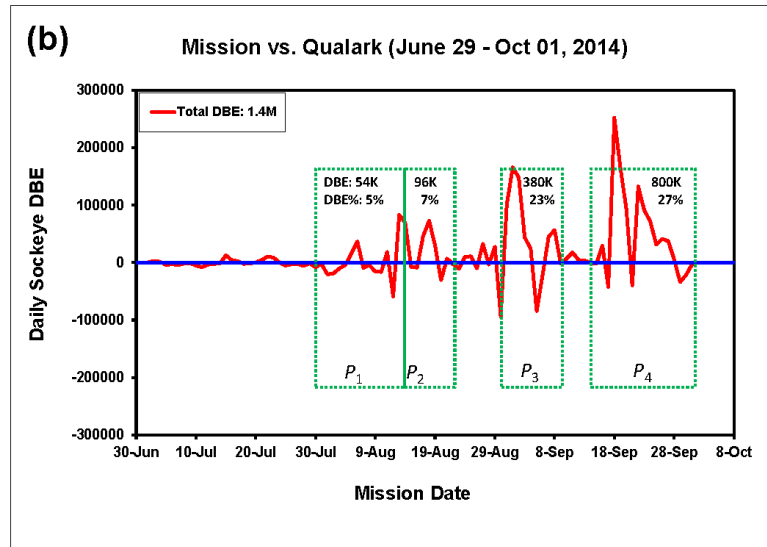


Figure 17. (a). Mission projected vs. Qualark estimated daily sockeye in 2014. (b) Daily DBE between the two estimates; also shown are the DBE's for each period. The DBE time series is divided into four periods (denoted as  $P_1$  to  $P_4$ ) for the covariance analysis. Also shown in (b) are difference and percent difference for each period.

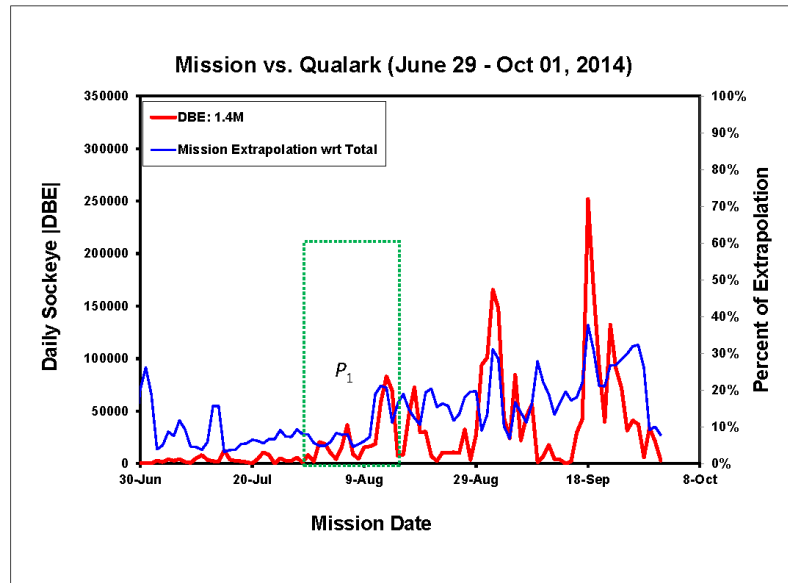
Table 12 is a correlation matrix among the DBE and the twelve variables for Period 1 (July 29 – Aug 14) of 2014. During this two-week period, Mission projected 54K fewer sockeye than estimated by Qualark, resulting in a relative DBE of 5%.

Table 12. Correlation matrix among DBE and the twelve influential variables for Period 1 of the 2014 season (July 29 – Aug 14). Values in red are correlation coefficients with respect to the DBE with  $p$ -values < 0.05 under the null hypothesis test; values in blue are correlations between influential variables with  $p$ -values < 0.05.

	DBE	M.Set	M.Drf	M.Off	Ext.L B	Ext.T T	Q.Set	Q.Dr f	Q.Off	ThrQ %	Catc h	Disch g	Temp
DBE	1.00	-0.04	-0.05	-0.04	0.63	0.71	-0.22	-0.05	-0.38	0.55	0.53	-0.63	0.71
M.Set	-0.04	1.00	0.67	0.73	-0.10	-0.45	-0.49	-0.37	-0.68	0.31	0.48	-0.08	0.10
M.Drf	-0.05	0.67	1.00	0.88	0.09	-0.30	-0.33	-0.33	-0.54	0.37	0.07	-0.14	0.10
M.Off	-0.04	<b>0.73</b>	<b>0.88</b>	1.00	0.01	-0.40	-0.24	-0.08	-0.49	0.24	0.22	-0.02	0.19
Ext.LB	<b>0.73</b>	-0.10	0.09	0.01	1.00	0.86	-0.42	-0.31	-0.33	0.50	0.07	-0.56	0.47
Ext.TT	<b>0.89</b>	-0.45	-0.30	-0.40	0.86	1.00	-0.26	-0.11	-0.05	0.40	0.09	-0.62	0.35
Q.Set	-0.22	-0.49	-0.33	-0.24	-0.42	-0.26	1.00	0.47	0.73	-0.62	-0.47	0.65	-0.15
Q.Drf	-0.05	-0.37	-0.33	-0.08	-0.31	-0.11	0.47	1.00	0.56	-0.39	0.20	0.14	0.00
Q.Off	-0.38	-0.68	-0.54	-0.49	-0.33	-0.05	<b>0.73</b>	<b>0.56</b>	1.00	-0.72	-0.45	0.47	-0.53
ThrQ	<b>0.55</b>	0.31	0.37	0.24	0.50	0.40	-0.62	-0.39	-0.72	1.00	0.45	-0.87	0.49

Catch	0.53	0.48	0.07	0.22	0.07	0.09	-0.47	0.20	-0.45	0.45	1.00	-0.55	0.31
Dischg	-0.63	-0.08	-0.14	-0.02	-0.56	-0.62	0.65	0.14	0.47	-0.87	-0.55	1.00	-0.35
Temp	0.71	0.10	0.10	0.19	0.47	0.35	-0.15	0.00	-0.53	0.49	0.31	-0.35	1.00

Figure 18 shows the Period 1 temporal pattern of the 2014 DBE and the top co-varying variable: *extrapolation to Mission total passage*. It appears that the extrapolation is highly co-varied with magnitude of the DBE with a small phase shift.



**Figure 18.** Temporal pattern (data within dashed green box) of the 2014 DBE in Period  $P_1$  (July 29 – Aug 14) vs. temporal pattern of Mission extrapolation to Mission total fish passage.

Similar analyses were performed for all four periods of 2014 DBE. Covariance matrices can be downloaded from **Item10** sub-folder. Key features of the DBE and likely causes for Periods 1-4 DBE's are summarized in Table 13.

Table 13. DBE patterns and likely causes for Periods 1-4 DBEs in 2014 season. Note: not all the proposed likely causes listed in the table are revealed by the correlation analysis with the DBE.

Period	DBE Pattern & Managers Concerns/Actions	Ranking of covarying fishery, behavior, acoustic, stock ID variables with DBE & Comments	Ranking of covarying environmental variables with DBE & Comments	Likely Causes of DBE & Comments
P <sub>1</sub> : July 29 - Aug 14	<p><u>DEB Pattern:</u> Somewhat oscillatory pattern. Mission projected: 1.22M Qualark estimated: 1.16M DBE: 5%</p> <p><u>Managers Concerns &amp; Actions:</u> No concerns from managers</p>	<p><u>Correlations w/ DBE:</u> 1. Mission Extrapolation (<math>r=0.89</math>; <math>p&lt;0.001</math>); 2. Lower-river estimated Thru-Qualark stocks (<math>r=0.55</math>; <math>p&lt;0.05</math>);</p> <p><u>Comments:</u> 1. Mission extrapolation accounts for 50% of the DBE variability for this period. 2. Correlation of %Thru-Qualark stocks with the DBE is significant (<math>p&lt;0.05</math>) and %Thru-Qualark stocks is increasing rapidly from 56% to 98% over this period.</p>	<p><u>Correlations w/ DBE:</u> River temperature (<math>r=0.71</math>; <math>p&lt;0.05</math>) River discharge (<math>r=-0.63</math>; <math>p&lt;0.02</math>);</p> <p><u>Comments:</u> Mean temperature: 19.8°C; Mean discharge: 3250 m<sup>3</sup>/sec; 1. DBE correlations with both temperature &amp; discharge are statistically significant (<math>p&lt;0.05</math>). 2. Temperature climbing to 21°C towards end of this period. 3. Discharge decreasing from 3900 to 2700 m<sup>3</sup>/sec over this period.</p>	DBE is only 5% which may have resulted partially from extrapolation at Mission. However, the decreasing discharge is found significantly correlating with 1. Mission extrapolation ( $r=-0.62$ ), 2. Qualark offshore counts ( $r=0.47$ ), and 3. Proportion of Thru-Qualark stocks ( $r=-0.87$ ).
P <sub>2</sub> : Aug 15 - Aug 23	<p><u>DEB Pattern:</u> 1. Mission consistently higher than Qualark. 2. Mission projected: 1.4M 3. Qualark estimated: 1.3M 4. DBE: 7%.</p> <p><u>Managers Concerns &amp; Actions:</u> 1. Mission might have overestimated sockeye escapement. 2. Instructed field program staff to double check sampling systems and data. But no major errors were found in the field program at Mission.</p>	<p><u>Correlations w/ DBE:</u> Mission Drift-net (<math>r=0.78</math>; <math>p&lt;0.05</math>)</p> <p><u>Comments:</u> 1. Mission drift-net opening appears to be the sole fisheries variable co-varying closely with the DBE for this period. 2. No fisheries openings at Qualark for this period.</p>	<p><u>Correlations w/ DBE:</u> River discharge (<math>r=0.64</math>; <math>p&lt;0.05</math>);</p> <p><u>Comments:</u> 1. Mean discharge: 2760 m<sup>3</sup>/sec; 2. Mean temperature: 19.5°C; 3. Discharge decreasing rapidly from 3000 to 2400 m<sup>3</sup>/sec (low discharge). 4. Temperature ranges from 18.4-20.7°C (warm river);</p>	1. Fishing activities might have disrupted normal migration behavior at Mission which could bias the Mission estimate; 2. The warm river coupled with low discharge could cause en-route loss.
P <sub>3</sub> : Aug 30 - Sept 08	<p><u>DEB Pattern:</u> 1. Mission significantly higher than Qualark. 2. Mission projected: 1.6M 3. Qualark estimated: 1.2M 4. DBE: 23% (much higher than Periods 1&amp;2) 5. The DBE of 380K in this period accounts for 27% of the seasonal total DBE of 1.4M.</p> <p><u>Managers Concerns &amp; Actions:</u> 1. Regular drift-net fishing at Mission site (3 days per week) might have affected the estimate. Concerns were raised to FRP and some Commissioners (see e-mail communications below) 2. Instructed Mission field program staff to double check sampling systems and data. But no major errors were found in the field program at Mission. However, the offshore sampling system at Mission</p>	<p><u>Correlations w/ DBE:</u> Mission Extrapolation (<math>r=0.83</math>; <math>p&lt;0.01</math>);</p> <p><u>Comments:</u> 1. Mission extrapolation accounts for nearly 70% of the DBE variability for this period. 2. Qualark Bin2&amp;3 count is significantly correlated with set-net opening hours (<math>r=0.93</math>; <math>p&lt;0.01</math>). 3. The %Bin2&amp;3 Qualark count accounted for an average of 20% of total passage for this period with a peak of 56% on Sept 07.</p>	<p><u>Correlations w/ DBE:</u> River Temperature (<math>r=0.55</math>; <math>p&gt;0.05</math>);</p> <p><u>Comments:</u> Temperature ranges from 14.5-17.8°C. Normal temperature range for this period.</p>	1. Fishing activities might have disrupted normal migration behavior at both sites, which could bias estimates at either or both sites; 2. Biased high extrapolation at Mission; 3. Biased low fish counts by Bin2&3 at Qualark due to set-net fishing causing fish to migrate offshore.

	site was not designed to handle such frequent fishing interferences.			
P4: Sept 15 – Oct 01	<u>DBE Pattern:</u> 1. Mission significantly higher than Qualark. 2. Mission projected: 3.0M 3. Qualark estimated: 2.2M 4. DBE: 27% 5. The DBE of 800K in this period accounts for 57% of the seasonal total DBE of 1.4M.	<u>Correlations w/ DBE:</u> Mission Extrapolation ( $r=0.6$ ; $p\leq 0.01$ );  <u>Comments:</u> 1. Mission extrapolation accounts for 35% of the DBE variability for this period. 2. No fisheries openings at either site for this period. 3. The %Bin2&3 Qualark count accounted for an average of 16% of total passage even though there was no fishery opening for this period.	<u>Correlations w/ DBE:</u> River discharge ( $r=-0.58$ ; $p\leq 0.015$ );  <u>Comments:</u> Discharge decreased to 1500 m <sup>3</sup> /sec on Sept 21 (the record low discharge between 2008 and 2015 Qualark operation seasons) and the daily DBE reached its maximum of 250,000 for the 2014 season.	1. Biased high extrapolation at Mission; 2. Biased low fish counts by Bin2&3 at Qualark due to abnormally high offshore distributions of fish passage at record low discharge levels.

Excerpts of e-mail communications on fishing activities at Mission site

From: Lapointe, Mike  
Sent: September-08-14 11:27 AM  
To: Ned, Murray; Nener, Jennifer  
Cc: Field, John ([field@psc.org](mailto:field@psc.org))  
Subject: RE: drift fishing at the Mission site

Thanks Murray,

*Pls note that this year the level of effort has had a dramatic effect on the fish distribution at the Mission site – pushing fish into the mid channel areas which is the least robust part of our estimation. These effects appear to be local; we do not observe similar impacts from other activities. For example the fish passage is lower after an Area E opening, but the distribution is not impacted. Having persistent fishing on wed, sat, sun through the single most important assessment site for Fraser River sockeye is not acceptable. While I appreciate that you and perhaps a few others may be trying to pull your nets prior to reaching the transect line, the reports from my staff at the site are that fishers are not attempting to do so.*

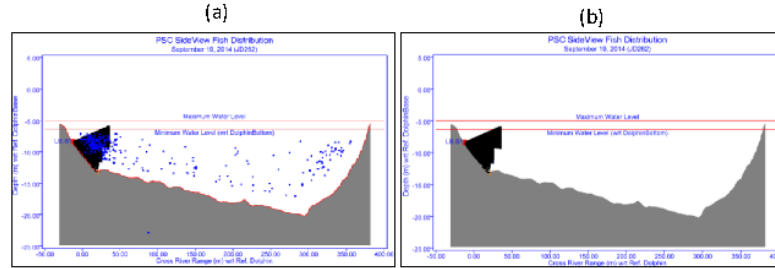
*We are at the point where we must ask that the boundaries be enforced to preserve our capacity to do the assessments.*

*Sincerely, Mike Lapointe*

Summary of DBE analysis for the 2014 season:

1.  $P_1$  and  $P_2$  periods (July 29 - Aug 14 and Aug 15 – Aug 23) saw small DBEs ranging from 5-7% with Mission projecting 150K more sockeye than Qualark estimate of 2.5M. No clear causes for the DBEs are proposed from the analysis.
2.  $P_3$  period (Aug 30 – Sept 08) saw a DBE of 23% with Mission projecting 380K more sockeye than Qualark estimate of 1.2M. Based on the analysis and field program records, we propose the following likely causes:
  - Biased high extrapolation at Mission;
  - Biased low fish counts by Bin2&3 at Qualark when fish were forced offshore by fisheries;
  - Regular and frequent openings of fisheries at both sites in this period forced the migration offshore. This abnormal fish behavior may have created challenges for accurate counting of fish passage by shore-based sonar systems at both sites.
3.  $P_4$  period (Sept 15 – Oct 01) saw a larger DBE of 27% with Mission projecting 800K more sockeye than Qualark estimate of 2.2M. Based on the analysis and field program records, we propose the following likely causes:
  - Biased high extrapolation at Mission.
  - Biased low fish counts by Bin2&3 at Qualark due to abnormally high offshore distributions of fish passage.
  - The record low discharge level (1500 m<sup>3</sup>/sec) in this period forced the migration at Qualark further offshore. This abnormal fish behavior may have created challenges for accurate counting of total fish passage by the shore-based sonar systems at Qualark which was range limited within 30m from either shore.

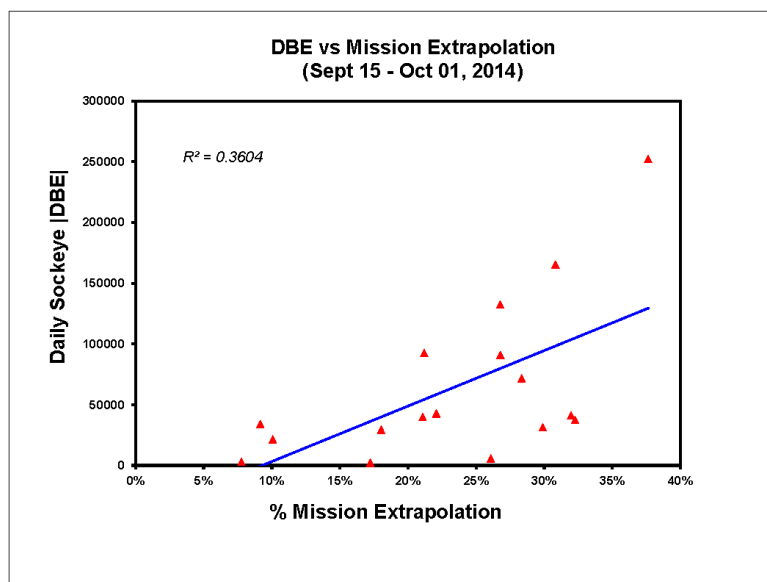
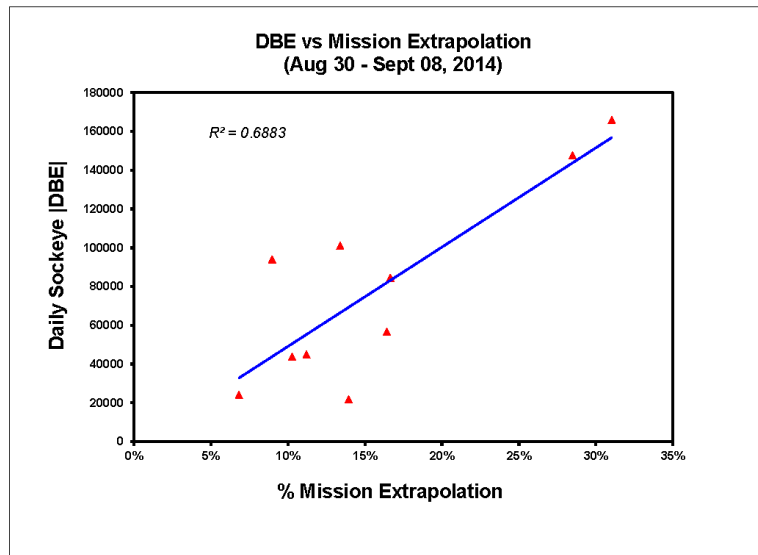
Since all the major fisheries were closed in all reaches between Mission and Qualark by the second week of September, the observed DBE for this period were most likely caused by hydroacoustics estimation errors, such as over extrapolation at Mission and/or undercounting of fish passage at Qualark. To assess the maximum possible error from the extrapolation method, a case study was presented to Prof. Carl Walters (see: link to the PPT file??) for a 3-day period that saw the largest daily DBE and the lowest discharge in 2014 season. The study analyzed the DBE from Sept. 18-20 when Mission projected 1.3M sockeye whereas Qualark estimated a total of 800K (from Sept. 21-23). To eliminate the impact on the projection from extrapolation, we used only observed fish counts by the left-bank split-beam system to generate the projection. Figure 19b shows the fish targets used for the study in comparison to the fish targets used for the official projection (Fig. 19a).



**Figure 19.** (a) Fish targets acquired by the left-bank split-beam (black dots) and mobile sampling (blue dots) system; (b) fish targets used for the case study.

Since there were definitely migrations in the left-bank blind zone, the mid-channel and the right-bank area, we expected a biased low projection for Qualark passage from the observed left-bank fish counts without any spatial expansions. However, based on the observed fish counts, we projected a total of 770K sockeye for the 3-day period, which is essentially the same as the Qualark estimate of 800K. While we cannot conclude for all the migration scenarios that the extrapolation method for the Mission blind zones is unbiased, this case study does not support the hypothesis that the extrapolation causes positive bias for the investigated period. The finding strongly suggests that Qualark underestimated the passage for the 3-day period.

4. While there was a lack of data to investigate the hypothesized cause of bias due to undercounting of fish passage at further ranges at Qualark, our analysis indicated noticeable correlations between the DBE and Mission extrapolation for  $P_3$  and  $P_4$  periods as shown in Figure 20.



**Figure 20.** DBE vs. proportion of extrapolation of estimates at Mission for (a) Period 3 and (b) Period 4.



## References

- R0. Fraser River Sockeye Review Board (Canada). 1995. *Fraser River sockeye 1994: problems and discrepancies*. Public Works and Government Services Canada, 1995.
- R1. Mission Hydroacoustic Facility Working Group. 1994. *Report of the Mission Hydroacoustic Facility Working Group*. Part 1: Main Report. Institute of Ocean Sciences, Department of Fisheries and Oceans, Sidney, B.C., Canada.
- R2. Banneheka, S.G., R.D. Routledge, I.C. Guthrie and J.C. Woodey. 1995. *Estimation of in-river fish passage using a combination of transect and stationary hydroacoustic sampling*. Can. J. Fish. Aquat. Sci. 52: 335-343.
- R3. Xie, Y., G. Cronkite and T.J. Mulligan. 1997. *A split-beam echosounder perspective on migratory salmon in the Fraser River: A progress report on the split-beam experiment at Mission, B.C., in 1995*. Pacific Salmon Comm. Tech. Rep. No. 8.
- R4. Bowman, A. W., and A. Azzalini. 1997. *Applied smoothing techniques for data analysis. The kernel approach with S-Plus illustrations*. Oxford Science Publications, Clarendon Press. Oxford.
- R5. Enzenhofer, H.J., N. Olsen, and T.J. Mulligan. 1998. *Fixed-location riverine hydroacoustics as a method of enumerating migrating adult Pacific salmon: a comparison of split-beam acoustics vs. visual counting*. Aquat. Living Resources. 11(2). 61-74.
- R6. Xie, Y. 2000. *A range-dependent echo-association algorithm and its application in split-beam sonar tracking of migratory salmon in the Fraser River watershed*. IEEE, Journal of Oceanic Engineering, Vol. 25. No. 3, pp. 387-398.
- R7. Xie, Y., T. J. Mulligan, G.M.W. Cronkite, and A. P. Gray. 2002. *Assessment of potential bias in hydroacoustic estimation of Fraser River sockeye and pink salmon at Mission, B.C.* Pacific Salmon Comm. Tech. Rep. No. 11: 42 p.
- R8. Chen, D.G., Y. Xie and T. J. Mulligan. 2004. *Optimal partition of sampling effort between observations of fish density and migration speed for a riverine hydroacoustic duration-in-beam method*. Fisheries Research, Vol. 67, 275-282.
- R9. Xie, Y., A. P. Gray, F. J. Martens, J. L. Boffey and J. D. Cave. 2005. *Use of dual-frequency identification sonar to verify salmon flux and to examine fish behaviour in the Fraser River*. Pacific Salmon Comm. Tech. Rep. No. 16: 58 p.

- R10. Xie, Y., A. P. Gray, F.J. Martens, and J.D. Cave. 2007. *Development of a shore-based hydroacoustics system on the right bank of the Lower Fraser River to monitor salmon passages: A project report to Southern boundary restoration and enhancement fund*. Pacific Salmon Commission, Vancouver, British Columbia. April, 2007.
- R11. Vagle, S., Ding, L., Boesen, M., Cronkite, G., and Y., Xie. 2008. *A study to determine the feasibility of hydroacoustic monitoring of migrating sockeye and pink salmon in the marine area*. Southern Boundary Restoration and Enhancement Fund Project Final Report, Pacific Salmon Commission. 44 p.
- R12. Xie, Y., C. G. J. Michielsens, A. P. Gray, F. J. Martens, and J. L. Boffey. 2008. *Observations of avoidance reactions of migrating salmon to a mobile survey vessel in a riverine environment*. Can. J. Fish. Aquat. Sci. 65: 2178-2190.
- R13. Xie, Y., F. J. Martens and Andrew P. Gray. 2010. *A feasibility study on using a stationary hydroacoustic sub-sampling method to estimate offshore fish flux in the lower Fraser River: A project report to Southern boundary restoration and enhancement fund*. Pacific Salmon Commission, Vancouver, British Columbia. February, 2010.
- R14. Enzenhofer, H.J., Cronkite, G.M.W., and Holmes, J.A. 2010. *Application of DIDSON imaging sonar at Qualark Creek on the Fraser River for enumeration of adult pacific salmon: An operational manual*. Can. Tech.Rep. Fish. Aquat. Sci. 2869: iv +37 p.
- R15. Xie, Y., F. J. Martens, and J. L. Nelitz 2012. *Implementation of stationary sub-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*. Pacific Salmon Commission, Vancouver, British Columbia. May, 2012.
- R16. Xie, Y., C. G. Michielsens, and F. J. Martens. 2012b. *Classification of fish and non-fish acoustic tracks using discriminant function analysis*. ICES Journal of Marine Science 69:313–322.
- R17. Xie, Y., F. J. Martens, Catherine G. J. Michielsens and James D. Cave. 2013. *Implementation of stationary hydroacoustic sampling systems to estimate salmon passage in the Lower Fraser River: A final project report to the southern boundary restoration and enhancement fund*. Pacific Salmon Commission. May, 2013.
- R18. Martens, F.J. and Y.Xie. 2014. *Estimation of near-shore salmon passage using stratified vertical sampling by DIDSON sonar: A final project report to the southern boundary restoration and enhancement fund*. Pacific Salmon Commission. June, 2014.

R19. Xie, Y., F. J. Martens. 2014. *An empirical approach for estimating the precision of hydroacoustic fish counts by systematic hourly sampling*. North American Journal of Fisheries Management, 34:3, 535-545.

R20. Xie, Y. 2015. *Precision of Mission estimates and projection*. PSC Tech Report (in progress).

## Appendix A: Detailed list of work tasks with status as of September 26, 2016

Terms of Reference	Work Item	Targeted Completion Date	Status (Sept 26, 2016)
	Mission work items		
2b	1. Bibliography (technical reports & publications)	January 31, 2016	Complete
1 & 3	2. Systems used to produce daily total salmon & total sockeye estimate at Mission. (2008-2015; odd years for sockeye time period only)	January 31, 2016	Complete
1	3. Amount in daily estimate from direct sampling vs. amount derived from extrapolation. (2008-2015; odd years for sockeye time period only)	February 29, 2016	Completed for 5 of the 8 common operation seasons: 2008, 2010, 2012, 2014, 2015.
1	4. Fisheries removal of through Qualark stocks between Mission and Qualark. (2008-2015; odd years for sockeye time period only)	Complete	Complete
1	5. Mission projected Qualark estimate. (2008-2015; odd years for sockeye time period only)	Complete	Complete
1 & 2b	6. Cross aim fish flux due to vertical fish movements in the left-bank split-beam sampling areas. a. Do we want to repeat analysis for other years? (ie. 2010 & 2014 if data available) If available, analysis completion March 31, 2016.	Completed Analysis showing no bias from split-beam fish counts (PSC Tech Report #16, for 2004 data comparison; SEF project)	Completed with 36hrs of data (No data was collected for this testing purpose after 2004).
1 & 2b	7. Bias or randomness of the extrapolated left-bank fish flux a. Do we want to repeat analysis for other years? (ie. 2010 & 2014 if data	Completed Analysis showing no bias from	Completed with direct counting comparisons

Terms of Reference	Work Item	Targeted Completion Date	Status (Sept 26, 2016)
	available) If available, analysis completion March 31, 2016.	split-beam fish counts (PSC Tech Report #16, for 2005 data comparison; SEF project)	from 18 hrs of fish count data from 2005 season and 30 days flux comparison from 2014 (July) (No data was collected for direct counting comparison purpose after 2005 season.)
1 & 2b	8. Bias in the offshore fish flux estimates by the mobile system as fish start shifting offshore due to fishing or tidal influences. a. Comparing the fish behaviour (speed & downstream ratio) between the left-bank split-beam and the vessel based DIDSON. (Years available: 2014, 2015)	February 29, 2016	Completed with 10 days of 2015 data & 6 days of 2014 data.
1 & 2b	9. Bias in target recognition by the mobile system. a. Qualitative comparison between mobile split-beam flux and the vessel based DIDSON flux. (Years available: 2014, 2015)	February 29, 2016	Cannot be done with existing data
1	10. Inventory of when discrepancies between Mission & Qualark occurred. a. Based on relative difference to present the statistical description of the difference by providing various probability intervals for the outliers. Reader can look at table to examine DBE events of their choice according to the statistical description table.	February 29, 2016	Completed with detailed analyses for 2010 and 2014 DBE data.
1	11. Species Composition work	Longer term	No set start and end time.
	Qualark work items		
	12. Species Composition work	Longer term	No set start and end time
1 & 2b	13. Report out to Fraser Panel of results of September 2015 evaluations with ARIS looking beyond 30m	January 11, 2016	Complete
1 & 2b	14. Report out to Fraser Panel on results of September 2015 evaluations comparing DIDSON at 35 roll and with ARIS (with no roll and 1 aim) Note: PSC staff has suggested that a subset of recorded files be counted to quantify impacts of size threshold cutoff (30cm in DIDSON), recognizing that impact is likely small and PSC staff have been able to replicated 2010 DIDSON counts using threshold. Feb 8 proposed deadline	February 8, 2016	Complete

Terms of Reference	Work Item	Targeted Completion Date	Status (Sept 26, 2016)
	would not be expected to include this comparison.		
	Analysis steps (mainly by DFO staff )		
1	<p>15. Exploratory analyses by DFO staff</p> <p>a. PSC staff to provide Mission data</p> <p>i. Daily fish passage estimates produced with and without key pieces of equipment (i.e. without boat, without right bank, etc...)</p> <p>ii. Daily spp composition estimates used to with i. to get daily estimates of sockeye passage (with description of method(s) used and estimates of variability)</p> <p>iii. Daily stock ID estimates used with ii. For in season run size estimation (with description of method used and estimates of variability)</p> <p>b. DFO staff to provide Qualark data</p> <p>i. Daily fish passage estimates produced with and without key pieces of equipment (i.e. without beyond zone 3 without other bank, etc...)</p> <p>ii. Daily spp composition estimates used to with i. to get daily estimates of sockeye passage (with description of method used and estimates of variability)</p> <p>iii. Note: PSC staff suggest important to note when DIDSONS are moved down the ramp or quantify protocol used to move equipment as % in each Bin can vary with position of DIDSONs.</p> <p>c. Compare estimates of stock passage derived from Mission and Qualark estimates</p> <p>i. Quantify periods in data when proportions of the estimate coming from various estimation components at Mission tend to repeat (e.g. 30% of estimate from mobile for a period of X days in a row).</p>	May 31, 2016	<p>15 a. b complete</p> <p>c-e ongoing</p>

Terms of Reference	Work Item	Targeted Completion Date	Status (Sept 26, 2016)
	<ul style="list-style-type: none"> <li>ii. Quantify periods in the data when proportions of the migration associated with various proportions of the cross river distribution are repeated (e.g. X% beyond 50m at Mission), or (X% in Bin 3 @ Qualark). Note: PSC staff suggest important to note when DIDSONS are moved down the ramp or quantify protocol used to move equipment as % in each Bin can vary with position of DIDSONS.</li> <li>d. Evaluate patterns found in c above relative to total daily abundance (e.g. periods of high or low abundance?), <ul style="list-style-type: none"> <li>i. timing during the year, water level, water temperature, tidal cycle, human (e.g. fishing) activity, etc. Are these patterns predictable??</li> </ul> </li> <li>e. Compare estimates of total run size derived from Mission and Qualark estimates of fish passage. Are deviations between estimates from the two sites; 1) statistically significant, and 2) associated with periods of repeat patterns within the data at each site significant</li> </ul>		
	Panel Work Items		
2	16. Develop qualitative (and where possible quantitative) performance measures for alternative program designs and scenarios, considering the range of fish densities encountered, river conditions and other factors	May 31, 2016	Identified in-season run size estimate as one of the PMs
2, 4	17. Assess how well each program element meets management objectives (e.g. timeliness, precision, accuracy, cost-effectiveness, etc.).	September 2016	Completed impact analyses on In-season run size estimates for 2010 and 2014 using Mission vs. Qualark estimates. Conclusion: %difference < 10%
5.	18. Identify a program design option from the risk assessment in 17 above that falls within the Mission budget. If this option does not	September 2016	Work not commenced yet, pending on

<b>Terms of Reference</b>	<b>Work Item</b>	<b>Targeted Completion Date</b>	<b>Status (Sept 26, 2016)</b>
	adequately meet the defined fishery management objectives, explain why and identify a program design that would do so regardless of cost.		complete outcomes under Work Item 17

# Appendix 10: Qualark Technical Presentations

## Qualark Acoustics

FSRC Review of FRP workplan progress  
June 2016

Canada

### Context: Role of Qualark

**Role:** Complementary but independent acoustic program at a site with a greatly simplified set of environmental and fish behavior variables to cope with in generating daily fish passage estimates – may function as a reliable reference for Mission estimate comparison.

**Concern:** blind spots within the migratory habitat lead to negative bias in estimates generated by Qualark.

**Implications:** Qualark may not provide a reliable reference for Mission data comparison and will not help to resolve deviations observed.

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Canada

### Item 12: Qualark Species Composition

**Issue:** Qualark abundance estimates by species are biased due to test fishery data treatment.

**Concern:** failure to account for differential vulnerability of species, especially during periods with high pink salmon abundance.

**Implications:** overestimating sockeye numbers and underestimating pink numbers due to data treatment - change in analytic methods

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Canada

### Item 13: Long Range Assessment

**Issue:** Fraser River is 120-140m wide but only 60m is monitored, 30m from each bank – passage may be occurring offshore.

**Concern:** Salmon may be migrating mid river and thus will not be vulnerable to the acoustic gear.

**Implications:** Negative estimate bias reducing the utility of Qualark as a reference for Mission.

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Canada

### Context for Workplan Items Review

**Issue:** large increases in acoustic programming cost in 2000's, both Mission R&D and full reinstatement of Qualark, have realized little apparent improvement in estimate reliability.

**Concern:** persisting large differences between Mission hydroacoustic abundance estimates and upstream accounting reduces confidence in the tools available to fishery managers.

**Implications:** ongoing risk to achieving conservation and harvest objectives with acoustic investments yielding limited value added.

2

Canada

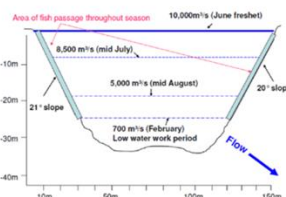


Figure 2. Fraser River cross section at the Qualark Creek site showing average discharge rates throughout the salmon migration period. Note that the vertical and horizontal scales differ. River flow is toward the viewer.

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Canada

### Item 13: Long Range Assessment

#### Program Elements addressing this concern:

- Mobile transecting.
- Split beam evaluation of cross channel distribution.
- Off-shore test set drifts.
- Range specific estimation.
- Observing fish behavior.

**Evaluation in 2015:** Paired acoustic system deployment in Summer 2015. DIDSON to 30m ; Aris aimed 30-50m in flat 0° aspect.

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Canada



### Item 13: Long Range Assessment

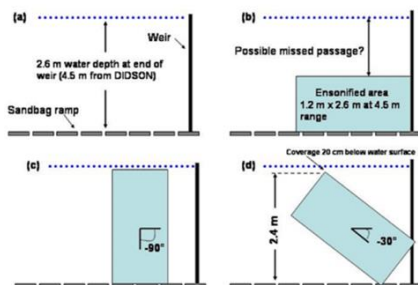
#### 2015 Observations:

- Technically feasible to operate paired acoustic systems at Qualark;
- 170 hrs of long range (29.2-40m) data were collected simultaneously with the regular DIDSON protocol.
- Over range of 4.5-29.2m (Bins1-3) 261,000 salmon were estimated, with Aris extended range, a 29.2-40m counting bin resulted in an estimate of 6 additional salmon over 8 days of migration.

**Conclusions:** no indication of a large undetected abundance migrating outside the DIDSON range, but limited by inability to monitor beyond 40m acoustically.

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Canada



13

Canada

### Item 14: Qualark's use of DIDSON in rolled aspect

#### Observations:

- Technically feasible to operate paired acoustic systems at Qualark;
- 87hrs of paired BIN-1 data collection at discharge 1,770-1,950cms.
- Hourly passage ranged from <100 to >4,000 salmon per hour ; 20-40K/day.
- Aris counts similar to but on average slightly less than DIDSON (APE <3%)
- Aris coverage ~50% of water column depth - bottom to half way to surface.
- Aris estimate 120,000, DIDSON 123,000 for same time period

**Conclusions:** no indication of large undetected abundance in DIDSON data but limited by inability to resolve vertical distribution. Can be resolved with two aim Aris deployment in 2016.

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Canada

### Item 13: Long Range Assessment

#### Summary:

- Weight of evidence does not currently point to a large undetected abundance of salmon migrating beyond the 30m DIDSON range. Mid channel migration was not identified as a significant source of negative estimate bias at Qualark in September 2015, consistent with earlier observations.
- Additional work in 2016 will provide an opportunity to directly confirm offshore distribution during sockeye migration periods over a wider range of discharge conditions.

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Canada

### Item 14: Qualark's use of DIDSON in rolled aspect

**Issue:** At low discharge there may be an acoustic blind spot along the bottom at a range of ~8-9.2m from the DIDSON (end of BIN1).

**Concern:** Salmon may pass undetected through a portion of BIN1 when river discharge is low due to the use of the rolled aspect deployment.

**Implications:** negative bias in total salmon passage estimates during periods of low discharge, reducing utility of Qualark as a reference under those conditions.

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Canada

### Item 14: Qualark's use of DIDSON in rolled aspect

#### Program Elements addressing this concern:

- Modified river bank – planar bottom profile, no acoustic shadows.
- Constant acoustic geometry over discharge range 1,800 - 8,000cms
- DIDSON aiming procedures – achieves strong bottom signal over the complete length of BIN-1 (4.2 – 9.2m) for full range of river discharge encountered (<1,800 - > 8,000cms).

**Evaluation in 2015:** Paired acoustic system deployment in September 2015. DIDSON in 30° rolled aspect ; Aris in flat 0° aspect .

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Canada

### Item 14: Qualark's use of DIDSON in rolled aspect

#### Summary:

- Weight of evidence does not currently point to a blind spot at the end of BIN-1 under low flow conditions as representing a significant source of negative estimate bias at Qualark.
- Additional work in 2016 will provide an opportunity to directly confirm vertical distribution patterns during sockeye migration dominated periods to address final outstanding data gap for this question.

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Canada



# Appendix 11: Assessment of Estimation Methods for the Mission Mobile Count of Salmon

## APPENDIX 10

### Assessment of Model-based Estimation Methods for the Mission Mobile Estimate of Salmon

One of the recommended cost-saving options in the Walter's report (September 2015) was "to discontinue the mobile single beam sampling and apply a simple expansion factor to the data from the nearshore split beam and DIDSON systems". It was further recommended that the resulting cost savings could be directed to fund Qualark or explore the use of a hydroacoustic system at Chatham Point to assess incoming Fraser sockeye abundance. This appendix presents a summary of the analyses conducted to assess the feasibility of replacing the Mission Mobile (MMb) salmon estimates with estimates from models that are based on data from the left-bank (LB) and right bank (RB) hydroacoustic systems at Mission or from the Qualark hydroacoustic systems.

Since the MMb assessment of salmon passage is an estimate, and to reduce confusion when referring to the estimates from the model-based methods, the MMb estimates that were produced for each day examined, and for the period and season totals, are referred to as MMb actual. Three different model-based estimation methods were examined:

- 1) assume the mobile hydroacoustic unit assesses a constant fraction of the total salmon migration passing Mission each day (Fixed%),
- 2) use the salmon passage estimates from the LB and RB units at Mission to estimate MMb actual on a daily basis (LB+RB), and
- 3) use the salmon passage estimates at Qualark to estimate MMb actual on a daily basis with the data lagged appropriately to correspond to the Qualark data (QLK).

For the purposes of these analyses, the daily estimates by the shore-based hydroacoustic systems at Mission and Qualark are assumed to have very little measurement error. Previous work with these data has shown that the coefficient of variation for these estimates is relatively small,  $\approx 5\%$ , and support this assumption (see Summary of PSC Work Items for the Fraser River Strategic Review Committee, June 2016, references R19 and R20). Though other sources of error may affect the accuracy of shore-based estimates, for this analysis we are solely interested in how well the mobile portion of Mission passage could be estimated using data from the shore-based systems.

Note this appendix evaluates different methods of replacing the MMb estimate of the daily number of salmon migrating past Mission in the mid-channel area not assessed by the bank-based hydroacoustic systems, not the number of sockeye. Similarly, salmon abundance data from the shore-based hydroacoustic units at Mission and Qualark are used for the analyses. Total salmon before apportionment to species is used because estimates of species composition introduce an additional source of variability into the estimation process. Current methods of apportioning numbers by species (and into sockeye stocks) would be applied to any estimates of daily salmon passage substituted for the actual Mission mobile estimate.

## Methods

Data used for these analyses were:

- Estimates of daily salmon passage at Mission
  - Data for the years 2010-2016 were used. Earlier years' data were not used since RB assessment did not begin until 2010.
  - Daily abundance estimates were summarized by LB, RB, and MMb.
  - Only data from the sockeye-dominant period each year were used. In odd years, data during pink-dominant periods were excluded from the analysis to remove this additional source of variability.
  - Only days with data for all three Mission components (LB, RB, and MMb) were used<sup>1</sup>.
- Estimates of daily salmon passage at Qualark (summed left bank and right bank estimates)
  - MMb actual was matched with a Qualark estimate either two or three days after the Mission date to account for migration time between the hydroacoustic sites (a two-day travel time was used for all years but 2010 and 2014 where a three-day travel time was used<sup>2</sup>).

A jackknife (leaving-one-out) procedure was used to establish the data set to estimate MMb for each method each year. Specifically, the year being evaluated was not part of the data used to estimate the parameters for the models used to estimate MMb for that year. This should provide a realistic assessment of model performance and would be similar to the method used if MMb was to be estimated in future years. I.e., previous years of data would be used to estimate the parameters for the model used to estimate MMb in a future year.

### Fixed Percentage Method:

The fixed percentage model assumes that the mobile hydroacoustic unit assesses a constant fraction of the total salmon migrating past Mission each day relative to the bank-oriented hydroacoustic units. This fraction (expressed as a percentage) is estimated by:

$$\%MMb = \frac{MMb}{LB + RB + MMb} \times 100\% \quad [1]$$

where  $MMb$  = Mission mobile estimate,  $LB$  = corresponding estimate by left bank system, and  $RB$  = corresponding estimate by right bank system. The summed data used to estimate  $\%MMb$  must be for the same period during a season for all three hydroacoustic systems. Algebraically it can be shown that, given an estimate of the percentage of the total daily salmon migration assessed by the mobile unit ( $\%MMb$ ), then  $\widehat{MMb}_i$  can be estimated as:

$$\widehat{MMb}_i = \frac{\%MMb \times (LB + RB)_i}{1 - \%MMb} \quad [2]$$

where  $\widehat{MMb}_i$  = estimated Mission mobile salmon passage on day  $i$  and  $(LB + RB)_i$  = combined estimates of salmon by left bank and right bank systems at Mission on day  $i$ .

Only days with both LB and RB data at Mission were used in the fixed percentage analyses (Table 4) otherwise there is an additional source of variability being introduced. When the RB hydroacoustic unit at Mission is not being operated, the area of the river being included in the estimate from the mobile

<sup>1</sup> The reasons for this are explained in later text.

<sup>2</sup> Per Cory Lagasse, PSC.

unit is larger than when the RB unit is operational. When the RB hydroacoustic unit is operational, the data from the mobile unit are truncated so there is no double counting of fish being enumerated by the RB unit. Restricting the data as described should reduce the variability in  $\widehat{MMb}$  and represent a "best-case" scenario.

#### LB+RB Regression Method:

Ordinary least squares (OLS) regression was used to estimate the linear relationship between combined daily LB and RB estimates (only for days where both were available) to the MMb estimate on the same day. Because of the large range in the daily abundance data (thousands to hundreds of thousands of salmon), the LN of the estimates were used in the regression analysis. Data from the year of analysis were not used to estimate the OLS regression for the year being assessed.

$\widehat{MMb}$  was estimated using the slope and intercept coefficients estimated from the OLS regression for a particular year. For the year being analyzed, the number of salmon assessed by the mobile unit on day  $i$  was estimated as:

$$\widehat{MMb}_i = e^{\{\widehat{intercept} + (\widehat{slope} \times (LB+RB)_i)\}} \quad [3]$$

where  $\widehat{MMb}_i$  and  $(LB + RB)_i$  are defined above.

Similarly to the fixed percentage analysis, only days with both LB and RB data were used in the regression analyses and the model performance assessments. This presents a "best-case" scenario for the regression method as otherwise there is an additional source of variability in the independent data (right bank data present or not present). The relationship between LB+RB estimates and MMb actual differs somewhat depending upon whether the RB data are present or not. The strongest annual and overall (all years combined) relationships (based on  $R^2$ ) are for days when both LB+RB data are available (Table 1).

Table 1. Comparison of adjusted  $R^2$  statistics for regression models estimating  $\widehat{MMb}_i$  using all days regardless of availability of data from the RB units (ALL), and models which include only days where both LB+RB data are available (LB+RB).

Year	ALL	LB+RB
2010	0.599	0.687
2011	0.708	0.720
2012	0.680	0.733
2013	0.705	0.788
2014	0.612	0.719
2015	0.633	0.691
2016	0.628	0.664
Mean	0.652	0.715
Minimum	0.599	0.664
Maximum	0.708	0.788

#### Qualark Regression Method:

Ordinary least squares regression was also used to estimate the linear relationship between Qualark salmon estimates (left bank and right bank systems combined) to the MMb estimate two or three days earlier. Because of the large range in the daily abundance data (thousands to hundreds of thousands of salmon), the LN of the estimates were used in the regression analysis. Data from the year of analysis were not used to estimate the OLS regression for the year being assessed.

$\widehat{MMb}$  was estimated using the slope and intercept coefficients estimated from the OLS regression for a particular year. For the year being analyzed, the number of salmon assessed by the mobile unit on day  $i$  was estimated as:

$$\widehat{MMb}_i = e^{\{\widehat{intercept} + (\widehat{slope} \times QLK_{i+2 \text{ or } 3})\}} \quad [4]$$

where  $(QLK_{i+2 \text{ or } 3})$  = estimated salmon passage at Qualark, by the left bank and right bank systems combined, two or three days later.

The same days used for the (LB+RB) model assessment were used in the Qualark model regression analyses and the model performance assessment so that the performance of the models could be directly compared.

#### Model Performance Statistics:

To compare the performance of the different estimation methods, several summary statistics comparing MMb actual to model-estimated MMb ( $\widehat{MMb}$ ) were used. The statistics were calculated only for the days in the model assessment period (i.e., during the sockeye-dominant period) where LB, RB, and MMb data were all available. The model evaluation statistics examined were:

- 1) The difference in number of salmon defined as daily  $\widehat{MMb}$  - MMb actual summed over the model assessment period (note that negative values indicate an under-estimate and positive values indicate an over-estimate relative to MMb actual).
- 2) The percent difference defined as the summed differences from 1) divided by the summed MMb actual. The mean of these percentages across years is the mean percent error (MPE) and the mean of the absolute values of these percentages across years is the mean absolute percent error (MAPE).
- 3) Average difference per day, in number of salmon, summarized for (a) the total assessment period, (b) July dates only, (c) August dates only, and (d) September dates only. The breakdown by month is to demonstrate that differences between the MMb actual and  $\widehat{MMb}$  are not constant over time and, therefore, will have varying impacts on management groups with different timing.
- 4) Root mean squared error (RMSE), defined as the square root of the average of the squared daily differences. This is a common statistic for comparing model performance.

## Results

### Fixed Percentage Method:

Table 2 summarizes the percentage of the total migration during the estimation period that was assessed by the mobile unit at Mission (%MMb) for all days during the sockeye-dominant migration period and for the restricted period used in the estimation analysis (i.e., only days when both the LB and RB data were available). For the seven years analyzed, the mean %MMb for the restricted period was 27% and ranged from 16% to 41%. The estimate for 2016 (41%) was considerably greater than the other years; the next highest year was 2015 with 32%. Table 2 also shows the jackknife estimate of %MMb used for the MMb estimation procedure each year which was calculated using the restricted (LB+RB data both available) data set.

Table 2. Summary of each year's percentage of the total estimated salmon passing Mission that were assessed by the Mission mobile unit (%MMb) for all days of data in the sockeye-dominant period (All), for days during the sockeye-dominant period when both LB+RB data were available at Mission (restricted), and the jackknife<sup>a</sup> estimate of %MMb (% $\overline{MMb}$ ) used to generate estimates of  $\overline{MMb}$  in each year.

Year	All Days %MMb	Restricted %MMb	Jackknife % $\overline{MMb}$
2010	30.5%	28.9%	27.2%
2011	32.0%	25.2%	27.8%
2012	28.7%	22.5%	28.3%
2013	20.2%	16.5%	29.3%
2014	25.9%	25.7%	27.7%
2015	32.3%	32.1%	26.7%
2016	41.5%	41.2%	25.2%
Mean	30.2%	27.4%	27.4%
Minimum	20.2%	16.5%	25.5%
Maximum	41.5%	41.2%	29.3%

<sup>a</sup> The jackknife estimate is the mean of all years restricted %MMb excluding the year being estimated.

### Mission LB+RB and Qualark Regression Methods:

The estimated slope and intercept parameters for each of the regression models used were significant (all  $P < 0.001$ ) and model  $R^2$  values ranged from 0.658 to 0.789 (Table 3). Figure 1 shows the regression lines with 95% prediction intervals and data used in the regressions for the LB+RB and QLK regression models estimated using the entire 2010 through 2016 data set. Although both models explain a significant portion of the variability in LN MMb actual (both  $P < 0.001$  and  $R^2 > 0.70$ ), the prediction intervals are relatively wide, especially when considering the data must be transformed from the LN scale to produce an estimate in number of salmon.

Table 3. Summary of the estimated slope and intercept parameters, and model  $R^2$ , for each of the annual regressions estimated using the Mission LB+RB and Qualark data. All regressions were LN(X), LN(Y) regressions.

Year	Sample Size	Estimation Method	Slope Parameter			Intercept Parameter			Model $R^2$
			Estimate	St. Error	Signif.	Estimate	St. Error	Signif.	
2010	242	LB+RB	0.6743	0.0293	<0.001	2.5149	0.3021	<0.001	0.689
		Qualark	0.7553	0.0302	<0.001	1.6014	0.3151	<0.001	0.722
2011	291	LB+RB	0.7343	0.0269	<0.001	2.0102	0.2849	<0.001	0.721
		Qualark	0.7249	0.0272	<0.001	1.9979	0.2925	<0.001	0.711
2012	286	LB+RB	0.7126	0.0255	<0.001	2.2785	0.2717	<0.001	0.734
		Qualark	0.7090	0.0264	<0.001	2.2172	0.2849	<0.001	0.718
2013	271	LB+RB	0.7435	0.0235	<0.001	1.9988	0.2502	<0.001	0.789
		Qualark	0.7318	0.0252	<0.001	2.0166	0.2718	<0.001	0.759
2014	220	LB+RB	0.7593	0.0321	<0.001	1.7111	0.3377	<0.001	0.720
		Qualark	0.7290	0.0321	<0.001	1.9267	0.3423	<0.001	0.703
2015	262	LB+RB	0.7302	0.0302	<0.001	2.0458	0.3247	<0.001	0.692
		Qualark	0.7137	0.0302	<0.001	2.1303	0.3280	<0.001	0.683
2016	258	LB+RB	0.7324	0.0325	<0.001	2.0211	0.3537	<0.001	0.665
		Qualark	0.7181	0.0324	<0.001	2.0975	0.3559	<0.001	0.658
2010-16	305	LB+RB	0.7309	0.0262	<0.001	2.0433	0.2783	<0.001	0.720
		Qualark	0.7280	0.0266	<0.001	1.9769	0.2866	<0.001	0.712



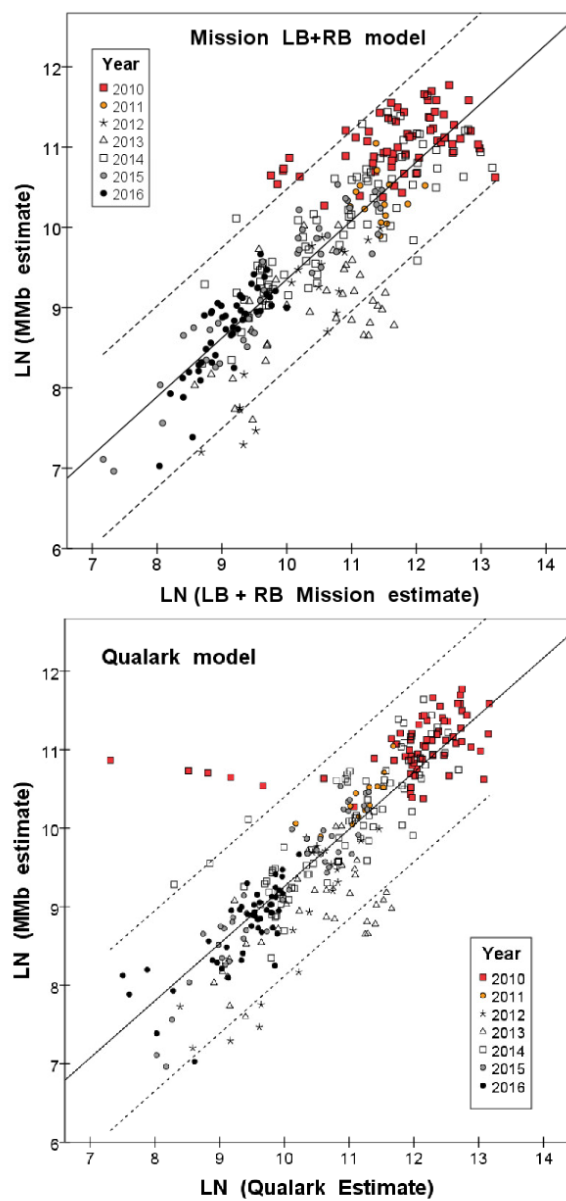


Figure 1. Estimated regression lines and 95% prediction intervals relative to the 2010-2016 data for the LN (Mission LB+RB salmon estimates) and LN (Qualark salmon estimate) models used to estimate LN (Mission mobile salmon estimate).

#### Comparison of Model Performance:

Table 4 compares the model evaluation statistics for the fixed percentage, Mission LB+RB, and Qualark models. These analyses are for the sockeye-dominant period of each year's migration and only include days when there were both LB and RB data for Mission.

There is no evidence of bias (consistent over-estimation or under-estimation relative to MMb actual) for the model estimates of  $\widehat{MMb}$  across years based upon the estimation periods examined each year. For the fixed percentage model, there were three years where the estimates were less than MMb actual and four years where the estimates were greater than MMb actual. For the two regression models, there were four years where the estimates were less than MMb actual and three years where the estimates were greater than MMb actual (Figure 2). In two of the years the direction of the difference was not the same for the two regression models (2011 and 2016). Although the MPE statistic for each of the models is >10%, if the results for the 2013 return year are excluded (when all three models over-estimated MMb actual by >100%) the MPE statistics become -3.6, -0.7%, -6.0% for the Fixed%, LB+RB, and QLK models, respectively. Percent errors for the last three years (2014-2016) were all less than  $\pm 20\%$  for the two regression models.

The fixed percentage model had the largest RMSE statistic in six of the seven years. The QLK regression model had the lowest RMSE statistic in every year although, generally, the RMSE statistic for the LB+RB models was relatively close to the RMSE statistic from the corresponding QLK model.

The annual mean absolute percent errors for the three models were very similar but the median MAPE for the LB+RB method was about half that of the Fixed% and QLK methods (Table 5).

Table 5. Comparison of mean and median annual MPE and MAPE statistics for the three models across the seven years of data analyzed.

Method	Mean Percent Error		Mean Absolute Percent Error	
	Mean	Median	Mean	Median
Fixed%	12.4%	11.1%	36.2%	23.0%
LB+RB	17.5%	-6.7%	36.4%	10.1%
QLK	10.8%	-16.2%	33.7%	23.7%

For the five years where there were data for multiple months, the average difference/day for each month shows that the differences varied considerably across the season for all three models (Table 4).

Figures 3 through 9 compare daily estimates ( $\widehat{MMb}$ ) from each model to the MMb actual. Three comparisons are made for each year in these figures:

- Panel a compares the daily estimates to the Mission actual,
- Panel b show the difference in number of salmon between  $\widehat{MMb}$  for each method and the MMb Actual (i.e., difference =  $\widehat{MMb}$  - MMb actual), and
- Panel c expresses the daily difference in number of salmon as a percentage of MMb actual for that day.

For Panels b and c, the horizontal axis corresponding to 0 (the heavy black line) indicates no difference between an estimate and MMb actual. These figures also demonstrate how the direction and

Table 4. Summary of model performance statistics for each of the annual regression models estimated using the fixed percentage, Mission LB+RB, and Qualark models (assessment and estimate units are number of salmon).

Year	Estimation Period	Number of Days	Total Estimate	Mobile Actual	Estimation Method	Mobile Est - Actual			Average Difference/Day (salmon)				RMSE
						Estimate	Difference	Percent Difference	Total	July	August	Sept.	
2010	Aug. 1 - Oct. 3	63 <sup>a</sup>	14,501,149	4,191,948	Fixed%	3,852,816	-339,133	-8.1%	-5,383	NA	-19,020	11,667	41,044
					LB+RB	2,431,156	-1,760,793	-42.0%	-27,949	NA	-32,953	-22,016	36,765
					Qualark	3,196,561	-995,388	-23.7%	-15,800	NA	-17,194	-11,500	27,584
2011	Aug. 12 - Aug. 25	14	1,827,436	460,284	Fixed%	527,075	66,790	14.5%	4,771	NA	4,771	NA	16,989
					LB+RB	477,458	17,174	3.7%	1,227	NA	1,227	NA	13,384
					Qualark	350,760	-109,524	-23.8%	-7,823	NA	-7,823	NA	10,343
2012	Aug. 6 - Aug. 24	19	866,898	195,090	Fixed%	264,803	69,713	35.7%	3,669	NA	3,669	NA	6,555
					LB+RB	309,049	113,959	58.4%	5,998	NA	5,998	NA	7,466
					Qualark	283,874	88,784	45.5%	4,673	NA	4,673	NA	6,223
2013	Jul. 18 - Aug. 20	34	1,847,673	305,599	Fixed%	638,048	332,448	108.8%	9,778	3,001	14,522	NA	16,248
					LB+RB	692,525	386,926	126.6%	11,380	5,843	15,256	NA	15,910
					Qualark	632,334	326,735	106.9%	9,610	4,212	13,388	NA	13,566
2014	Jul. 9 - Oct. 1	85	10,380,093	2,666,343	Fixed%	2,961,545	295,203	11.1%	3,473	-3,504	-6,078	19,498	30,770
					LB+RB	2,489,008	-177,335	-6.7%	-2,086	-1,168	-10,228	6,170	19,925
					Qualark	2,168,646	-497,697	-18.7%	-5,855	-871	-10,144	-4,843	15,668
2015	Jul. 14 - Aug. 25	43	1,975,057	633,736	Fixed%	487,971	-145,765	-23.0%	-3,390	-2,161	-4,275	NA	6,991
					LB+RB	586,454	-47,282	-7.5%	-1,100	218	-2,048	NA	5,556
					Qualark	563,373	-70,363	-11.1%	-1,636	374	-3,084	NA	5,033
2016	Jul. 13 - Aug. 28	47	795,717	328,043	Fixed%	157,159	-170,884	-52.1%	-3,636	-2,287	-4,551	NA	4,241
					LB+RB	294,917	-33,126	-10.1%	-705	435	-1,478	NA	2,202
					Qualark	348,762	20,719	6.3%	441	582	345	NA	1,929

<sup>a</sup> one day dropped because of missing RB count.

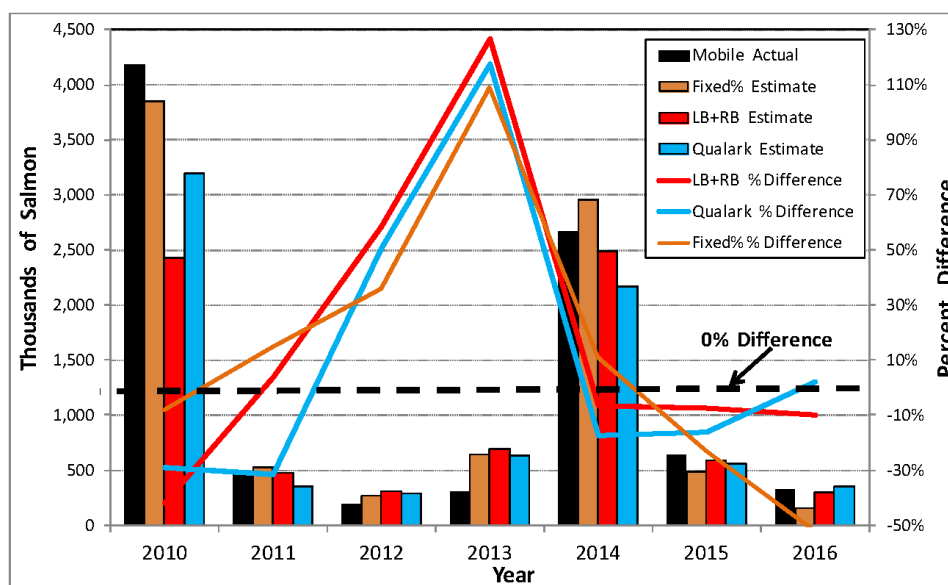


Figure 2. Comparison of MMB actual to fixed percentage, Mission LB+RB, and Qualark model estimates. Statistics are for each year's period of estimation only.

magnitude of differences between MMB actual and its estimates from the three models change during a season which would impact different segments of the Fraser sockeye return differently throughout a season. Although the daily estimate lines for all three models often track the MMB actual, there are numerous periods during each year where they diverge considerably.

For example:

- In 2010 (Figure 3), there are periodic sharp peaks in the MMB actual that are not fully captured by the estimation models (panel a). These peaks can generally be linked to in-river fishery openings. The Fixed% model also shows a large peak in mid-September that is not present in the MMB data or shown by the two regression models. Also, the estimates of  $\widehat{MMb}$  at the end of September decline rapidly but MMB actual remains above 40,000 per day.
- In 2011 (Figure 4), the large peak in the MMB actual on August 20 was not captured by the estimation models. The LB+RB and Fixed% models show a peak two days later on August 22. The QLK model consistently underestimates MMB actual throughout the season (panels b and c).
- In 2012 (Figure 5), the declining trend in the MMB actual throughout the estimation period is mirrored by the estimates from all three models but after August 12 the three models consistently over-estimate MMB actual with the exception of one day for the Fixed% model (panel c).
- In 2013 (Figure 6), all three models greatly over-estimate MMB actual after August 7 when MMB actual gradually declined while the three model-based estimates generally increased.

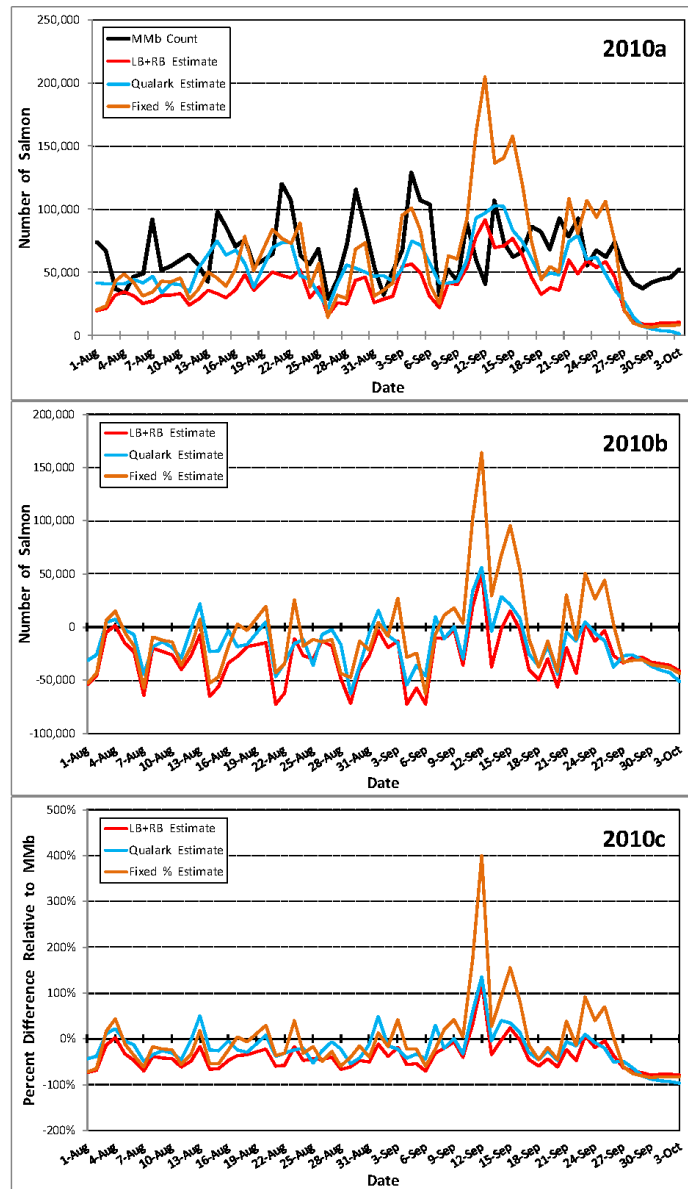


Figure 3. Comparison of daily MMB actual in 2010 to (a) estimates from the fixed percentage, Mission LB+RB, and Qualark models. Panels b and c show daily differences between estimates and MMB actual expressed in numbers of salmon and percentage of MMB actual, respectively.

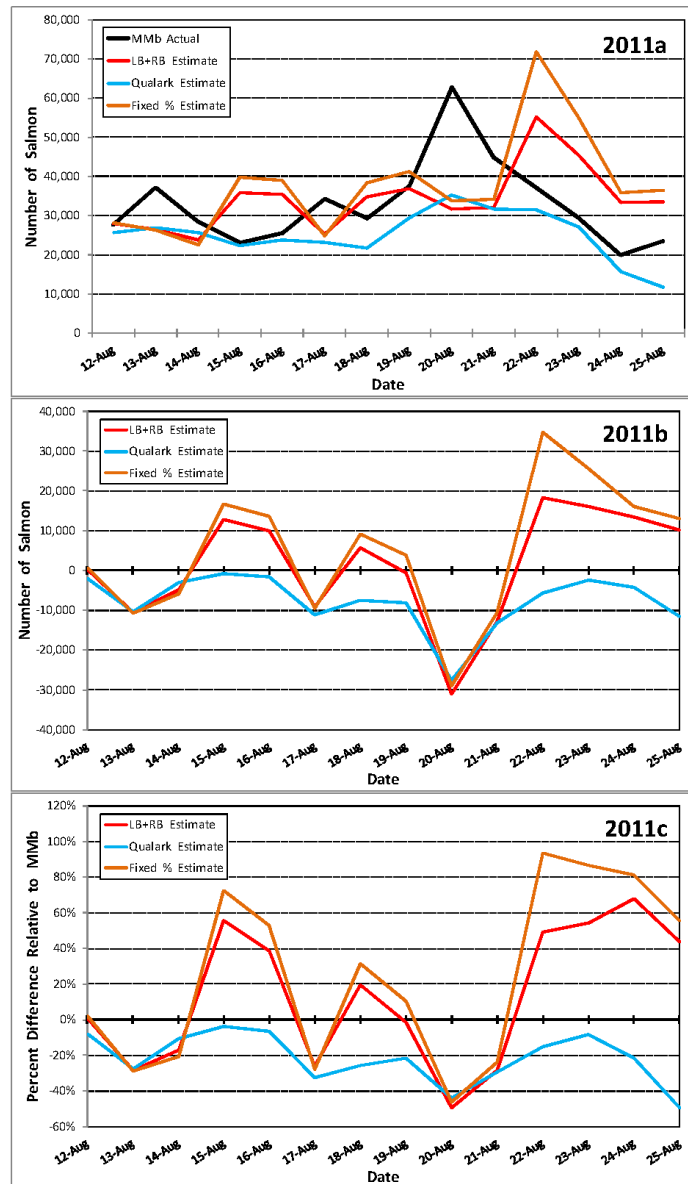


Figure 4. Comparison of daily MMB actual in 2011 to (a) estimates from the fixed percentage, Mission LB+RB, and Qualark models. Panels b and c show daily differences between estimates and MMB actual expressed in numbers of salmon and percentage of MMB actual, respectively.

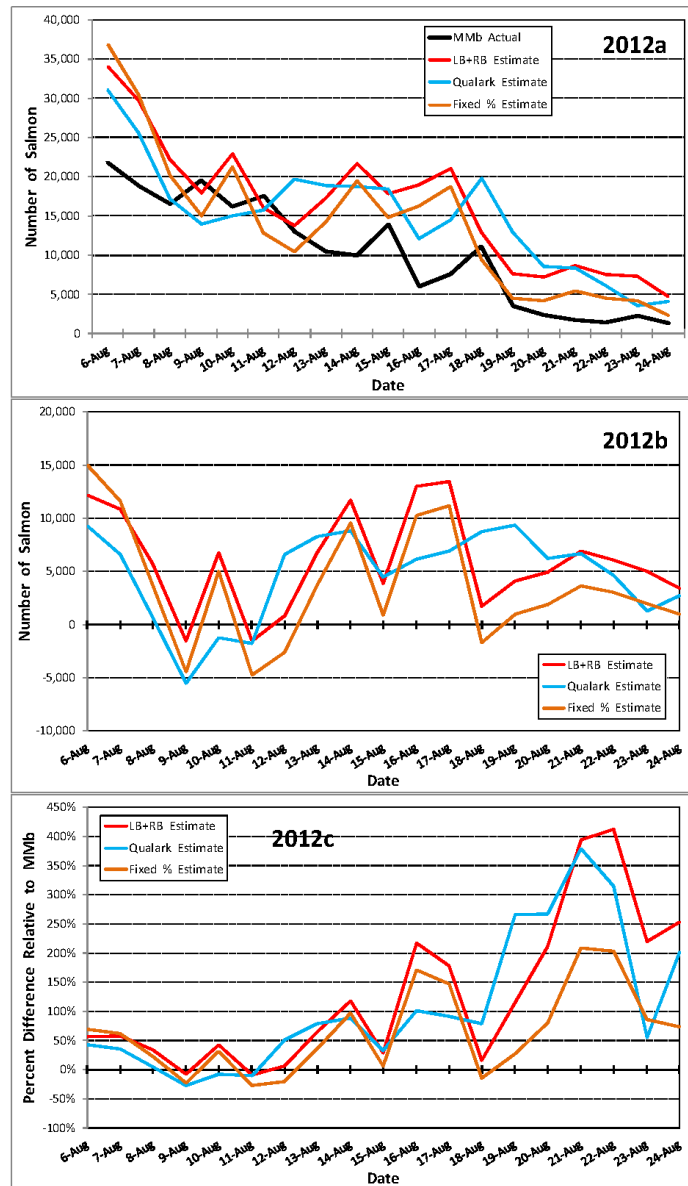


Figure 5. Comparison of daily MMB actual in 2012 to (a) estimates from the fixed percentage, Mission LB+RB, and Qualark models. Panels b and c show daily differences between estimates and MMB actual expressed in numbers of salmon and percentage of MMB actual, respectively.

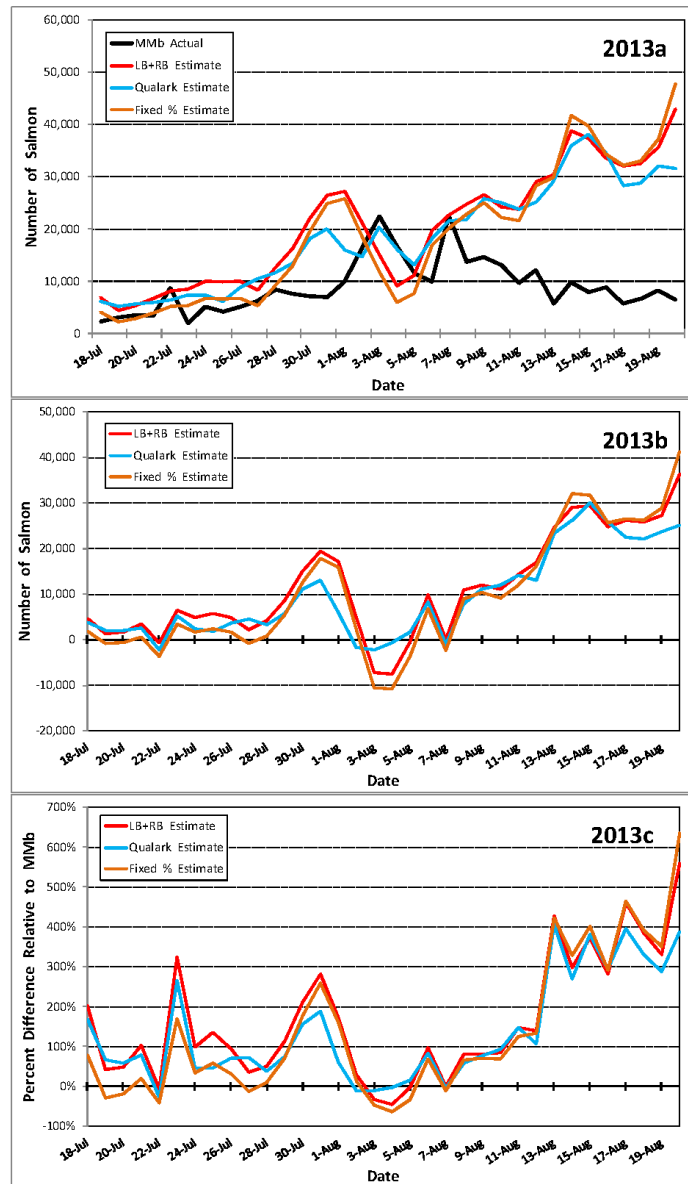


Figure 6. Comparison of daily MMB actual in 2013 to (a) estimates from the fixed percentage, Mission LB+RB, and Qualark models. Panels b and c show daily differences between estimates and MMB actual expressed in numbers of salmon and percentage of MMB actual, respectively.



- In 2014 (Figure 7), the three estimation models follow daily MMb actual relatively closely. The exception was during the mid-to-late September period when the Fixed% and LB+RB models consistently over-estimated MMb actual. But even in this year of relatively good performance, the total MMb actual during the estimation period was over-estimated by 11% (295,000 fish) by the Fixed% model and under-estimated by -7% (177,000 fish) and -19% (498,000 fish) for the LB+RB and QLK models, respectively.
- In 2015 (Figure 8), from July 14 through August 4 the increasing trend in MMb actual is followed closely by the estimates from the two regression models. The Fixed% model consistently under-estimates MMb actual during this same period (panel c). After August 4, the estimates from all three models are do not closely correspond to MMb actual.
- In 2016 (Figure 9), the estimates from the two regression models follow daily MMb actual relatively closely. After August 7, the LB+RB model tends to slightly under-estimate MMb actual while the QLK model slightly over-estimates MMb actual (panel b). The Fixed% model consistently under-estimates MMb actual (panel c). The total MMb actual during the estimation period was under-estimated by -10% (33,000 fish) and over-estimated by 6% (21,000 fish) for the LB+RB and QLK models, respectively.

### Discussion

No single method was clearly superior to the others in estimating MMb actual on a daily basis. The mean absolute percent errors for the three models across the seven years analyzed were very similar (see Results). While the QLK models consistently had the smallest annual RMSE statistics, the models with the lowest annual MAPE varied year-to-year. The LB+RB models had the smallest MAPE in three years while the other two methods had the lowest MAPE in two years each (Table 4). For the estimation periods during the seven years examined:

- the LB+RB model had four years where the annual percent error  $< \pm 15\%$ ,
- the Fixed% model had three years where the annual percent error  $< \pm 15\%$ , and
- the QLK model had two years where the annual percent error  $< \pm 15\%$ .

Accurate daily estimates of MMb actual are critical so that escapements and run sizes of different timed stocks in the Fraser escapement can be properly assessed. Figure 10 (upper panel) compares the distribution of daily differences between MMb actual and the model estimates in numbers of salmon. The Fixed% model has a tendency to under-estimate MMb actual more often (65% of the daily estimates) than the regression based models (56% for LB+RB and 54% for QLK). Figure 10 (lower panel) compares the distribution of daily differences between MMb actual and the model estimates expressed as a percentage of the total MMb actual on each day. This shows the potential error in the Mission daily salmon assessment when an estimation model is used rather than actual MMb acoustic data. The Fixed% model typically results in larger daily differences in Mission passage assessment of the total salmon migration than the regression-based models: only 34% of the daily differences expressed as a percentage of the daily total are within  $\pm 10\%$  for the Fixed% model, while the percentage within  $\pm 10\%$  is 47% and 54% for the LB+RB and QLK models, respectively.

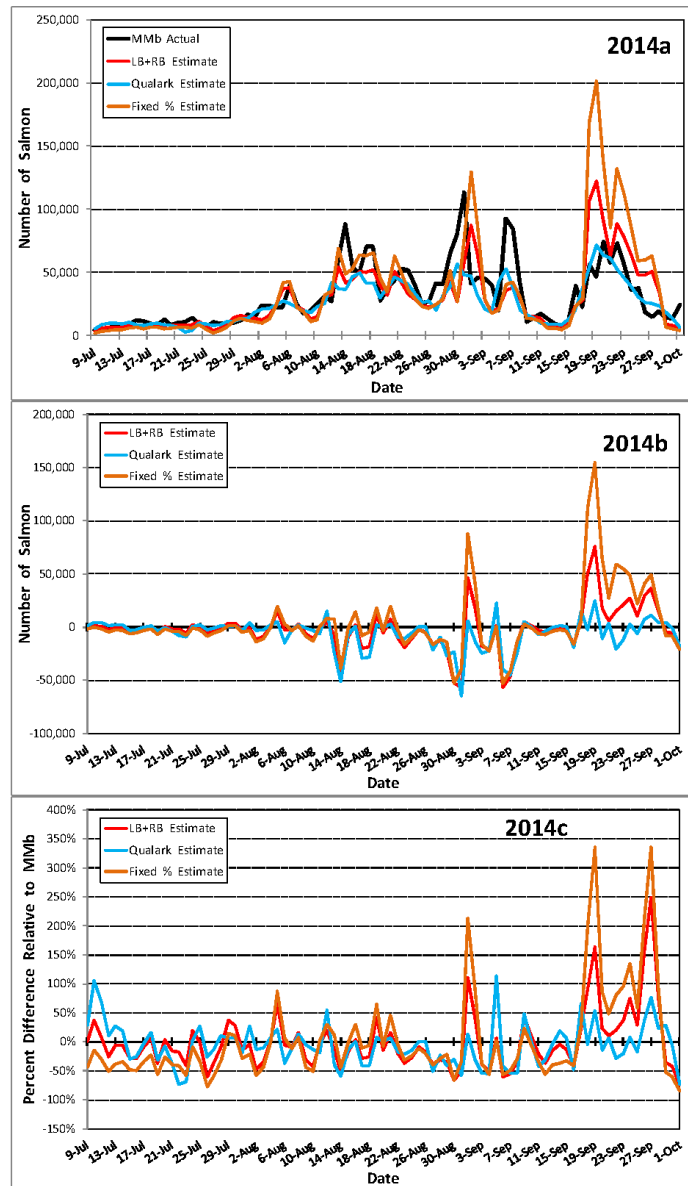


Figure 7. Comparison of daily MMB actual in 2014 to (a) estimates from the fixed percentage, Mission LB+RB, and Qualark models. Panels b and c show daily differences between estimates and MMB actual expressed in numbers of salmon and percentage of MMB actual, respectively.

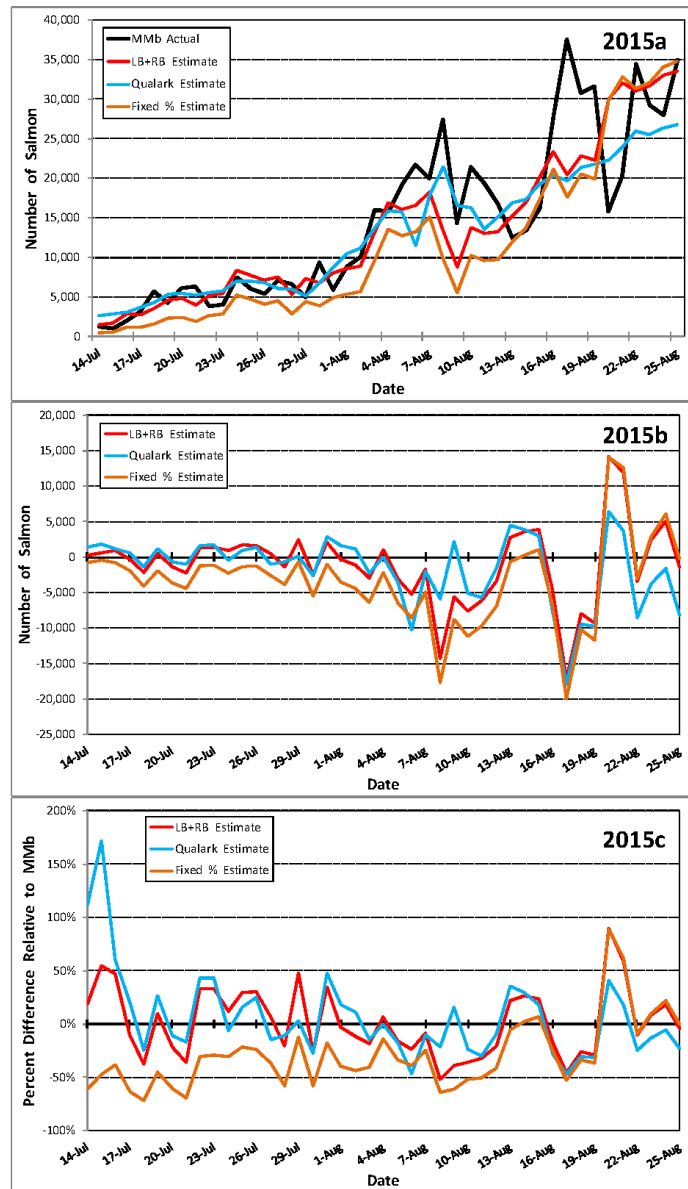


Figure 8. Comparison of daily MMB actual in 2015 to (a) estimates from the fixed percentage, Mission LB+RB, and Qualark models. Panels b and c show daily differences between estimates and MMB actual expressed in numbers of salmon and percentage of MMB actual, respectively.

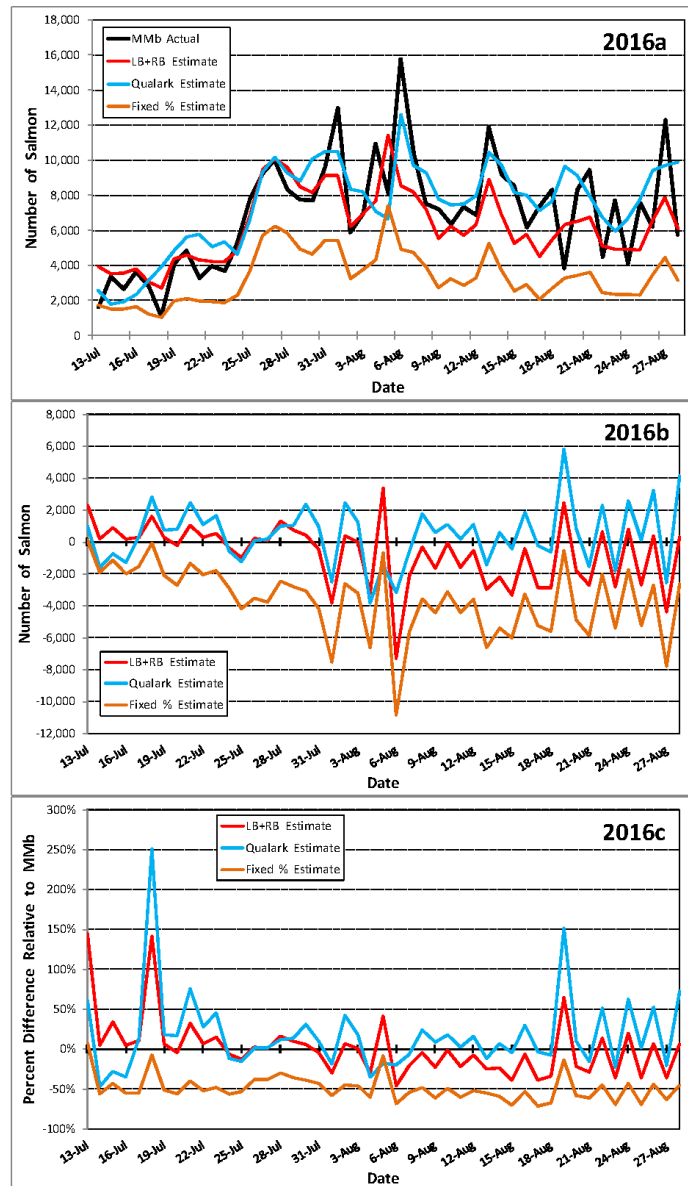


Figure 9. Comparison of daily MMB actual in 2016 to (a) estimates from the fixed percentage, Mission LB+RB, and Qualark models. Panels b and c show daily differences between estimates and MMB actual expressed in numbers of salmon and percentage of MMB actual, respectively.

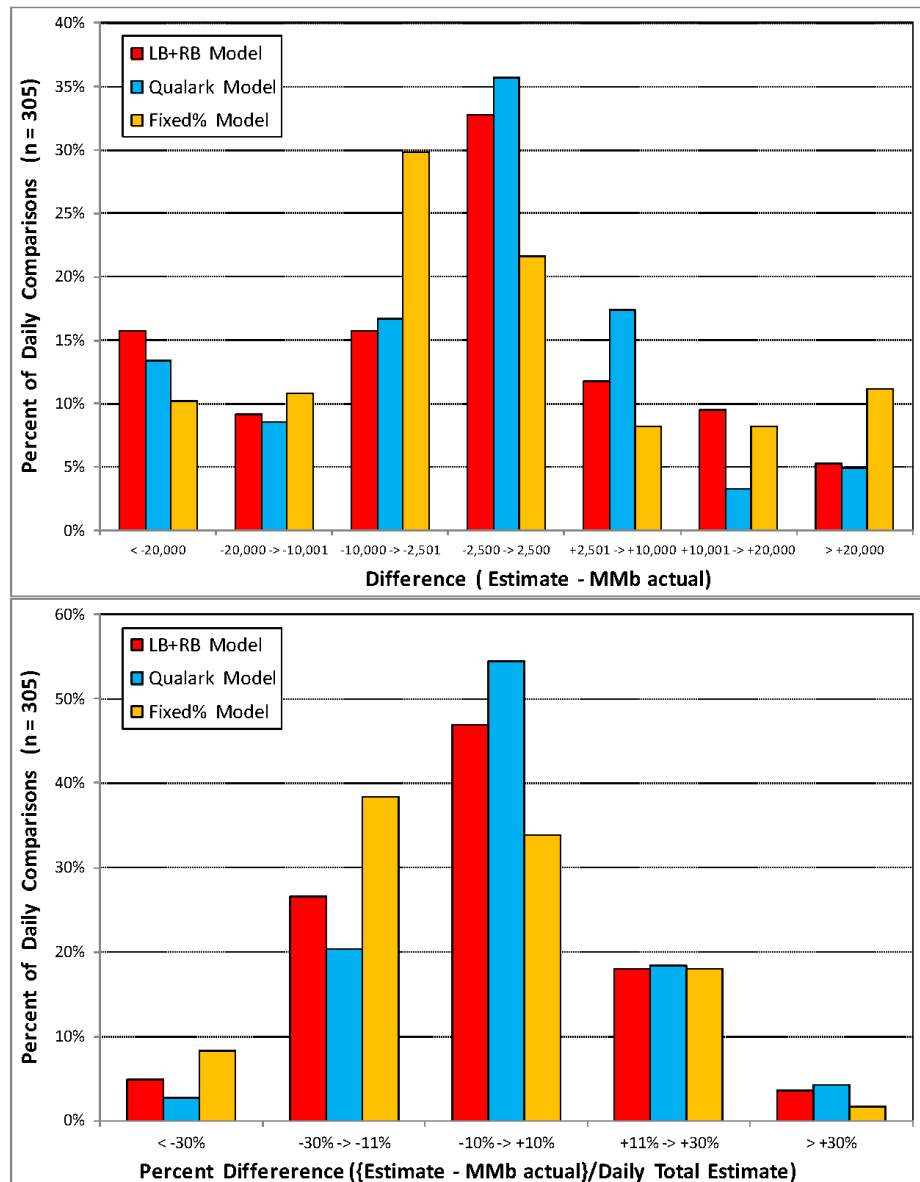


Figure 10. Frequency histograms comparing (top panel) daily differences between model estimates and MMB actual and (bottom panel) the percentage of each day's total estimated daily salmon migration at Mission represented by these daily differences. Summary includes only days in the estimation period for all years analyzed (2010 - 2016).

While the overall difference between the MMb estimate and MMb actual might be relatively small and acceptable summed over an entire assessment period (for example, the estimates by the LB+RB and QLK models for 2014, 2015, and 2016), the magnitude and direction of differences between estimates and MMb actual for specific temporal segments of the sockeye return may be different during the assessment period and add uncertainty to the assessment of the status of some Fraser sockeye management groups and/or stocks. For example, in 2014 there was a -6.7% difference (-177,335 salmon) between the estimate from the LB+RB model (2,489,008) and MMb actual (2,666,343) during the July 9 to October 1 assessment period. However, the magnitude and direction of the differences between the MMb estimates and MMb actual varied considerably during that period (Table 6). Similarly, in 2016 there was only a 6.3% difference (20,719 salmon) between the estimate from the Qualark model (348,762) and MMb actual (328,043) during the July 13 to August 28 assessment period. However, the magnitude and direction of the differences between the MMb estimates and MMb actual varied considerably during that period (Table 7).

Table 6. Differences between the estimate of the Mission mobile abundance based on the LB+RB model and MMb actual for three different time periods during the 2014 return.

Assessment Dates	Difference (Estimate - actual)	Difference as % of actual
July 9 to 31	-26,853	-12.0%
August 1 to 31	-317,053	-23.7%
Sep. 1 to Oct. 1	+166,571	+15.1%

Table 7. Differences between the estimate of the Mission mobile abundance based on the Qualark model and MMb actual for three different time periods during the 2016 return.

Assessment Dates	Difference (Estimate - actual)	Difference as % of actual
July 13 to 31	+11,058	+11.0%
August 1 to 14	-4,013	-3.2%
August 15 to 28	+13,674	+13.7%

If a model was used to estimate the mid-channel salmon passage at Mission, there is no indication of how the model is performing on a daily basis and whether the estimates are corresponding closely to actual salmon passage (as during the August 1 to 14 period in Table 7) or being consistently over- or under- estimated (relative to MMb actual).

None of the models examined provide consistent and precise daily estimates of the number of salmon assessed by the mobile unit at Mission. Other problematic issues, other than the accuracy and precision of the estimates, introduced by using a model to estimate MMb are:

- Post season, when comparing spawning ground estimates to Mission-projected escapement estimates, DBEs (differences between estimates) would now have a new major source of uncertainty, the uncertainty due to the estimation of Mission mobile passage from a model.

- For the fixed percentage model, there is no indication inseason if salmon migration behavior is deviating substantially from "average" in terms of the proportion of the daily sockeye migration not being counted by the bank-oriented units. For example, in 2016 a much higher proportion of the migration was assessed by the Mission mobile unit than in previous years (Table 1).
- For the Qualark model, if this model were to be used inseason there would be a 2-3 day delay before the complete estimate of the number of salmon passing Mission on a day would be available. This introduces additional uncertainty and possibly delays management decisions on the status of Fraser sockeye management groups and/or stocks.

To give perspective to the size of the differences between MMB actual and MMB estimates of total salmon, Table 8 compares these differences to the sockeye passage estimate differences (PEDs) between the Mission-projected Qualark estimates and the actual Qualark sockeye estimates during the same assessment periods. Although the differences are in different units (number of salmon versus number of sockeye), the size of the absolute differences that are due to estimating MMB relative to the Mission-thru-Qualark PEDs are summarized below.

- For the Fixed% model, the differences between the Mission through Qualark projection and the Qualark estimate of sockeye were greater than the differences between the MMB estimate and MMB actual in five of the seven years.
- For the LB+RB model, the differences between the Mission through Qualark projection and the Qualark estimate of sockeye were greater than the differences between the MMB estimate and MMB actual in three of the seven years.
- For the QLK model, the differences between the Mission through Qualark projection and the Qualark estimate of sockeye were greater than the differences between the MMB estimate and MMB actual in six of the seven years.

### Conclusions

Removing the mobile system would considerably increase the uncertainty in the Mission estimates of mid-channel salmon passage (i.e., the portion of the upstream migration not assessed by the bank-oriented hydroacoustic systems at Mission); in the years examined, from 20% to 40% of the upstream migration was assessed by the mobile unit. Removing the Mission mobile system would therefore add considerable uncertainty into estimates generated by the Mission program for a cost savings of approximately \$70,000 annually. This would also impact the dataset based on the difference between Mission escapement and spawning ground estimates which is used in both the MA models and RSA processes.

Ultimately the decision on whether these models can be used to replace the estimates generated from the Mission mobile unit is a matter of risk tolerance by the managers. For example, while the MMB estimation differences during the sockeye-dominant period for the LB+RB model may be acceptable for the last three years (2014-2016) in terms of overall percentages (less than  $\pm 11\%$ ) and numbers of salmon (30,000 to 180,000) for the total salmon escapement past Mission estimate, it may not be acceptable when considering how these differences impact the estimates for the component stocks and the managers' ability to assess the status of stock-specific escapement goals inseason.

Table 8. Comparison of differences in salmon abundance at Mission that result from using model-based estimates of MMB and the differences in sockeye for the Mission projection of through-Qualark sockeye and the Qualark sockeye abundance estimate over the same assessment periods.

Year	Assessment Period	Estimation Method	Mission Mobile Estimate-Actual Difference (salmon)	Mission thru Qualark Projection-Qualark Difference (sockeye)
2010	Aug. 1 - Oct. 3	Fixed%	-339,133	-1,699,673
		LB+RB	-1,760,793	
		Qualark	-995,388	
2011	Aug. 12 - Aug. 25	Fixed%	66,790	-212,057
		LB+RB	17,174	
		Qualark	-109,524	
2012	Aug. 6 - Aug. 24	Fixed%	69,713	-93,612
		LB+RB	113,959	
		Qualark	88,784	
2013	Jul. 18 - Aug. 20	Fixed%	332,448	+24,489
		LB+RB	386,926	
		Qualark	326,735	
2014	Jul. 9 - Oct. 1	Fixed%	295,203	+1,441,878
		LB+RB	-177,335	
		Qualark	-497,697	
2015	Jul. 14 - Aug. 25	Fixed%	-145,765	+187,986
		LB+RB	-47,282	
		Qualark	-70,363	
2016	Jul. 13 - Aug. 28	Fixed%	-170,884	-27,266
		LB+RB	-33,126	
		Qualark	20,719	



# Appendix 12: Sub-sampling with Mission Mobile as an Alternative to Daily Operation

## APPENDIX 11

### Sub-sampling with Mission Mobile as an Alternative to Daily Operation

Appendix 10 examined completely replacing the Mission Mobile (MMb) assessment of the number of salmon migrating mid-channel with estimates based on a fixed percentage (Fixed%) of the run migrating mid-channel or regression-based methods using the salmon enumeration data collected from the left-bank and right bank (LB+RB) hydroacoustic systems at Mission or the enumeration data from the Qualark (QLK) systems. Appendix 11 examines the impact on MMb assessment from sub-sampling (i.e., sampling only on specific days) throughout the season instead of operating the mobile unit daily. Cost savings from sub-sampling are not as great as those realized by completely eliminating the mobile unit and are dependent upon the MMb sampling frequency throughout the season.

As in Appendix 10, this appendix evaluates different methods of replacing the MMb estimate of the daily number of salmon migrating past Mission in the mid-channel area not assessed by the bank-based hydroacoustic systems, not the number of sockeye. Total salmon before apportionment to species is used because estimates of species composition introduce an additional source of variability into the estimation process. Current methods of apportioning numbers by species (and into sockeye stocks) would be applied to any estimates of daily salmon passage substituted for the actual Mission mobile estimate.

The methods used for the sub-sampling analysis were for the purpose of evaluating the feasibility of sub-sampling - they are not a retrospective evaluation of any proposed method that would be used in-season if sub-sampling were to be implemented. Additional work would be needed to determine the optimal method for implementing a sub-sampling program in-season.

Since the MMb assessment of salmon passage is also an estimate, and to reduce confusion when referring to the estimates from either the model-based or sub-sampling methods, the MMb estimates that were produced for each day examined, and for the period and season totals, are referred to as MMb actual in this appendix.

An important issue with the methods examined in Appendix 10 is that the daily estimates often have extended periods throughout a season where salmon passage is consistently over- or under- estimated (relative to MMb actual). So even though the total estimate of mid-channel salmon passage for a season may be assessed with acceptable error (e.g., within  $\pm 15\%$ ), the errors for particular temporal periods during the season (which affects the assessment of the sockeye stocks migrating past Mission at that time) may not be acceptable. For the three model-based estimation methods examined in Appendix 10, the direction of estimation error could not be identified in-season. The advantage of sub-sampling is that an actual MMb observation of daily salmon passage is periodically collected throughout the season which can be used as the basis for previous and subsequent days' estimates and reduce the probability of extended periods of over- or under- estimation (again relative to MMb actual).

## Methods

The same daily MMb salmon data used for the analyses in Appendix 10 were used for the sub-sampling analyses:

- Data for the years 2010-2016 were used.
- Only MMb actual estimates during the sockeye-dominant period each year were used<sup>1</sup>.

The same days used for the assessment of estimation models in Appendix 10 were used in Appendix 11 so that the performance of the sub-sampling methods could be directly compared to the model-based methods.

### Sub-sampling Schemes:

Various systematic sampling schemes were applied to the MMb actual data for the years examined. Seven basic systematic sampling schemes were explored. The application of any systematic sampling scheme involves the random selection of a starting point (in this case a starting date) to initiate sampling. For example, if every third day is to be sampled (i.e., the Mission mobile unit is operated every third day), the starting date for initiating sampling could be day  $i$ ,  $i+1$ , or  $i+2$ . Therefore, we examined each potential starting date for each systematic sampling scheme. Hypothetical systematic sampling schemes of every 2<sup>nd</sup>, 3<sup>rd</sup>, 4<sup>th</sup>, 5<sup>th</sup>, 6<sup>th</sup>, and 7<sup>th</sup> day were applied to each year's MMb data set. When alternative starting dates were applied this generated a total of 27 possible systematic samples. In addition, one scheme was examined where three consecutive days were sampled followed by four days with no sampling (SS3|4). Three different starting days were examined for this sub-sampling pattern. Therefore, there was a total of 30 different sub-sampling methods examined.

### Estimation Methods:

Simple linear interpolation was used to estimate salmon passage between actual MMb sampling dates, with subscript  $P$  indicating the last MMb actual preceding the day being estimated ( $i$ ) and subscript  $N$  indicating the next MMb actual following day  $i$ . MMb salmon passage on day  $i$  ( $\widehat{MMb}_i$ ) was estimated as:

$$\widehat{MMb}_i = MMb_P + \left( \frac{MMb_N - MMb_P}{F} \times J \right) \quad [1]$$

where  $F$  = the sampling frequency (2 for every second day, 3 for every third day, etc.) and  $J$  is the number of days difference between sample  $MMb_P$  and day  $i$ .

Interpolation was also needed whenever the first day of the sockeye-dominant period examined each year was not a MMb sample day in order to have either an MMb actual or MMb estimate for each day in the sockeye-dominant period for each sampling scheme. For interpolation, the MMb actual for the day preceding the sockeye-dominant period was used for  $MMb_P$  in the interpolation calculation when the first day of hypothetical sampling did not occur on the first day of the sockeye-dominant period defined for a year.

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<sup>1</sup> See Table 4 in Appendix 10 for the dates used in each year's assessment.

Similarly, interpolation was also needed whenever the last day of the sockeye-dominant period was not a MMb sample day. In pink years (odd years), the MMb actual for the day following the last day of the sockeye-dominant period was used for  $MMb_N$  in the interpolation calculation. In even years, there was not a MMb actual following the last day of the sockeye-dominant period so the average of the last two MMb actuals in the sockeye-dominant period was used for  $MMb_N$  in the extrapolation calculation.

For the SS3 | 4 sampling scheme, the averages of the daily MMb actuals for the three-day period of observation were used for  $MMb_P$  and  $MMb_N$ . Linear interpolation for the non-sample days then used these averages ( $\overline{MMb_P}$  and  $\overline{MMb_N}$ ) in Equation 1.

#### Performance Statistics:

To compare the performance of the different sub-sampling schemes, summary statistics comparing MMb actuals to estimated MMb counts ( $\widehat{MMb}$ ) were used. The statistics were calculated for the same days during the sockeye-dominant period that were analyzed in Appendix 10. Two of the same model performance statistics used in Appendix 10 were calculated:

- The difference in number of salmon defined as daily  $\widehat{MMb}$  - MMb actual summed over the model assessment period (DIFF)<sup>2</sup> (note that negative values indicate an under-estimate and positive values indicate an over-estimate relative to MMb actual).
- The percent difference defined as DIFF divided by the summed MMb actual (%DIFF).

These two statistics are based on sockeye-dominant estimation period totals.

For the different sub-sampling approaches,  $\widehat{MMb}_i$  was estimated for a varying number of days depending upon the sampling scheme and starting point. Four additional model performance statistics were examined which calculated the percentage of days in the sockeye-dominant estimation period that met certain criteria. The four additional performance criteria were:

- 1) the percentage of days when the difference between the daily estimate of  $\widehat{MMb}_i$  and MMb actual was within  $\pm 5\%$  of MMb actual<sup>3</sup> (PW $\pm 5\%$ ).
- 2) the percentage of days when the difference between the daily estimate of  $\widehat{MMb}_i$  and MMb actual was  $\geq \pm 50\%$  of MMb actual (P $\geq 50\%$ ).
- 3) the percentage of days when the difference between the daily estimate of  $\widehat{MMb}_i$  and MMb actual was within  $\pm 1,000$  salmon of MMb actual (PW $\pm 1000$ ).
- 4) the percentage of days when the difference between the daily estimate of  $\widehat{MMb}_i$  and MMb actual was  $\geq \pm 5,000$  salmon of MMb actual (P $\geq 5000$ ).

These four statistics were calculated based on the daily estimates of  $\widehat{MMb}_i$  relative to the criteria and tallied across the sample period.

While other performance statistics could be examined, those specified above provided sufficient information for an initial evaluation of alternate estimation methods and sampling schemes. If needed, a more detailed examination of model performance on a limited set of methods can be conducted at a later time.

<sup>2</sup> Performance statistics acronyms are in {}.

<sup>3</sup> Days when MMb sampling occurred were included in these percentages and obviously had 0 difference.

## Results

The following notation was used to denote each of the systematic sub-sampling schemes:

$$SSX\#Y(n)$$

where  $X$  = the sub-sampling frequency (e.g., 2 = every 2<sup>nd</sup> day, 3 = every 3<sup>rd</sup> day, etc.),  $Y$  = the starting day for initiating sampling (where  $Y = 1 \dots X$ ), and  $n$  specifies the number of days for which estimates were generated during the sockeye-dominant period.

### Comparison of Model Performance:

Table 1 compares the mean model performance statistics for the three model-based estimation methods from Appendix 10 and the 30 systematic sub-sampling methods applied to the MMB data. These analyses are for the sockeye-dominant period of each year and only include days when there were both LB and RB counts for Mission (to correspond to the Appendix 10 analyses). The number of days in each sockeye-dominant period are shown in Table 4 in Appendix 10. While the three model-based methods examined in Appendix 10 estimate  $\overline{MMb}$  for each day in each annual sockeye-dominant period, the sub-sampling methods estimate  $\overline{MMb}$  on 50% to 86% of the days in the same annual period depending upon sampling frequency.

In general, the three model-based estimates had the largest values for mean absolute DIFF across the seven years examined with the exception of sub-sampling schemes SS7#4 and SS7#7 (sampling every 7th day with sampling initiated on either the fourth or seventh day). When DIFF is expressed as a percentage of the annual sockeye-dominant period total (MMb actual), the mean absolute values of %DIFF for the three model-based estimates were more than twice that of any of the sub-sampling schemes. The mean percentage of days with large differences between the estimation method and MMB actual ( $P \geq 50\%$  and  $P \geq 5000$ ) was also larger for the three model-based methods than for any of the sub-sampling methods.

Figure 1 compares methods for 2014 and 2015 using the  $PW \pm 5\%$  and  $P \geq 50\%$  evaluation statistics. The black bars show the percentage of days when the difference between the daily estimate of  $\overline{MMb}_i$  and MMB actual was within  $\pm 5\%$  of MMB actual ( $PW \pm 5\%$ ): higher values indicate better performing methods. The red line shows the percentage of days when the difference between the daily estimate of  $\overline{MMb}_i$  and MMB actual was  $\geq \pm 50\%$  of MMB actual ( $P \geq 50\%$ ): for this statistic lower values indicate better performing methods. In both years:

- The three model-based methods examined in Appendix 10 had the lowest percentage of days meeting the  $PW \pm 5\%$  criterion,
- Sub-sampling every 2<sup>nd</sup> or 3<sup>rd</sup> day or the 3|4 sub-sampling scheme had the highest percentage of days meeting the  $PW \pm 5\%$  criterion,
- Sub-sampling every 2<sup>nd</sup> or 3<sup>rd</sup> day or the 3|4 sub-sampling scheme had the lowest percentage of days with relative differences  $\geq 50\%$  with the exception of the LB+RB and QLK methods in 2015 which had similar performance to these sub-sampling schemes (this was somewhat anomalous for these two methods and occurred only in 2015 and 2016).

The other years had similar patterns for these two performance statistics (see Appendix 11A).

Table 1. Summary of performance statistics for the three model-based estimates (see Appendix 10) and the systematic sub-sampling with linear interpolation methods. Values presented are the means across the seven years sampled (2010-2016). DIFF and %DIFF were calculated using absolute values of annual numbers and therefore do not represent directionality.

Method	DIFF	%DIFF	PW±5%	P≥50%	PW±1000	P≥5000
Fixed%	202,847	36.2%	3.4%	49.0%	9.6%	52.3%
LB+RB	362,371	36.4%	9.0%	37.8%	15.4%	46.9%
QLK	301,315	33.7%	9.4%	32.1%	12.5%	44.0%
SS2#1	48,538	3.3%	58.0%	8.2%	65.4%	13.3%
SS2#2	47,061	3.2%	54.5%	8.9%	59.9%	14.8%
SS3#1	44,603	7.3%	41.2%	12.9%	47.9%	17.4%
SS3#2	48,271	4.6%	42.4%	13.8%	50.5%	19.1%
SS3#3	52,478	6.3%	38.7%	13.5%	45.7%	23.3%
SS3 4#1	54,358	6.6%	50.2%	12.9%	56.9%	20.9%
SS3 4#2	141,860	9.4%	49.6%	13.3%	55.8%	19.4%
SS3 4#3	141,239	7.7%	50.0%	14.9%	53.2%	16.8%
SS4#1	127,310	8.9%	33.3%	19.1%	38.0%	21.9%
SS4#2	55,909	5.5%	33.7%	17.1%	39.1%	24.7%
SS4#3	108,418	8.4%	30.5%	13.7%	39.3%	24.9%
SS4#4	97,327	5.9%	33.0%	16.6%	38.7%	21.5%
SS5#1	46,559	6.1%	29.8%	17.1%	36.1%	25.4%
SS5#2	42,603	4.1%	27.1%	19.4%	34.1%	27.8%
SS5#3	102,269	7.4%	26.1%	19.1%	34.4%	26.2%
SS5#4	39,693	6.1%	25.3%	19.3%	35.7%	28.5%
SS5#5	74,087	6.1%	26.1%	21.4%	31.3%	24.6%
SS6#1	118,298	11.4%	24.2%	23.4%	30.5%	30.3%
SS6#2	92,745	10.3%	24.9%	22.8%	33.7%	28.5%
SS6#3	106,730	12.4%	23.9%	18.2%	33.6%	32.3%
SS6#4	115,884	6.9%	25.5%	20.3%	33.0%	25.7%
SS6#5	61,760	13.2%	26.1%	23.0%	31.4%	28.4%
SS6#6	111,342	6.9%	25.0%	22.7%	29.2%	27.4%
SS7#1	158,331	9.1%	26.5%	19.3%	38.4%	30.4%
SS7#2	130,452	12.6%	22.9%	24.3%	32.3%	32.6%
SS7#3	167,702	13.8%	24.8%	20.9%	29.1%	27.6%
SS7#4	260,781	15.0%	22.1%	21.8%	30.4%	30.5%
SS7#5	137,345	9.1%	21.9%	22.9%	24.8%	27.2%
SS7#6	113,741	12.0%	19.7%	24.5%	25.7%	34.9%
SS7#7	275,377	16.7%	20.3%	29.6%	27.5%	32.0%

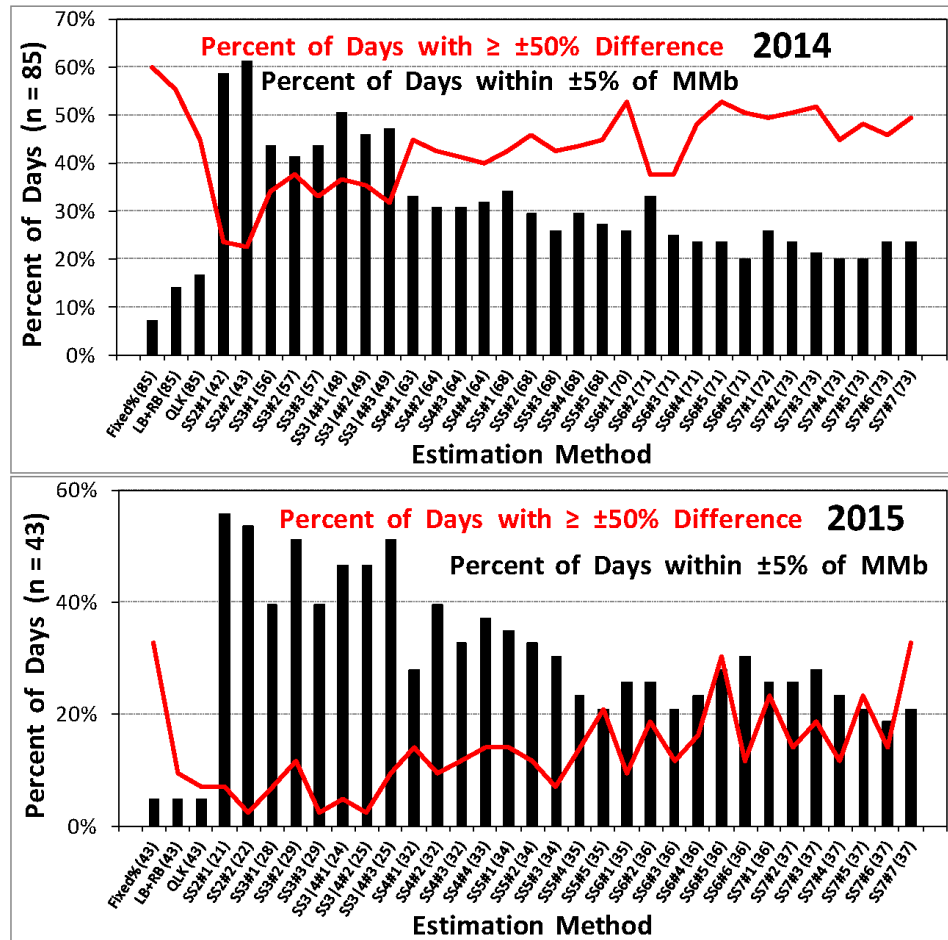


Figure 1. Comparison of estimation methods for the  $PW \pm 5\%$  and  $P \geq 50\%$  performance statistics in 2014 and 2015. The black bars show the percentage of days when the difference between the daily estimate of  $\widehat{MMb}_i$  and MMb actual was within  $\pm 5\%$  of MMb actual. The red line shows the percentage of days when the difference between the daily estimate of  $\widehat{MMb}_i$  and MMb actual was  $\geq \pm 50\%$  of MMb actual.

The means across years of the performance statistics presented in Table 1 were ranked to facilitate comparisons. Lower values of the DIFF, %DIFF,  $P \geq 50\%$ , and  $P \geq 5000$  statistics indicated better performance so ranks were assigned from low to high values (with 1 = lowest). For the  $PW \pm 5\%$  and  $PW \pm 1000$  statistics, higher values indicated better performance so ranks were assigned from high to low (with 1 = highest). Table 2 summarizes the ranks for each performance statistic based on the means in Table 1 and shows the mean rank across all statistics. Not surprisingly the every 2<sup>nd</sup> day sub-sampling

scheme (SS2), which is based on the largest number of actual MMb days of observation and has the fewest number of days being estimated, performed the best for all statistics except DIFF and had the lowest (best) mean ranks. Based on the mean ranks of the performance statistics, the every 3<sup>rd</sup> day sub-sampling scheme (SS3) was ranked next best overall. The SS3|4 sub-sampling scheme had relatively low ranks for the four daily percentage-based statistics (PW±5%, P≥50%, PW±1000, and P≥5000) but the ranks for DIFF and %DIFF were in the medium range.

Only the SS2, SS3, SS3|4, and SS5 sub-sampling schemes had annual values for %DIFF that were all less than ±20% (Table 3). However, the SS5 sub-sampling schemes all had a lower proportions of days meeting the PW±5% and PW±1000 criteria and a higher proportion of days exceeding the P≥50% and P≥5000 criteria relative to the SS2, SS3, and SS3|4 sub-sampling schemes (see tables in Appendix 11A).

An interesting inconsistency of the sub-sampling schemes is that sometimes one of the samples associated with a particular frequency of sampling and starting date will perform much better or much worse than the others during a particular year. For example, for the every 6<sup>th</sup> day sub-sampling scheme in 2015 the sub-sample initiated on July 14 performed considerably better (-502 DIFF, -0.1% %DIFF) than the sample initiated on July 12 (+115,489 DIFF, +18.2% %DIFF; see Figure 2). Because there is no indication of this when collecting the data inseason or after the season, the performance of any sub-sampling scheme must be evaluated across all possible starting dates.

In the evaluation of the model-based methods of estimating MMb (Appendix 10), it was identified that while the overall difference between the MMb estimate and MMb actual might be relatively small and acceptable summed over the entire assessment period, the magnitude and direction of differences between daily estimates and MMb actual for specific temporal segments of the return were often very different. For example, in 2014 there was only a -6.7% difference (-177,335 salmon) between the estimate from the LB+RB model (2,489,008) and MMb actual (2,666,343) during the July 9 to October 1 assessment period. However, from August 1 to 31 the difference was -317,000 salmon (-24%) compared to a difference of +167,000 salmon (+15%) from September 1 to October 1. This adds additional uncertainty to the assessment of the status of some Fraser sockeye management groups and/or stocks when their timing coincides with these periods.

To evaluate performance across different temporal periods within each year, six time periods were established: July 1-15, July 16-31, August 1-15, August 16-31, September 1-15, and September 16-30. DIFF was then calculated for each of these periods in each year for each method. Figure 3 compares the temporal calculations of DIFF for three of the methods: LB+RB (the "best" performing model from Appendix 10), SS2#1, and SS3|4#2 (two of the better performing sub-sampling methods). The sub-sampling methods had noticeably fewer occurrences of large values of DIFF across the different temporal periods compared to the LB+RB method.

Table 2. Ranks for mean performance statistics for the three model-based estimates and the systematic sub-sampling with linear interpolation methods (see Table 1 for data that were ranked).

Method	DIFF	%DIFF	PW±5%	P≥50%	PW±1000	P≥5000	Average Rank
Fixed%	29	32	33	33	33	33	32.2
LB+RB	33	33	32	32	31	32	32.2
QLK	32	31	31	31	32	31	31.3
SS2#1	7	2	1	1	1	1	2.2
SS2#2	5	1	2	2	2	2	2.3
SS3#1	3	14	7	4	7	4	6.5
SS3#2	6	4	6	8	6	5	5.8
SS3#3	8	10	8	6	8	10	8.3
SS3 4#1	9	11	3	3	3	7	6.0
SS3 4#2	26	21	5	5	4	6	11.2
SS3 4#3	25	16	4	9	5	3	10.3
SS4#1	22	18	10	14	13	9	14.3
SS4#2	10	5	9	12	10	12	9.7
SS4#3	17	17	12	7	9	13	12.5
SS4#4	14	6	11	10	11	8	10.0
SS5#1	4	7	13	11	14	14	10.5
SS5#2	2	3	14	18	17	20	12.3
SS5#3	15	15	18	15	16	16	15.8
SS5#4	1	9	20	16	15	23	14.0
SS5#5	12	8	17	21	23	11	15.3
SS6#1	21	23	24	27	24	24	23.8
SS6#2	13	22	22	24	18	22	20.2
SS6#3	16	25	25	13	19	28	21.0
SS6#4	20	12	19	19	20	15	17.5
SS6#5	11	27	16	26	22	21	20.5
SS6#6	18	13	21	23	26	18	19.8
SS7#1	27	19	15	17	12	25	19.2
SS7#2	23	26	26	28	21	29	25.5
SS7#3	28	28	23	20	27	19	24.2
SS7#4	30	29	27	22	25	26	26.5
SS7#5	24	20	28	25	30	17	24.0
SS7#6	19	24	30	29	29	30	26.8
SS7#7	31	30	29	30	28	27	29.2



Table 3. Summary of annual %DIFF statistics for the three model-based estimates and the systematic sub-sampling with linear interpolation methods (mean, minimum, and maximum is based on absolute value of %DIFF).

Method	2010	2011	2012	2013	2014	2015	2016	Mean	Minimum	Maximum
Fixed%	-8%	15%	36%	109%	11%	-23%	-52%	36.2%	8%	109%
LB+RB	-42%	4%	58%	127%	-7%	-7%	-10%	36.4%	4%	127%
QLK	-24%	-24%	46%	107%	-19%	-11%	6%	33.7%	6%	107%
SS2#1	-4%	0%	-4%	6%	-5%	1%	-4%	3.3%	0%	6%
SS2#2	4%	1%	3%	-4%	4%	-1%	5%	3.2%	1%	5%
SS3#1	0%	-12%	15%	-8%	5%	4%	7%	7.3%	0%	15%
SS3#2	3%	0%	-12%	8%	-5%	3%	0%	4.6%	0%	12%
SS3#3	-4%	14%	-4%	4%	0%	-9%	-8%	6.3%	0%	14%
SS3 4#1	-2%	17%	-3%	8%	-5%	-2%	-8%	6.6%	2%	17%
SS3 4#2	-17%	15%	-2%	11%	3%	-14%	4%	9.4%	2%	17%
SS3 4#3	-15%	-5%	0%	10%	9%	-10%	5%	7.7%	0%	15%
SS4#1	-10%	7%	8%	21%	12%	1%	-2%	8.9%	1%	21%
SS4#2	-4%	10%	9%	-4%	5%	-5%	-3%	5.5%	3%	10%
SS4#3	2%	-6%	-15%	-8%	-21%	-1%	-5%	8.4%	1%	21%
SS4#4	11%	-8%	-4%	0%	4%	3%	10%	5.9%	0%	11%
SS5#1	0%	-1%	-1%	18%	7%	5%	-11%	6.1%	0%	18%
SS5#2	-4%	-6%	-5%	7%	2%	-6%	0%	4.1%	0%	7%
SS5#3	-4%	-9%	3%	4%	-14%	-11%	-6%	7.4%	3%	14%
SS5#4	2%	18%	-4%	-13%	-1%	-3%	2%	6.1%	1%	18%
SS5#5	5%	2%	4%	0%	6%	11%	15%	6.1%	0%	15%
SS6#1	-12%	-21%	16%	-16%	4%	0%	10%	11.4%	0%	21%
SS6#2	6%	3%	-11%	-16%	-6%	-13%	17%	10.3%	3%	17%
SS6#3	-1%	29%	-14%	5%	-15%	-19%	-4%	12.4%	1%	29%
SS6#4	13%	0%	13%	7%	6%	6%	4%	6.9%	0%	13%
SS6#5	1%	-6%	-13%	36%	-3%	18%	-16%	13.2%	1%	36%
SS6#6	-7%	-2%	6%	7%	14%	1%	-11%	6.9%	1%	14%
SS7#1	18%	-5%	-9%	-6%	-7%	10%	-9%	9.1%	5%	18%
SS7#2	-13%	41%	-10%	15%	4%	-3%	3%	12.6%	3%	41%
SS7#3	-12%	7%	6%	20%	-14%	-19%	-18%	13.8%	6%	20%
SS7#4	-26%	-9%	-4%	4%	19%	-18%	26%	15.0%	4%	26%
SS7#5	-5%	-14%	-1%	7%	23%	7%	6%	9.1%	1%	23%
SS7#6	11%	-10%	24%	-30%	-4%	-4%	0%	12.0%	0%	30%
SS7#7	26%	-12%	-11%	21%	-20%	20%	-7%	16.7%	7%	26%

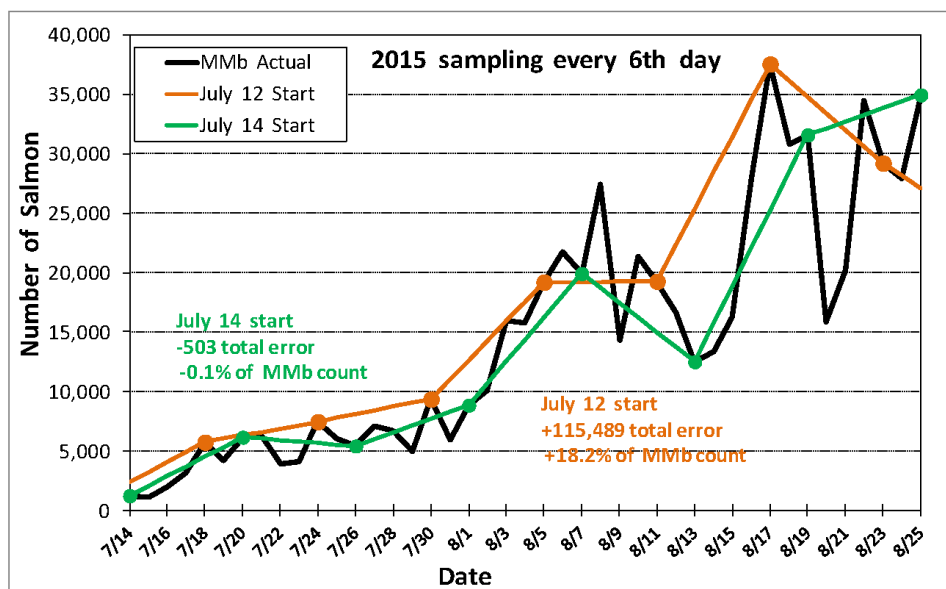


Figure 2. Comparison of MMb actual to estimates from two of the six possible starting dates for the every 6<sup>th</sup> day sub-sampling scheme. Large dots indicate MMb actual for the day for each of the sub-sampling methods.

Appendix 11B summarizes DIFF for each temporal period for each method for each year. The size of the differences are colored coded so that differences during a period that average  $\geq -1,000$  salmon/day are coded yellow, differences that average  $\geq +1,000$  salmon/day are coded orange, and differences that average  $< \pm 1,000$  salmon/day are uncolored. The last line in Appendix Table B1 shows the number of time periods that had average differences between the MMb estimates and MMb actual of  $< \pm 1,000$  salmon/day during the time period across the seven years analyzed.

Out of the 25 time periods for which there were data across the seven years, the three model-based methods (Fixed%, LB+RB, and QLK) had  $\leq 5$  periods where the average daily difference between the MMb estimate and MMb actual (DIFF/day) was within  $\pm 1,000$  salmon. The every 6<sup>th</sup> and 7<sup>th</sup> day sub-sampling schemes (SS6 and SS7) had  $\leq 10$  periods where average DIFF/day was within  $\pm 1,000$  salmon. The every 2<sup>nd</sup> day (SS2) and the SS3|4 sub-sampling schemes had the highest number of time periods where average DIFF/day was within  $\pm 1,000$  salmon (average of 15 and 13, respectively<sup>4</sup>). The other sub-sampling schemes averaged from 11 to about 12 of these periods across years).

<sup>4</sup> Average for the results for different starting days in a sub-sampling scheme.

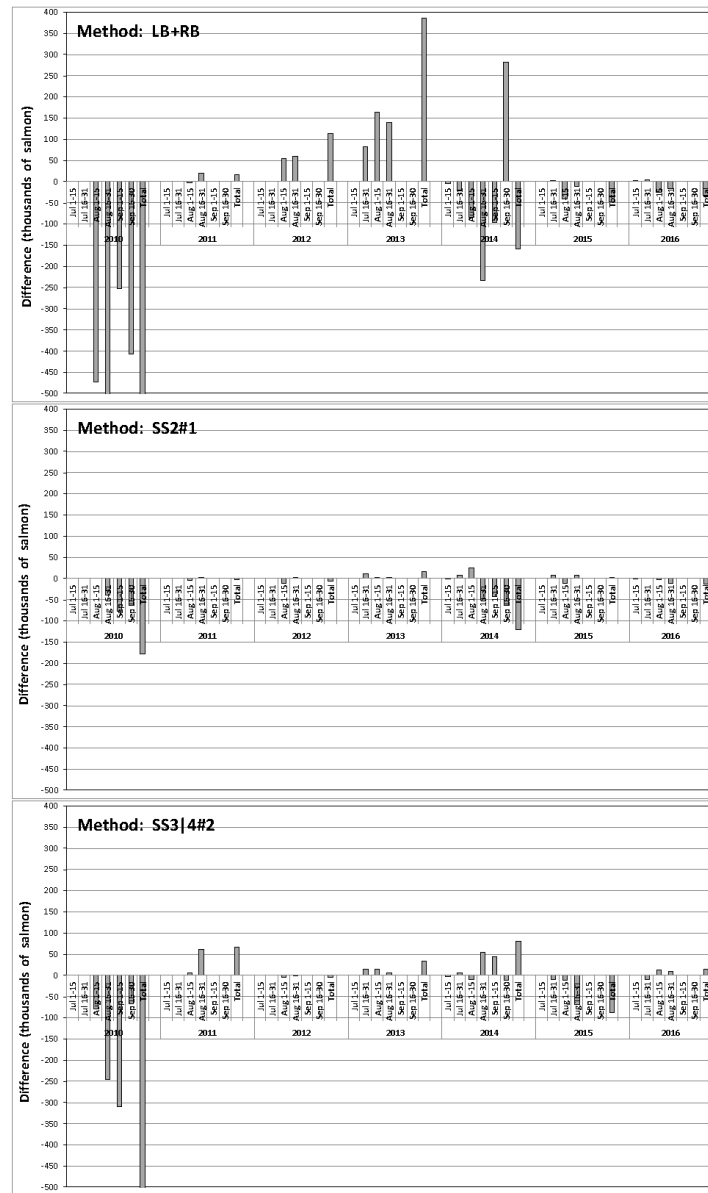


Figure 3. Comparison of differences between MMB estimates of salmon and MMB actual summarized by standard time periods for the years 2010 to 2016 for the LB+RB, SS2#1, and SS3|4#2 methods (time periods: July 1-15, July 16-31, August 1-15, August 16-31, September 1-15, September 16-30, and season total).

## Discussion

Based on the performance statistics examined, almost all the sub-sampling schemes are clearly superior to the three model-based methods examined in Appendix 10. Of the seven basic sub-sampling schemes examined, the schemes based on sampling every 2<sup>nd</sup> (SS2) or 3<sup>rd</sup> (SS3) day or sampling three consecutive days then not sampling for four days (SS3|4) generally performed better across all statistics than the other sub-sampling schemes. These three sub-sampling methods tracked daily MMB actual over each of the annual sockeye-dominant periods examined better than the model-based methods and had fewer extended stretches of days with consistent over- or under- estimates of MMB actual (see Appendix Figure C1).

As would be expected, the every 2<sup>nd</sup> day sub-sampling scheme (SS2) which has the largest number of actual MMB days of observation and the fewest number of days being estimated, was the best performing method:

- SS2 was ranked highest for all statistics except DIFF and had the highest mean ranks for both of its two possible sets of estimates based on different starting dates.
- Annual total percent differences (%DIFF) between MMB actual and the estimates from SS2 for the sockeye-dominant period ranged from <1% to 6%. For all other sub-sampling schemes except one (SS5#2), some of the annual differences were  $\geq 10\%$ .
- SS2 was the only sub-sampling scheme where consistently more than half the days in the sockeye-dominant period had relatively small differences from MMB actual (PW $\pm 5\%$  and PW $\pm 1000$  salmon).
- On average, less than 10% of the days in the sockeye dominant-period had differences from MMB actual greater than  $\pm 50\%$  (relative to MMB actual) and less than 15% of the days in the sockeye dominant-period had differences from MMB actual greater than  $\pm 5,000$  salmon.
- SS2 had the largest number of 15-16 day time periods during the 2010-2016 sockeye-dominant periods with average differences per day (relative to MMB actual)  $< \pm 1,000$  salmon/day.

The SS3 and SS3|4 sub-sampling schemes perform similarly. The SS3|4 scheme samples at a slightly higher frequency than SS3; over a four-week period, SS3|4 would collect 12 samples compared to 9 or 10 for SS3 (about 8-10% more samples per month). In general, the SS3 sub-sampling scheme performed better than SS3|4 for the two statistics based on sockeye-dominant period totals (DIFF and %DIFF). However, the SS3|4 sub-sampling scheme performed better than SS3 for the two statistics which expressed differences from MMB actual as a percentage of days with relatively small differences (PW $\pm 5\%$  and PW $\pm 1000$  salmon). These two methods were similar for the P $\geq 50\%$  and P $\geq 5000$  performance statistics. The SS3|4 sub-sampling scheme also had 12-14 time periods where the average daily difference between the MMB estimate and MMB actual (DIFF/day) was within  $\pm 1,000$  salmon compared to SS3 which had two schemes with  $\leq 10$  periods (Appendix Table B1).

Figure 4 compares the average difference per day for each time period in each year for the SS2#1, SS3#1, and SS3|4#1 sampling methods. For the SS2#1 method, greater than  $\pm 1,500$  salmon per day differences occurred only in the years with large Adams returns (2010 and 2014).

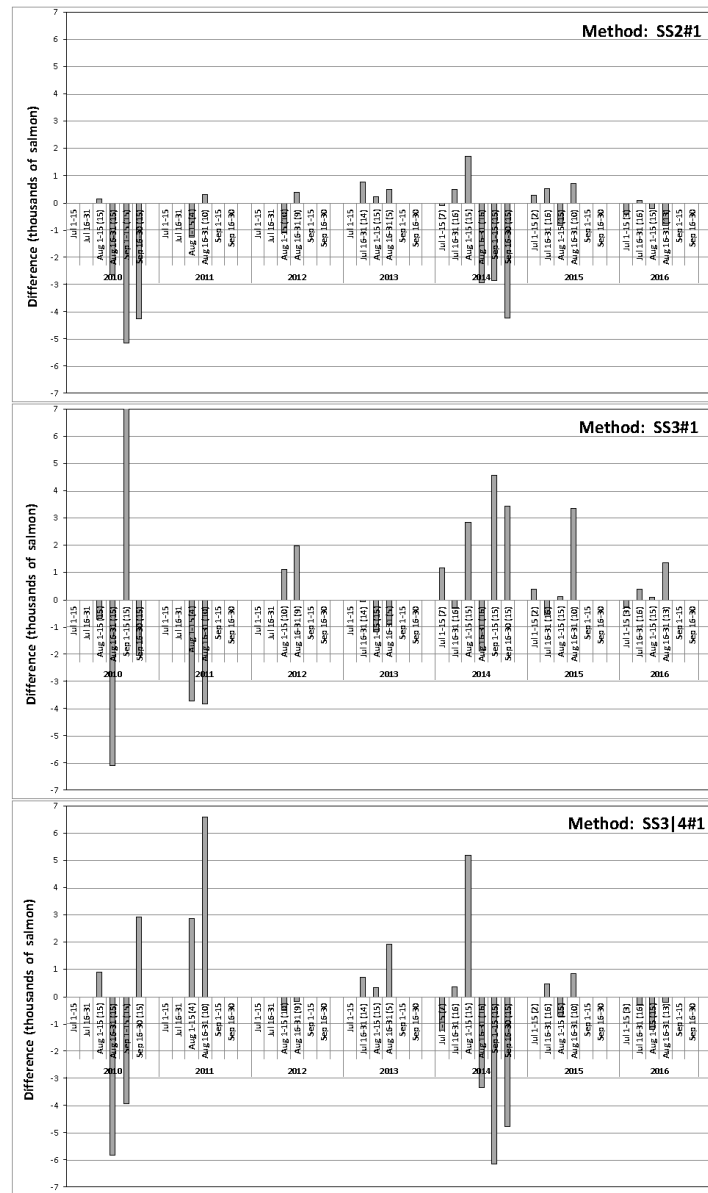


Figure 4. Comparison of average difference/day in number of salmon between MMB estimate and MMB actual summarized by standard time periods for the SS2#1, SS3#1, and SS3|4#1 methods (number in parentheses = number of days with data in the time period).

#### Potential Costs Savings, Feasibility, and Implementation Challenges:

Cost savings from a reduced mobile sampling program are primarily due to reduced staffing requirements for boat operators. The wage costs of operating the boat for 24 hours is approximately \$600. The other daily cost that would be reduced is fuel to operate the vessel, which costs approximately \$100 per 24 hours of operation. There would also be some savings in maintenance and boat capital costs (engine and parts replacements). The average annual maintenance and boat capital costs between 2014-2016 were \$12,000, however, some of these costs are fixed and would not scale relative to operating hours.

The number of sampling days included in this analysis for 2014, 2015, and 2016 were 85, 43, and 47, respectively. If we assume a savings of \$700 per day of boat operation, then the savings in operating costs by sampling every 2<sup>nd</sup> day during these years would be about \$30,00, \$15,000, and \$16,000. The savings from sampling every 3<sup>rd</sup> day would be about \$40,000, \$20,000 and \$22,000. If we optimistically assume a savings of 50% of the maintenance and capital costs, this would add another \$6,000 in savings for each year.

The analysis and savings estimated here do not include periods of pink-dominant migration during September on odd years, or periods in early July when the right bank system is not yet operational and the estimate is being produced using only the left bank split-beam and mobile split-beam. Since the pink-dominant migration is very near-shore oriented, reducing mobile sampling during this period would result in additional savings and is unlikely to have a significant effect on the Mission estimate. In 2015, there were an additional 25 days of sampling during the pink period that could be sub-sampled, which would save an additional \$8,400 if sampling every 2<sup>nd</sup> day or \$11,500 if sampling every 3<sup>rd</sup> day. During the early July period a large portion of salmon passage occurs in the offshore area, and the effect of reduced mobile sampling during this period has not been evaluated. Overall, the annual savings from reduced sampling with the mobile system could range from \$22,000 to \$45,000 depending on the cycle year and the frequency of sub-sampling, assuming sampling occurs at least every 3<sup>rd</sup> day.

From a logistics perspective, a reduced mobile sampling program should be feasible to operate. Finding reliable boat operators to work every 2<sup>nd</sup> or 3<sup>rd</sup> day may be difficult, so a sampling schedule consisting of 2 or 3 days of consecutive operation would be easier to manage. It would also be necessary to find a secure location to store the hydroacoustic equipment while it is not in use on the boat.

Though operating the boat and hydroacoustics equipment is the main role of the boat operator, they also record information on fishing activity at the Mission site and salmon mortalities observed drifting downstream. These data sets would also be affected if sub-sampling was implemented.

A consequence of using an interpolation method is that the modeled Mission mobile estimate would not be available until the next set of mobile observations were collected, which may occur up to a week later depending upon the sampling scheme. Therefore, an interim estimate of mobile passage would need to be produced until the full set of observations were available. This interim estimate would likely be more uncertain than the interpolated estimate because it would rely upon an extrapolation rather than interpolation of observations. Overall, this would likely have a small impact on uncertainty in the total Mission passage estimate. However, the most recent Mission estimates are also used to update the catchability coefficient for marine test fisheries and these estimates could be more significantly affected.

## Conclusions

For the years and time periods examined, the Mission estimates of mid-channel salmon passage (i.e., the portion of the upstream migration not assessed by the bank-oriented hydroacoustic systems at Mission) accounted for 20% to 40% of the upstream salmon migration (Table 4). Therefore, it is important that this segment of the upstream migration is estimated with reasonable accuracy and precision and minimal bias. The three sub-sampling methods discussed above seem to present feasible alternatives with varying levels of cost savings.

However, it is important to note that there would be other consequences of using a new method of estimating mid-channel passage. Any change in the method would impact the current dataset based on the difference between Mission escapement and spawning ground estimates which is used in both the MA models and RSA processes. Daily Mission passage is currently estimated using observed data for each 24-hour period, but if sub-sampling of the mobile system is implemented, a model would be used instead of observations for some portion of days for the offshore passage estimate. There would be no way to re-evaluate the predictive accuracy of this model for unobserved days once a sub-sampling plan is implemented.

Table 4. Summary of each year's percentage of the total estimated salmon passing Mission that were assessed by the Mission mobile unit (%MMb) for all days in the sockeye-dominant period (All) and for days during the sockeye-dominant period when both LB+RB data were available at Mission (Restricted).

Year	All Days %MMb	Restricted %MMb
2010	30.5%	28.9%
2011	32.0%	25.2%
2012	28.7%	22.5%
2013	20.2%	16.5%
2014	25.9%	25.7%
2015	32.3%	32.1%
2016	41.5%	41.2%
Mean	30.2%	27.4%
Minimum	20.2%	16.5%
Maximum	41.5%	41.2%

Ultimately the decision on whether a sub-sampling method could be applied to the operation of the Mission mobile hydroacoustic unit is a matter of risk tolerance by the managers. For example, while sub-sampling may be acceptable in terms of overall percentages (less than  $\approx \pm 15\%$ ) and numbers of salmon (less than  $\approx \pm 50,000$  for all years except years with large Adams returns) for the total salmon escapement past Mission estimate, it may not be acceptable when considering how these differences impact the estimates for the component stocks and the managers' ability to assess the status of stock-

specific escapement goals in season. Temporal differences (within a season) between MMB actuals and the MMB estimates were considerably smaller for the sub-sampling methods compared to the model-based methods. For the three sub-sampling methods discussed above, about half of the 15-16 day time periods examined over all years had daily differences averaging  $\leq 1,000$  salmon per day.



# Appendix 11A

Table A1. Number of days where Mission mobile passage was estimated by a model or through interpolation for each method for each year.

Method	2010	2011	2012	2013	2014	2015	2016
Fixed%	63	14	19	34	85	43	47
LB+RB	63	14	19	34	85	43	47
QLK	63	14	19	34	85	43	47
SS2#1	31	7	9	17	42	21	23
SS2#2	32	7	10	17	43	22	24
SS3#1	42	9	12	22	56	28	31
SS3#2	42	9	13	23	57	29	31
SS3#3	42	10	13	23	57	29	32
SS3 4#1	36	8	10	19	48	24	26
SS3 4#2	36	8	10	19	49	25	26
SS3 4#3	36	8	10	19	49	25	26
SS4#1	47	10	14	25	63	32	35
SS4#2	47	10	14	25	64	32	35
SS4#3	47	11	14	26	64	32	35
SS4#4	48	11	15	26	64	33	36
SS5#1	50	11	15	27	68	34	37
SS5#2	50	11	15	27	68	34	37
SS5#3	50	11	15	27	68	34	38
SS5#4	51	11	15	27	68	35	38
SS5#5	51	12	16	28	68	35	38
SS6#1	52	11	15	28	70	35	39
SS6#2	52	11	16	28	71	36	39
SS6#3	52	12	16	28	71	36	39
SS6#4	53	12	16	28	71	36	39
SS6#5	53	12	16	29	71	36	39
SS6#6	53	12	16	29	71	36	40
SS7#1	54	12	16	29	72	36	40
SS7#2	54	12	16	29	73	37	40
SS7#3	54	12	16	29	73	37	40
SS7#4	54	12	16	29	73	37	40
SS7#5	54	12	16	29	73	37	40
SS7#6	54	12	17	29	73	37	41
SS7#7	54	12	17	30	73	37	41

Table A2. Annual differences in the number of salmon estimated for the sockeye-dominant period total (MMb estimated - MMb observed). Mean, minimum, and maximum DIFF are for the absolute value of the annual statistics.

Method	2010	2011	2012	2013	2014	2015	2016	Mean	Minimum	Maximum
Fixed%	-339,130	66,790	69,711	332,450	295,198	-145,762	-170,885	202,847	66,790	339,130
LB+RB	-1,760,793	17,174	113,958	386,926	-177,333	-47,284	-33,128	362,371	17,174	1,760,793
QLK	-995,387	-109,525	88,783	326,735	-497,695	-70,361	20,720	301,315	20,720	995,387
SS2#1	-175,769	-1,942	-7,261	16,814	-120,910	3,437	-13,633	48,538	1,942	175,769
SS2#2	165,143	5,499	5,740	-11,338	118,848	-7,744	15,113	47,061	5,499	165,143
SS3#1	19,611	-53,147	28,900	-23,213	135,773	27,266	24,309	44,603	19,611	135,773
SS3#2	142,939	-2,244	-23,866	24,642	-123,817	19,246	1,145	48,271	1,145	142,939
SS3#3	-188,168	63,117	-8,572	13,714	-12,786	-55,833	-25,155	52,478	8,572	188,168
SS3 4#1	-90,497	77,585	-6,753	24,434	-141,877	-11,848	-27,509	54,358	6,753	141,877
SS3 4#2	-710,287	66,842	-4,800	34,221	75,900	-87,557	13,415	141,860	4,800	710,287
SS3 4#3	-609,742	-25,127	242	29,054	245,640	-63,107	15,762	141,239	242	609,742
SS4#1	-437,194	32,464	15,235	65,624	326,574	7,040	-7,038	127,310	7,038	437,194
SS4#2	-146,787	44,293	18,090	-11,104	129,108	-33,216	-8,764	55,909	8,764	146,787
SS4#3	86,568	-26,109	-30,212	-23,436	-568,342	-6,248	-18,008	108,418	6,248	568,342
SS4#4	468,350	-38,653	-7,599	-1,515	115,187	16,312	33,670	97,327	1,515	468,350
SS5#1	2,921	-5,677	-1,373	54,531	196,809	29,271	-35,332	46,559	1,373	196,809
SS5#2	-162,007	-26,538	-9,368	21,592	42,468	-35,297	-948	42,603	948	162,007
SS5#3	-186,848	-42,069	6,113	12,244	-380,060	-68,189	-20,358	102,269	6,113	380,060
SS5#4	104,785	81,833	-8,652	-38,920	-18,458	-20,261	4,939	39,693	4,939	104,785
SS5#5	222,978	7,727	7,292	-97	163,259	66,587	50,669	74,087	97	222,978
SS6#1	-502,366	-97,936	30,509	-50,239	113,574	-503	32,961	118,298	503	502,366
SS6#2	255,581	13,125	-21,812	-47,482	-171,503	-83,371	56,342	92,745	13,125	255,581
SS6#3	-33,153	135,662	-26,458	16,805	-404,046	-117,802	-13,184	106,730	13,184	404,046
SS6#4	560,973	-235	24,661	19,987	152,178	40,771	12,381	115,884	235	560,973
SS6#5	31,636	-29,011	-24,875	108,877	-68,657	115,489	-53,776	61,760	24,875	115,489
SS6#6	-309,904	-9,119	11,282	22,261	385,336	6,574	-34,919	111,342	6,574	385,336
SS7#1	770,333	-21,368	-16,610	-17,068	-189,552	62,667	-30,722	158,331	16,610	770,333
SS7#2	-528,844	187,592	-19,330	46,390	104,953	-16,032	10,023	130,452	10,023	528,844
SS7#3	-521,835	31,357	12,277	61,515	-366,185	-121,117	-59,626	167,702	12,277	521,835
SS7#4	-1,070,166	-42,050	-7,266	11,834	494,589	-114,292	85,268	260,781	7,266	1,070,166
SS7#5	-199,817	-65,481	-2,840	22,472	608,290	41,744	20,773	137,345	2,840	608,290
SS7#6	475,535	-46,195	47,537	-90,600	-110,249	-25,267	-803	113,741	803	475,535
SS7#7	1,105,649	-53,608	-21,630	63,306	-533,642	126,276	-23,526	275,377	21,630	1,105,649

Table A3. Annual percentage of days in the sockeye-dominant period where the difference between the daily estimate of  $\widehat{MMb}_i$  and the observed MMb was within  $\pm 5\%$  of the observed MMb ( $PW \pm 5\%$ ).

Method	2010	2011	2012	2013	2014	2015	2016	Mean	Minimum	Maximum
Fixed%	5%	7%	0%	0%	7%	5%	0%	3.4%	0%	7%
LB+RB	5%	14%	0%	6%	14%	5%	19%	9.0%	0%	19%
QLK	6%	14%	5%	6%	17%	5%	13%	9.4%	5%	17%
SS2#1	57%	57%	58%	62%	59%	56%	57%	58.0%	56%	62%
SS2#2	56%	57%	47%	56%	61%	54%	51%	54.5%	47%	61%
SS3#1	40%	57%	37%	35%	44%	40%	36%	41.2%	35%	57%
SS3#2	44%	36%	37%	47%	41%	51%	40%	42.4%	36%	51%
SS3#3	41%	36%	32%	41%	44%	40%	38%	38.7%	32%	44%
SS3 4#1	52%	43%	63%	47%	51%	47%	49%	50.2%	43%	63%
SS3 4#2	52%	43%	58%	53%	46%	47%	49%	49.6%	43%	58%
SS3 4#3	51%	50%	47%	50%	47%	51%	53%	50.0%	47%	53%
SS4#1	37%	43%	32%	29%	33%	28%	32%	33.3%	28%	43%
SS4#2	41%	29%	26%	35%	31%	40%	34%	33.7%	26%	41%
SS4#3	37%	21%	32%	27%	31%	33%	34%	30.5%	21%	37%
SS4#4	32%	36%	37%	32%	32%	37%	26%	33.0%	26%	37%
SS5#1	30%	21%	32%	27%	34%	35%	30%	29.8%	21%	35%
SS5#2	27%	29%	21%	24%	29%	33%	28%	27.1%	21%	33%
SS5#3	24%	29%	21%	29%	26%	30%	23%	26.1%	21%	30%
SS5#4	29%	21%	26%	21%	29%	23%	28%	25.3%	21%	29%
SS5#5	37%	29%	21%	21%	27%	21%	28%	26.1%	21%	37%
SS6#1	19%	29%	26%	21%	26%	26%	23%	24.2%	19%	29%
SS6#2	24%	29%	21%	24%	33%	26%	19%	24.9%	19%	33%
SS6#3	27%	14%	26%	27%	25%	21%	28%	23.9%	14%	28%
SS6#4	29%	29%	26%	21%	24%	23%	28%	25.5%	21%	29%
SS6#5	30%	29%	26%	21%	24%	28%	26%	26.1%	21%	30%
SS6#6	30%	29%	21%	24%	20%	30%	21%	25.0%	20%	30%
SS7#1	27%	36%	21%	27%	26%	26%	23%	26.5%	21%	36%
SS7#2	24%	14%	21%	27%	24%	26%	26%	22.9%	14%	27%
SS7#3	30%	21%	21%	27%	21%	28%	26%	24.8%	21%	30%
SS7#4	24%	29%	26%	18%	20%	23%	15%	22.1%	15%	29%
SS7#5	24%	29%	26%	15%	20%	21%	19%	21.9%	15%	29%
SS7#6	19%	21%	21%	18%	24%	19%	17%	19.7%	17%	24%
SS7#7	16%	14%	32%	15%	24%	21%	21%	20.3%	14%	32%

Table A4. Annual percentage of days in the sockeye-dominant period where the difference between the daily estimate of  $\widehat{MMb}_i$  and the observed MMb was  $\geq \pm 50\%$  of the observed MMb ( $P \geq 50\%$ ).

Method	2010	2011	2012	2013	2014	2015	2016	Mean	Minimum	Maximum
Fixed%	35%	43%	53%	65%	60%	33%	55%	49.0%	33%	65%
LB+RB	38%	21%	63%	71%	55%	9%	6%	37.8%	6%	71%
QLK	19%	0%	63%	74%	45%	7%	17%	32.1%	0%	74%
SS2#1	2%	0%	5%	12%	24%	7%	9%	8.2%	0%	24%
SS2#2	8%	0%	11%	9%	22%	2%	11%	8.9%	0%	22%
SS3#1	6%	0%	21%	9%	34%	7%	13%	12.9%	0%	34%
SS3#2	14%	0%	5%	15%	38%	12%	13%	13.8%	0%	38%
SS3#3	11%	7%	11%	18%	33%	2%	13%	13.5%	2%	33%
SS3 4#1	10%	14%	5%	18%	37%	5%	2%	12.9%	2%	37%
SS3 4#2	6%	7%	0%	29%	35%	2%	13%	13.3%	0%	35%
SS3 4#3	6%	7%	16%	24%	32%	9%	11%	14.9%	6%	32%
SS4#1	13%	7%	21%	24%	45%	14%	11%	19.1%	7%	45%
SS4#2	18%	7%	21%	12%	42%	9%	11%	17.1%	7%	42%
SS4#3	13%	0%	5%	15%	41%	12%	11%	13.7%	0%	41%
SS4#4	18%	0%	0%	24%	40%	14%	21%	16.6%	0%	40%
SS5#1	16%	0%	5%	21%	42%	14%	21%	17.1%	0%	42%
SS5#2	22%	7%	11%	24%	46%	12%	15%	19.4%	7%	46%
SS5#3	18%	0%	32%	21%	42%	7%	15%	19.1%	0%	42%
SS5#4	13%	14%	16%	18%	44%	14%	17%	19.3%	13%	44%
SS5#5	14%	7%	5%	38%	45%	21%	19%	21.4%	5%	45%
SS6#1	27%	7%	32%	15%	53%	9%	21%	23.4%	7%	53%
SS6#2	24%	7%	21%	24%	38%	19%	28%	22.8%	7%	38%
SS6#3	16%	29%	5%	18%	38%	12%	11%	18.2%	5%	38%
SS6#4	19%	7%	16%	21%	48%	16%	15%	20.3%	7%	48%
SS6#5	16%	0%	5%	50%	53%	30%	6%	23.0%	0%	53%
SS6#6	13%	7%	32%	27%	51%	12%	19%	22.7%	7%	51%
SS7#1	24%	0%	5%	21%	49%	23%	13%	19.3%	0%	49%
SS7#2	13%	43%	5%	29%	51%	14%	15%	24.3%	5%	51%
SS7#3	14%	7%	21%	29%	52%	19%	4%	20.9%	4%	52%
SS7#4	14%	0%	26%	24%	45%	12%	32%	21.8%	0%	45%
SS7#5	13%	7%	21%	35%	48%	23%	13%	22.9%	7%	48%
SS7#6	24%	14%	42%	15%	46%	14%	17%	24.5%	14%	46%
SS7#7	43%	7%	16%	38%	49%	33%	21%	29.6%	7%	49%

Table A5. Annual percentage of days in the sockeye-dominant period where the difference between the daily estimate of  $\widehat{MMb}_i$  and the observed MMb was within  $\pm 1000$  salmon of the observed MMb (PW $\pm 1000$ ).

Method	2010	2011	2012	2013	2014	2015	2016	Mean	Minimum	Maximum
Fixed%	0%	7%	16%	15%	5%	16%	9%	9.6%	0%	16%
LB+RB	2%	14%	5%	9%	8%	19%	51%	15.4%	2%	51%
QLK	2%	7%	5%	6%	11%	16%	40%	12.5%	2%	40%
SS2#1	56%	57%	79%	74%	58%	63%	72%	65.4%	56%	79%
SS2#2	52%	57%	63%	59%	57%	65%	66%	59.9%	52%	66%
SS3#1	38%	50%	47%	53%	45%	51%	51%	47.9%	38%	53%
SS3#2	37%	36%	63%	62%	37%	58%	62%	50.5%	36%	63%
SS3#3	38%	29%	58%	44%	42%	54%	55%	45.7%	29%	58%
SS3 4#1	44%	43%	79%	62%	48%	56%	66%	56.9%	43%	79%
SS3 4#2	46%	43%	68%	62%	45%	61%	66%	55.8%	43%	68%
SS3 4#3	48%	43%	53%	56%	45%	61%	68%	53.2%	43%	68%
SS4#1	33%	36%	47%	38%	32%	37%	43%	38.0%	32%	47%
SS4#2	27%	29%	37%	53%	28%	56%	45%	39.1%	27%	56%
SS4#3	32%	21%	58%	38%	31%	42%	53%	39.3%	21%	58%
SS4#4	29%	21%	58%	44%	29%	49%	40%	38.7%	21%	58%
SS5#1	24%	21%	58%	41%	31%	40%	38%	36.1%	21%	58%
SS5#2	21%	21%	47%	41%	26%	40%	43%	34.1%	21%	47%
SS5#3	22%	29%	32%	41%	26%	47%	45%	34.4%	22%	47%
SS5#4	21%	21%	53%	41%	28%	37%	49%	35.7%	21%	53%
SS5#5	30%	21%	42%	24%	27%	30%	45%	31.3%	21%	45%
SS6#1	19%	29%	32%	44%	21%	35%	34%	30.5%	19%	44%
SS6#2	21%	21%	42%	38%	31%	47%	36%	33.7%	21%	47%
SS6#3	22%	14%	53%	35%	27%	37%	47%	33.6%	14%	53%
SS6#4	21%	21%	42%	38%	25%	33%	51%	33.0%	21%	51%
SS6#5	21%	21%	63%	27%	18%	28%	43%	31.4%	18%	63%
SS6#6	24%	14%	26%	41%	19%	42%	38%	29.2%	14%	42%
SS7#1	14%	36%	63%	44%	27%	42%	43%	38.4%	14%	63%
SS7#2	19%	14%	53%	44%	19%	30%	47%	32.3%	14%	53%
SS7#3	18%	14%	32%	38%	20%	40%	43%	29.1%	14%	43%
SS7#4	22%	29%	42%	27%	22%	33%	38%	30.4%	22%	42%
SS7#5	18%	14%	32%	21%	21%	28%	40%	24.8%	14%	40%
SS7#6	14%	14%	21%	35%	21%	37%	36%	25.7%	14%	37%
SS7#7	14%	14%	37%	27%	21%	33%	47%	27.5%	14%	47%

Table A6. Annual percentage of days in the sockeye-dominant period where the difference between the daily estimate of  $\widehat{MMb}_i$  and the observed MMB was  $\geq \pm 5,000$  salmon ( $P \geq 5000$ ).

Method	2010	2011	2012	2013	2014	2015	2016	Mean	Minimum	Maximum
Fixed%	92%	86%	32%	59%	33%	37%	28%	52.3%	28%	92%
LB+RB	87%	79%	53%	65%	18%	26%	2%	46.9%	2%	87%
QLK	84%	57%	63%	56%	20%	26%	2%	44.0%	2%	84%
SS2#1	40%	29%	5%	3%	4%	7%	6%	13.3%	3%	40%
SS2#2	40%	29%	5%	12%	7%	9%	2%	14.8%	2%	40%
SS3#1	56%	21%	5%	6%	15%	19%	0%	17.4%	0%	56%
SS3#2	52%	36%	11%	6%	9%	12%	9%	19.1%	6%	52%
SS3#3	54%	57%	5%	15%	9%	16%	6%	23.3%	5%	57%
SS3 4#1	43%	50%	5%	9%	21%	12%	6%	20.9%	5%	50%
SS3 4#2	43%	50%	0%	15%	12%	16%	0%	19.4%	0%	50%
SS3 4#3	43%	36%	0%	6%	17%	16%	0%	16.8%	0%	43%
SS4#1	59%	29%	5%	15%	19%	21%	6%	21.9%	5%	59%
SS4#2	54%	50%	11%	15%	19%	21%	4%	24.7%	4%	54%
SS4#3	57%	57%	11%	12%	15%	16%	6%	24.9%	6%	57%
SS4#4	64%	43%	0%	12%	12%	16%	4%	21.5%	0%	64%
SS5#1	64%	50%	11%	18%	18%	14%	4%	25.4%	4%	64%
SS5#2	70%	64%	0%	15%	14%	26%	6%	27.8%	0%	70%
SS5#3	67%	64%	11%	9%	8%	19%	6%	26.2%	6%	67%
SS5#4	59%	64%	11%	15%	21%	28%	2%	28.5%	2%	64%
SS5#5	62%	36%	5%	18%	20%	21%	11%	24.6%	5%	62%
SS6#1	75%	57%	16%	12%	26%	16%	11%	30.3%	11%	75%
SS6#2	70%	64%	11%	18%	12%	21%	4%	28.5%	4%	70%
SS6#3	70%	86%	11%	12%	14%	28%	6%	32.3%	6%	86%
SS6#4	65%	36%	11%	9%	24%	23%	13%	25.7%	9%	65%
SS6#5	60%	50%	11%	24%	22%	26%	6%	28.4%	6%	60%
SS6#6	65%	57%	0%	18%	27%	21%	4%	27.4%	0%	65%
SS7#1	70%	57%	11%	18%	31%	19%	9%	30.4%	9%	70%
SS7#2	62%	86%	11%	18%	29%	21%	2%	32.6%	2%	86%
SS7#3	65%	57%	5%	18%	17%	23%	9%	27.6%	5%	65%
SS7#4	71%	50%	11%	9%	31%	19%	23%	30.5%	9%	71%
SS7#5	68%	57%	0%	18%	22%	19%	6%	27.2%	0%	68%
SS7#6	73%	64%	26%	24%	20%	33%	4%	34.9%	4%	73%
SS7#7	83%	50%	5%	29%	22%	28%	6%	32.0%	5%	83%

# Appendix 11B

Table B1. Differences in the number of salmon estimated for time periods within the sockeye-dominant period (MMb estimated - MMb observed), 2010-2016. The number of days in the time period for which there were data are in the column labeled "n". The differences during a period are color coded so that differences which average  $\geq -1,000$  salmon/day are coded yellow and differences that average  $\geq +1,000$  salmon/day are coded orange, and differences during a period that average  $\geq \pm 1,000$  salmon/day are uncolored.

n	Year	Estimation Period			METHOD																	
		Fixed%	LB+RB	QLK	S\$2#1	S\$2#2	S\$3#1	S\$3#2	S\$3#3	S\$3#4#1	S\$3#4#2	S\$3#4#3	S\$4#1	S\$4#2	S\$4#3	S\$4#4	S\$5#1	S\$5#2	S\$5#3	S\$5#4	S\$5#5	
15	2010	Jul 1-15																				
		Jul 16-31																				
		Aug 1-15	-338,672	-472,251	-207,206	1,971	-16,647	-10,499	59,486	-95,805	13,618	-79,676	-137,144	-103,856	83,766	111,068	-157,539	14,944	167,608	-227,336	-15,918	-12,485
		Aug 16-31	-231,919	-516,331	-308,610	-39,294	36,404	-91,634	61,485	19,752	-87,385	-244,938	-262,910	16,669	-241,082	-130,585	320,838	-50,498	-58,983	16,411	46,105	-7,936
		Sep 1-15	390,824	-253,025	-38,466	-77,328	90,122	156,864	-7,547	-107,225	-58,959	-309,656	-163,725	-212,628	20,573	97,242	176,244	-7,244	380,371	98,878	181,253	226,750
15	2010	Sep 16-30	-40,800	-407,460	-306,548	-63,684	62,659	-30,621	35,749	-8,788	43,541	-67,522	-38,354	-132,879	-5,403	5,612	134,832	50,212	111,733	-81,516	-97,569	22,677
Total		-220,566	-1,649,067	-860,830	-178,335	170,577	24,109	149,174	-192,067	-89,185	-701,791	-602,132	-432,695	-142,147	83,336	474,375	7,414	-160,013	-194,462	113,871	229,006	
4	2011	Jul 1-15																				
		Jul 16-31																				
		Aug 1-15	496	-2,593	-16,295	-5,060	10,577	-14,897	20,054	7,389	11,501	5,232	-2,840	-8,912	29,577	5,619	-4,330	2,333	26,908	7,246	-4,330	7,171
		Aug 16-31	66,294	19,767	-93,229	3,118	-5,078	-38,252	-22,298	95,729	66,085	61,611	-22,288	41,376	14,716	-31,727	-34,321	-8,011	-53,445	-49,315	66,164	956
		Sep 1-15																				
10	2011	Sep 16-30																				
Total		66,790	17,174	-109,524	-1,943	5,499	-53,148	-2,444	63,116	77,586	66,844	-25,128	32,464	44,294	-26,108	-38,651	-5,678	-26,537	-42,069	81,834	7,727	
10	2012	Jul 1-15																				
		Jul 16-31																				
		Aug 1-15	37,638	55,464	36,277	-130,682	4,983	11,188	-15,327	-8,302	-5,199	-4,320	-2,788	-3,344	12,768	-20,547	-7,220	7,360	-11,101	-20,431	-4,165	1,594
		Aug 16-31	32,075	58,495	52,507	3,421	756	17,712	-8,537	-270	-1,553	-479	3,029	18,579	5,321	-9,666	-380	-8,734	1,732	26,545	-4,488	5,697
		Sep 1-15																				
19	2012	Sep 16-30																				
Total		69,713	113,959	88,784	-7,261	5,739	28,900	-23,865	-8,572	-6,752	-4,799	241	15,235	18,090	-30,212	-7,599	-1,373	-9,369	6,114	-8,653	7,291	
14	2013	Jul 1-15																				
		Jul 16-31	42,017	81,804	58,972	10,760	-7,145	-1,022	15,164	-2,071	9,956	14,751	21,636	16,516	-11,189	13,860	7,310	3,305	12,849	-1,726	-2,303	33,850
		Aug 1-15	141,929	164,564	148,417	9,505	-4,568	-17,678	4,222	6,857	4,861	13,923	3,453	41,799	-2,209	-41,171	-15,142	46,075	5,272	4,369	-35,962	-50,882
		Aug 16-31	148,502	140,557	119,347	2,549	373	-4,514	5,256	8,931	9,617	5,546	3,966	7,311	2,296	3,874	6,317	5,150	3,470	9,602	-658	16,938
		Sep 1-15																				
34	2013	Sep 16-30																				
Total		332,448	386,926	326,735	16,815	-11,340	-23,213	24,642	13,716	24,434	34,220	29,054	65,626	-11,102	-29,437	-1,514	54,530	21,592	12,245	-30,922	-95	
7	2014	Jul 1-15	-20,589	-4,968	10,637	-582	597	8,190	-5,675	-1,616	-8,507	-2,859	-619	-7,274	-5,534	5,727	8,922	-3,373	3,171	-120	6,494	-4,753
		Jul 16-31	-60,009	-21,385	-30,482	7,570	-5,043	-5,325	6,336	1,690	5,830	6,248	1,495	-12,006	-2,292	34,998	-10,752	7,180	-19,112	17,698	-2,177	16,958
		Aug 1-15	-53,140	-84,847	-89,476	25,364	-26,593	42,768	-41,889	-12,987	77,888	-9,168	77,741	149,579	87,478	-129,776	-9,664	37,802	62,293	42,395	1,880	64,085
		Aug 16-31	-114,464	-232,207	-225,001	-47,083	13,326	-30,117	26,904	-69,987	63,265	54,407	165,663	84,024	12,367	-182,174	-95,139	19,950	-87,041	-100,265	4,259	-9,229
		Sep 1-15	-39,812	-96,936	-145,650	-42,722	92,584	68,730	-79,164	126,651	-92,074	44,435	203,965	167,879	120,376	-216,935	131,843	195,063	36,109	-116,639	-64,339	265,385
15	2014	Sep 16-30	624,749	282,038	355	-63,458	55,143	51,529	-28,285	-48,433	-21,742	-12,618	-41,164	-55,627	47,075	-73,118	37,455	-32,652	52,461	-111,137	43,594	-31,405
Total		315,934	-158,804	-479,790	-120,910	127,023	135,774	-116,753	-4,608	-141,875	80,466	251,499	326,574	134,523	-561,279	123,964	203,179	47,881	-372,598	-10,280	163,259	
2	2015	Jul 1-15	-1,254	805	3,185	518	69	791	69	1,174	0	553	2,832	1,294	69	1,174	1,952	766	69	1,174	1,952	3,300
		Jul 16-31	-37,639	3,117	5,541	8,423	-7,390	-8,947	20,830	-10,206	-5,861	-9,495	1,925	5,737	-10,569	11,022	-2,277	2,311	13,407	-6,106	-3,892	2,272
		Aug 1-15	-60,264	-40,549	-20,254	-12,658	17,095	1,851	23,116	-8,267	3,194	-10,434	3,636	11,527	37,583	-21,305	4,944	30,964	-36,744	10,807	34,990	11,466
		Aug 16-31	-16,607	-10,655	-56,835	7,156	-17,519	33,571	-24,767	-30,535	-9,181	-68,181	-71,500	-11,516	-60,300	2,857	11,691	-4,769	-12,029	-74,064	-53,313	49,548
		Sep 1-15																				
43	2015	Sep 16-30																				
Total		-145,765	-47,282	-70,363	3,439	-7,744	27,266	19,248	-55,834	-11,849	-87,557	-63,107	7,042	-39,217	-6,252	16,310	29,272	-35,296	-68,189	-20,263	66,586	
16	2016	Jul 1-15	-2,922	3,395	-1,335	-1,239	1,579	-778	1,249	-1,019	0	653	-651	-1,927	887	-1,019	-217	-3,091	1,593	-1,019	-217	-1,944
		Jul 16-31	-40,524	4,864	12,393	1,463	-254	6,053	5,014	-9,063	1,081	-9,124	-8,759	-5,699	-6,712	5,931	9,092	-21,713	-4,858	7,011	9,152	13,518
		Aug 1-15	-74,368	-25,486	-4,420	-3,005	115	1,300	14,895	-21,962	-20,846	12,321	16,220	5,497	-11,800	-10,869	7,835	-18,182	-5,682	-2,675	-18,806	31,031
		Aug 16-31	-53,071	-15,898	14,080	-10,851	13,672	17,736	-20,011	6,889	-7,745	9,565	8,950	-4,910	8,859	-12,052	16,961	7,653	8,000	-23,677	14,810	8,064
		Sep 1-15																				
47	2016	Sep 16-30																				
Total		-170,884	-33,126	20,719	-13,632	15,113	24,310	1,147	-25,155	-27,509	13,416	15,760	-7,038	-8,765	-18,008	33,671	-35,332	-947	-20,359	4,939	50,669	
# periods w/ $\geq 1,000$ salmon/day difference		3	5	5	16	14	10	9	14	13	14	12	9	14	11	11	13	11	9	12	12	

- continued -

Table B1. Differences in the number of salmon estimated for time periods within the sockeye-dominant period (MMb estimated - MMb observed), 2010-2016. The number of days in the time period for which there were data are in the column labeled "n". The differences during a period are color coded so that differences which average  $\geq -1,000$  salmon/day are coded yellow and differences that average  $\geq +1,000$  salmon/day are coded orange, and differences during a period that average  $< \pm 1,000$  salmon/day are uncolored (continued).

		Estimation						METHOD							
n	Year	Period	SS6#1	SS6#2	SS6#3	SS6#4	SS6#5	SS6#6	SS7#1	SS7#2	SS7#3	SS7#4	SS7#5	SS7#6	SS7#7
	2010	Jul 1-15													
		Jul 16-31													
15		Aug 1-15	142,443	142,038	-59,665	-126,045	-43,805	-119,944	89,339	16,178	-101,718	-142,271	-124,353	-165,635	387,768
15		Aug 16-31	-430,688	122,024	241,745	187,607	-11,660	-181,916	54,905	-193,034	-129,623	-444,017	-251,029	323,804	553,639
15		Sep 1-15	-173,141	-177,413	-203,112	481,850	206,945	15,083	486,342	-296,915	-307,832	-300,927	143,829	311,008	130,469
15	Sep 16-30	-36,481	167,805	-26,873	20,719	-110,758	-17,101	131,430	-51,913	26,422	-176,925	36,233	7,561	10,422	
60		Total	-497,867	254,454	-47,905	564,131	40,722	-303,879	762,016	-525,684	-512,751	-1,064,140	-195,321	476,739	1,082,298
	2011	Jul 1-15													
		Jul 16-31													
4		Aug 1-15	-4,142	31,853	11,158	-4,330	7,171	25,470	2,761	42,655	7,781	-4,330	7,171	25,470	18,581
10		Aug 16-31	-93,795	-18,728	124,503	4,097	-36,182	-34,588	-24,130	144,936	23,576	-37,719	-72,652	-71,665	-72,190
		Sep 1-15													
14	Sep 16-30														
	Total	-97,936	13,125	135,661	-234	-29,011	-9,118	-21,369	187,591	31,357	-42,049	-65,481	-46,195	-53,609	
	2012	Jul 1-15													
		Jul 16-31													
10		Aug 1-15	1,280	-18,888	-21,678	15,798	-16,977	2,888	-10,862	-15,341	-1,223	-5,076	-9,973	10,254	-19,849
9		Aug 16-31	29,227	-2,924	-4,780	8,862	-7,900	8,395	-5,748	-3,987	13,500	-2,192	7,133	37,284	-1,782
		Sep 1-15													
	Sep 16-30														
19	Total	30,507	-21,812	-26,459	24,660	-24,876	11,283	-16,610	-19,328	12,277	-7,268	-2,840	47,538	-21,632	
	2013	Jul 1-15													
14		Jul 16-31	-2,635	-8,714	4,596	16,143	56,165	1,388	-5,340	14,169	23,052	20,280	39,640	-8,350	8,897
15		Aug 1-15	-52,114	-45,528	6,889	1,939	35,806	3,934	-28,637	13,423	33,545	-13,723	-28,325	-77,693	31,698
5		Aug 16-31	4,510	6,759	5,323	1,906	16,907	16,938	16,907	18,798	4,917	5,276	11,158	-4,557	22,711
		Sep 1-15													
	Sep 16-30														
34	Total	-50,239	-47,484	16,809	19,987	108,877	22,260	-17,070	46,390	61,514	11,834	22,474	-90,600	63,306	
7	2014	Jul 1-15	6,129	-4,196	-4,300	4,955	-2,097	1,445	-1,970	-9,822	-7,174	8,932	-4,456	1,758	14,318
16		Jul 16-31	18,372	11,539	18,249	-12,719	6,938	-7,834	36,149	8,480	-30,047	40,304	-8,892	356	7,435
15		Aug 1-15	100,313	-68,136	-85,086	-44,759	3,638	27,265	164,802	160,838	-102,219	-96,840	-30,861	-41,602	-145,834
16		Aug 16-31	-202,802	-125,358	-79,077	134,131	111,865	-68,843	-164,095	-66,907	66,786	124,055	238,647	-126,915	-356,193
15		Sep 1-15	222,820	13,572	-142,066	-27,650	-109,407	470,587	-82,428	-21,527	-152,633	395,078	474,466	21,511	75,395
15		Sep 16-30	-31,257	6,593	-105,394	103,631	-72,528	-29,106	-142,011	36,731	-135,384	29,435	-55,198	41,708	30,206
84	Total	113,575	-165,985	-397,675	157,588	-61,591	393,515	-189,554	107,793	-360,671	500,963	613,706	-103,185	-525,463	
2	2015	Jul 1-15	988	69	1,174	1,952	3,300	2,124	894	69	1,174	1,952	3,300	2,124	2,758
16		Jul 16-31	4,270	10,203	-5,564	-17,600	29,323	-6,740	12,222	-21,934	-3,623	2,747	12,249	-2,717	23,519
15		Aug 1-15	-23,847	17,183	-26,657	37,546	49,933	14,806	20,567	9,905	-7,155	-27,531	39,548	-18,428	66,315
10		Aug 16-31	18,088	-110,825	-86,757	18,875	32,932	-3,616	28,983	-4,071	-111,512	-91,462	-13,355	-6,247	33,684
		Sep 1-15													
	Sep 16-30														
43	Total	-501	-83,370	-117,803	40,772	115,487	6,573	62,664	-16,031	-121,115	-114,294	41,743	-25,268	126,276	
3	2016	Jul 1-15	-1,558	1,692	-1,019	-217	-1,944	-3,885	-1,417	1,435	-1,019	-217	-1,944	-3,885	-1,315
16		Jul 16-31	11,576	28,631	1,237	-3,724	-14,454	-20,664	16,569	-2,827	-10,508	-13,066	-4,510	7,522	9,051
15		Aug 1-15	29,006	33,207	-22,579	-23,828	-14,488	-20,827	-33,560	-1,621	-25,989	58,704	11,361	3,009	-37,229
13		Aug 16-31	-6,060	-7,186	9,174	40,152	-22,891	10,458	-12,316	13,036	-22,113	39,847	15,866	-7,448	5,967
		Sep 1-15													
	Sep 16-30														
47	Total	32,963	56,344	-13,186	12,383	-53,777	-34,918	-30,724	10,022	-59,629	85,269	20,772	-802	-23,526	
# periods w/ $\pm 1,000$ salmon/day difference			9	10	9	9	8	10	8	9	7	7	8	10	7



# Appendix 11B

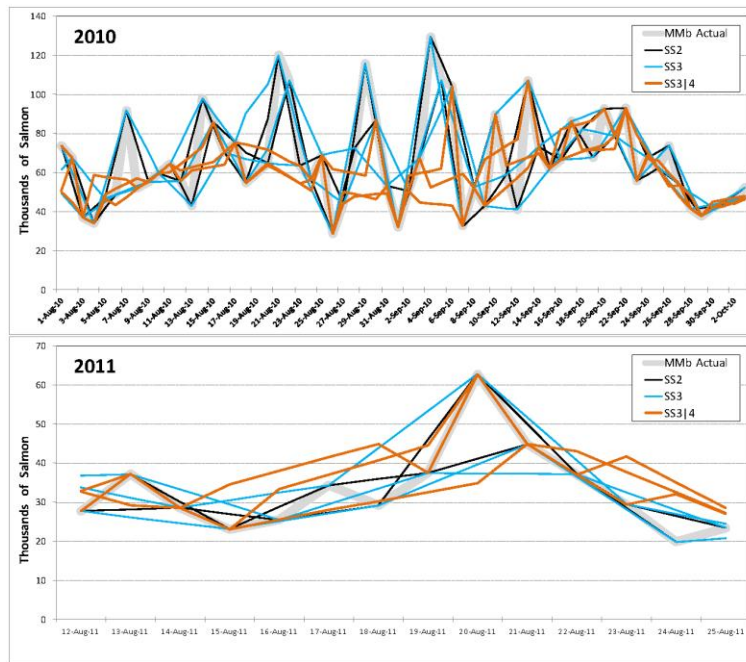


Figure C1. Comparison of daily MMB actual to estimates from the SS2, SS3, and SS3|4 methods (continued).

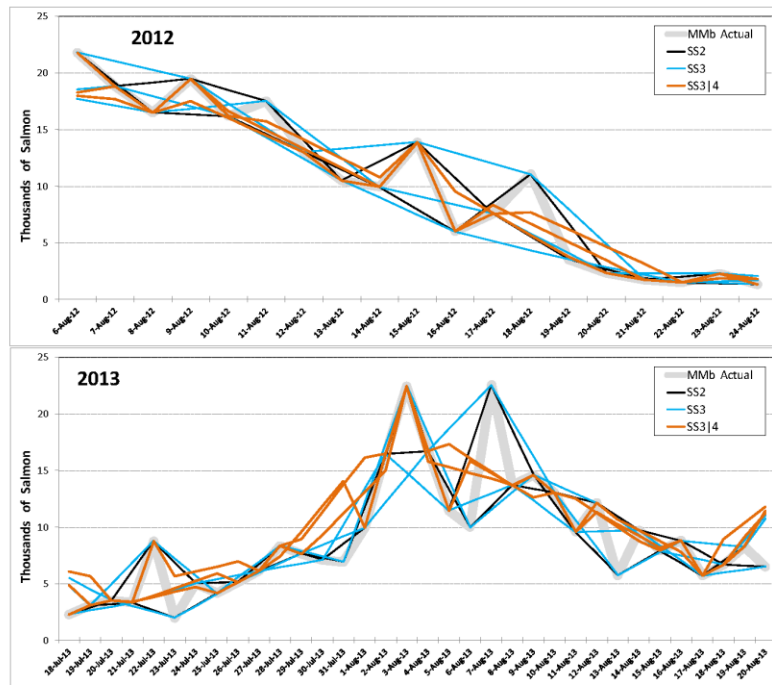


Figure C1. Comparison of daily MMB actual to estimates from the SS2, SS3, and SS3|4 methods (continued).

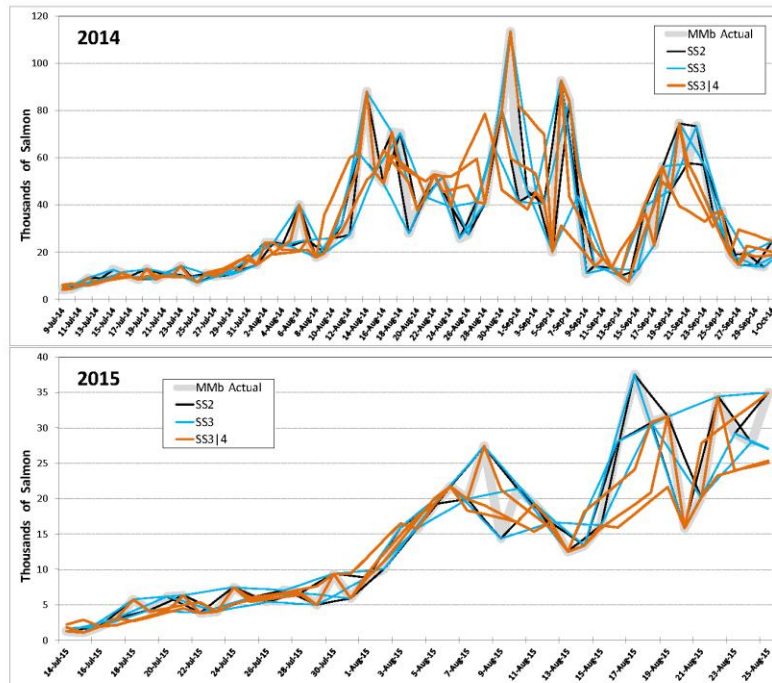


Figure C1. Comparison of daily MMB actual to estimates from the SS2, SS3, and SS3|4 methods (continued).

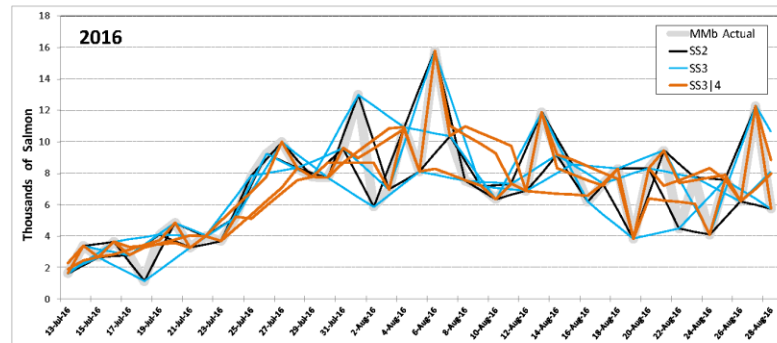


Figure C1. Comparison of daily MMb actual to estimates from the SS2, SS3, and SS3|4 methods.

## Appendix 13: Sockeye Stocks assessed at Mission and Qualark

Summary of Fraser sockeye potential spawning escapement assessed by each site**									
	2008	2009*	2010	2011*	2012	2013*	2014	2015*	Average
<b>Proportion of potential spawning escapement</b>									
Mission	98%	97%	100%	99%	93%	91%	99%	94%	96%
Qualark	90%	75%	94%	63%	70%	78%	93%	83%	81%
Difference	8%	21%	6%	35%	23%	13%	6%	11%	16%
<b>Number of sockeye</b>									
Mission	1,247,686	885,804	13,582,744	1,981,234	1,474,893	1,909,479	9,507,124	1,449,555	4,004,815
Qualark	1,002,171	680,047	12,146,312	1,098,080	974,131	1,599,562	8,365,019	1,255,051	3,390,047
Difference	245,515	205,757	1,436,432	883,154	500,762	309,917	1,142,105	194,504	614,768

\*due to differences in species composition at the two sites, periods of pink dominated migration were excluded from totals during odd years

\*\*To eliminate differences due to hydroacoustic estimation at either site, numbers are based on Mission estimates and projections to Qualark

# **Appendix 14a: Alternative Hydroacoustic Estimates For Run Size Assessment**

## **Evaluation of alternative hydro-acoustics estimates for in-season run size assessment of Fraser sockeye salmon**

Catherine Michielsens (PSC)

May 2016

### **Introduction**

During the Fraser River Strategic Review, the main emphasis has been on the comparison of sockeye abundances at Mission or Qualark. These estimates however are not used as such for management purposes. Instead, the Fraser River Panel uses in-season run size estimates for sockeye management. This document presents the results of the comparison of total run size estimates derived from Mission versus Qualark data and evaluates the impact of the use of the different time series on in-season run size estimates when used in-season in the run size assessment model. This document does not evaluate the validity of the different hydro-acoustic programs themselves but evaluates the impact of the use of the different programs on in-season run size estimates. In order to do this comparison, it is assumed that Qualark abundances are correct and deviations from the Qualark based estimates represent a bias in the estimates.

### **Method**

In order to compare Qualark derived abundances with hydro-acoustics estimates at Mission, a backward reconstruction has been performed to transform abundance at Qualark into abundances at Mission by adding catches in between Qualark as Mission as well as stocks that do not migrate past Mission. The resulting time series of reconstructed Mission abundance based on Qualark hydro-acoustic data can then be compared against the actual Mission abundance but can also be used as an alternative hydro-acoustic time series with the in-season stock assessment model. A retro-spective analysis using the original Mission time series, the new reconstructed time series of Mission abundances based on Qualark and a combination of both, has been performed for 2010 and 2014, the two years with the largest percent difference between the Mission and Qualark time series.

## Data

In order to make analyses relevant for the Fraser River Strategic Review Committee, exactly the same data were used as provided to Prof. Carl Walters, covering 2008 to 2014.

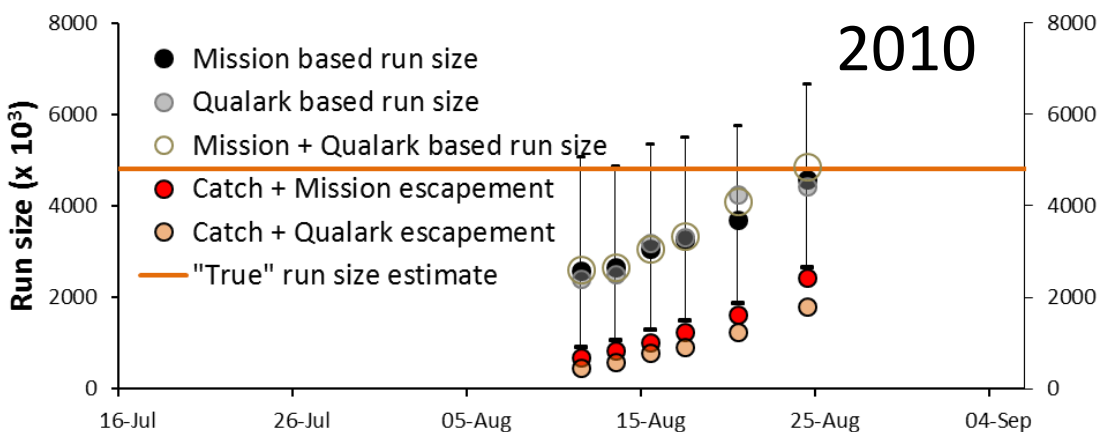
## Results

- Several stocks including Chilliwack, Pitt, Harrison, Birkenhead, Big Silver, Weaver and Cultus do not migrate past Qualark. As a result, Qualark data can only be used to assess and verify 30 to 80% of the total Fraser sockeye run in-season (based on 2008-2014). Late Shuswap stocks migrate past Qualark but because of the delay in the migration, these hydro-acoustic estimates can only be used post-season to assess the run size. Including post-season application, about 50-90% of the run can be assessed and verified at Qualark.
- When comparing total Fraser River run sizes, the difference between the total run size estimate derived from hydro-acoustic data collected at Mission versus the estimate derived from data collected at Qualark is less than 10% (2008-2014), with the largest differences observed in 2010 (7%) and 2014 (8%).
- In 2010, the discrepancies in abundance derived from Mission versus Qualark occurred early in the season, resulting in 11-13% difference between estimates of Early Summer-run and Summer-run and only a 5% difference for Late-run sockeye. The Mission program produced lower abundance estimates than Qualark and this can be explained by the fact that in 2010, the Mission program was still experimental and the mobile system was used during the early part of the season to generate abundance estimates on the right bank. Since then, vessel based abundance estimates are known to be biased low and instead, a DIDSON is used during the early part of the season to generate right bank abundance estimates.
- In 2014, the discrepancy in abundances derived from Mission versus Qualark occurred late in the season, resulting in 13% difference between estimates for Late-run sockeye and 2-4% difference between estimates for Early Summer-run and Summer-run. Because of the delay in the migration of some of the Late-run stocks, hydro-acoustic derived abundance estimates are not used for the in-season assessment of their run size.
- When using abundances derived from the hydro-acoustic program at Qualark instead of Mission for in-season run size assessment, the variability in the run size estimates increase due to the fact that 9 days of test fisheries data are relied upon instead of 6 days when using hydro-acoustic data collected at Mission.
- Assuming the Qualark derived abundance estimates are correct, the positive impact of using Qualark data for in-season run size estimation increases as more fish migrate past Qualark and the impact of the test fishery data on the run size decreases.
- Qualark data can be used in combination with Mission data within the in-season run size assessment model but resulting improvements in mean percent error in run size are limited (< 10% in 2010) or non-existent (2014).
- Regardless of which hydro-acoustic data are used in-season, the run size estimates may be substantially biased. In 2010, the in-season run size estimates were substantially biased low due to the shape of the run and an early drop in test fishing catches despite continued high abundances at both Mission and Qualark. Only near the end of the season when 67% of the run of Chilko/Quesnel/Raft/North Thompson

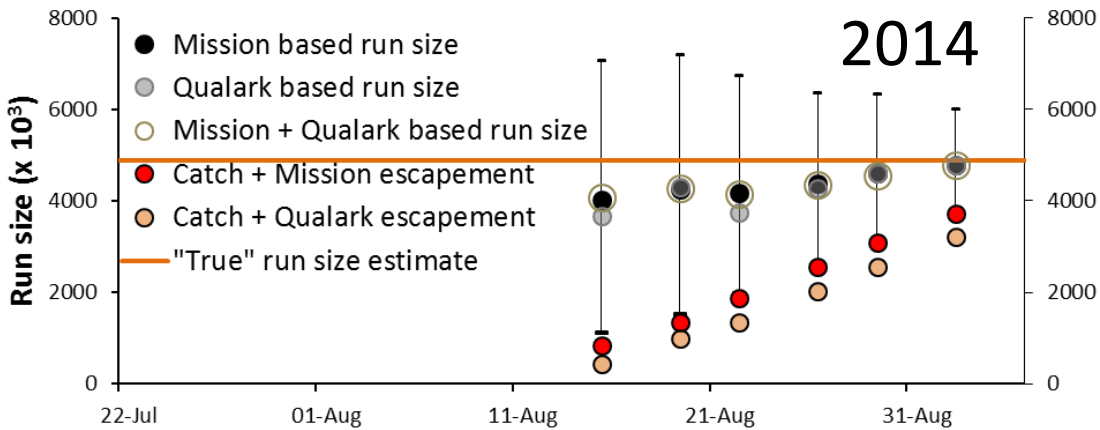
had migrated through the marine areas, did the use of Qualark data in combination with Mission data improve run size estimates by 13%.

## Conclusions

- Differences between Mission and Qualark decrease substantially when comparing differences in run size estimates rather than abundance at the Qualark and Mission sites. Based on data from 2008-2014, differences in derived run size estimates are less than 10% for total Fraser sockeye and less than 15% when evaluating individual assessment groups.
- When using the hydro-acoustic data within run size estimates models, the resulting run size estimates differ due to the difference in the reliance on test fishery data (9 days when using Qualark derived data compared to 6 days when using Mission data) and due to the differences in abundance estimates used as input into the model. Because of the large variability of the test fishery data, the reliance on 9 days of test fishery data will negatively impact in-season run size estimates using Qualark data versus Mission unless there is a large discrepancy between the two time series and assuming Qualark is correct. In addition, there can be a substantial bias in the in-season run size estimates, regardless of the hydro-acoustics time series used and using 2010 as an example, this bias may be much larger than any bias created through the use of one set of data versus the other.
- The presented methodology can be used to evaluate the performance of alternative hydro-acoustic time series e.g. Mission hydro-acoustic estimates generated without the use of the mid-channel or right bank.
- Additional details of the analyses and the results have been presented to the Fraser River Panel and Technical Committee and can be found at the following location on the secure site:  
[https://secure.psc.org/frp/Panel/2016/2016-05-04\\_Quadra/6a\\_AlternativeHydroAcousticEstimatesForRunSizeAssessment.pptx](https://secure.psc.org/frp/Panel/2016/2016-05-04_Quadra/6a_AlternativeHydroAcousticEstimatesForRunSizeAssessment.pptx)

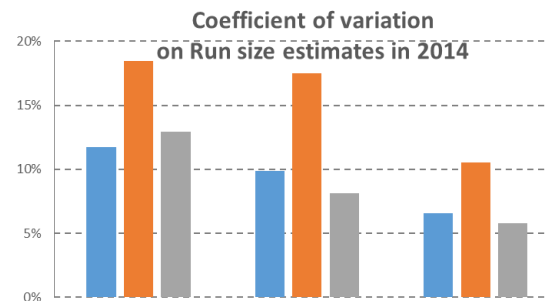
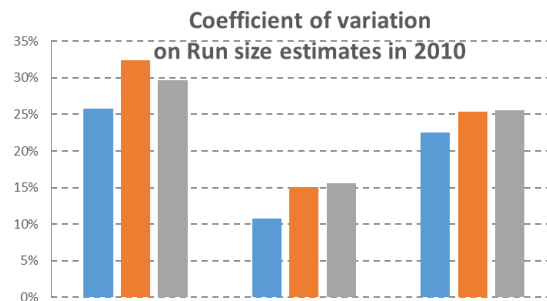
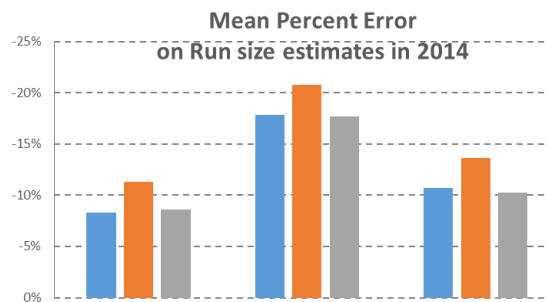
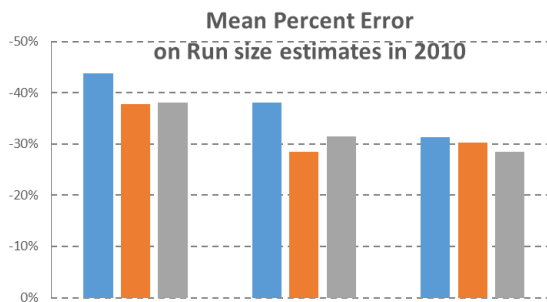






**Figure 1:** Results of the retro-spective analysis of the in-season assessment of Chilko, Quesnel, Raft and North Thompson for 2010 and 2014. It is assumed that the true run size equals the sum of the marine abundance estimates derived from Qualark hydro-acoustic data.

■ Mission ■ Qualark ■ Both



Early Thompson Late Stuart Chilko/RaNT  
 Thompson Stellako Quesnel

Early Thompson Late Stuart Chilko/RaNT  
 Thompson Stellako Quesnel

**Figure 2:** Overview of the results of the Retro-spective analysis for 2010 and 2014 in terms of mean percent error on run size estimates as well as the coefficient of variation (CV) for the three main assessment groups using hydro-acoustic data in 2010 and 2014: Early Thompson, Late Stuart and Stellako and Chilko, Quesnel and Raft, North Thompson. The CV gives an indication of the variation in the run size from one Panel meeting to the next.

# Appendix 14b: Alternative Hydroacoustic Estimates For Run Size Assessment Handout



Evaluating alternative hydro-acoustic estimates for in-season run size assessment

Michielsens, PSC  
May 2016, Quadra

1

### Alternative hydro-acoustic time series

**At Mission** ✓

- The hydro-acoustic data collected at Mission is the default time series used within the in-season run size assessment model.
- Alternative permutations of the hydro-acoustic time series can be created, e.g. replacing right bank or mid-channel mobile sampling.

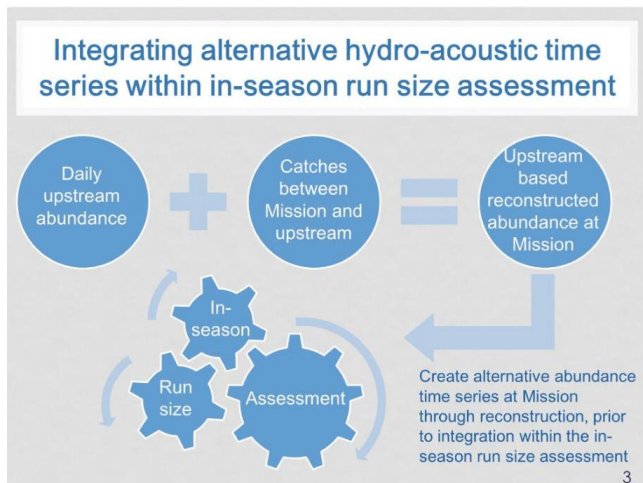
**At Qualark** ✓

- Qualark can be used as alternative assessment data for stock migrating past Qualark by accounting for catches in between both sites and assuming no en route loss occurs between Mission and Qualark.

**Close to the spawning grounds**

- In-season hydro-acoustic estimates of abundance are obtained for Chilliwack (lower and upper), Chilko, Stellako and Birkenhead.
- Accounting for catches between Mission and the upstream hydro-acoustics site allows to use the upstream abundance estimate as a minimum due to the unknown level of en route loss.

2



### Illustration of evaluation method using historic daily abundance at Mission and Qualark

- Use Qualark hydro-acoustics data to create an alternative time series of reconstructed daily abundances at Mission
- Evaluate the resulting in-season run size based on Qualark against hydro-acoustics estimates obtained at Mission
  - What proportion of the run can be assessed using alternative time series?
  - What is the percent difference in total run size between the different hydro-acoustics estimates?
  - Used within the in-season run size model, does the use of Qualark derived Mission abundance lead to more precise (percent error) run size estimates with reduced fluctuations (CV) in the run size estimates across the season?
- This presentation makes the assumption that the abundance estimated at Qualark is the "True" abundance.

This presentation does not assess the validity of Qualark versus Mission but evaluates if the use of Qualark could improve in-season run size estimates assuming Qualark abundance estimates are correct.

4

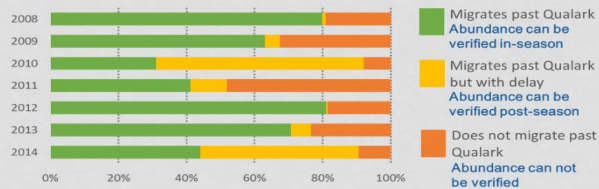
2016-05-02

6a\_AlternativeHydroAcousticEstimatesForRunSizeAssessment.pptx

CM, FRP Quadra May 2016

## A. Proportion of the total Fraser River sockeye run that can be assessed at Qualark

Proportion of the total Fraser River sockeye run that:

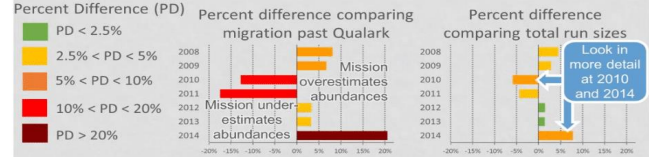


- Using Qualark data in-season allows to assess and verify between 30 to 80% of the total Fraser sockeye run
- Post-season, the Qualark data allows to assess and verify 50 to 90% of the total Fraser sockeye run size

5

## B. Percent difference when comparing total run size estimates based on Mission vs Qualark

- Migration past Qualark is converted into total run size by adding stocks that do not migrate past Qualark as well as catches below Qualark.
- Because of the lack of independent information, stocks that do not migrate past Qualark as well as catches will substantially decrease the percent difference in the total run size.



- Based on 2008-2014 data, using hydro-acoustic data obtained at Mission instead of Qualark results in less than 10% difference in total run size. 6

### 2010

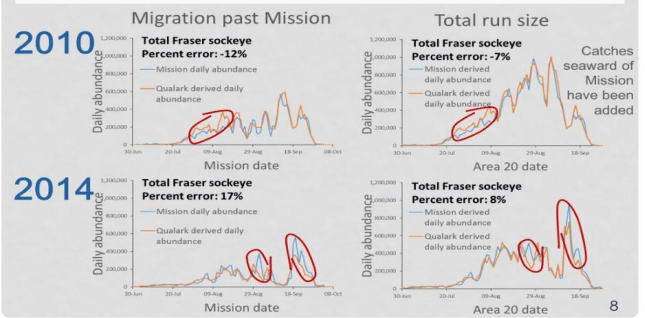
- Experimental Mission program
- No right bank in-shore DIDSON data available early and late in the season
- Right bank in-shore fish passage estimated by mobile splitbeam system for these two periods
- Vessel-based estimates of Mission abundance on the right bank are biased low

### 2014

- Fully developed Mission program
- Right bank in-shore and offshore DIDSON start early in the season
- No obvious directional bias in the Mission data

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## B. Percent difference when comparing abundance at Mission versus total Run Size



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2016-05-02

6a\_AlternativeHydroAcousticEstimatesForRunSizeAssessment.pptx

CM, FRP Quadra May 2016

## B. Percent difference on Run Size using Mission versus Qualark data

- Given the limited Early Stuart run sizes, discrepancies in abundances can be substantial and different in amount or cause from other stock groups

Stock group	2010	2014
Total Fraser sockeye	-7%	8%
Early Stuart	NA*	-12%
Early Thompson	-13%	2%
Late Stuart/Stellako	-13%	4%
Chilko/Quesnel/RaNT	-11%	4%
Late run excl. Birkenhead	-5%	13%

\*No Qualark estimate

- In 2010, the discrepancy in abundances derived from Mission versus Qualark occurred early in the season, resulting in 11-13% difference between estimates of Early Summer-run and Summer run
- In 2014, the discrepancy in abundances derived from Mission versus Qualark occurred late in the season, resulting in 13% difference between estimates of Late run but because of the delay in late run migration, these estimates can not be used for in-season run size assessment

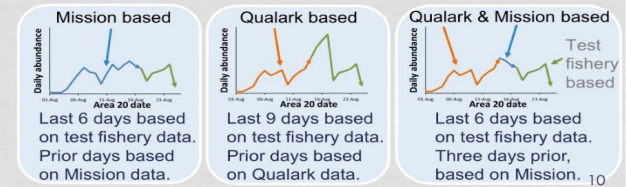
9

## C. Method to use Mission, Qualark or both time series when estimating run size

### Test fishery data

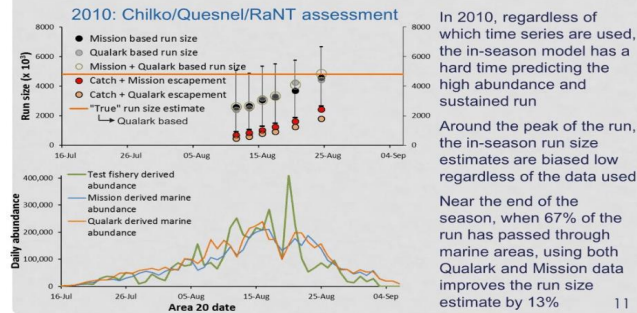
All 3 methods use test fishery data up to the day prior to the assessment date and assessment dates are chosen to correspond with those in 2010 and 2014 respectively

### Reconstructed marine daily abundance



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## C. Using alternative in-season hydro-acoustic time series for in-season run size assessment



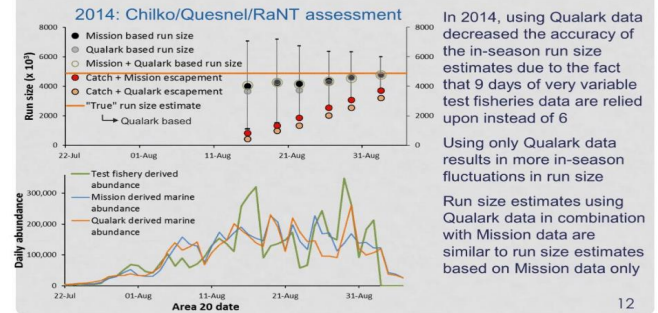
In 2010, regardless of which time series are used, the in-season model has a hard time predicting the high abundance and sustained run

Around the peak of the run, the in-season run size estimates are biased low regardless of the data used

Near the end of the season, when 67% of the run has passed through marine areas, using both Qualark and Mission data improves the run size estimate by 13%

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## C. Using alternative in-season hydro-acoustic time series for in-season run size assessment



In 2014, using Qualark data decreased the accuracy of the in-season run size estimates due to the fact that 9 days of very variable test fisheries data are relied upon instead of 6

Using only Qualark data results in more in-season fluctuations in run size

Run size estimates using Qualark data in combination with Mission data are similar to run size estimates based on Mission data only

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2016-05-02

6a\_AlternativeHydroAcousticEstimatesForRunSizeAssessment.pptx

CM, FRP Quadra May 2016



### Conclusions based on 2008-2014 data (1)

- Qualark data can be used to assess and verify 30 to 80% of the total Fraser sockeye run in-season and 50 to 90% of the run post-season.
- Post season estimates are used as stock-recruit data to generate the pre-season forecasts and informative priors on run size used early in the season.
- Using hydro-acoustic data obtained at Qualark instead of Mission results in less than 10% difference in total Fraser sockeye run size, with the largest differences observed in 2010 and 2014.

13

### Conclusions based on 2008-2014 data (2)

- In 2010, the discrepancy in abundances derived from Mission versus Qualark occurred early in the season, resulting in 11-13% difference between estimates of Early Summer-run and Summer run (the Mission estimates being lower than the Qualark estimate).
- In 2010, part of the Mission program was still experimental and near the start and end of the season, vessel-based abundance estimates were used for the right bank instead of DIDSON derived estimates. Vessel-based abundance estimates for the right bank are biased low.
- In 2014, the discrepancy in abundances derived from Mission versus Qualark occurred late in the season, resulting in 13% difference between estimates of Late run but because of the delay in late run migration, these abundance estimates can not be used for in-season run size assessment.

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### Conclusions based on retro-spective in-season run size assessment for 2010 and 2014 (1)

Assuming abundances based on Qualark are correct, the benefits of using Qualark instead of Mission will depend on:

- The size of the discrepancies. The discrepancy between Qualark and Mission need to be substantial enough to offset the loss of 3 days of hydro-acoustics based abundance estimates.
- The timing of the discrepancies. Discrepancies after the peak of the run will have a smaller impact on in-season run size estimates than earlier discrepancies.

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### Conclusions based on retro-spective in-season run size assessment for 2010 and 2014 (2)

- Using Qualark instead of Mission for in-season run size assessment increases the variability of the run size estimates due to the fact that 9 days of test fishery data are relied upon instead of 6.
- The positive impact of using Qualark data increases as more fish migrate past Qualark and the impact of the test fishery data on the run size decreases.
- Large biases in run-size estimates in-season may remain, regardless of the hydro-acoustic time series used e.g. underestimation of run size in 2010.

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2016-05-02

6a\_AlternativeHydroAcousticEstimatesForRunSizeAssessment.pptx

CM, FRP Quadra May 2016

### Conclusions on the feasibility of the use of Qualark for in-season assessment

- The methodology to incorporate Qualark data within the current in-season run size model relies on a back-reconstruction of daily abundances at Mission based on the daily abundances at Qualark
- In-season use of Qualark for run size assessment would require:
  - All Qualark abundance estimates to be available by 8:30 on meeting days
  - Timely estimates of catches taken between Mission and Qualark
  - Timely and unbiased in-season stock-ID estimates from Qualark test fisheries
  - Alternative assessment methodology for stocks not migrating past Qualark

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### Conclusions on the methodology

- By back-reconstructing Mission abundance based on alternative hydro-acoustic time series, resulting abundance time series can be evaluated within the existing run size assessment framework.
- The value of the alternative hydro-acoustic time series can be evaluated by comparing the resulting in-season run size estimates.
- Evaluations of the results are based on the assumption that one of the abundance time series is correct.
- This methodology can be adapted to evaluate other alternative hydro-acoustic based time series e.g. Mission hydro-acoustic estimates generated without the use of mid-channel or right bank data.
- The methodology can also be adapted to evaluate alternative test fishery time series, for example alternative time series generated for the test fishing workshop.

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## **Appendix 14c: Technical Summary Fall 2016 with Run Size and Total Allowable Catch Summary**

# Hydroacoustics Technical Working Group

Fall 2016 Summary

*presented to FRP small group at January 2017 PST Post Season meeting*

## Introduction

---

In the fall of 2016, the Fraser River Strategic Review Committee (FRSC) of the Pacific Salmon Commission deferred its recommendations regarding Lower Fraser hydroacoustic configurations until the fall of 2017. One outcome of this delay is that more time was available to conduct work on elements of the Fraser Panel's agreed workplan that was designed to assist the FRSC with their deliberations. For example, workplan item 16: "Develop qualitative (and where possible quantitative) performance measures for alternative program designs and scenarios, considering the range of fish densities encountered, river conditions and other factors" remained incomplete. A small technical workgroup<sup>1</sup> was struck with two main objectives: 1. Identify and quantify some alternative performance measures that could be considered useful by the Panel's hydroacoustics oversight committee<sup>2</sup>. 2. Guide a consultant (Wor) in the construction of a simulation model that could be used to: a. generate time series of DBEs from alternative hydroacoustics configurations and b. quantify the sampling errors associated with estimates at both sites to provide context for the differences between estimates. Objective 2 related to elements of item 15 in the workplan. Below we report on the progress on these two objectives.

## Overview

---

- work done in the fall of 2016 to quantitatively compare the two hydroacoustics systems at Mission and Qualark using the following performance measures:
  - % of total run directly assessed
  - %DBE in escapement of Qualark-bound stocks
  - DBE & %DBE in run size of Qualark-bound stocks
  - DBE & %DBE in international TAC of total Fraser Sockeye
- important assumption
  - assuming Qualark number is "correct" for purposes of comparing estimates from the two sites (i.e., Qualark = "reference")

---

<sup>1</sup> Technical workgroup members (reverse alphabetical):

*Yunbo Xie, Timber Whitehouse, Catarina Wor, Mike Staley, Catherine Michielsens, Fiona Martens, Mike Lapointe, Cory Lagasse, Ann-Marie Huang, Mike Hawkshaw, Aaron Dufault, Bob Conrad*

<sup>2</sup> Oversight committee members:

Kirt Hughes, Jennifer Nener, Lorraine Loomis, Les Jantz, James Dixon, Mike Staley



- methods summary
  - Mission & Qualark are backwards reconstructed to get abundances for marine areas
  - in-season models are used to estimate run size for Qualark-bound stocks at 3 time periods around the peak of the Summer run for Early Summer & Summer
  - Early Summer & Summer non-Qualark bound stocks are scaled up based on p50 run size forecast
  - TACs are calculated using 2014 TAMs (Raft, North Thompson & Harrison in Summers), Early Stuart & Late TACs are the adopted in-season run sizes (excl. Har) on the calculation dates.
- things to be aware of
  - 2010 was selected for comparison purposes because it is the year with largest DBE between Mission and Qualark escapement estimates, however, the Mission program was still experimental in this year contributing to the large DBEs
  - “Mission” TACs shown in part 1 is not the same as actual 2010 TAC
  - hydroacoustics information is not used in the in-season models to estimate run size of Harrison, Late Run (excl. BK), or Pinks
  - *stock ID - Qualark estimate is Qualark total abundance but using Mission stock ID*
  - species composition was not part of this evaluation
  - comparison of SK in pink salmon years are truncated to periods of low PK abundance
  - An estimate of the total Fraser pink salmon escapement cannot be obtained from the Qualark site
  - we do NOT know what the TRUE abundance of fish passage is

## Results

### Part 1 – comparison tables

#### 1a. Hydroacoustics configurations considered

- gray = eliminated: minimal cost savings or not logistically feasible
- white = primary interest – full evaluation completed
- blue = secondary interest – based on evaluation of the two configurations of primary interest (in white), the tech WG proposes that further evaluation of run size & TAC beyond those summarized in this document (i.e., the two white configurations) is *not* warranted because further comparisons using Mission to Qualark DBE should be sufficient

Mission LB+RB+Mobile
Qualark
Mission LB+RB+Mobile+Qualark
Mission LB+RB
Mission LB+RB +Qualark
Mission LB
Mission LB + Mobile
Mission LB +Qualark
Mission LB + Mobile+ Qualark
Qualark RB only
Mission, no night operation
Qualark, no night operation

1b. diagnostics: stocks assessed, %DBEs in escapement and post-season run size estimates.

2010	Hydro Acoustic Gear Scenarios	Stocks assessed	Mission to Qualark DBE	Post-season run size DBE
<b>Stocks examined</b>		Run size assessment in-season using hydro-acoustic data (and post-season) <b>1</b>	Early Summers & Summers ( and all through-Qualark stocks)	Early Summers & Summers (and all through-Qualark stocks)
<b>Description</b>		% of total sockeye run size estimated by hydroacoustics	%DBE in escapement at Qualark when both programs operating, and species composition predominantly sockeye	%DBE in total run size estimates using Mission vs Qualark
	Mission LB+RB+Mobile	39% (99.8%)	-20% (-14%)	-12% (-7%)
	Qualark	31% (92%)	Reference <b>2</b>	Reference

footnotes:

1. Large differences between in-season and post-season percentages relate to stocks that delay their upstream migration (e.g. Late Shuswap) for which escapement data cannot be used for in-season run-size estimation at either site.
2. "reference" = assuming Qualark number is "correct" for purposes of comparing estimates from the two sites.

1c. diagnostics: %DBE in-season run size and TAC

Hydro Acoustic Gear Scenarios	2010 In-season run size DBE			2010 in-season TAC DBE		
	15-Aug	20-Aug	24-Aug	15-Aug	20-Aug	24-Aug
<i>Stocks examined</i>	Early Thompson, Late Stuart/ Stellako, Chilko/Quesnel			Early Summers & Summers (and total FR SK)		
<i>Description</i>	August 15: 6 days after the peak of the Early Summers, 1 day after peak of Summer run	August 20: 6 days after peak of Summer run and 3 days before peak of the Late run	August 24: during the last meeting with run size estimates for Summer run from the model and 1 day after the peak of the Late-run	%DBE.TAC for International TAC of ESum+Sum (and total). See in-season run size DBE for date rationale.		
Mission LB+RB+Mobile	-9%	-16%	-2%	-9% (-4%)	-17% (-7%)	-1% (-1%)
Qualark	Reference	Reference	Reference	Reference	Reference	Reference

1d. diagnostics: International TAC, US TAC, CDN TAC and DBE.TAC (#fish)

August 15

	Mission.TAC	Qualark.TAC	DBE.TAC
int'l TAC	6.7M	6.9M	-260k
US TAC	1.1M	1.1M	-40k
CDN TAC	6.0M	6.2M	-220k

August 20

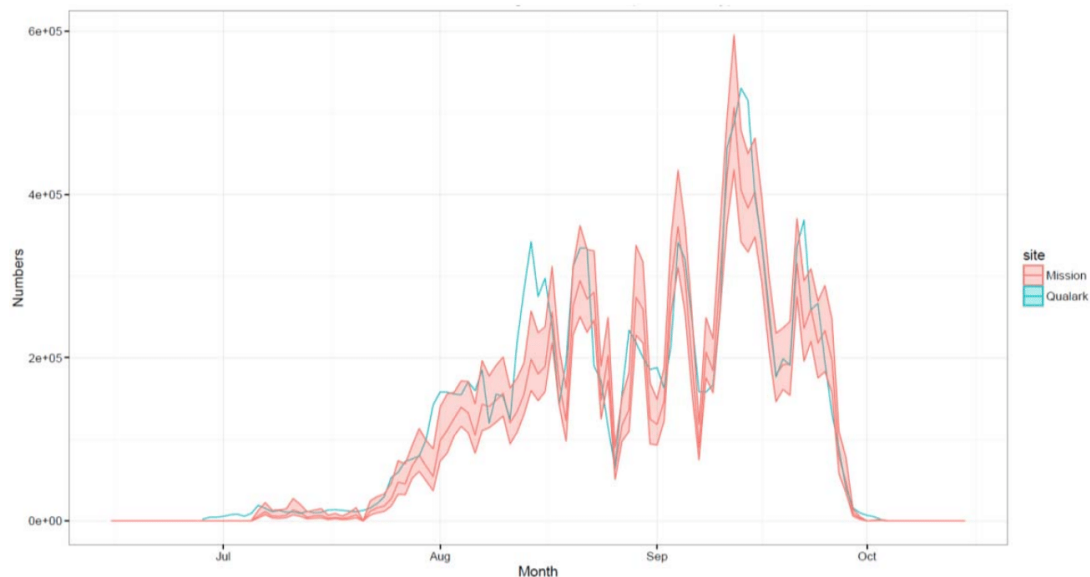
	Mission.TAC	Qualark.TAC	DBE.TAC
int'l TAC	9.2M	10.0M	-730k
US TAC	1.5M	1.6M	-120k
CDN TAC	8.1M	8.7M	-610k

August 24

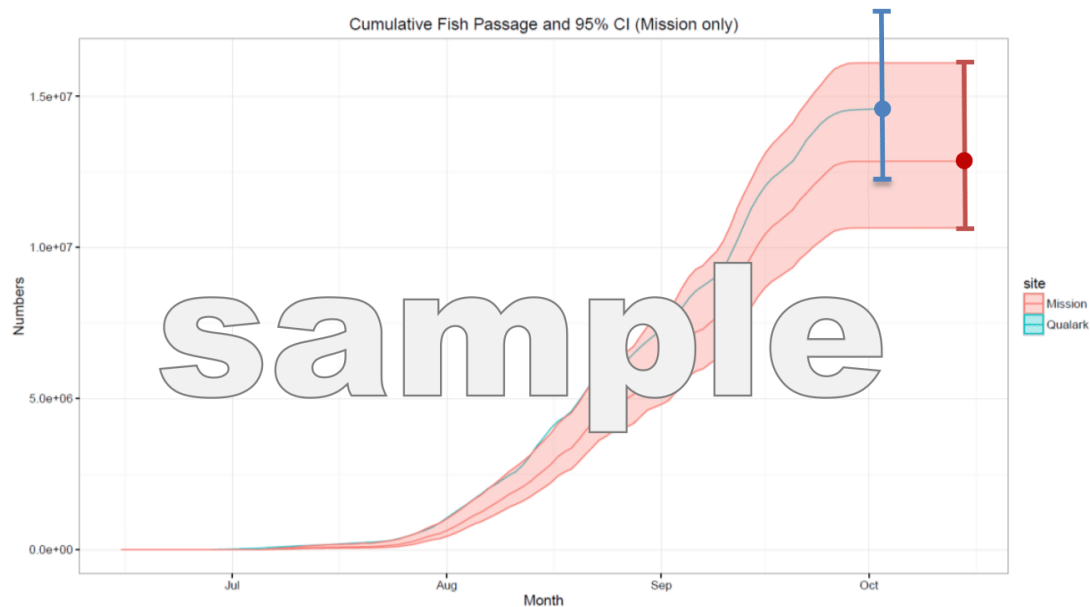
	Mission.TAC	Qualark.TAC	DBE.TAC
int'l TAC	12.9M	12.9M	-70k
US TAC	2.1M	2.1M	-10k
CDN TAC	11.2M	11.2M	-60k

**Part 2 – PRELIMINARY graphs: quantification of uncertainties (incl. TF sample size & stock ID)**

2a. 2010 – Daily Qualark bound sockeye passage estimates with preliminary quantification of uncertainties for 2010. Mission estimates are presented with 95% confidence intervals in red. Qualark estimate presented without uncertainties in blue.



2b. Hypothetical impacts of error on the cumulative Mission estimates of Qualark-bound sockeye shown in red cone. Qualark estimate presented as point estimates in blue



## Key Points

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### Part 1.

1. Comparisons of in-season TAC and run sizes in 2010 demonstrates the largest potential magnitude of differences in these performance measures over the 8 years of comparison (however, the direction of this difference is not indicative of other years; e.g. Differences in 2014 are in the opposite direction from those in 2010).
2. Given that differences in these performance measures will be smaller in other years, comparisons of Mission to Qualark escapement DBE should be sufficient for evaluating other years and hydroacoustic sampling configuration options

### Part 2.

3. The simulation model developed by the consultant provides a tool for quantifying random errors from various sources (acoustic counting, species proportions, stock ID and catch) that contribute to DBEs (in 2. above) for different hydroacoustics sampling configurations.
4. The goal of the simulation model is to quantify the degree to which DBEs may be expected based on sampling errors (precision) associated with generating estimates at both sites. This would allow one to judge whether observed differences between estimates are “statistically significant.”

## Next Steps

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- use following pieces of information to evaluate options:
  - Escapement DBE section of the evaluation table
  - Quantify sources of error contributing to escapement DBE using the consultant’s model projecting from Mission to Qualark. Tech WG will look at different methods of presenting this info and provide new graphs after reviewing model results.
  - Evaluate DBEs for different hydroacoustic sampling configurations using the consultant’s model
  - above to be used in conjunction with the more detailed analyses of run size and TAC impacts conducted on 2010
- tech WG will not be dealing with cost comparisons. suggest seeking expert help.
- Qs for small group - request answers for February FRP meeting in order for technical work to proceed:
  - is the technical work done to date sufficient for evaluation purposes?
  - if not:
    - what *type* of information is missing?
    - what comparison/performance measure is missing?

## **Appendix 15: Fraser River salmon migration model and analysis of hydroacoustic data from Mission and Qualark stations**

# **Fraser River salmon migration model and analysis of hydroacoustics data from Mission and Qualark stations**

Author:

Catarina Wor – Fisheries and Oceans Canada

## **1. Background**

Two hydroacoustic stations for counting Pacific salmon passage are currently operating along the Fraser River in British Columbia. The first hydroacoustic site is located at Mission and the second site is located at Qualark Creek, near Yale, BC. Measurements of sockeye escapement from both sites are generally similar but sometimes persistent differences between sites are observed throughout the season. Possible causes for such discrepancies have been investigated by both the Department of Fisheries and Oceans and the Pacific Salmon Commission (Walters, 2015; Pacific Salmon Commission, 2016). These reports pointed to various possible causes for the differences in salmon passage estimates including the possibility that the differences are associated with random sampling error. Currently, enumeration of sockeye salmon passage at both sites are based on estimates of the number of salmon migrating upstream using data from hydroacoustic systems and estimates of species and stock composition measurements from test fishing samples. All these measurements are assumed to be known with error. As a result, there is currently no reporting of confidence intervals in escapement reports associated with the sockeye passage estimates, rendering it impossible to determine if the observed differences are just due to random variation or if they are the result of a true difference caused by an unknown process.

In this report we use a statistical model to produce confidence intervals associated with random errors for the Mission and Qualark sockeye passage estimates. This model allows for comparison between the estimates at both sites and identification of periods when there is a significant passage estimate difference (PEDs). A database containing the sockeye salmon passage estimates, confidence intervals,

and presence/absence and magnitude of significant PEDs was compiled. The PED database was combined with a series of covariates that were thought to have potential impact in fish behavior and, therefore, on the fish passage estimates at both sites. The relationship between the occurrence of significant PEDs and their magnitude was investigated through a series of correlation and regression analyses.

This report is organized into four main components: data processing, development of the statistical model, identification of significant PEDs, and correlation and regression analyses.

## **2. Objectives**

- Produce confidence intervals for sockeye passage estimates at Mission and Qualark.
- Identify when significant PEDs occur, their magnitude and direction.
- Identify the relationship between occurrence and magnitude of PEDs and potential covariates that could affect passage estimates.

## **3. Data processing**

Several sources of data from both sites were used in this analysis. These data were summarized to provide daily estimates of fish passage and species composition at both Mission and Qualark hydroacoustic sites. Stock composition data for the sockeye salmon arriving at Mission and catch data between the two sites were also used. The processing of the raw data was a large part of this analysis and is described in detail in the following sections. The data analysis and formatting was performed using Microsoft Excel and R (R Development Core Team, 2017).

### ***3.1. Mission: fish counts***

The Mission site provided hourly salmon counts (all species), which was used to derive estimates of daily salmon passage by summing counts from all of the sonar counters sampling the entire river width (Table 1). The raw data provided by the PSC staff included multiple excel spreadsheets as well as some data analyses (formulas and graphs). These data were manually formatted and converted into



“.csv” files (Table 1). These files were then imported into R for further data treatment. In R, the dataset was tabulated with a fixed time frame from June 15th to October 15th for all years (2008-2015). Unavailable data or measurements on this time frame were represented with NAs.

Table 1: Data sources for observed Mission hydroacoustic counts.

Information	Raw data	Compiled data
Hourly counts for Mission left bank hydroacoustic gear	MissionHourlyCount s2008-2015.xlsx	Mission_LB_hourly.csv
Daily counts and CVs for all hydroacoustic gears at Mission	MissionByGear_CV_all_yrs.xlsx	MissionByGear_CV_all_yrs.csv
Code for data exploration and treatment		Data_evaluation_all_yrs.R

### 3.2. Mission: species and stock composition

Similarly to the fish count measurements at Mission, the species and stock composition information was stored in multi-tab spreadsheets, sometimes containing formulas and graphs. These spreadsheets were manually combined and saved under simpler “.csv” spreadsheets (Table 2). The species composition datasets differentiated between sockeye salmon and other salmon species, based on the catches by the lower river gillnet test fisheries at Whonnock and Cottonwood (downstream of Mission). A species composition ratio was provided by the PSC and the sample size for that estimate was assumed to be equal to the total catch reported by the Whonnock gillnet test fisheries. Other sources of information (such as historical catches and data from other test fisheries) can also be used in estimating species composition passing through Mission. However, for the sake of simplicity we considered that the Whonnock catch was a good representation of the effective sample size for species composition. It is possible that this assumption

affected the variability associated with the species composition, but we believe that the majority of the variability was accounted for when considering the Whonnock catch size and composition. A detailed analysis of all the information that goes into the species composition estimate would be needed in order to quantify the true variability of these estimates.

The stock composition data were reported on a daily basis and therefore was assumed to be constant for all hours in the day. The data are also based on the gillnet test fisheries occurring downstream of Mission. The stock composition sample size was based on a weighted average of sample sizes from multiple sources of sockeye salmon captured for species composition analysis by the gillnet test fisheries; the calculations for this sample size are in the excel spreadsheet MissionSIDs2008-2015\_valuesonly (Table 2). For the purpose of the modeling exercise, the stock composition information was further aggregated into three large groups: 1. groups that leave the Fraser at the Chilliwack River, 2. leave the Fraser at the Harrison River, and 3. stocks that stay in the Fraser River past the Qualark hydroacoustic site. It was assumed that the stock composition within each sample was measured without bias.

All the data were imported into R in tabulated form over the same fixed time frame from June 15th to October 15th for all years (2008-2015). The data were tabulated on this fixed time frame to facilitate the plotting routines once the analysis was completed (so all years had the same length of data series). Unavailable data values in this time frame were set to zero for both stock and species composition, and these were turned into NAs in the process of calculating the confidence intervals.

Table 2: Data sources for observed Mission species and stock composition.

Information	Raw data	Compiled data (.csv)
Daily species composition information: daily sockeye and total salmon counts	DailyMissionSockeyeProjectioVsQualarkSockeyeEstimate2008-2016.xlsx	species_comp_mission.csv
Daily stock composition for sockeye salmon and sample sizes used in stock composition and species composition estimates	MissionSIDs2008-2015_valuesonly_totcat.xlsx	MissionSID.csv
Code for data exploration and treatment		Data_evaluation_2010.R

### 3.3. Qualark: fish counts and species composition

For the Qualark site two sources of data were combined: hourly fish passage counts for the left and right banks (LB and RB), and species composition. On most days the test fishing dataset included two fishing events per day, morning and afternoon, and each event was comprised of three drift net sets with differing mesh sizes. In order to obtain an hourly estimate of species composition, we divided each day into two parts (before and after noon) and assumed that the species composition was constant in each of these periods.

Similarly to the compilation of Mission data described previously, all data were imported into R and stored in tabulated forms on the same fixed time frame from June 15th to October 15th for all years (2008-2015). Qualark dates were transformed in “Mission dates” by subtracting 3 days from the recorded dates based on discussions with PSC staff. Sensitivity analyses on the migration times were not included in the current report due to time limitations. Future work could implement the timing scenario used in-season by PSC staff of three days travel time for Adams

dominated years (i.e., 2010 and 2014) and two days travel time on the Adams non-dominated years (2008, 2009, 2011, 2012, 2013, 2015).

Table 3: Data sources for Qualark hydroacoustic counts.

Information	Raw data	Compiled data (.csv)
Hourly counts for the total salmon passage estimate at the Qualark hydroacoustic site	QualarkAcousticsHourly 2008-2015.xls	Qualark_hourly.csv
Daily species composition based on test fisheries at the Qualark hydroacoustic site	QualarkAcousticsTestFishingCatch2008-2015.xlsx	Qualark_speciescomps.csv
Code for data exploration and treatment		R/data_process/Data_eval_yrs.R

### 3.4. Catch data

The catch data for fisheries occurring between the Mission and Qualark sites were obtained from PSC records of commercial, ceremonial, and recreational fisheries. For this data set, all compilation and formatting were done by PSC staff. The catches based on the catch reports were assumed to be accurate without error and subtracted from the Mission estimates to produce the projected Qualark passage.

## 4. Statistical model

The goal of the statistical model was to estimate the variability that can be expected from observation error (not bias) associated with the sockeye salmon passage estimates at both hydroacoustic sites. In this model a daily time step was implemented, therefore all data were either aggregated into daily estimates or used in the raw data format if they were originally reported as daily estimates. The statistical model was built in R and distributed in four files (Table 4).

Table 4: Data sources for Mission hydroacoustic counts.

Functions	path to R file (from github folder)
Functions for adding random error to various components of the Mission sockeye salmon daily estimates	R/modeling/MIS_err_model_all.R
Function for adding random error to the various components of the Qualark sockeye salmon daily estimates	R/modeling/QLK_err_model.R
Code for producing Mission and Qualark estimates with error through simulation	R/modeling/Obs_Mission_and_Qualark_all_yrs.R
Code for plotting Mission and Qualark estimates with error	R/plot_lib/plot_obsMIS_obsQLK_all_yrs.R

#### 4.1 Mission

The objective of this analysis was to generate random error estimates for the number of sockeye that pass through Mission and are bound for Qualark. For this reason, three layers of uncertainty were identified for the observation model at Mission: acoustic counting error, species composition sampling error, and stock composition error. In order to obtain the estimate of sockeye bound for Qualark after passing through Mission, a routine was created and the pseudo-code of this model is given by:

1. Calculate acoustic counts with lognormal error.
2. Calculate the proportion of sockeye salmon with binomial species composition error (sockeye vs non-sockeye).
3. Calculate the sockeye multinomial stock composition with error.

4. Multiply the observed number with error by the species composition with error.
5. Multiply the remaining sockeye numbers by the proportion of sockeye stocks that are bound for Qualark (derived from stock composition with error).
6. Subtract the sockeye catches (assumed to be known without error).
7. Repeat  $n$  times, where  $n$  is the number of simulation runs being considered.

The hydroacoustic sampling was modeled for each acoustic gear separately. These gears include LBD1 (left-bank DIDSON), LBS1 (left-bank split-beam) and LBSI extrapolation of the blind-zone on the left bank, M (offshore mobile sounding gear) RBD3 (right-bank offshore DIDSON) and RBD2 (right-bank inshore DIDSON). Estimates of standard deviation for each of those estimates were based on the method described by Xie and Martens (2014). We assumed that acoustic counting error is lognormally distributed. We also assumed that fish counts from individual gears were correlated with a coefficient  $\rho = 1$ . The high correlation coefficient was used as an estimate of the “worst case scenario” for the hydroacoustic measurements. Estimates were also assumed to be temporally correlated across days, with a correlation coefficient  $\rho = 0.5$ . A lower value of  $\rho$  was used for temporal correlation relative to gear type correlation because it is believed that correlation across days is not as strong when compared to correlation among gear measurements on the same day. An extension of this study could be to analyze alternate correlation coefficients.

Error in species composition was assumed to follow a binomial distribution with the two possible outcomes being sockeye salmon or other salmon. Species composition was assumed to be uncorrelated across days. We assumed the Whonnock test fishery daily catch for the species composition sample size. In reality the species composition is determined by a compilation of information from various sources, including other test fisheries and historical seasonal species abundances. However, we believe that using the Whonnock test fishery salmon catch as the sample size

was a good proxy to quantify the amount of variability around the species composition estimates.

The sockeye stock composition estimates were combined into three groups: 1. stocks that leave the Fraser at the Harrison confluence; 2. stocks that leave the Fraser at the Chilliwack confluence, and 3. stocks that stay in the Fraser River past the Qualark acoustic station. The error around each measurement was assumed to follow a multinomial distribution. Sockeye stock composition was also assumed to be uncorrelated across days. Currently, only the multinomial error associated with sampling variability has been considered for the stock composition error. However, some error is also associated with the genetic analysis used to determine the stock composition in the sample. An extension of this study could seek to analyze the magnitude of this stock identification error and incorporate such errors into the estimates. The functions for adding fish counts, species composition and stock composition error are located MIS\_err\_model\_all.R (Table 4). Catch data were assumed to be known and constant across simulation runs. We used 1000 simulation runs to generate the confidence intervals presented here.

#### **4.2. Qualark**

The observation model at Qualark has two uncorrelated sources of errors: acoustic sampling error and species composition error. The estimates of sockeye passage then follow a simple routine:

1. Calculate acoustic measurement with error.
2. Calculate the proportion of sockeye salmon with species composition error.
3. Repeat  $n$  times, where  $n$  is the number of simulation runs being considered.

The acoustic measurements at the left and right banks at Qualark were added together to generate a single measurement. The error around that measurement was assumed to be lognormally distributed with a 5% CV (Enzenhofer et al. 2010). The species composition error was determined from the daily estimates of species composition and total catch sample size derived from the Qualark test fisheries.

## **5. Identification of significant Passage Estimate Differences (PEDs) and their direction and magnitude.**

We used the statistical simulation model to generate 95% confidence intervals for the passage estimates at both Mission and Qualark. The confidence intervals were based on 95% quantiles of 1000 simulation runs. Significant differences were defined as the days in which the 95% confidence intervals did not overlap. When the confidence intervals for the passage estimates did not overlap, we calculated the passage estimate difference (PED). Significant (non-overlapping) PEDs are presented in absolute value (Mission-Qualark using medians) and as a percentage of the Qualark estimate  $((\text{Mission-Qualark})/\text{Qualark} \times 100)$ .

The years 2010 and 2014 had the largest number of significant PEDs; 26 and 35 occurrences, respectively. Those were also the years of highest sockeye salmon abundance in the time series. The low abundance years 2008, 2009, and 2015 had the lowest numbers of significant PEDs (7, 3 and 4 days respectively) but the annual time-series length was also shorter for those years. A brief summary of the significant PED patterns is presented in Table 5.



Table 5: Description of significant PEDs patterns for all years between 2008 and 2015.

Year	Figure #	significant PEDs (#)	Description
2008	Figure 1	7	In 2008 there was no apparent pattern in the significant PEDs. An exception was the period between July 29 <sup>th</sup> and 31 <sup>st</sup> , when Mission estimates were significantly higher than Qualark for three days in a row.
2009	Figure 1	3	In 2009, only three significant PEDs were identified. Two significant PEDs occurred early in the season (July 20 <sup>th</sup> and 21 <sup>st</sup> ). The third significant PED occurred on August 19 <sup>th</sup> , near the end of the data series. All PEDs were negative, i.e. Qualark estimates were higher than Mission estimates.
2010	Figure 1	26	In 2010, the significant PEDs were spread throughout the extent of the season. The majority of the PEDs were negative, with the exception of August 23 <sup>rd</sup> and 25 <sup>th</sup> and September 8 <sup>th</sup> , when PEDs were positive.
2011	Figure 1	12	In 2011 negative PEDs (Mission lower than Qualark) occurred in the mid-season and positive PEDs occurring in the early and late seasons.
2012	Figure 2	13	In 2012 the pattern of the significant PEDs was somewhat similar to 2011 with negative PEDs occurring in the mid-season and positive PEDs occurring in the early and late season.
2013	Figure 2	9	In 2013 the significant PEDs occurred throughout the season but appeared to increase in magnitude later in the season.
2014	Figure 2	35	2014 was a year of high abundance and most significant PEDs were positive (Mission higher than Qualark). The magnitude of the PEDs increased as the season progressed.
2015	Figure 2	4	In 2015 only four significant PEDs were observed and these were scattered throughout the season with no apparent pattern.

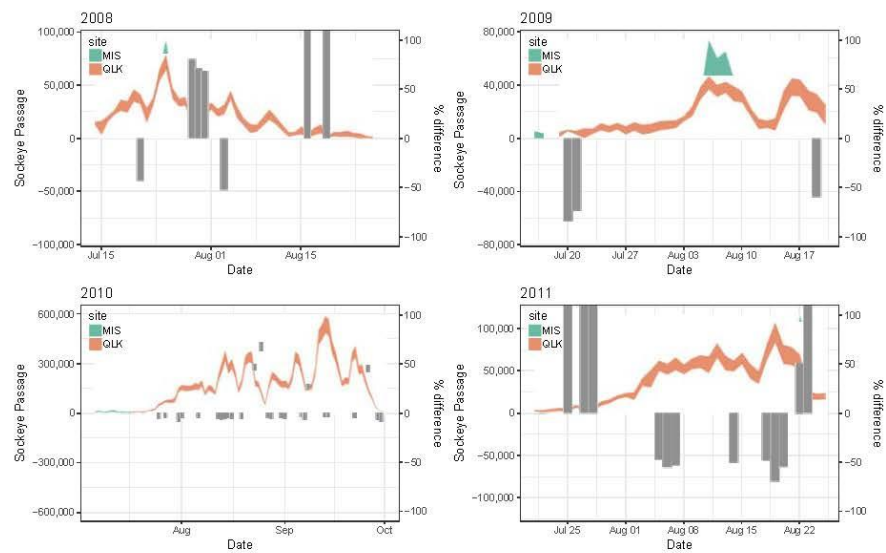


Figure 1 – Passage estimates and confidence intervals for Mission (green) and Qualark (orange) for the years between 2008 and 2011. Bars represent % difference between estimates when confidence intervals did not overlap.

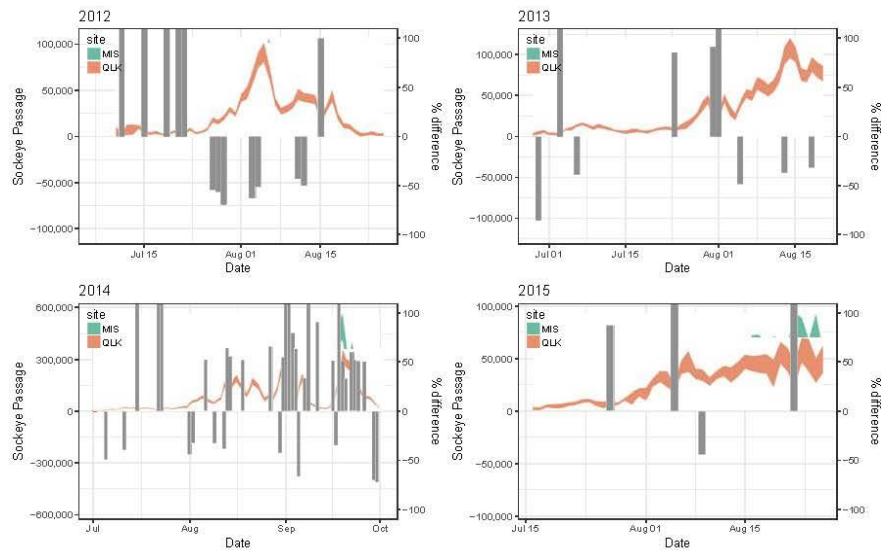


Figure 2 – Passage estimates and confidence intervals for Mission (green) and Qualark (orange) for the years between 2012 and 2015. Bars represent % difference between estimates when confidence intervals did not overlap.

## 6. Regression analyses

The relationship among a series of covariates and the occurrences and magnitude of significant PEDs was investigated through a series of correlation analyses. The first step in this analysis was to identify covariates that could be associated with the significant PEDs. Once the list was assembled, we selected a narrower list of representative covariates by excluding variables that were highly cross-correlated. The selected covariates were then used in a two-step regression analysis to model the presence/absence of significant PEDs and their magnitude.

### 6.1. Selection of covariates

A list of potential variables that may affect the occurrence of significant PEDs was assembled based on previous analyses and new suggestions made by the hydroacoustics technical committee. The initial list of covariates was based on the correlation analysis reported in Pacific Salmon Commission (2016). This list

included fisheries variables at both the Mission and Qualark sites, environmental variables (temperature and river discharge), and hydroacoustic measurements (proportion of offshore measurement passage). In addition to the PSC dataset, we also included in the analysis data on the number and proportion of hydroacoustic counts registered by the mobile gear and the extrapolated blind spot at Mission. Finally, we included the variable year to account for possible changes due to interannual variability in the characteristics of the runs. The variable year was grouped into three categories: even years with high abundance (evenHigh), even years with low abundance (evenLow), and odd years (odd). The complete list of covariates included 20 variables. Some of these variables were represented in proportions and scaled between 0 and 1. We applied a logit transformation to those covariates and the transformed versions were used in the correlation and regression models. A complete list of the variables considered is found in Table 6.

Table 6 - Complete list of variables considered to explain occurrence and magnitude of significant PEDs.

<b>Variable</b>	<b>Reason for including the variable</b>	<b>Kept in the analyses ?</b>
Year (odd, even high and even low)	Represent the unique characteristics of run type of brood year.	yes
Mission mobile counts	Bias might arise when a high number of fish go through the mid-river channel	
logit of Mission mobile proportion	Bias might arise when a high proportion of the fish go through the mid-river channel	yes
Mission extrapolation counts	The extrapolation accounts for fish that were not observed by the left bank gear due to the shadowing of acoustic sampling beams by the morphology of the river bottom. Since the true value of salmon passage in this area is unknown, direct estimates of bias and random variability cannot be made. For modeling purposes, the amount of random error estimated for the areas of fish passage neighboring the blind zone was applied to the extrapolated counts.	

logit Mission extrapolation proportion	The amount of uncertainty associated with this estimate can be estimated (see above).	
Mission set net opening hours (EO)	Fisheries activity is believed to alter fish behavior and potentially cause biased measurements.	
Mission set net opening hours (CL)	Fisheries activity is believed to alter fish behavior and potentially cause biased measurements.	
Mission drift net opening hours (EO)	Fisheries activity is believed to alter fish behavior and potentially cause biased measurements.	
Mission drift net opening hours (CL)	Fisheries activity is believed to alter fish behavior and potentially cause biased measurements.	
Mission drift net opening hours (CL LP)	Fisheries activity is believed to alter fish behavior and potentially cause biased measurements.	
Mission total opening hours	Fisheries activity is believed to alter fish behavior and potentially cause biased measurements.	yes
Qualark set net opening hours (EO)	Fisheries activity is believed to alter fish behavior and potentially cause biased measurements.	
Qualark set net opening hours (CL)	Fisheries activity is believed to alter fish behavior and potentially cause biased measurements.	
Qualark set net opening hours (CL LP)	Fisheries activity is believed to alter fish behavior and potentially cause biased measurements.	
Qualark drift net opening hours (EO)	Fisheries activity is believed to alter fish behavior and potentially cause biased measurements.	
Qualark drift net opening hours (CL)	Fisheries activity is believed to alter fish behavior and potentially cause biased measurements.	
Qualark total opening hours	Fisheries activity is believed to alter fish behavior and potentially cause biased measurements.	yes
Qualark offshore counts (bin 2 & 3)	Higher offshore counts might be an indication of changes in fish migration behavior.	yes

River discharge at Hope	River discharge affects the fish migration behaviour and might cause bias in measurements.	yes
River temperature at Qualark	River temperature might affect the behavior and travel speed of fish.	yes

A correlation analysis was performed to evaluate the level of cross-correlation between the candidate continuous covariates and narrow down the number of covariates used in the regression analyses (Figure 3). We used a correlation ( $r$ ) threshold of 50% to indicate a strong correlation and justify dropping one of the covariates as a potential explanatory variable in the regression analyses if  $r < 0.50$ . The correlation analysis showed that the fisheries-related variables at both the Mission and Qualark sites were highly correlated (Figure 3). For this reason, we decided to use the total fishing hours as indicators of fishing activity at both sites (Mission total opening hours and Qualark total opening hours). We also found that the water discharge measurement at Hope was strongly negatively correlated with both the mobile counts and the Mission left bank extrapolation proportion (Figure 3). We used the water discharge measurement at Hope as an indicator for these three variables.

In addition to the variables selected through the correlation analysis we also considered the interaction between the Mission Total Opening hours and the logit of mobile proportion, and the interaction between the Qualark total opening hours and the logit of Qualark offshore proportion. These interaction terms were considered because it is believed that after encountering fishing gear, fish tend to move offshore, despite the higher water flow encountered towards the center of the river.

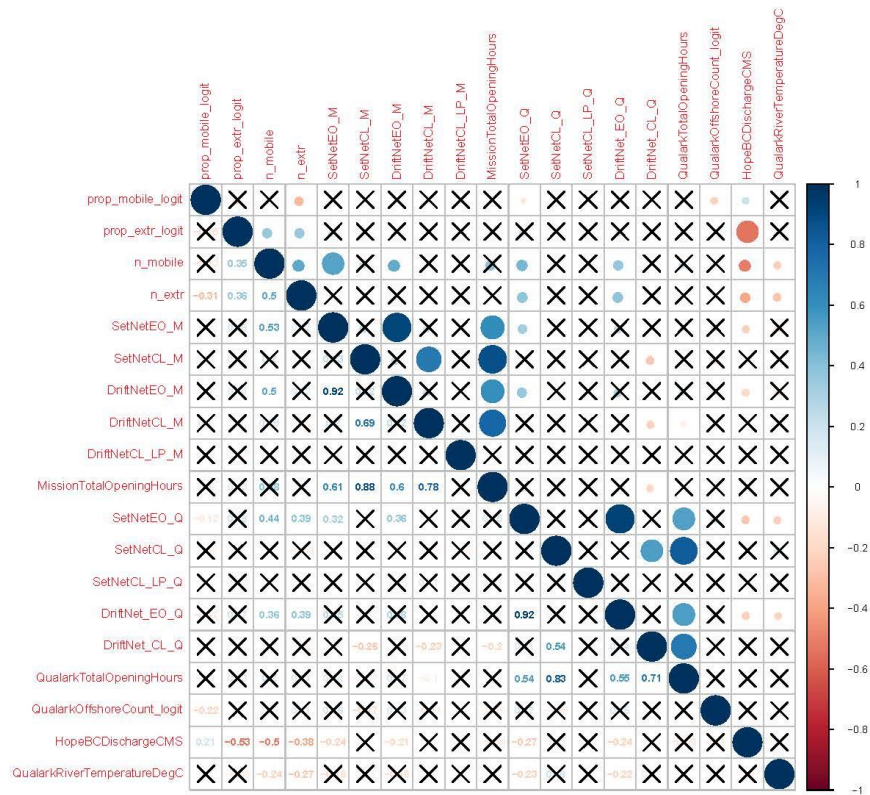


Figure 3 - Correlation between continuous covariates. Blue shades indicate positive correlation and red indicated negative correlations. 'X' indicates non-significant correlation with an alpha value of 0.05.

## 6.2 Presence/absence model

We modeled the presence-absence of significant PEDs with a binomial generalized linear model (GLM) with a logit link. We started the analysis by fitting the full model (considering all the pre-selected variables and interaction terms). In order to identify the best fitting model, we used the R function `drop1()`. This function works by dropping all the single terms from the model one at a time and computes a table of the changes in fit. The changes in fit are measured with an F-test. We followed the recommendation of `drop1()` and dropped the extrapolation counts, water discharge

at Hope, and the interaction terms. We kept the variable year despite the suggestion to drop it.

The final model coefficients are shown in Table 7. Only 7% of the total deviance was explained by the model. The  $\Delta AIC$  between the base model (all variables) and the final model (presented here) was 3.01, indicating that the final model was a better fit to the data. The variables year, Mission total opening hours, and river temperature at Qualark had significant effects (statistically different from zero, p-value < 0.05). The predicted effects indicate that the probability of a significant PED increases as the Mission total opening hours increases. Conversely, the probability of a significant PED decreases as temperature increases (Figure 4).

Table 7 - Coefficients from the binomial GLM fit to the presence/absence data of significant PEDs.

Parameter	Estimate	Std. Error	p-value	
Intercept	1.85	1.11	0.09	.
year (evenLow)	-0.29	0.39	0.45	
year (odd)	-0.61	0.29	0.04	*
logit of mobile proportion	-0.14	0.12	0.25	
Mission total opening hours	0.02	0.01	0.00	**
Qualark total opening hours	0.01	0.01	0.19	
river temperature at Qualark	-0.16	0.06	0.01	*
logit of Qualark offshore proportion	0.05	0.06	0.46	



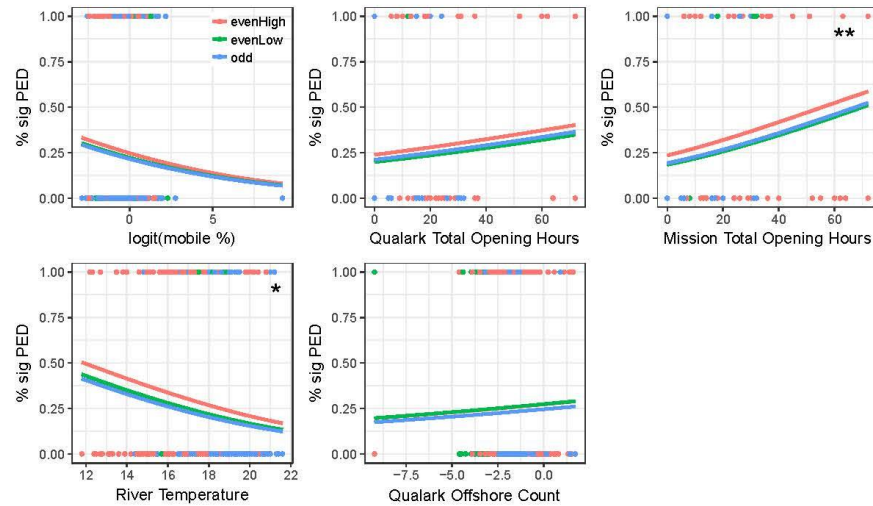


Figure 4 – Predicted effects of covariates on the probability of a significant PED occurring, if all other covariates are constant and equal to their mean.

### 6.3. Magnitude of significant PEDs model

We initially attempted to model the raw magnitude of PEDs; these data were negative when Mission was lower than Qualark, and positive when Mission was higher than Qualark. We initially assumed that these data were normally distributed. This initial model did not yield a good fit, as diagnosed with graphic model fit diagnostics and by the p-value of 29%. The next step was to transform the data by taking the absolute values of the PEDs and log-transforming the data, i.e., the response variable was  $\log(\text{abs}(\text{PED}))$ . We started with the same base explanatory variables that were used for the presence/absence data. Once again, we used the function `drop1()` to select the most parsimonious model. The function suggested we drop the river temperature at Qualark and the interactions terms. We followed those recommendation and the coefficients for the final model are shown in Table 8. Except for the logit of Qualark offshore proportion and Qualark total opening hours,

all coefficients were significant (statistically different from zero with  $p < 0.05$ ). The final model had an adjusted  $R^2$  of 71%. The extrapolation counts, Mission total opening hours, and Qualark total opening hours had a predicted positive effect on the log of absolute significant PEDs (Figure 5). The logit of mobile proportion and the water discharge at Hope had a negative predicted effect (Figure 5).

Table 8 - Coefficients from the lognormal GLM fit to the magnitude data of significant PEDs.

Parameter	Estimate	Std. Error	p-value	
Intercept	10.56	0.22	0.00	***
year (evenLow)	-0.38	0.22	0.09	.
year (odd)	-0.41	0.16	0.01	*
extrapolation counts	0.00	0.00	0.00	***
logit of mobile proportion	-0.39	0.07	0.00	***
Mission total opening hours	0.02	0.00	0.00	***
Qualark total opening hours	0.00	0.00	0.24	
water discharge at Hope	-0.00	0.00	0.00	***
logit of Qualark offshore proportion	0.01	0.03	0.87	

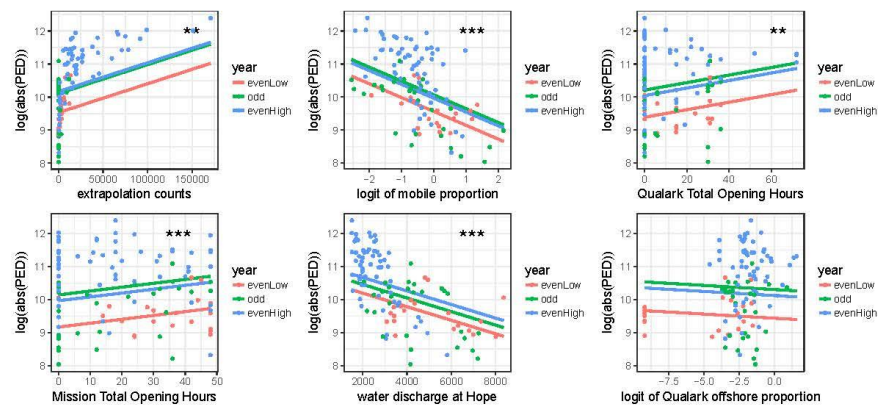


Figure 5 - Predicted effects of covariates on the log magnitude of a significant PED occurring, if all other covariates are constant and equal to their mean.

## 7. Key outputs and findings

### 7.1 ID significant PEDs

- A stochastic simulation statistical model to generate 95% confidence intervals for sockeye salmon passage estimates for the Mission and Qualark hydroacoustic stations was developed. Significant Passage Estimate Differences (PEDs) were identified as occurring on days when the 95% confidence intervals for the estimates of sockeye salmon passage at each of the sites did not overlap (after adjusting for migration time between the two sites).
- Significant PEDs were more frequent in the Adams-dominant years (2010 and 2014) and less frequent in lower abundance years (2008, 2009, and 2015). In the two Adams-dominant years in the dataset, 61 days with significant PEDs were identified in the 169 days examined (36% of the days). For comparison, during the other six years examined 48 days with significant PEDs were identified in the 258 days examined (19% of the days).
- Methodology for generating confidence intervals for passage estimates at both Mission and Qualark could be applied in-season, allowing for prompt identification of significant PEDs.
- Confidence intervals could also be incorporated in the calculation of management quantities, resulting in better accountability of the uncertainty associated with the measurements.

### 7.2 What is causing significant PEDs

- The list of potentially influential variables on passage estimates previously compiled by the PSC was expanded to include more detailed fishing information at Mission and mobile hydroacoustic measurements (in numbers and proportions).
- Correlation analysis between potentially influential factors was used to identify high correlation among factors and avoid multicollinearity in explaining occurrence and magnitude of significant PEDs. Correlations above 50% were considered strong and this criteria was used to narrow the number of covariates used in the regression analyses.
- The occurrence of PEDs was modeled with a binomial GLM. The variables year-type, Mission total fisheries opening hours, and river temperature were significant. However, the model fit for the occurrence model was poor with only 7% of the total deviance explained by the model.
- The absolute magnitude of PEDs was modeled with a log-normal GLM. The variables year-type, extrapolation counts, logit of mobile proportion,

Mission total opening hours, and water discharge at Hope were all significant. The model fit was significant with  $R^2 = 71\%$ .

- Although the magnitude GLM model yielded a good fit, it is important to note that the data had to be transformed to absolute values, therefore we cannot make inferences regarding the directionality of the significant differences.
- It seems unlikely that the GLM models would result in good predictive tools for the occurrence of significant PEDs in the future.

## References

Enzenhofer, H.J., Cronkite, G.M.W., and Holmes, J.A. 2010. Application of DIDSON imaging sonar at Qualark Creek on the Fraser River for enumeration of adult pacific salmon: An operational manual. Can. Tech.Rep. Fish. Aquat. Sci. 2869: iv +37 p.

Pacific Salmon Commission (2016). Summary of PSC Work Items for the Fraser River Strategic Review Committee (FSRC).

R Development Core Team (2008). R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0.

Walters, C. (2015). Comparison of Mission and Qualark Hydroacoustic Facilities for Providing Escapement Information for Management of Fraser River Sockeye and Pink Fisheries. 45 p.

Xie, Y. and Martens, F. J. (2014). An Empirical Approach for Estimating the Precision of Hydroacoustic Fish Counts by Systematic Hourly Sampling. North American Journal of Fisheries Management 34, 535–545.

**Appendix 1. Passage estimate confidence interval and differences in terms of percentage and absolute number.**

This appendix contains the figures with the confidence intervals for all years and the significant passage estimate differences shown in terms of percentage and absolute number. We used the Qualark estimate as reference so PEDs are positive when the Mission estimate is higher.

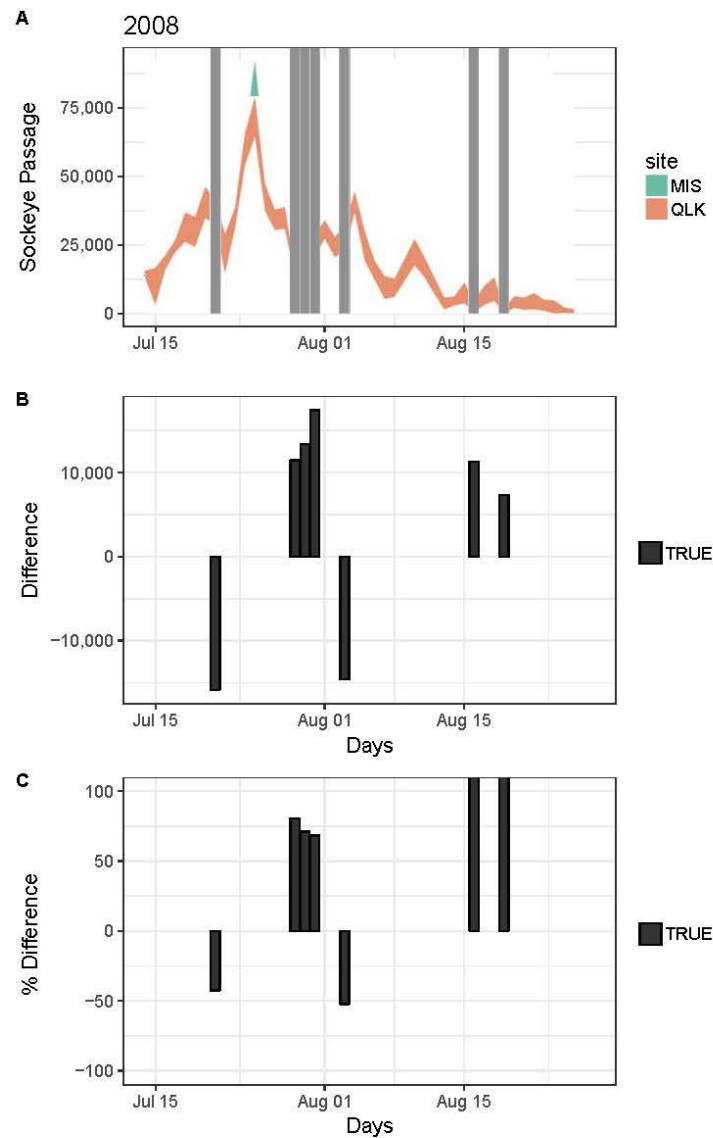


Figure A1 - A) Estimates and confidence intervals of sockeye salmon passage (bound to Qualark) at the Mission and Qualark hydroacoustic sites for 2008. B) Passage estimate differences for days when significant differences occurred. C) Passage estimate differences in % (relative to Qualark) for days when significant differences occurred.

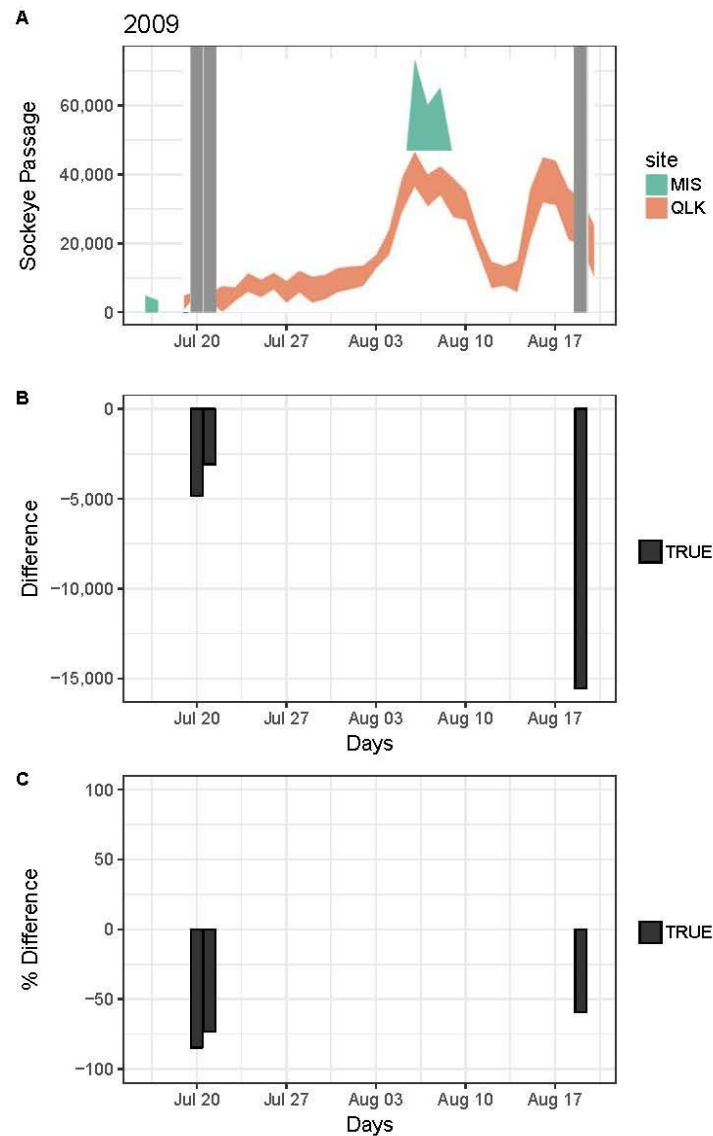


Figure A2 -A) Estimates and confidence intervals of sockeye salmon passage (bound to Qualark) at the Mission and Qualark hydroacoustic sites for 2009. B) Passage estimate differences for days when significant differences occurred. C) Passage estimate differences in % (relative to Qualark) for days when significant differences occurred.

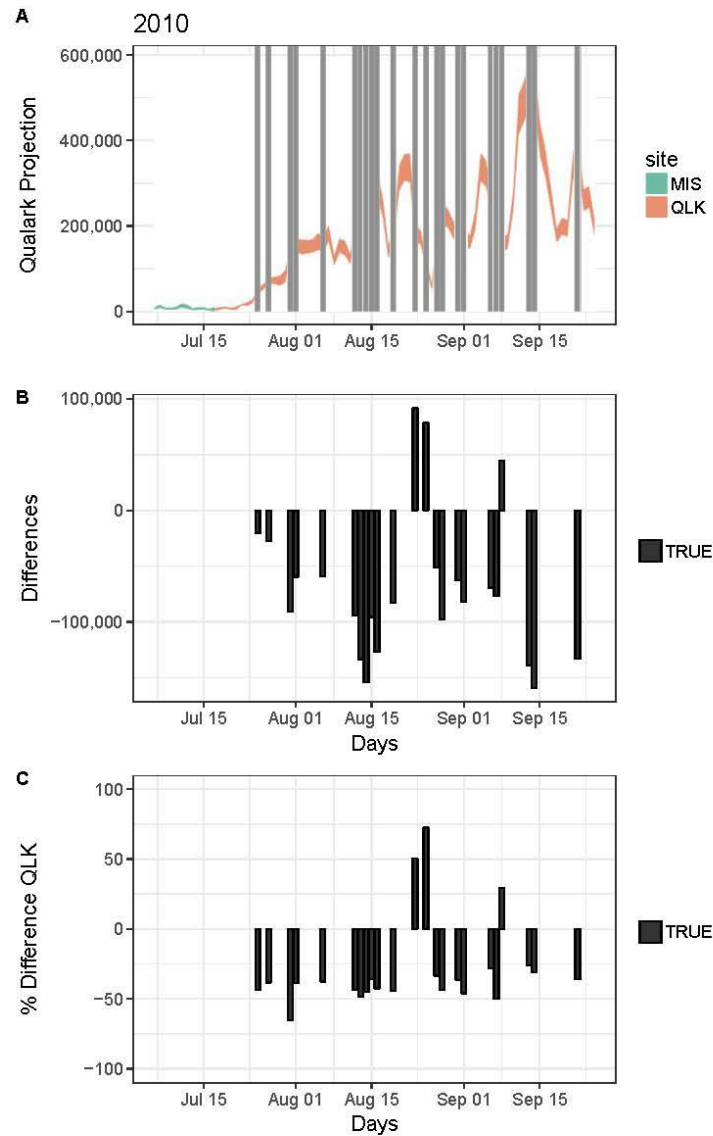


Figure A3 -A) Estimates and confidence intervals of sockeye salmon passage (bound to Qualark) at the Mission and Qualark hydroacoustic sites for 2010. B) Passage estimate differences for days when significant differences occurred. C) Passage estimate differences in % (relative to Qualark) for days when significant differences occurred.



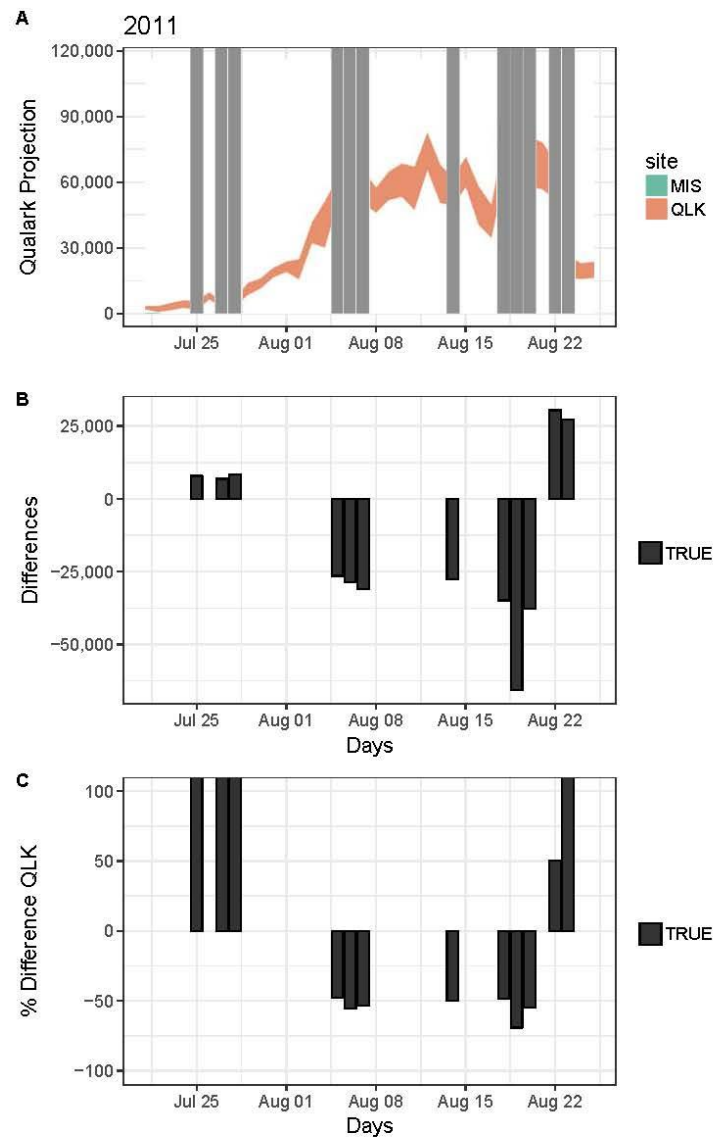


Figure A4 - A) Estimates and confidence intervals of sockeye salmon passage (bound to Qualark) at the Mission and Qualark hydroacoustic sites for 2011. B) Passage estimate differences for days when significant differences occurred. C) Passage estimate differences in % (relative to Qualark) for days when significant differences occurred.

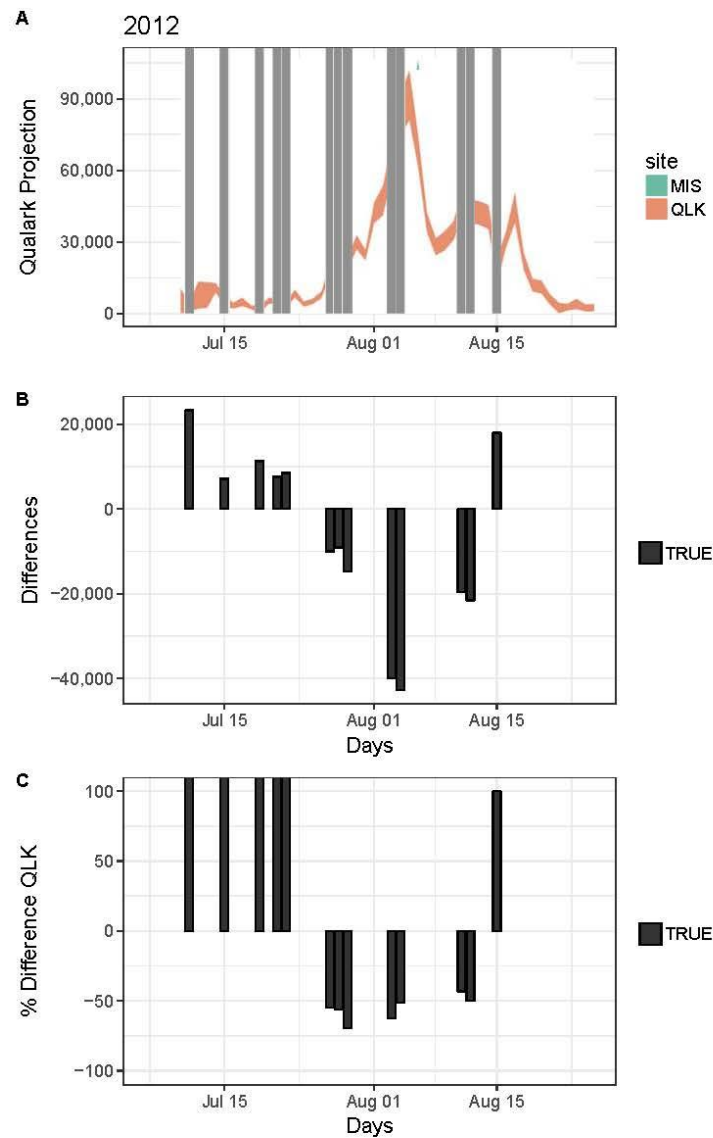


Figure A5- A) Estimates and confidence intervals of sockeye salmon passage (bound to Qualark) at the Mission and Qualark hydroacoustic sites for 2012. B) Passage estimate differences for days when significant differences occurred. C) Passage estimate differences in % (relative to Qualark) for days when significant differences occurred.

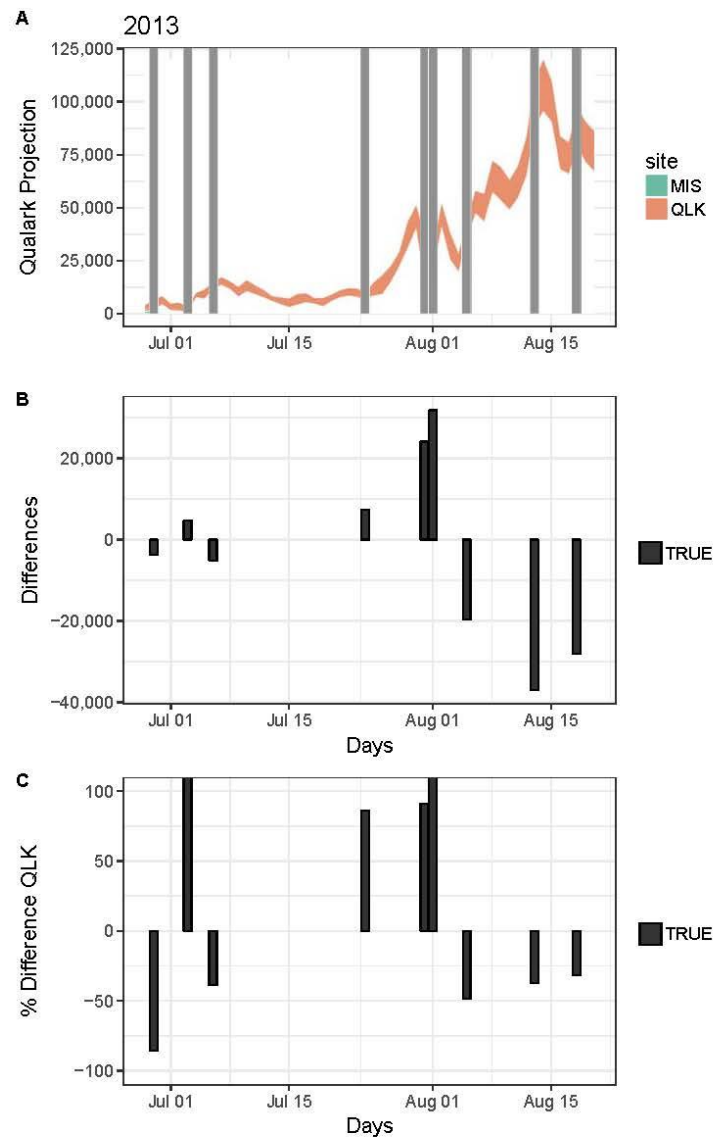


Figure A6- A) Estimates and confidence intervals of sockeye salmon passage (bound to Qualark) at the Mission and Qualark hydroacoustic sites for 2013. B) Passage estimate differences for days when significant differences occurred. C) Passage estimate differences in % (relative to Qualark) for days when significant differences occurred.

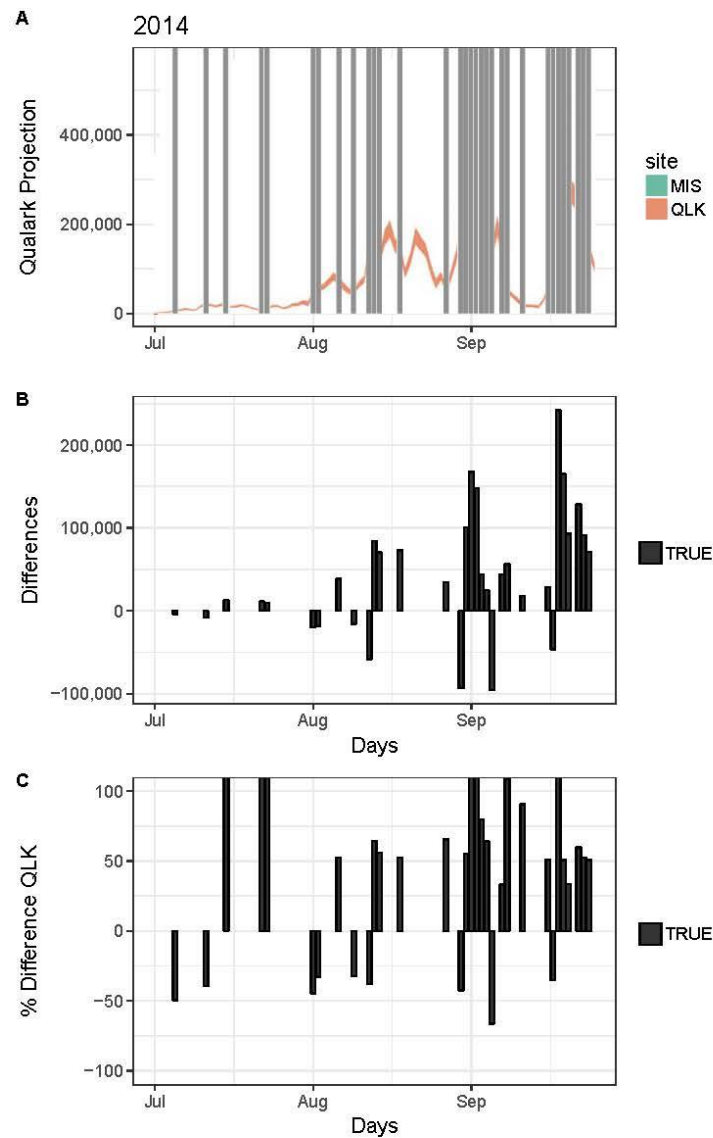


Figure A7 - A) Estimates and confidence intervals of sockeye salmon passage (bound to Qualark) at the Mission and Qualark hydroacoustic sites for 2014. B) Passage estimate differences for days when significant differences occurred. C) Passage estimate differences in % (relative to Qualark) for days when significant differences occurred.

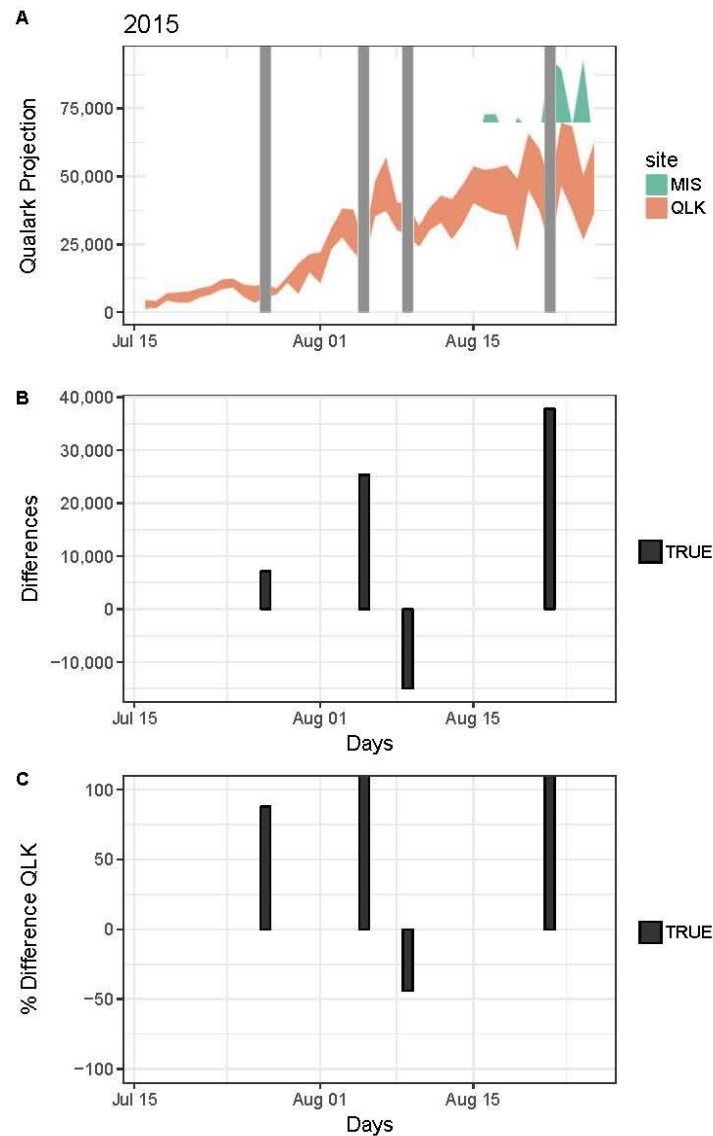


Figure A8 - A) Estimates and confidence intervals of sockeye salmon passage (bound to Qualark) at the Mission and Qualark hydroacoustic sites for 2015. B) Passage estimate differences for days when significant differences occurred. C) Passage estimate differences in % (relative to Qualark) for days when significant differences occurred.

## **Appendix 2. Manual for use of the model to reproduce the analysis in this report.**

### **Download analysis files**

All the files used in this data analysis are found in <https://github.com/catarinawor/salmonDFO> (private link). You can choose to download the files or fork and clone the repository if you are a github user. To get access to the folder, please contact Catarina Wor (write to [catarinawor@gmail.com](mailto:catarinawor@gmail.com))

### **Download data**

Upon request (write to [catarinawor@gmail.com](mailto:catarinawor@gmail.com)) if after July 7<sup>th</sup> 2017.

Remember to save all the .csv files in the same folder. The list of required CSV files is:

Mission\_LB\_hourly.csv, MissionByGear\_CV.csv, species\_comp\_mission.csv and Qualark\_hourly.csv

### **Re run the analysis in this report**

Once you have the analysis files in your computer, you will need to customize the directories.R file. This file contains all the paths that you will need to use in your analysis. A template for this file is found within the R folder, customize and save the directories\_template.R as directories.R

The second step is to calculate the confidence intervals for the passage estimates and the regression analyses on presence absence and magnitude of PEDs. To do that, run the file “calc\_CI\_all\_years.R” and follow all the instructions on the file.

## **Appendix 3. Manual for use of the model for generation of confidence interval for sockeye passage - new data.**

The steps for running the analysis on new data are available on the file “calc\_CI\_new\_years.R”.

### **Download analysis files**

All the files used in this data analysis are found in <https://github.com/catarinawor/salmonDFO> (private link). You can choose to download the files or fork and clone the repository if you are a github user. To get access to the folder, please contact Catarina Wor (write to [catarinawor@gmail.com](mailto:catarinawor@gmail.com)).

### **Format data**

#### **Mission data**

The mission data is divided in three spreadsheets: Hydroacoustic counts by gear, species composition and stock composition. The column names and descriptions of each spreadsheets are given below.

**Mission daily counts by gear (expMIS\_day\_all\_yrs.csv)**

The columns of this spreadsheet are:

**date** : formatted as "2008-06-15"

**MisTotal**: Total salmon counts by gear for the entire mission system

**MisSockeye**: Total sockeye daily counts by gear for the entire mission system

**year**: four digit year formatted as "2008"

**MisLBD1**: Mission daily counts for left bank D1

**MisLBS1**: Mission daily counts for left bank S1

**MisLBext**: Mission daily counts for left bank extrapolation (blind zone)

**MisM**: Mission daily counts for mobile gear

**MisRBD3**: Mission daily counts for right bank D3

**MisRBD2**: Mission daily counts for right bank D2

**Mis\_sigma\_LBD1**: Daily Standard deviations for measurement left bank D1

**Mis\_sigma\_LBS1**: Daily Standard deviations for measurement left bank S1

**Mis\_sigma\_Lbext**: Daily Standard deviations for measurement left bank extrapolation.

**Mis\_sigma\_M**: Daily Standard deviations for measurement mobile gear.

**Mis\_sigma\_RBD3**: Daily Standard deviations for measurement right bank D3.

**Mis\_sigma\_RBD2**: Daily Standard deviations for measurement right bank D2.

**Mission species composition "sample\_spcomps\_all.csv"**

**date**: formatted as "2008-06-15" – Same dates for the hydroacoustic counts

**salmon\_sample\_size**: Sample size used to generate the species composition proportions.

**Mission stock composition ("MIS\_Stk\_day\_all\_yrs.csv")**

**date:** formatted as “2008-06-15” – Same dates for the hydroacoustic counts

**year:** four digit year formatted like “2008”

**lv\_Chilliwack:** proportion of sockeye stocks that leave the Fraser river at the Chilliwack confluence.

**lv\_Harrison:** proportion of sockeye stocks that leave the Fraser river at the Harrison confluence.

**stay:** proportion of sockeye stocks that stay in the Fraser river past the Qualark hydroacoustic station.

**nw\_Total:** sample size used to generate the stock composition proportions

#### **Qualark data**

##### **Qualark daily hydroacoustic counts (“expQLK\_day\_all\_yrs.csv”):**

**date:** adjusted “Mission dates” . formatted as “2008-06-15” – Same dates for the Mission hydroacoustic counts

**year:** four digit year formatted like “2008”.

**count:** combined hydroacoustic counts for all gears at the qualark site

##### **Qualark daily species composition:**

**date:** adjusted “Mission dates” . formatted as “2008-06-15” – Same dates for the Mission hydroacoustic counts

**sockeye:** number of Sockeye caught in a day by the test fisheries

**chinook:** number of Chinook caught in a day by the test fisheries

**coho:** number of Coho caught in a day by the test fisheries

**pink:** number of Pink caught in a day by the test fisheries

**sample\_size:** Total number of Fish caught by the Qualark test fisheries in a day

#### **Run analysis**

Once the input data is formatted all the files should be saved in the data\_dir (specified in the directories.R file). Once data is saved an properly formatted, follow the instructions on the “calc\_CI\_new\_years.R” file.



**Appendix 4. Manual to implement the species composition correction at Qualark based on the species CPUE and total fish passage - Appendix E of Walters report (2015).**

In addition to the analysis described in the main body of this report, we also wrote the code for implementing the species composition correction described in Appendix E of the Walters report. The implementation of this code was conducted after the main analysis had been completed and, for this reason, the correction was not used in the main analysis.

This analysis has two steps: 1) Calculate the daily CPUE for the fish caught at the Qualark site. 2) Implement the species composition correction.

1) Calculate the daily CPUE for the fish caught at the Qualark site

This part of the analysis can be found on the R file `data_process/calc_QLK_CPUE.R`. Run this file line by line. To make sure you get no errors. The example input data file is `test_fisheries_qlk.csv` and includes the test fisheries data for the years 2008 to 2010. If the analysis is to be expanded, it is highly recommended that the formatting of the data stay the same as the one in `test_fisheries_qlk.csv`. The code in `calc_QLK_CPUE.R` processes the test fisheries data and calculates the CPUE based on net length – default to 30 m – and the duration of the sets in minutes. The CPUE time series are then expanded so that all years have data from June 15<sup>th</sup> to October 15<sup>th</sup>. NAs are inserted when data for a given day are not available. This measure helps with the plotting later.

2) Implement the species composition correction.

This code is found on the file `data_process/correct_Qual_catch.R`. This file contains two separate sections: a) Correct the species composition based on the CPUE calculated in the previous step. b) reproduce the analysis shown in the Walters report. This file too should be run line by line.

## PART 2

# Appendix 1: 5-species Proportion Correction Model

## MEMO

**From:** Yunbo Xie

**To:** Technical Working Group for Fraser Strategic Review Committee

**CC:** Catherine Michielsens, Fiona Martens

**Date:** June 28, 2019

**RE:**

1. A mathematical correction model for catch per unit effort (CPUE)-based species proportion estimates of 5 species;
2. Fitting of Qualark and Whonnock CPUE data to a 5-species model to estimate *relative* catchabilities for salmon species at the 2 test fishing sites;
3. CPUE-based vs. correction model-based sockeye estimates;
4. Derivations of  $K$ -species correction model;
5. Prediction of the occurrence of maximum sockeye bias.

## Background

Multiple methods have been used to estimate species composition at the Mission hydroacoustic site (contact PSC fisheries management division for details). At Qualark hydroacoustics site, species proportions have been derived from Qualark test-fishing catch proportions of salmon species assuming all salmon species are equally vulnerable to the fishing net or equivalently the net has the same catchability for all species. In October 2015, Professor Carl Walters, a consultant to review the Mission and Qualark programs, submitted a report to the Fraser Strategic Review Committee (FSRC) on his assessment based on the sockeye escapement data produced by the two programs from 2008-2015. In the report, he identified a potential bias in proportioning salmon species using test fishing catches due to unequal catchabilities among species, especially for sockeye, pink, and Chinook salmon. He proposed a mathematical model to derive the ‘true’ proportions by removing the effect of non-equal catchabilities from catch per unit effort (CPUE)-based proportion estimates. To illustrate the principle of this model, Professor Walters provided the mathematical expressions of corrected sockeye proportions for 2-species (sockeye and pink) and 3-species (sockeye, pink, Chinook) (see eq. (E4) and (E5) in Walter’s Report). Since that report, the equations have been reviewed and rectified for their mathematical

singularities. The model has now extended to and incorporated into a model that accounts for all five species of Pacific Salmon. Furthermore, a larger data set including recent years (2008 - 2018) has been included in the fitting tests of the model for its robustness and stability in the estimation of key parameters. The following memo describes the 5-species correction model and its application at the Mission and Qualark Hydroacoustics sites.

## 1. A mathematical correction model for CPUE-based species proportion estimates of $K$ species

### a. *K-species proportion correction model*

If a test-fishing operation targets  $K$  species, the correction model for CPUE-based proportion estimates of individual species are given by Formula (2) using the following variables:

- Catchability of the bench-mark species  $s$ :  $q_s$
- Relative catchability (wrt  $q_s$ ) of species  $j$ :  $R_j = q_j/q_s$
- CPUE-based observed proportion of species  $j$ :  $P_{oj}$
- True proportion of species  $j$ :  $P_j$
- Observed proportion of the bench-mark species  $s$ :  $P_{os}$
- True proportion of the bench-mark species  $s$ :  $P_s$

$$P_s = \frac{P_{os}}{\sum_{i=1}^k \left[ \frac{P_{oi}}{R_i} \right]} \quad (1)$$

$$P_j = \frac{P_{oj}/R_j}{\sum_{i=1}^k \left[ \frac{P_{oi}}{R_i} \right]}, \quad j = 1, 2, \dots, k \quad (2)$$

Formula (2) is a general expression for any of the  $K$  species, including the bench-mark species. Setting  $j$  to  $s$  in (2) leads (2) to (1). It is also evident from (2) that  $\sum_{j=1}^k P_j = 1$ . Detailed derivations of (2) are provided in section 4a.

*b. 5-species correction model*

If the catch data comprises 5 species denoted as *s* (sockeye), *p* (pink), *c* (Chinook), *cm* (chum), and *co* (coho), choosing sockeye as the bench-mark species, according to Formula (2) the corrected proportions for the 5 species are:

$$P_s = \frac{P_{os}}{P_{os} + \frac{P_{op}}{R_p} + \frac{P_{oc}}{R_c} + \frac{P_{o\_cm}}{R_{cm}} + \frac{P_{o\_co}}{R_{co}}} \quad (3)$$

$$P_p = \frac{P_{op}/R_p}{P_{os} + \frac{P_{op}}{R_p} + \frac{P_{oc}}{R_c} + \frac{P_{o\_cm}}{R_{cm}} + \frac{P_{o\_co}}{R_{co}}} \quad (4)$$

$$P_c = \frac{P_{oc}/R_c}{P_{os} + \frac{P_{op}}{R_p} + \frac{P_{oc}}{R_c} + \frac{P_{o\_cm}}{R_{cm}} + \frac{P_{o\_co}}{R_{co}}} \quad (5)$$

$$P_{cm} = \frac{P_{o\_cm}/R_{cm}}{P_{os} + \frac{P_{op}}{R_p} + \frac{P_{oc}}{R_c} + \frac{P_{o\_cm}}{R_{cm}} + \frac{P_{o\_co}}{R_{co}}} \quad (6)$$

$$P_{co} = \frac{P_{o\_co}/R_{co}}{P_{os} + \frac{P_{op}}{R_p} + \frac{P_{oc}}{R_c} + \frac{P_{o\_cm}}{R_{cm}} + \frac{P_{o\_co}}{R_{co}}} \quad (7)$$

Formula (2) can readily accommodate catch data that comprises more than 5 species such as 5 salmon species plus steelhead. In fact, one can simply add one more term to the denominator of the above formulae ( $P_{o\_steelhead}/R_{steelhead}$ ) to accommodate the 6 species CPUE data.

*c. The nonlinear CPUE models for K species*

Following the gillnet catchability models (Eq. (5) of Link and Petermans 1998 for mono-species, and Eq. (E1) of Walters 2015 for multi-species), we have the following CPUE expressions denoted as  $Y$ 's, for  $K$  species:

$$Y_j = \frac{q_j N_j}{1 + \sum_{i=1}^k h_i q_i N_i} \quad , \quad j = 1, 2, \dots, k \quad (8)$$

where  $q_j$  is the catchability for species  $j$ , and  $N_j$  is the abundance. The term  $h_j$  represents the net saturation factor, which is the inverse of the maximum CPUE of species  $j$  when  $N_j$  approaches a very large number beyond the capacity of the net for species  $j$ . This can be seen by letting  $N_j$  become so large that  $h_j q_j N_j$  in the denominator of (3) is much greater than any other terms in the denominator such that

$$Y_j|_{max} = \frac{q_j N_j}{1 + \sum_{i=1}^k h_i q_i N_i} \Big|_{h_j q_j N_j \gg \text{much greater than other terms}} \approx \frac{q_j N_j}{h_j q_j N_j} = \frac{1}{h_j} \quad (9)$$

Using relative catchability of species  $j$  to the bench-mark species  $s$ :  $R_j = q_j/q_s$ , and true proportion of species  $j$ :  $P_j = N_j/N$  with  $N$  being the total abundance of all  $K$  species, Eqn. (8) can be rewritten as:

$$Y_j = \frac{q_s R_j P_j N}{1 + q_s N \sum_{i=1}^k h_i R_i P_i} \quad , \quad j = 1, 2, \dots, k \quad (10)$$

*d. The nonlinear CPUE models for the 5 salmon species*

For the 5 Fraser salmon species of sockeye, pink, Chinook, chum, and coho, the corresponding CPUE models are (derived from eq. 10):

$$Y_s = \frac{q_s P_s N}{1 + q_s N (h_s P_s + h_p R_p P_p + h_c R_c P_c + h_{cm} R_{cm} P_{cm} + h_{co} R_{co} P_{co})} \quad (11)$$

$$Y_p = \frac{q_s R_p P_p N}{1 + q_s N (h_s P_s + h_p R_p P_p + h_c R_c P_c + h_{cm} R_{cm} P_{cm} + h_{co} R_{co} P_{co})} \quad (12)$$

$$Y_c = \frac{q_s R_c P_c N}{1 + q_s N (h_s P_s + h_p R_p P_p + h_c R_c P_c + h_{cm} R_{cm} P_{cm} + h_{co} R_{co} P_{co})} \quad (13)$$

$$Y_{cm} = \frac{q_s R_{cm} P_{cm} N}{1 + q_s N (h_s P_s + h_p R_p P_p + h_c R_c P_c + h_{cm} R_{cm} P_{cm} + h_{co} R_{co} P_{co})} \quad (14)$$

$$Y_{cm} = \frac{q_s R_{co} P_{co} N}{1 + q_s N (h_s P_s + h_p R_p P_p + h_c R_c P_c + h_{cm} R_{cm} P_{cm} + h_{co} R_{co} P_{co})} \quad (15)$$

where true proportions of the 5 species  $P_s, P_p, P_c, P_{cm}$ , and  $P_{co}$  are given by Eqns. (3)-(7).

## 2. Fitting of Qualark and Whonnock CPUE data to a 5-species model

### a. Data-based estimates of model parameters of the 5-species CPUE models

In the right-hand sides (RHS's) of the CPUE models of (11)-(15), together with (3)-(7), there are a total of 10 parameters which define the models. These parameters are

- Catchability of sockeye:  $q_s$ ;
- Relative catchability (wrt  $q_s$ ) of pink, Chinook, chum and coho salmon:  $R_p, R_c, R_{cm}, R_{co}$ ;
- Saturation factors for the 5 species:  $h_s, h_p, h_c, h_{cm}, h_{co}$ .

If catch (or CPUE) data for the 5 species are available, then the catch data can be substituted to the left-hand sides (LHS's) of (11)-(15) to match the RHS's of the formulas under a set of particular values of the 10 parameters so that the models best represent the data. In the following we present a mathematical approach to search for global solutions to these particular values by minimizing the error function of  $E$  defined as follows:

$$E = (Y_s - \hat{Y}_s)^2 + (Y_p - \hat{Y}_p)^2 + (Y_c - \hat{Y}_c)^2 + (Y_{cm} - \hat{Y}_{cm})^2 + (Y_{co} - \hat{Y}_{co})^2 \quad (16)$$

where variables with ^ are the CPUE data for the corresponding species while variables without ^ are given by the RHSs of (11)-(15).  $E$  is a function of the 10 parameters. Our goal is to search for a set of values for the parameters in this error function so that  $E$  is minimized globally. Our approach is to find a best fit of the 5-species CPUE data to the model using Newtonian nonlinear minimization (*nlm*) algorithms provided under the *R* statistical package. We employed a suite of *nlm* algorithms to search for the global minimum of (16), which led to a suite of numerical outputs as solution candidates for minimizing  $E$ . Only the candidates producing the minimum value of  $E$  with a close-to-zero gradient are chosen as the solutions. A summary description of these *nlm* algorithms can be found under *R*'s help documentation (The R Foundation for Statistical Computation. 2016. R version 3.3.1. <http://www.r-project.org/>).

*b. Parameter Estimates for Qualark site based on Qualark catch data from 2008-2018*

A total of 769 days of daily catch data at the Qualark site from 2008-2018 seasons (excluding 2010 data; see Walters 2015 for comments on the 2010 data) were used for parameter estimates from Eq. (16) using nonlinear minimization algorithms described previously. The best solutions were obtained by the unconstrained (or box constrained) minimization algorithm of *nlnmb*. The estimates of the 10 parameters are listed in Table 1. The model fit results are shown in Figure 1. Note: the Qualark data used in this analysis and in Walters (2015) were daily salmon catches.

**Table 1.** Estimated model parameters for Qualark site based on daily Qualark test-fish catch data from 2008-2018 seasons (excl. data from 2010 season). Values in row 3 are the inverses of values in row 2 (saturation factor).

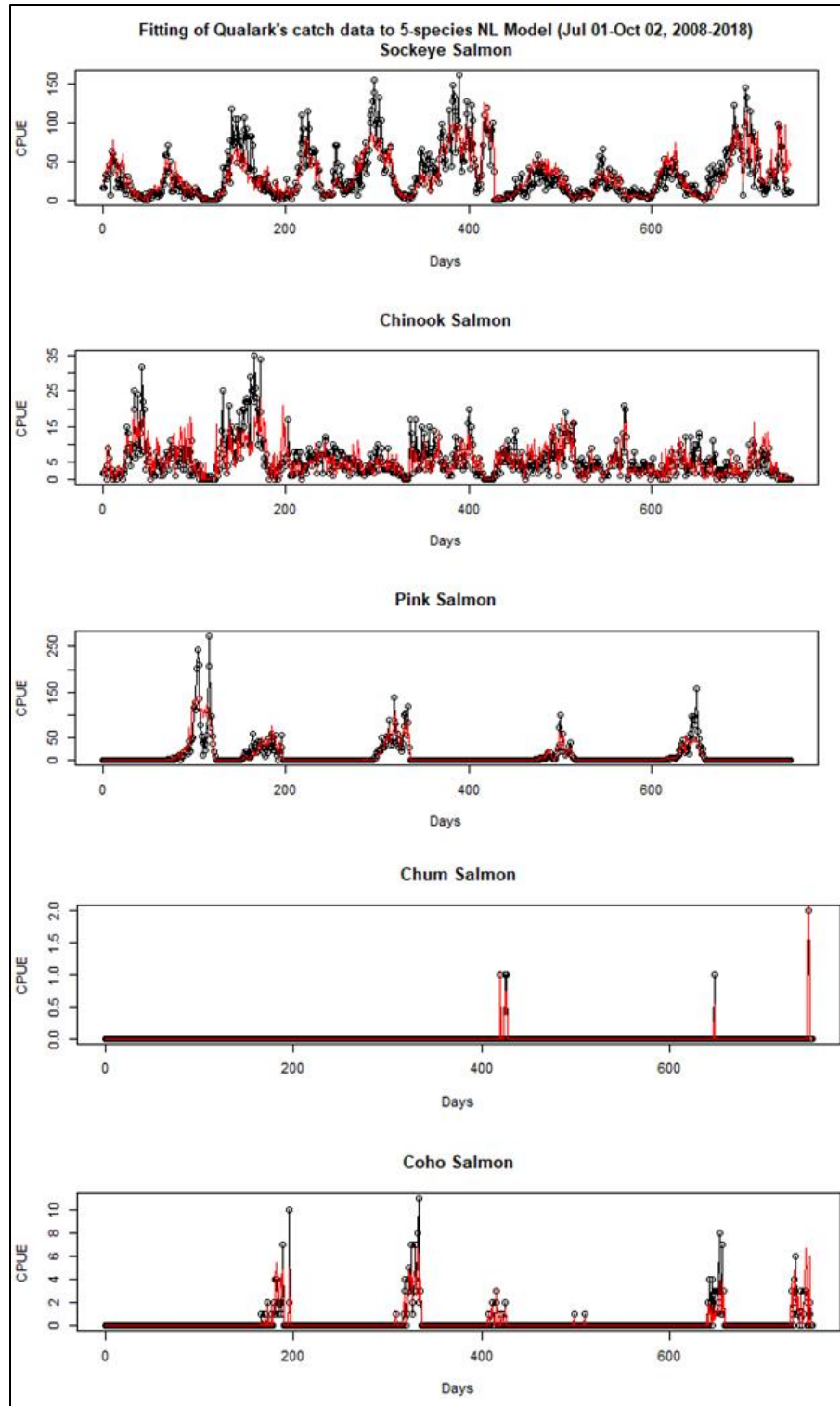
species	sockeye	pink	Chinook	chum	coho
catchability	$q_s=0.0024$	$R_p=0.531$	$R_c=1.447$	$R_{cm}=1.290$	$R_{co}=1.175$
saturation factor	$h_s=0.0067$	$h_p=0.0045$	$h_c=0.0286$	$h_{cm}=0.1153$	$h_{co}=0.0818$
max CPUE	149	220	35	9	12

The estimated catchabilities by fitting the data to the model appear to be reasonable and stable for sockeye, pink and Chinook. However, estimated catchabilities for chum and coho are very sensitive to the imported segment of the data, making estimated  $R_{cm}$  and  $R_{co}$  unreliable. We do not recommend treating the values for chum and coho in Table 1 as reliable estimates due to the following observations of data features:

- (1) The occurrences of chum and coho are extremely impulsive, meaning no catches for these species until to the very end of a monitoring season (see the two bottom panels in Fig. 1);
- (2) When they do occur in the catch, their numbers (on a season basis) are extremely small compared to catches of other primary species (on a seasonal basis). For instance, over the 10 years (2008-2018), there were a total of 227 coho and only 7 chums caught at Qualark while for sockeye, pink and chinook, the total is: 24,000, 7,700, and 4,200, respectively.

From time series point of view, such impulsive data series with many zeros should have minimum impact on the error function  $E$  (eq.16) on parameters estimates for sockeye, pink and chinook, but it can also make  $E$  insensitive to variations of parameters relating to coho and chum, meaning parameters associated with chum and coho can have a very large range of variations yet, these variations do not significantly affect stabilities of parameters for sockeye, pink and Chinook. The information from the data for chum and coho is likely too little to obtain reliable parameter estimates for these two species as the data is heavily weighted by catches of sockeye, pink and Chinook.





**Figure 1.** Time series of fittings of 5-species catch data (black) to the 5-species CPUE models (red) of Eqns. (11) - (15). Data: daily salmon catch at Qualark site from 2008-2018 seasons (excl. 2010).

c. Parameter Estimates for Mission site based on Whonnock CPUE data from 2008-2018

A total of 839 days of daily CPUE data from 2008-2018 seasons acquired from Whonnock test-fish program were used for the estimates of the 10 parameters. The best solutions were obtained by the unconstrained (or box constrained) minimization algorithm of *nlsminb*. The estimates of the 10 parameters are listed in Table 2. The model fit results are shown in Figure 2.

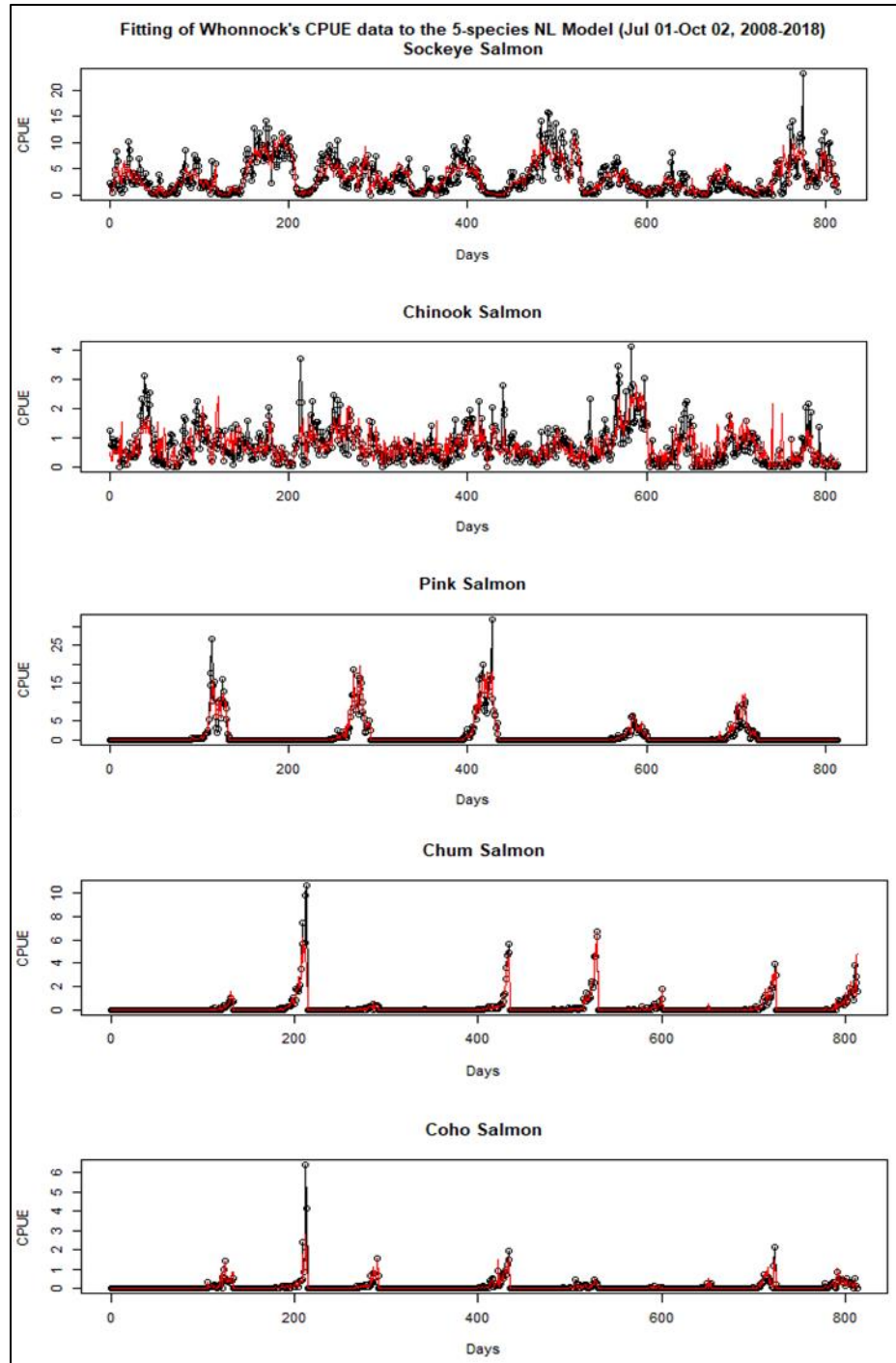
**Table 2.** Estimated model parameters based on daily CPUE data from 2008-2018 seasons from Whonnock, BC test-fish program. Values in row 3 are the inverses of values in row 2 (saturation factor).

species	sockeye	pink	chinook	chum	coho
catchability	$q_s=0.00018$	$R_p=0.583$	$R_c=1.271$	$R_{cm}=3.474$	$R_{co}=5.518$
saturation factor	$h_s=0.07369$	$h_p=0.01856$	$h_c=0.2463$	$h_{cm}=0.078$	$h_{co}=0.0549$
max CPUE	13.57	53.89	4.06	12.83	18.22

The estimated catchabilities by fitting the data to the model appear to be reasonable and stable for sockeye, pink and Chinook. However, estimated catchabilities for chum and coho are very sensitive to the imported segment of the data, making estimated  $R_{cm}$  and  $R_{co}$  unreliable. We do not recommend treating the values for chum and coho in Table 2 as reliable estimates due to the following observations of data features:

- (1) Chum and coho CPUE time series are also impulsive (see the two bottom panels in Fig. 2) though the spikes (the pulsing durations) are slightly wider compared to Qualark's chum and coho data;
- (2) Over the 11 years (2008-2018), there were a total of 1,126 coho and 3,228 chums caught at Whonnock while for sockeye, pink and chinook, the total is: 38,000, 15,400, and 7,700, respectively.

For the same reasons as observed in Qualark's catch data, the information from Whonnock's catch data for chum and coho is likely too little to obtain reliable parameter estimates for these two species as the data is heavily weighted by catches of sockeye, pink and Chinook.



**Figure 2.** Time series of data fit of 5-species CPUE data (black) to the 5-species CPUE model (red) of Eqns. (11)-(15). Data: daily salmon CPUE data at Whonnock, BC from 2008-2018 seasons.

### 3. CPUE-based vs. correction model-based sockeye estimates

#### *a. Estimate of Chinook salmon at Mission by the correction model based on Whonnock parameters*

Using the parameters estimated from Whonnock CPUE data from 2008-2018 (Table 2), with equation (13), we can numerically calculate the Chinook abundance for the monitoring periods of these years between the two methods. For comparison purpose, we list in Table 3 both uncorrected (assume equal catchabilities across all species) and corrected (corrected for unequal catchability w.r.t. sockeye) Chinook abundances.

**Table 3.** Comparisons between CPUE-based and 5-species correction-model-based Chinook escapement estimates at Mission from 2008-2018 seasons.

Years	Monitoring Period	Chinook Escapement at Mission	
		CPUE Method	5-species Correction Model
2008	Jul 10 - Aug 23	298,530	253,273
2009	Jun 25 - Sep 24	900,812	612,268
2010	Jul 07 - Oct 03	769,421	808,360
2011	Jul 11 - Sep 27	1,309,969	890,319
2012	Jul 06 - Aug 26	237,192	199,669
2013	Jun 26 - Sep 26	1,189,303	806,668
2014	Jun 28 - Oct 01	783,018	664,234
2015	Jul 11 - Sep 20	1,579,315	1,025,336
2016	Jul 08 - Aug 29	188,163	167,767
2017	Jul 07 - Sep 25	602,191	409,158
2018	Jul 05 - Oct 09	329,603	285,194
Grand Total	839 days of estimates	8,187,518	6,122,246

Footnotes to Table 3: Not listed are the PSC adopted Chinook estimates which were based on a suite of estimators, including historic daily means and 95% percentiles (contact PSC fisheries management division for details). The total Chinook adopted by PSC for in-season management for the same period is 3.6M.

The CPUE method generated 2M more Chinook than the 5-species correction model, potentially deflating the sockeye estimate had it been used to estimate Chinook escapement at Mission.

#### *b. Potential bias effect of CPUE based Chinook estimate on Mission sockeye estimate in non-pink return years*

The impact of inflated Chinook estimates (based on the CPUE method) on sockeye estimates is best demonstrated by escapement data from non-pink return years (even years) as the estimate is

not subject to pink salmon bias leaving Chinook as the sole source of species estimate bias (the interferences from chum and coho salmon can be ignored for most part of the monitoring periods). From 2008-2018, we identified 6 even years when the largest bias in species proportion estimates was likely due to the test fishing CPUE-based Chinook proportion. Table 4 summarizes the numerical differences between CPUE based and 5-species correction model based sockeye estimates for the 6 non-pink years.

**Table 4.** Numerical differences between CPUE-based and 5-species correction model-based sockeye escapement estimates at Mission in non-pink return years between 2008 and 2018.

Years	Monitoring Period	Sockeye Escapement at Mission		Mission Sockeye Difference
		CPUE Method	5-species Correction Model	(CPUE_Est – Correction Model_Est)
2008	Jul 10 - Aug 23	1,347,398	1,392,655	-45,257
2010	Jul 07 - Oct03	11,004,640	11,490,389	-485,750
2012	Jul 06 - Aug 26	1,625,007	1,662,530	-37,523
2014	Jun 28 - Oct 01	9,072,636	9,636,633	-563,997
2016	Jul 08 - Aug 29	628,334	659,588	-31,254
2018	Jul 05 - Oct 09	5,165,765	5,503,970	-338,206
Grand Total	423 days of estimates	28,843,779	30,345,765	-1,501,986

**Footnotes to Table 4:** Not listed are the PSC adopted sockeye estimates which were derived from a suite of estimators for the removal of Chinook, including historic daily means and 95% percentiles (contact PSC fisheries management division for details). The total sockeye adopted by PSC for in-season management for the same period is 32M.

Differences in Table 4 show that if the CPUE method had been used to estimate escapement at Mission in those years, the inflated Chinook proportion would have resulted in an overall underestimation of sockeye abundance by 5%. The differences are directional across all non-pink return years, and the magnitude of differences in dominant return years (2010, 2014, 2018) is in the order of 0.5M.

*c. Estimate of pink salmon at Qualark by the correction model based on Qualark parameters*

Using the parameters estimated from Qualark catch data from 2008-2018 (Table 1), with Equation (12), we can calculate the pink salmon abundance. For comparison purposes, we list in

Table 5 both uncorrected (assume equal catchabilities across all species) and corrected (corrected for unequal catchability) pink salmon abundances.

**Table 5.** Comparisons between CPUE-based and 5-species correction model-based pink salmon estimates at Qualark from 2008-2018 seasons.

Years	Monitoring Period	Pink Escapement at Qualark	
		CPUE Method	5-species Correction Model
2009	Jul 18 - Oct 02	5,999,956	6,390,065
2011	Jul 22 - Oct 03	2,702,514	3,535,801
2013	Jun 30 - Sep 28	4,047,222	4,856,347
2015	Jun 28 - Sep 23	894,340	1,254,704
2017	Jul 02 - Sep 24	1,095,716	1,362,147
Grand Total	415 days of estimates	14,739,748	17,399,064

The overall difference between the two methods is 2.67M, with the CPUE method producing an estimate of pink salmon escapement 18% lower than the 5-species correction model.

*d. Potential bias effect of CPUE-based pink salmon estimate on Qualark sockeye estimate in pink salmon return years*

The impact of potentially deflated pink salmon estimates (based on the CPUE method) on sockeye estimates in pink return years is summarized in Table 6.

**Table 6.** Differences between CPUE based and 5-species correction model-based sockeye escapement estimates at Qualark in pink return years between 2008 and 2018.

Years	Monitoring Period	Sockeye Escapement at Qualark		Qualark Sockeye Differences
		CPUE Method	5-species Correction Model	(CPUE Est - Model Est)
2009	Jul 18 - Oct 02	1,187,367	996,905	190,462
2011	Jul 22 - Oct 03	2,883,881	2,516,396	367,484
2013	Jun 30 - Sep 28	3,976,922	3,410,972	565,950
2015	Jun 28 - Sep 23	1,820,595	1,682,983	137,612
2017	Jul 02 - Sep 24	1,321,510	1,183,621	137,890
Grand Total	415 days of estimates	11,190,276	9,790,878	1,399,398

Differences in Table 6 show that the deflated pink salmon proportion, combined with inflated Chinook salmon proportion estimated by the CPUE method resulted in an estimate of sockeye abundance 12.5% higher or 1.4M more than that produced by the 5-species correction model for the five pink salmon return seasons. It should be noted that in Walters (2015), a 2-species correction model (sockeye vs. pink) was used to generate a corrected estimate of sockeye abundance for 2009, 2011, 2013 and 2015 seasons. Because of the limitation of the 2-species model, the model is incapable of including correction for Chinook bias when correcting sockeye estimates resulting in a ‘2-species model corrected sockeye estimate’ that contains estimation error from Chinook. Therefore, the 5-species correction is more appropriate for the correction than the 2-species model. Using the same data as in Walters (2015), for a total CPUE method-based Qualark sockeye of 9.9M, Walters (2015) produces a total of 8M sockeye using a 2-species correction model (see Table E1 in Walters 2015) while the 5-species model produces a total of 8.6M sockeye. The reason for a reduced correction by the 5-species model (in comparison to the 2-species model) is that the 5-species model is able to take into account catch bias from all other species for the correction of sockeye estimates. In this example, the effect of the CPUE method from pink salmon is inflating the sockeye estimate while the effect from Chinook salmon is deflating the sockeye estimate. The 2 counter-effects both contribute to the correction for sockeye estimates resulting in a smaller correction for CPUE-based sockeye than using the 2-species model which only considered the bias effect from pink salmon but not from Chinook salmon.

#### 4. Derivations of K-species correction model

The goal of the subsequent derivations is to express  $P_j$ , the true proportion of species  $j$ , in terms of observed proportions and relative catchabilities. Noticing the denominators in (8) are identical for all  $K$  species, the CPUE-based observed proportion of species  $j$  can be expressed as:

$$P_{oj} = \frac{Y_j}{Y_1 + Y_2 + \dots + Y_k} = \frac{R_j P_j}{\sum_{i=1}^k R_i P_i} \quad (17)$$

Note: Formula (17) is valid regardless if saturation factor  $h$ 's in (8) are species-specific or uniform across all species.

There is more than one way to use (17) to search for the solution of  $P_j$  as a function of observed proportions and relative catchabilities across all species. Presented in the following is a simple and straightforward way to do so.

For the bench-mark species  $s$ , its observed proportion is, according to (17),

$$P_{os} = \frac{P_s}{\sum_{i=1}^k R_i P_i} \quad (18)$$

From (17) and (18), we have

$$P_j = \frac{P_{oj}}{R_j P_{os}} P_s \quad (19)$$

Eqn. (19) means that if we can find the relationship between the true proportion of the benchmark species  $P_s$  and observed proportions and relative catchabilities, then we can find such relationships for any of the  $K$  species. So, our goal is to find the relationship between  $P_s$  and observed proportions and relative catchabilities across all species.

Another relationship to be used for the derivation is that the sum of proportions of all  $K$  species must be constrained to 100% regardless of these proportions being true or observed, i.e.,

$$\sum_{i=1}^k P_i = 1 \quad (20)$$

and

$$\sum_{i=1}^k P_{oi} = 1 \quad (21)$$

First, we take a variant form of (18) as follows by explicitly expressing  $P_s$ :

$$P_{os} = \frac{P_s}{P_s + \sum_{i \neq s}^{k-1} R_i P_i + R_k P_k} \quad (22)$$

where the notation of summation index  $i \neq s$  means that the summation is for all  $k-1$  species except the benchmark species  $s$ . Variables associated with species  $k$  are explicitly noted in the denominator of (22) for implementing the constraint condition of (20) in the derivation with a variant form of  $P_k = 1 - \sum_{i=1}^{k-1} P_i$ . So, (22) becomes:

$$P_{os} = \frac{P_s}{P_s + \sum_{i \neq s}^{k-1} R_i P_i + R_k (1 - \sum_{i=1}^{k-1} P_i)} \quad (23)$$



From (19), we have two variant forms of the relationship:  $R_i P_i = P_{oi} P_s / P_{os}$  and  $P_i = P_{oi} P_s / (P_{os} R_i)$ . Substituting these two relationships to the corresponding two factors in the denominator of (23), we have:

$$P_{os} = \frac{P_s}{P_s + \frac{P_s}{P_{os}} \sum_{i \neq s}^{k-1} P_{oi} + R_k \left(1 - \frac{P_s}{P_{os}} \sum_{i=1}^{k-1} \frac{P_{oi}}{R_i}\right)} \quad (24)$$

Using an intermediate variable defined as  $x = P_s / P_{os}$ , (24) can be rewritten as

$$1 = \frac{x}{x P_{os} + x \sum_{i \neq s}^{k-1} P_{oi} + R_k \left(1 - x \sum_{i=1}^{k-1} \frac{P_{oi}}{R_i}\right)} \quad (25)$$

Or equivalently,

$$1 = \frac{x}{x \left[ P_{os} + \sum_{i \neq s}^{k-1} P_{oi} - R_k \sum_{i=1}^{k-1} \frac{P_{oi}}{R_i} \right] + R_k} \quad (26)$$

From (26), we solve for  $x$ , which yields:

$$x = \frac{R_k}{1 - P_{os} - \sum_{i \neq s}^{k-1} P_{oi} + R_k \sum_{i=1}^{k-1} \frac{P_{oi}}{R_i}} \quad (27)$$

Noticing that the 1<sup>st</sup> 3 terms in the denominator of (27) is, by the constraint condition of (21),  $P_{ok} = 1 - P_{os} - \sum_{i \neq s}^{k-1} P_{oi}$ , we have:

$$x = \frac{P_s}{P_{os}} = \frac{R_k}{P_{ok} + R_k \sum_{i=1}^{k-1} \frac{P_{oi}}{R_i}} \quad (28)$$

Or equivalently,

$$P_s = \frac{P_{os}}{\frac{P_{ok}}{R_k} + \sum_{i=1}^{k-1} \frac{P_{oi}}{R_i}} = \frac{P_{os}}{\sum_{i=1}^k \left[ \frac{P_{oi}}{R_i} \right]} \quad (29)$$

Therefore, the true proportion of the bench-mark species  $P_s$  is expressed in terms of the observed proportions and relative catchabilities across  $K$  species as shown by (29). Substituting (29) to (19), we obtain such relationships for any of the  $K$  species as follows:

$$P_j = \frac{P_{oj}/R_j}{\sum_{i=1}^k \left[ \frac{P_{oi}}{R_i} \right]}, \quad j = 1, 2, \dots, k \quad (30)$$

Eqn. (30), same as (2), is a general mathematical expression for the correction of CPUE-based species proportion estimates for  $K$  species. The right-hand-side of (30) indicates that if relative catchabilities of all concerned species are known, then the CPUE-based proportions can be corrected for non-equal catchability effect.

## 5. Maximum correction by the model

The amount of correction for the sockeye proportion varies nonlinearly with observed proportions of non-sockeye species. The nonlinearity feature can be readily illustrated by a 2-species comigration case (for 5 species, the mathematics are more tedious, therefore, not presented in this document). If, for example, sockeye are comigrating with one other species (such as Chinook salmon or pink salmon), and let us denote the relative catchability of the other species as  $R$ , the corrected sockeye proportion, according to (30), takes the form of

$$P_s = \frac{P_{os}}{P_{os} + (1 - P_{os})/R} = \frac{RP_{os}}{1 - P_{os}(1 - R)} \quad (31)$$

With Eq. (31), we can define a function  $\Delta$  to quantify the bias as follows:

$$\Delta = P_s - P_{os} = \frac{RP_{os}}{1 - P_{os}(1 - R)} - P_{os} \quad (32)$$

It is obvious from (32) that  $\Delta = 0$  at  $P_{os} = 0$  or 1. That is, if the catch contains no sockeye or only sockeye, there will be no correction. The maximum correction, or the maximum bias, occurs when the derivative of  $\Delta$  with respect to  $P_{os}$  is zero, i.e.,

$$\frac{d\Delta}{dP_{os}} = \frac{R}{[1 - P_{os}(1 - R)]^2} - 1 = 0 \quad (33)$$

Solving (33) leads to roots of  $P_{os}$  at which maximum correction occurs by the system. It can be shown that two roots exist for (33). These are:

$$P_{os} = \frac{1 \pm \sqrt{R}}{(1 + \sqrt{R})(1 - \sqrt{R})} \quad (34)$$

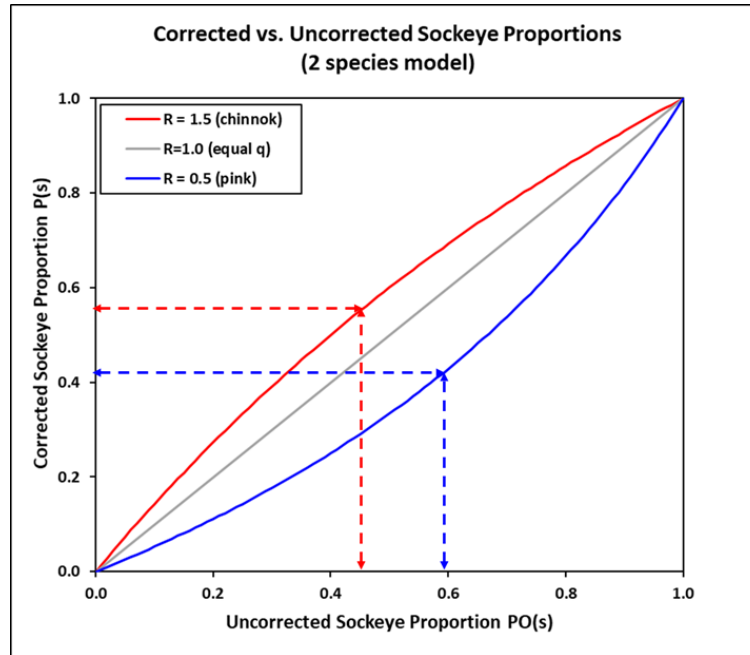
Since  $P_{os}$  is constrained within 0 to 1, the biologically meaningful root is

$$P_{os} = \frac{1}{1 + \sqrt{R}} \quad (35)$$

According to (35), the maximum correction for the observed sockeye proportion occurs at  $P_{os} = 1/(1 + \sqrt{R})$  which is solely determined by the relative catchability  $R$  of the other comigrating species. Substituting (35) into (32) leads to the maximum amount correction of

$$\Delta = \frac{\sqrt{R} - 1}{\sqrt{R} + 1} \quad (36)$$

It is evident from (36) that if  $R < 1$  (such as for pink salmon),  $\Delta < 0$ , the model will correct the CPUE-based sockeye estimate by downgrading it; if  $R > 1$  (such as for Chinook),  $\Delta > 0$ , the model will upgrade the CPUE-based sockeye estimate. In Figure 3, we display the amount of correction as a function of the CPUE-based sockeye proportion as defined by (32) for 3 contrasting  $R$  values.



**Figure 3.** Relationship between corrected and uncorrected sockeye proportions at 3 relative catchabilities. The dashed arrows to the horizontal axis point at uncorrected (observed) sockeye proportions at which maximum bias occurs (or maximum correction occurs); arrows to the vertical axis point at the corresponding values for the corrected proportions.

The three  $R$  values correspond to three migration scenarios:  $R = 1$  for equal catchability among the two species;  $R = 0.5$  for a comigrating species similar to pink salmon;  $R = 1.5$  for a comigrating species similar to Chinook salmon. Substituting  $R = 0.5$  and  $1.5$  into (35) leads to  $P_{os} = 0.5858$  and  $0.4495$ , respectively. According to (36) the maximum amount of correction is  $-0.172$  (downgrade by 17.2%) and  $0.101$  (upgrade by 10.1%), respectively. The above assessment can also be extended to the 5-species model.

In conclusion, we have the following key features of the correction model:

- (1) No correction if the catch contains zero or 100% sockeye;
- (2) If  $R < 1$ , the comigrating species is less vulnerable than sockeye to the fishing gear. The model will downgrade the CPUE sockeye proportion (see plot in Fig 3 for  $R = 0.5$  corresponding to pink salmon catchability);
- (3) If  $R > 1$ , the comigrating species is more vulnerable than sockeye to the fishing gear. The model will upgrade the CPUE sockeye proportion (see plot in Fig 3 for  $R = 1.5$  corresponding to Chinook salmon catchability);
- (4) The amount of correction is asymmetric to the zero-correction line (the 1:1 line) with peak correction occurring at observed sockeye proportions greater than 50% for  $R < 1$  comigrating species (pink salmon) and less than 50% for  $R > 1$  comigrating species (Chinook salmon).

- (5) Eq. (35) can be used to predict at which level of observed sockeye proportion the maximum bias will likely occur for sockeye estimates when the sockeye are comigrating with another dominant species with a known  $R$ . If  $R=0.5$  (typical for pink salmon at both Whonnock and Qualark), the maximum sockeye bias will likely occur at the CPUE-based sockeye proportion of  $P_{os} = 1/(1 + \sqrt{R}) = 58.6\%$  with sockeye being overestimated by 17.2%. If  $R = 1.5$  (simulating Chinook salmon at both sites),  $P_{os} = 1/(1 + \sqrt{R}) = 45\%$  with sockeye being underestimated by 10.1%.

## References

- Link, R. M. and R. M. Peterman. 1998. Estimating the value of in-season estimates of abundance of sockeye salmon (*Oncorhynchus nerka*). Can. J. Fish. Aquat. Sci. 55: 1408-1418.
- Walters, C. 2015, *Comparison of Mission and Qualark hydroacoustic facilities for providing escapement information for management of Fraser River sockeye and pink fisheries*. October 10, 2015 a Review Report to Fraser Strategic Review Committee.
- The R Foundation for Statistical Computation. 2016. R version 3.3.1 (<http://www.r-project.org/>).

## **Appendix 2: Summary of Mission Experiments (2016-2018)**

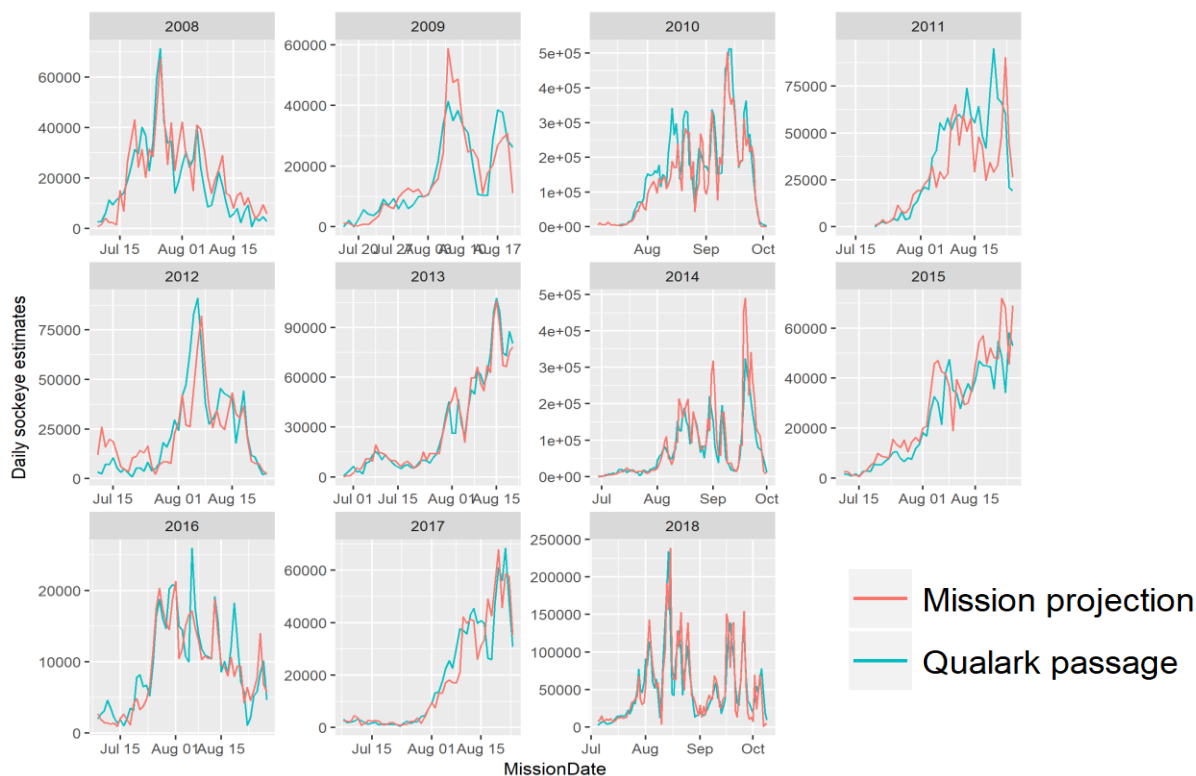
Summary of Presentations

Regarding Experiments at Mission 2016-2018

As Presented to the Fraser River Panel by C. Lagasse

## Introduction

Several experiments have been undertaken at the Mission Hydroacoustics site in recent years, in part to address concerns raised through the FSRC process regarding the Mission Hydroacoustics estimates of salmon passage. Some of these concerns were raised due to Passage Estimate Differences (PEDs) between the Mission and Qualark Hydroacoustic programs. Figure 1 shows comparisons of the Mission-based projection of sockeye escapement at Qualark (“Mission Projections”) with the sockeye passage estimates produced at the Qualark hydroacoustics facility (“Qualark estimate”) from the 2008 to 2018 seasons. A 2 to 3-day migration time was used in the Mission projections, and en-route catches and estimated escapements into terminal areas below Qualark were removed from Mission passage estimates to produce the Mission projections. Periods of migration dominated by pink salmon in odd numbered years were not included in the summary due to differences in methodology for estimating species proportions at the two sites. Comparisons for the years from 2008 to 2015, including potential causes for discrepancies, were previously summarized in the Hydroacoustics Review Technical Summary (Part 1, Appendix 9 , Work Item 5). Over the 11 years included in the analysis, the largest Passage Estimate Differences (PEDs) between Mission projections and Qualark estimates occurred in 2010 and 2014 (Table 1).



**Figure 1. A comparison of daily Mission projections and daily Qualark estimates of sockeye passage past the Qualark hydroacoustics site for the years 2008 - 2018.**

**Table 1. A comparison of Mission projections vs Qualark estimates of sockeye passage at the Qualark hydroacoustics site for the years 2008 to 2018.**

Year	Analysis Period	Mission projection	Qualark sockeye	Passage Estimate Difference (PED)	% PED
2008	Jul 9 - Aug 24	1,008,404	911,054	97,350	9.7%
2009	Jul 16 - Aug 20	572,366	568,887	3,479	0.6%
2010	Jul 7 - Oct 4	12,173,677	13,995,686	-1,822,009	-15.0%
2011	Jul 21 - Aug 25	1,079,638	1,332,647	-253,010	-23.4%
2012	Jul 11 - Aug 24	996,236	1,040,477	-44,240	-4.4%
2013	Jun 28 - Aug 20	1,633,738	1,604,604	29,134	1.8%
2014	Jun 29 - Oct 2	8,397,229	6,964,298	1,432,931	17.1%
2015	Jul 11 - Aug 26	1,255,620	1,065,633	189,986	15.1%
2016	Jul 10 - Aug 31	476,156	509,404	-33,248	-7.0%
2017	Jul 9 - Aug 26	860,043	895,106	-35,063	-4.1%
2018	Jul 7 - Oct 11	5,186,900	4,979,800	207,100	4.2%
TOTAL		33,637,124	33,867,604	-227,588	-0.7%

## Alternative measurement of offshore fish behavior with a DIDSON

The objective of this experiment (Part 1, Appendix 9, Work Item 8) was to assess the error introduced to offshore passage estimates by applying shore-based measurements of fish speeds and travel direction to offshore migrating fish. To estimate offshore passage, fish behavior statistics collected from the left-bank split-beam are applied to the fish-density split-beam data collected on the transecting vessel. This method could introduce error to the offshore passage estimates if salmon behave differently in the offshore area than in the nearshore area.

To measure salmon behavior in the offshore area, a Dual Frequency Identification Sonar (DIDSON) system was deployed from the transecting vessel during its regularly scheduled stationary data collection periods. The transecting vessel anchored 40m-50m offshore for an hour at a time, every four hours, alternating between the left and right banks of the river.

Data collected over eleven days from late July to early September 2018 were analyzed for the experiment. Seven of the analyzed days had fishing activity and four did not. The offshore DIDSON files

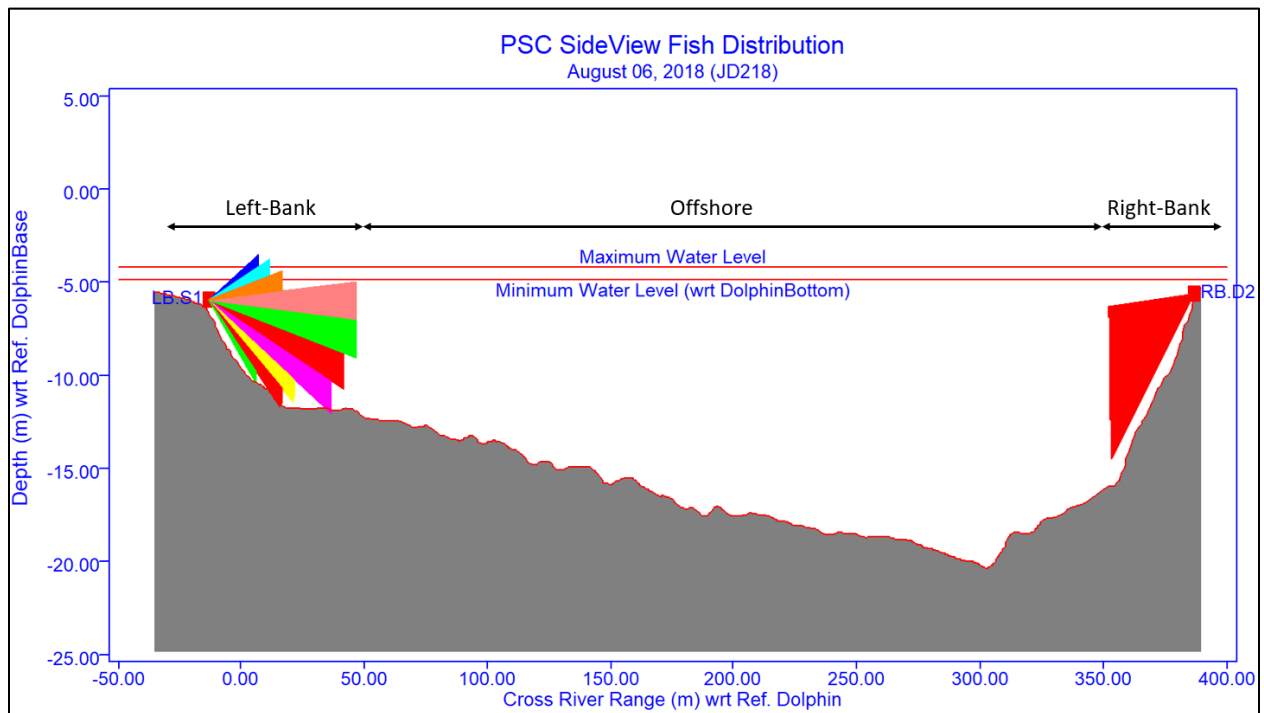


were manually counted to calculate the downstream ratio (i.e. the proportion of fish travelling downstream as opposed to upstream). Downstream ratio is calculated as:

$$\text{Downstream ratio} = \frac{\text{Downstream count}}{\text{Total count}}$$

Fish speeds were also measured from 20 fish per hour of offshore DIDSON data using DIDSON post-processing software and a linear-fit projection model. The average daily sample size for fish speeds was 97 fish. The statistics calculated from the offshore DIDSON data were compared to left bank split-beam data collected on the same days. The left bank split-beam downstream ratios and fish speeds were calculated using all observed targets in a 24-hour period.

The average downstream ratio calculated using the offshore DIDSON data for the eleven days was 6.3%, and the downstream ratio calculated using the left bank split-beam was 1.7%, a difference of 4.6% (p-value = 0.009), indicating that, on average a greater proportion of fish travel downstream in the offshore area than in the left-bank area (Figure 2). Based on this finding, applying the nearshore downstream ratios to the offshore passage estimates could result in an overestimate of offshore fish passage. The offshore DIDSON downstream ratios were also compared based on fishing activity. Days with fishing activity produced an average downstream ratio of 8.5%, while days without fishing activity produced an average downstream ratio of 2.6%, indicating the overestimates of fish passage might be more likely to occur on days with fishing activity.



**Figure 2.** Crossriver profile of the Fraser River at the Mission Hydroacoustics site with the left-bank, offshore, and right-bank areas defined.

The average fish speed calculated using offshore DIDSON data was 0.83 m/s compared to the left bank split-beam average speed of 0.78 m/s (0.5 m/s or 6% difference,  $p = 0.2$ ), this may indicate that fish speed is slightly higher in the offshore area, but the result was not statistically significant. If the swimming speed of fish in the offshore area is underestimated, this could lead to an underestimate of fish passage.

Over the eleven days examined, applying the offshore statistics calculated using the DIDSON system reduced the offshore passage estimates by 1.7% or 3,500 fish. When the difference in the offshore passage is incorporated into the total daily passage estimates for the same eleven days, the difference is -0.3%, indicating that applying nearshore fish behavior statistics to offshore passage has little effect on the total salmon passage estimates. These results are consistent with experiments conducted in 2014 and 2015 that found a difference of less than 1% over 16 days of study.

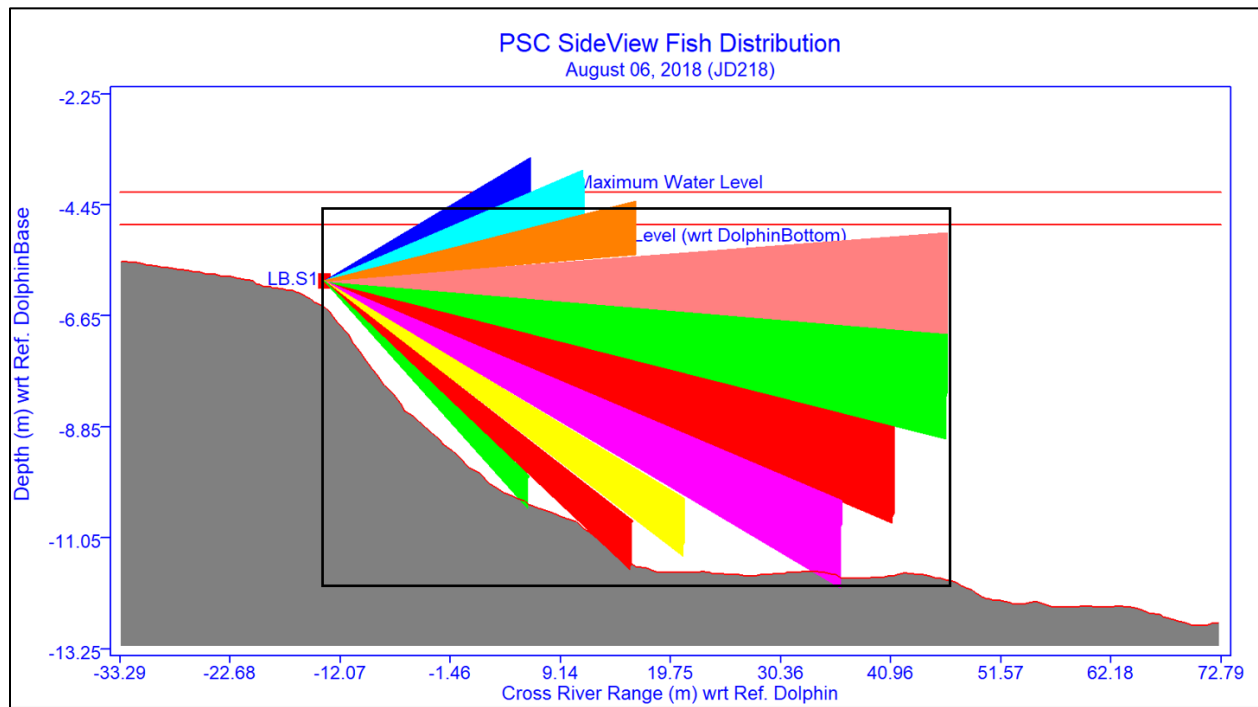
## **Comparison of ARIS and Split-beam Passage Estimates on the Left bank**

The objective of this experiment (Part 1, Appendix 9, Work Items 6 & 7) was to identify potential biases in salmon passage estimates near the left bank area by monitoring simultaneously with both a split-beam and an ARIS sonar, and comparing the estimates from the two systems. The majority of salmon migrate close to the left bank at the Mission hydroacoustics site making the left bank split-beam system a key monitoring tool. Potential sources of bias in the split-beam system include cross-aim fish movement and extrapolations of passage into blind zones. An ARIS imaging sonar system has been deployed on the left bank adjacent to the split-beam system since the 2017 season. The ARIS system can provide an alternative estimate of nearshore salmon passage. Due to the different characteristics of each system and the fundamentally different methodologies used to identify fish targets, they are unlikely to be susceptible to the same sources of bias.

The left bank split-beam utilizes a 2° vertical x 10° horizontal elliptical beam transducer. The split-beam system samples 10 vertical aims for 6 minutes every hour with a maximum range of 60 metres (Figure 3). The undetected salmon that migrate in the unsampled portion of the water column (near the water's surface and near the river bottom) are estimated using extrapolations based on observed passage from adjacent sampled areas. The validity of extrapolation is based on the assumption that fish passage in areas adjacent to the unsampled areas are representative for the undetected passage. However, if this assumption is violated or weakened, the passage estimate from the extrapolation would be biased. By using a wide beam imaging sonar like ARIS, we can minimize the unsampled area, thus eliminating the need for extrapolation.

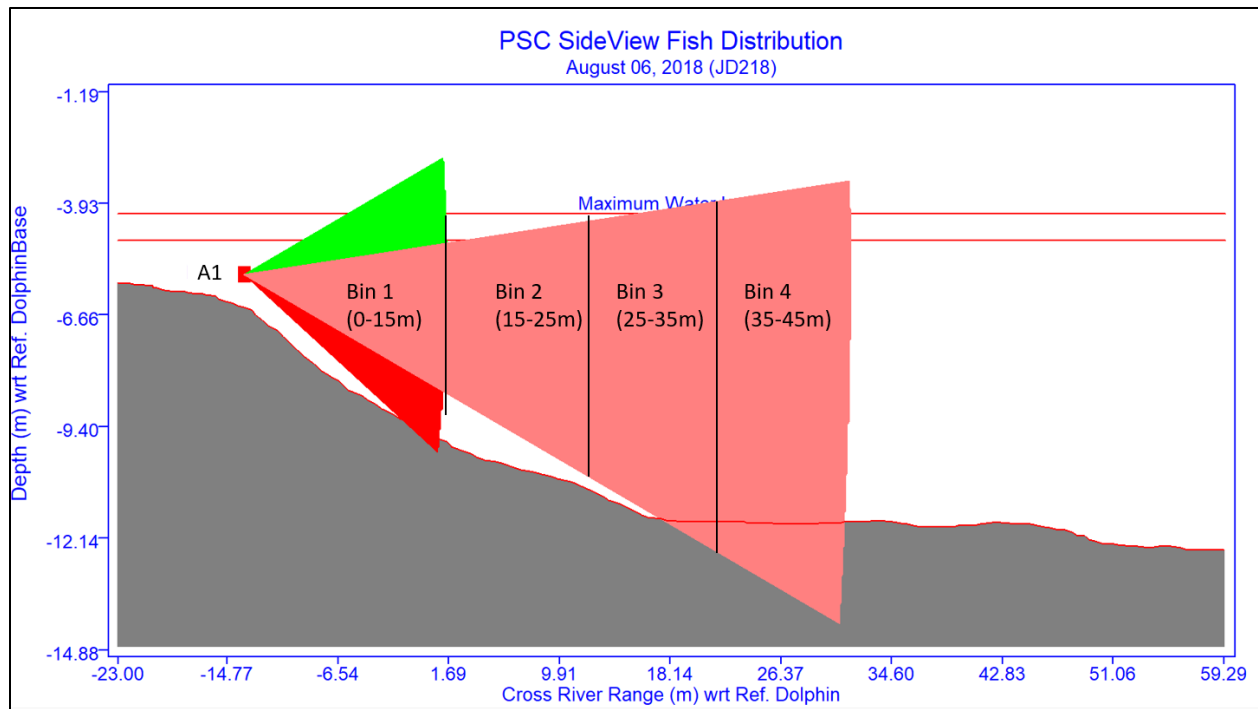
Another potential bias is due to the stratified sampling method if fish exhibit statistically significant vertical movements. The narrow vertical beam width creates opportunity for fish to swim in multiple vertical aims increasing the possibility of overestimating salmon passage by 'double counting' salmon as they migrate. This possible bias is tested by comparing the multiple narrow aims of the split-

beam to the wider 14° vertical beam width of the ARIS system (see Item 06 in Part 1, Appendix 9 for detailed descriptions).



**Figure 3. Schematic of the left bank split-beam sampling geometry.**

The ARIS system utilizes a 14° vertical beam stratified into 4 range bins extending to a maximum range of 45 metres (Figure 4). There are two aims for the first 10-m range bin sampling the majority of the water column. The ARIS vertical beam width is large enough that only one aim is needed for range bins beyond 10 m to cover most of the water column.



**Figure 4.** Schematic of the left bank ARIS sampling geometry.

The comparison between the left bank ARIS and split-beam systems was completed for the entire 2018 season using the full offshore range of the ARIS system and 45 metres of the left bank split-beam data. Throughout the study period, the ARIS system accounted for 3,835,000 salmon compared to the split-beam system which accounted for 3,710,000 salmon; a difference of 3.4% or 125,000 salmon (Figure 5). On most days, the difference between estimates was less than 15% with a median difference of 2.5%. The differences throughout the season did not display a strong directional bias, and suggest that there was minimal bias in left bank estimates due to cross aim fish movement, extrapolation of blind zones, or other sources.

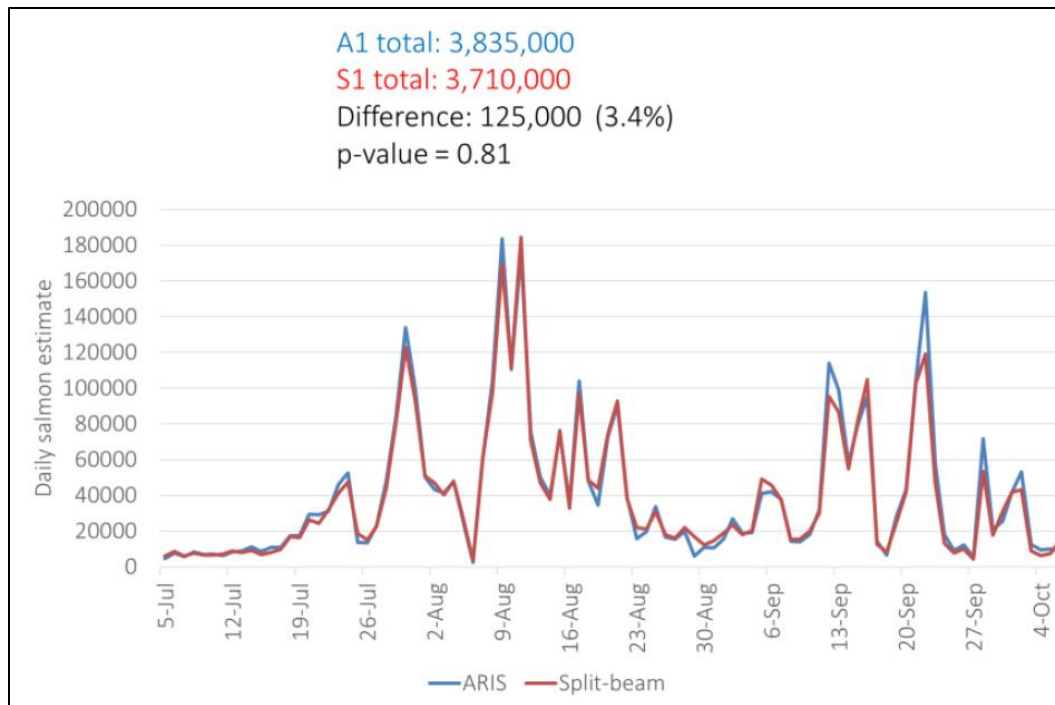


Figure 5. Comparison of left bank split-beam and ARIS salmon passage estimates for the 2018 season

## Potential Influence of Fishing Activity on Cross-river Fish Distributions

During the 2018 sockeye salmon fishing season, the relationship between fisheries openings and the proportion of fish migrating offshore was examined. The preliminary findings were achieved through visual and correlation analyses between the offshore proportion of fish passage and opening hours for fisheries of all gear types (as announced by DFO), as well as a comparison of the offshore proportion of fish passage on days with a presence or absence of fishing activities near the Mission site (Figure 6).

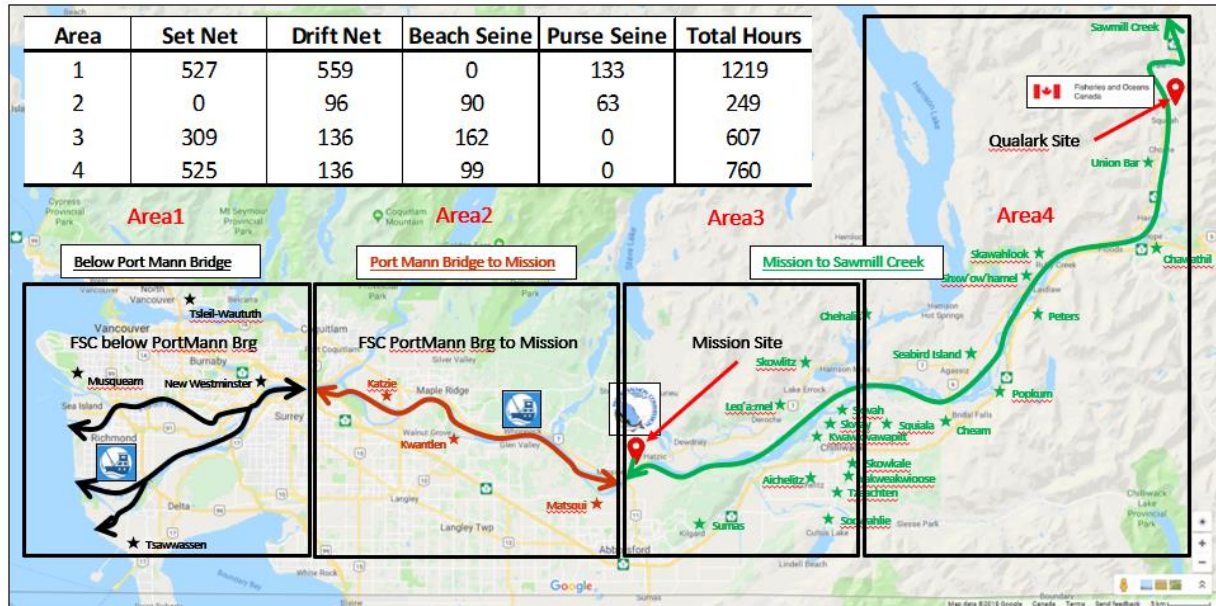
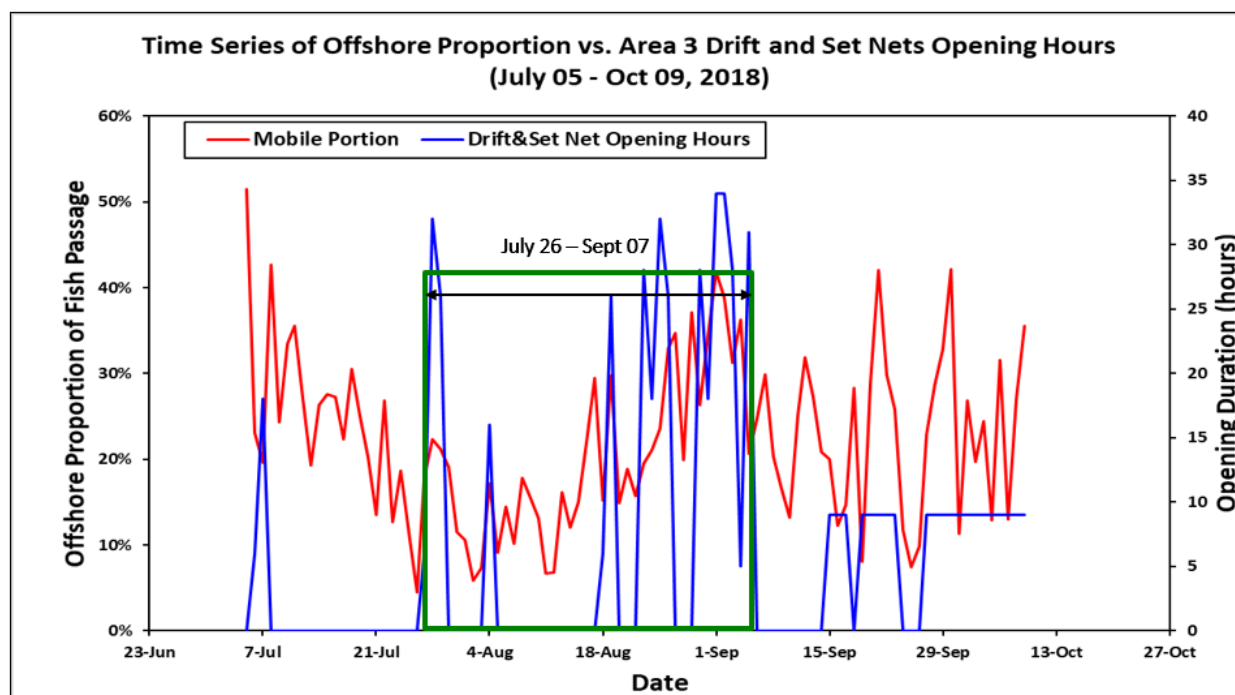


Figure 6. 2018 Lower Fraser River fisheries opening hours by gear type in the four reaches from July 5th to October 9th.

A correspondence was apparent between the offshore fish passage proportion and set net and drift net opening hours in Area 3 between July 26<sup>th</sup> and September 7<sup>th</sup>; during this time, higher proportions of offshore fish passage coincided with long duration drift and set net fisheries (Figure 7).



**Figure 7. Offshore fish passage and opening hours of Lower Fraser River Area 3 drift and set net openings. Note: higher proportions of offshore fish passage in July or earlier is due to low overall salmon passage.**

Furthermore, there was a significant difference ( $p$ -value = 0.0004) in offshore fish passage proportions between days when fisheries were open versus days when fisheries were closed. Days with fisheries openings had, on average, 27% of fish migrating offshore, while days of closed fisheries had an average of 16% of salmon migrating offshore. These results suggest that when fisheries are open in the lower Fraser, fish tend to migrate further offshore.

## Left-bank River Bottom Reprofiling

Natural features and large objects (such as submerged logs) on the river bottom create obstacles for sound to penetrate and add challenges when carrying out hydroacoustic surveys. In February of 2017, work was carried out at the Mission hydroacoustic site to remove woody debris and smooth out the river bottom to remove sampling blind zones. A long-reach excavator was operated over a three day period on top of a barge near the left bank and excavated an area up to 60 metres offshore. Several large snags were removed and many loads of river substrate were relocated downriver. ARIS footage taken before and after the reprofiling work was carried out demonstrates the improvements made in terms of image quality (Figure 8 & Figure 9).

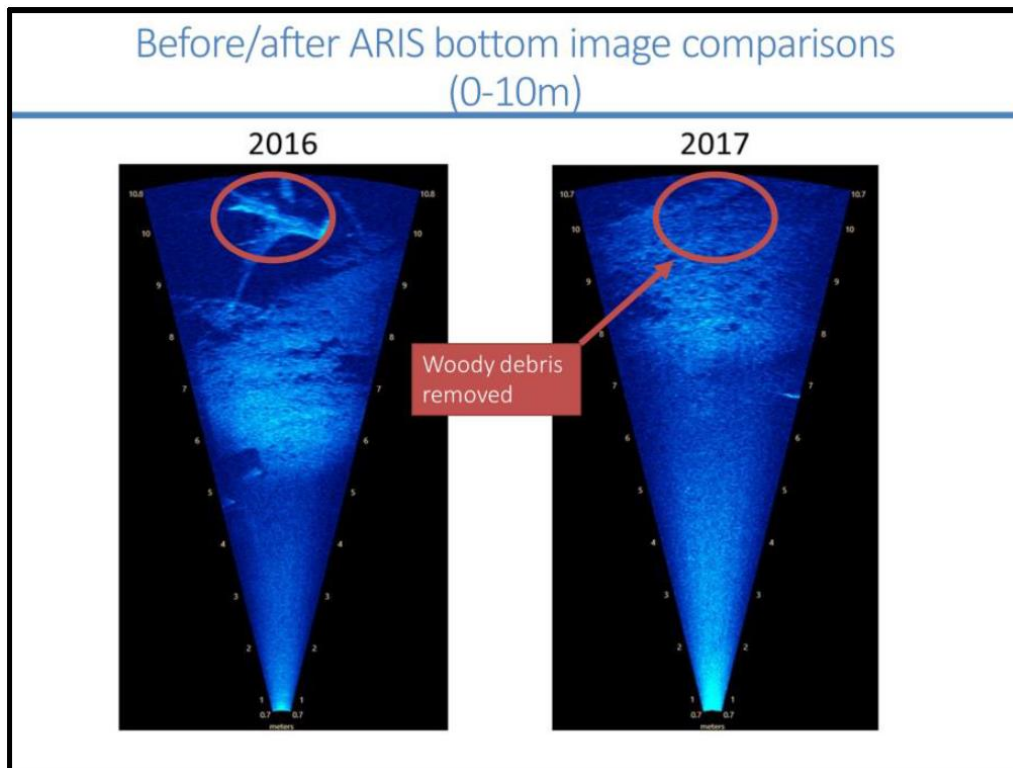


Figure 8. River bottom reprofiling results on the left bank in the 0-10 metre range.



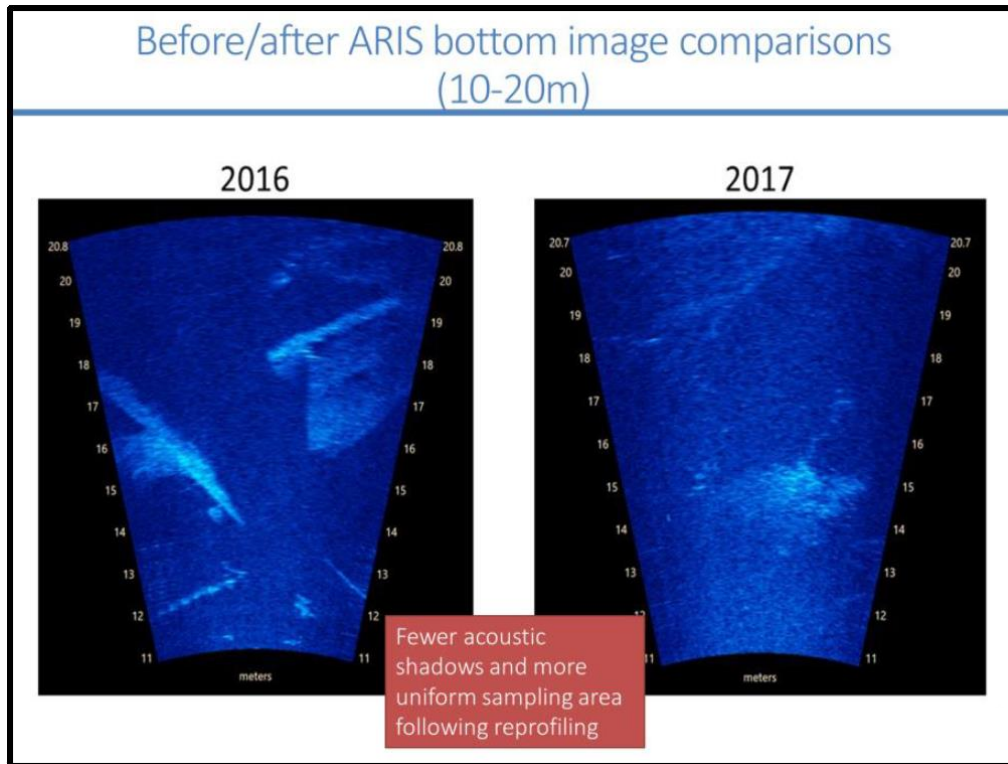


Figure 9. River bottom reprofiling results on the left bank in the 10-20 metre range.

Despite bottom reprofiling efforts, there was no significant reduction in the extrapolation of fish targets near the river bottom. The distribution of fish targets appeared to be more surface oriented in 2017, and this increased the proportion of extrapolations near the surface. There is no direct evidence to show that the reprofiling project caused an increase in surface orientation among salmon, it appeared to have been coincidental with the reprofiling project and likely due to other variables (e.g. river flow). The change in the vertical fish target orientation from bottom oriented to surface oriented made it difficult to compare the proportion of extrapolated targets to previous years, and thus to evaluate the effect of the bottom reprofiling. Based on this outcome, the hydroacoustics group hypothesized that a reduction in extrapolation could be achieved by increasing spatial sampling in the upper water column especially below the surface area, as described in the next section. Changing to a 10-aim configuration for the left bank split-beam reduced the proportion of extrapolated passage to 13% from 32%, less than half compared to the 6-aim configuration used in previous years. The combination of bottom reprofiling, increased split-beam sampling aims, and ARIS implementation improved the data quality and estimation accuracy in the left bank region.

### Six-aim vs Ten-aim Left Bank Split-beam Sampling Configuration

Prior to 2018, the left bank split-beam system sampled the nearshore area using six aims per hour, each with a 2° vertical beam height (Figure 10). Fish passage near the water's surface and river bottom were generally extrapolated to account for unsampled salmon swimming in these areas. In 2018, the number of aims was increased to ten, adding two aims to the top of the sampling geometry

and two aims to the bottom (Figure 11). In order to increase the number of aims per hour, the hourly sampling time of each aim was decreased from 10 minutes to 6 minutes.

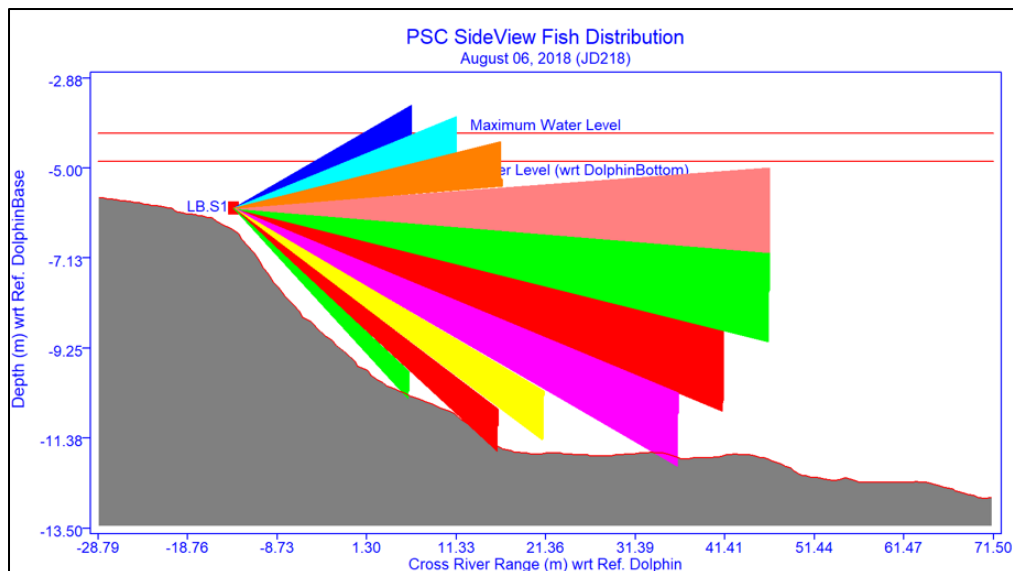


Figure 10. The 6-aim sampling configuration used prior to 2018.

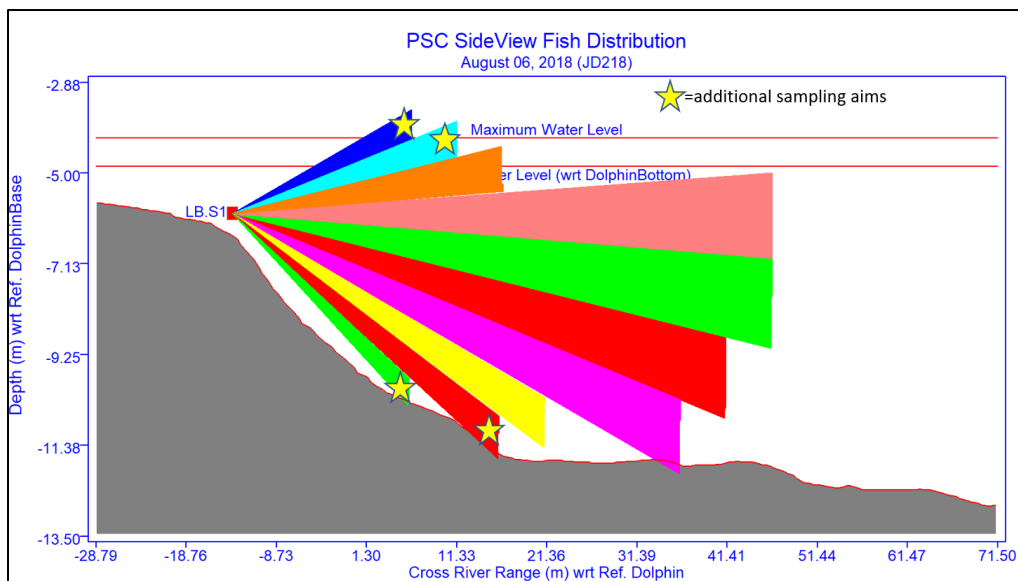
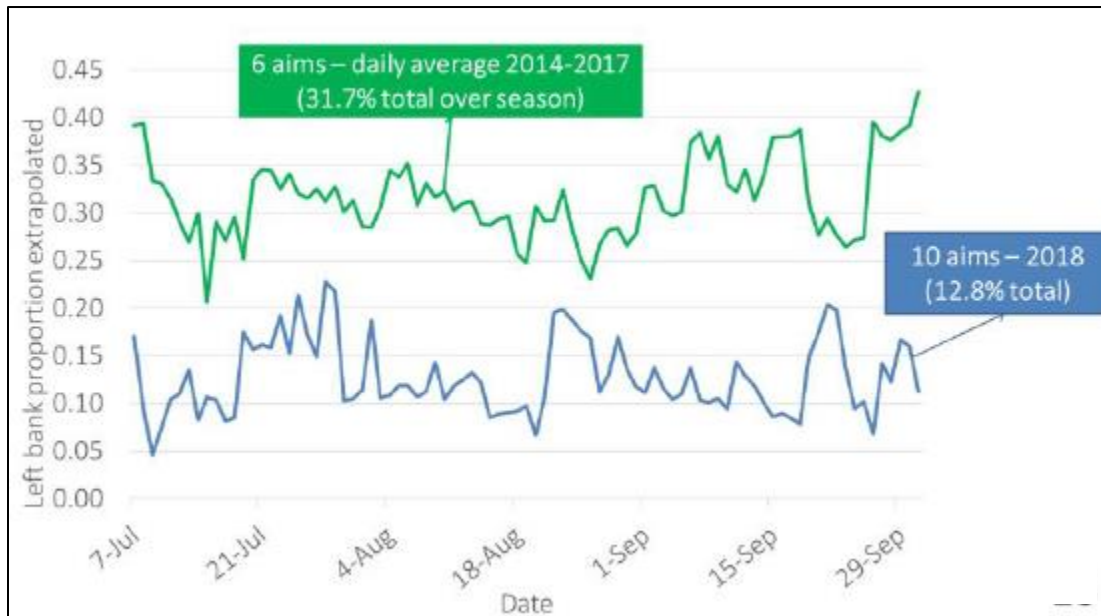


Figure 11. The 10-aim sampling configuration introduced in 2018 with new aims highlighted with a star.

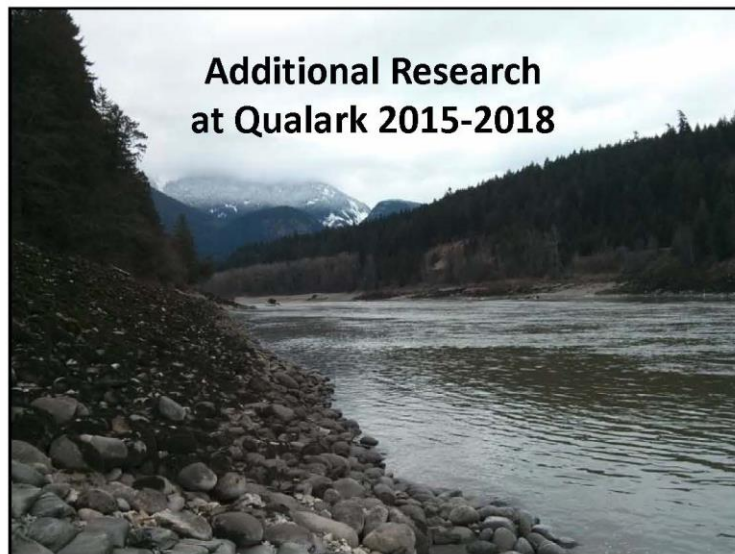
The change from a 6-aim hourly sampling configuration to a 10-aim hourly sampling configuration reduced the extrapolated proportions to less than half of what they were in 2017 (Figure 12). To understand the effect of the reduced extrapolation, a retrospective analysis was performed on a subset of days in 2018 to compare estimates using 6 or 10 aims. Targets that were sampled in the four additional aims were removed and passage in these areas was then extrapolated. The total left bank estimates were 8% higher using the 6-aim configuration over 14 days. This result suggests that switching

from a 6-aim configuration to a 10-aim configuration may have reduced an extrapolation-related overestimation bias in the left bank estimates.

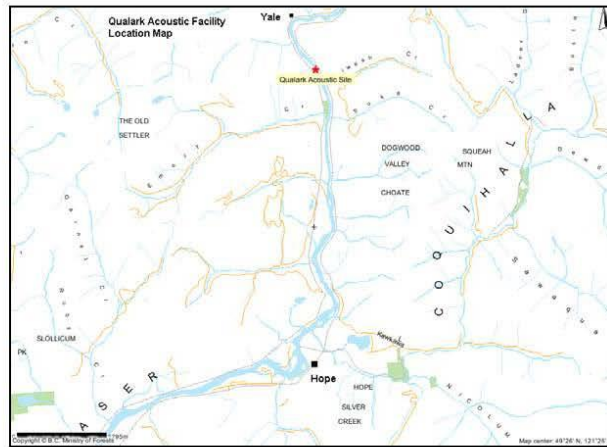


**Figure 12. Differences in the proportions extrapolated for left bank split-beam estimates using 6 and 10 aim sampling configurations.**

## **Appendix 3: Summary of Qualark Experiments (2016-2018)**



## Site Location



## DIDSON Systems on Both Banks

Right Bank

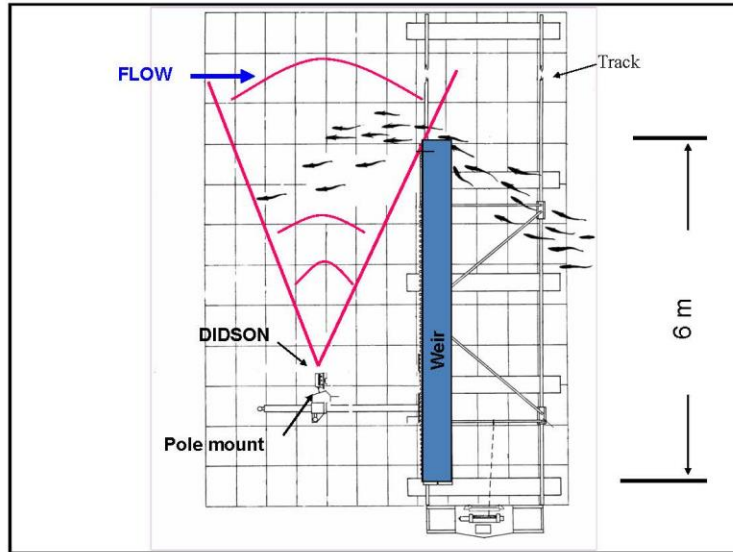


35 m track

Left Bank



30 m track



**DIDSON Mounted on Weir**

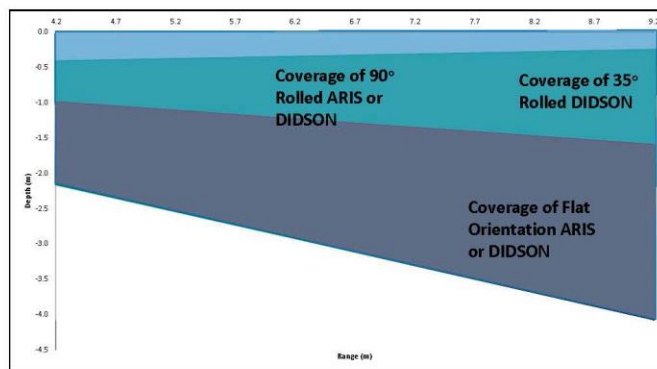




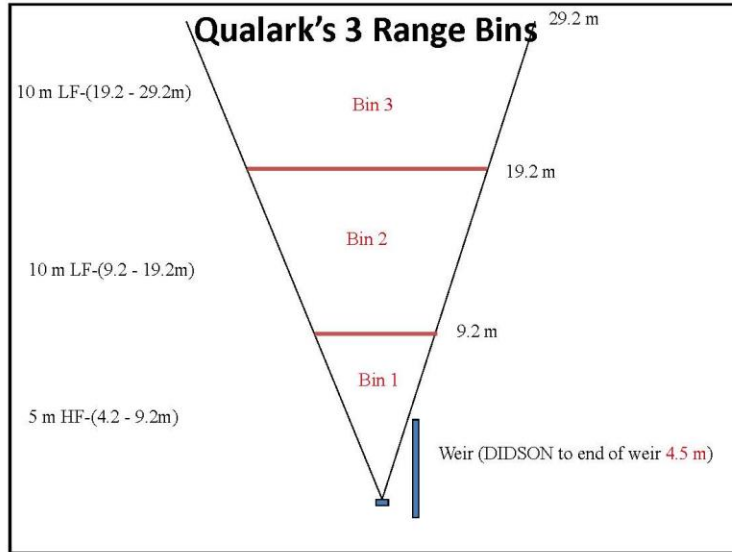
## DIDSON Roll



## Vertical water column coverage: 35° rolled DIDSON, flat and 90° Rolled ARIS

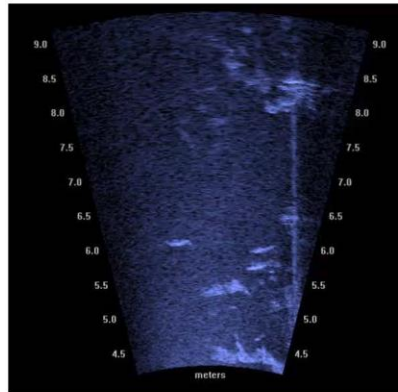






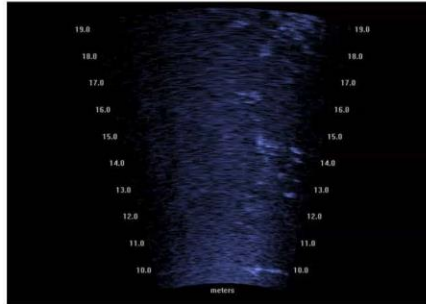
#### Bin 1: 5m Window (4.2 – 9.2 m ) High Frequency

- Majority of passage at 5 – 8m range
- Best image for counts
- Non-target fish easily excluded from count



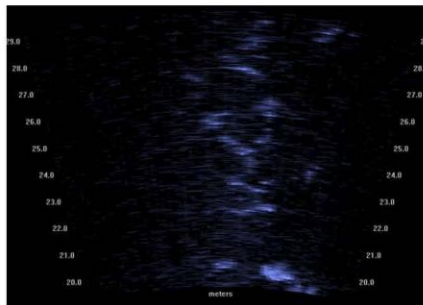
**Bin 2: 10 m Window (9.2 – 19.2 m) Low Frequency**

- Image resolution reduced
- Generally has minimal passage



**Bin 3: 10 m Window (19.2 – 29.2 m) Low Frequency**

- Rarely has passage



### **Qualark's Suggested Blind Zones**

- Walters (2015) identified 2 possible blind zones at Qualark.
  1. Offshore beyond the effective coverage of the hydro-acoustic systems (beyond 29m on both banks).
  2. At the end of Bin 1 (4.2-9.2m) near the bottom particularly at low water levels.
- Walters recommended: "Continued operation of Qualark should be contingent on careful tests of its possible blind spots, in particular by operating test Didson cameras in a way that is sure not to have blind spots along the river bottom and offshore..."

### **Research elements investigating prospective Qualark biases**

- 2015-2018: Long Range ARIS (30-40m)
- 2016-2017: Vertical Distribution of Salmon in Bin 1 using 90° Rolled Orientation ARIS
- 2018:
  - Acoustic Beam Mapping (Bin 1 near bottom 4.2-9.2m)
  - Acoustic Bottom Profiling

### Qualark Beam Mapping: Bin 1 (4.2-9.2m) near bottom

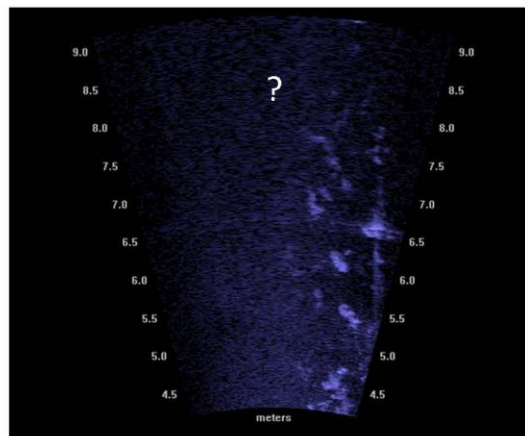
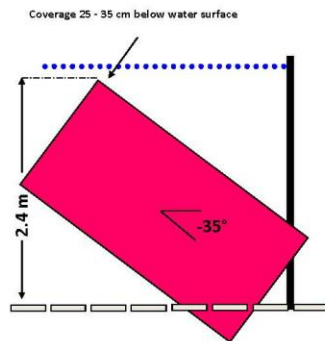


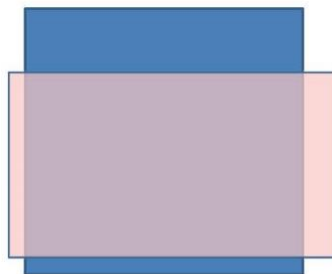
Figure 7 in Walters (2015). There are acoustic "blind spots" at both Mission and Qualark,...At Qualark, the near shore (high frequency 5-9 m offshore) imaging does not reach the bottom near the outside margin of the bin (the equipment rail on the bottom becomes invisible, particularly at low flows) so fish could move below the effective DIDSON beam area and not be included at all in the overall estimates....

## Coverage with 35° Roll

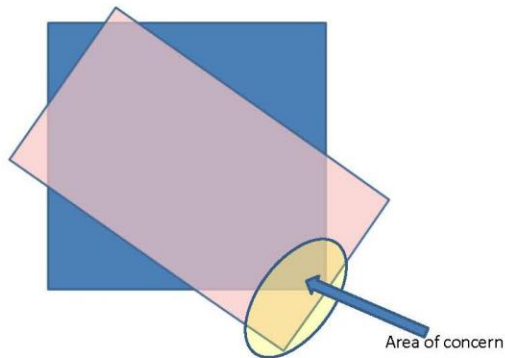


Xie (2016 pers. comm.): potential that, due to physical properties of the sound field in the DIDSON acoustic beam complex, there may be a blind zone in Qualark's Bin 1 near the river bottom, due to the rolled aim. This may account for, in part, Walters observation (Fig. 7)

Flat Aim (0 degree roll) Orientation (DIDSON or Aris)



Rotated Aim (35 degree) Orientation (DIDSON)



**Can we test definitively for a near-bottom Blind Zone in Bin 1?**

- Both the physical acoustic beam properties and the configuration of acoustic infrastructure in Bin 1 are constant over the entire monitoring range at Qualark (independent of water level).
- Our 2018 investigations focused on controlled target beam mapping within the suggested Bin 1 blind zone.

### **Experimental Approach**

- Introduce known targets into the acoustic field and confirm their detectability.
- Position known targets with a high degree of accuracy in x,y,z space to confirm consistency of detectability – particularly in the 8.0-9.2 m range
- Evaluate detectability of continuously mobile targets in the near bottom portions of Bin 1 over the complete bin range.

### **Targets Used for Beam Mapping**

- 10cm diameter toilet tank check valve float
- 25cm diameter buoy
- Fresh 58cm sockeye







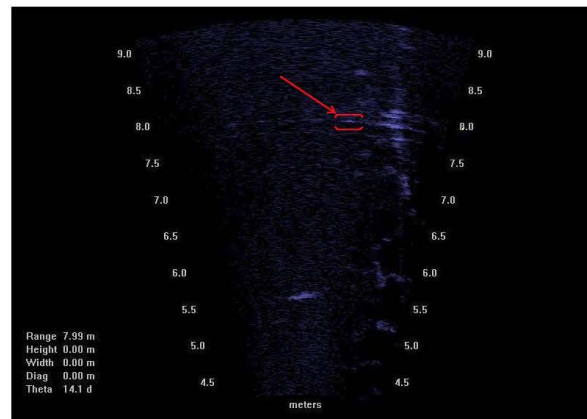
**12m Pole Attached to Carriage**



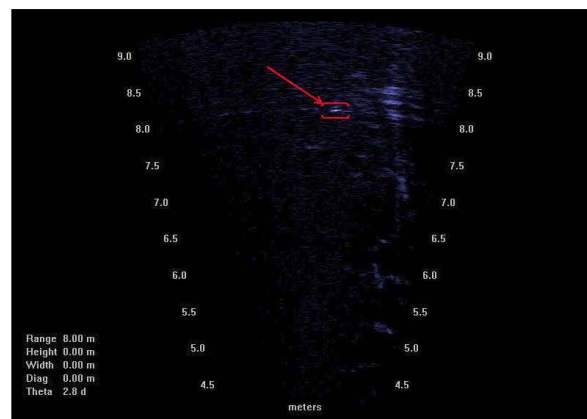
**Tethered 58 cm Sockeye**



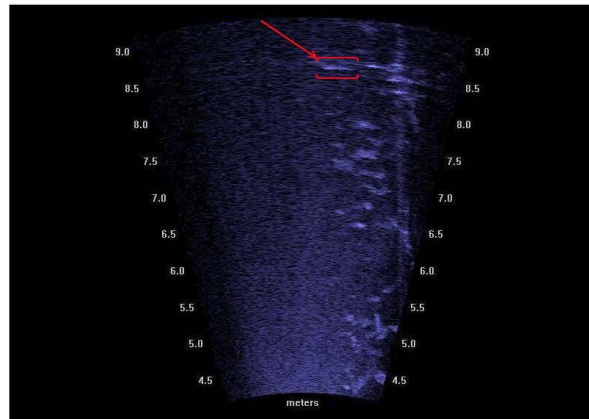
### 10 cm Toilet Float at 8m Range



### 25 cm Buoy at 8 m Range



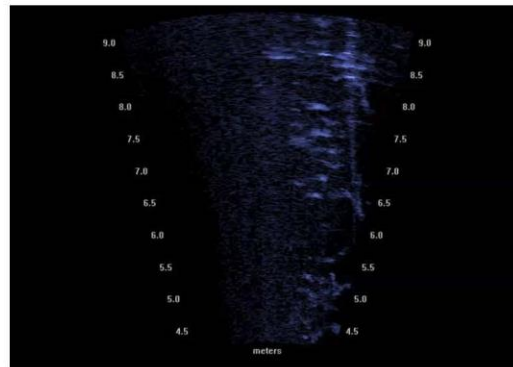
### 58 cm Fork Length Sockeye at 8.5m Range



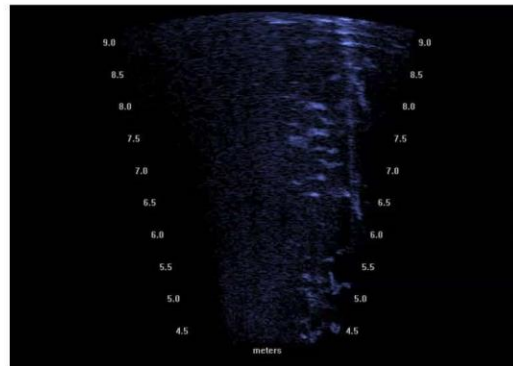
### Beam Map of Tethered Sockeye

- 48 discrete positions recorded
- Ranges recorded were 8.0m, 8.25m, 8.5m, 8.75m, 9.0m and 9.17m (end of 5m Bin 1)
- Each range position had 8 vertical and horizontal measurement positions
- Horizontal 125 cm and 70 cm upstream of track (measured at snout of sockeye)
- Vertical 15cm, 30cm, 45 cm and 60cm off the sandbag ramp
- Area mapped 1.25m x 1.2m x 0.75m
- After stationary recordings were completed target was recorded as it was retrieved through the entire length of Bin 1

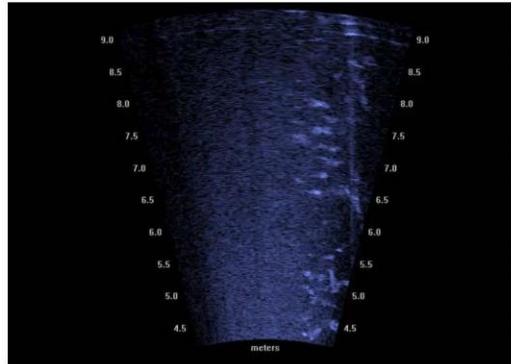
**58 cm Sockeye at 8.5 m Range**



**58 cm Sockeye at 9.0 m Range**



### Carriage with Attached Target Retrieved from the End of 5m Bin 1



### Beam Mapping Results

- All targets were fully visible throughout the entire near-bottom area that we mapped:
  - incrementally at: 8.0-9.25m range from transducer in 0.25m steps; 0.15-0.60m above the bottom in 0.15m steps; and, at 0.70 & 1.25m upstream of the equipment track;
  - continuously, over the full 5.0m range of Bin 1 for each target type, by height above bottom and upstream location combination.



### **Beam Mapping Conclusions**

- There is no near-bottom blind zone in DIDSON Bin 1 due to the rolled aim employed at Qualark.
- There are no undetectable salmon migrating through the bottom of Bin 1. Concern over negative estimate bias from this source can be eliminated.
- A rolled aim is the most effective means of providing vertical coverage in a large deep river system like the Fraser River.

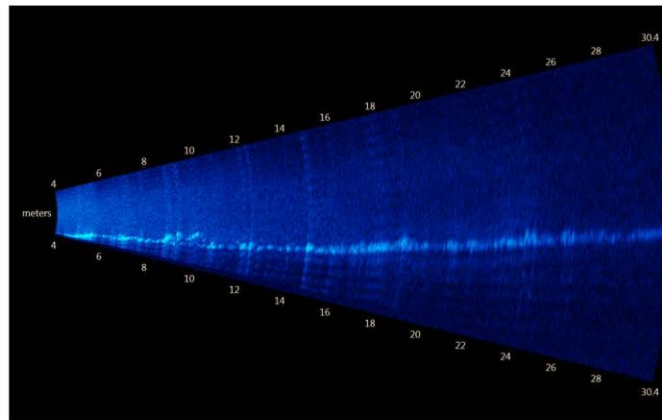
### **So ...Bin 1 Blind zone put to rest? .....not quite**

- The issue of a low water Bin 1 blind zone (Walters specific case) is not fully resolved with the beam mapping exercise just discussed because factors other than the roll used could be responsible for a blind zone.
- As Fraser River discharge falls a varying portion of the acoustic monitoring zone extends beyond the acoustic sandbag ramp and track, reaching out over natural river substrate.
- When monitoring occurs over the ramp the acoustic environment is free of physical obstructions that could provide acoustic blind spots through which fish could move undetected. This is not necessarily so over natural substrates....

### Bottom profiling beyond the acoustic ramp

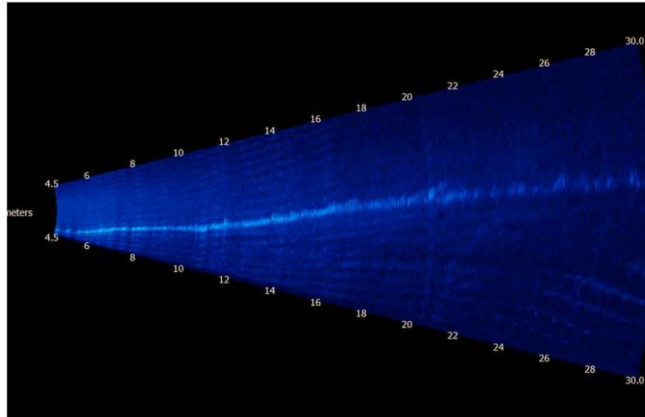
- Natural features of the physical environment could create acoustic blind zones:
  - Dips or valleys (scalloping) in the bottom substrate can result in acoustic blind spots.
  - Large boulders or other obstructions can create acoustic shadows (blind spots) behind the objects.
- At very low water levels up to 25 m of the monitoring zone extends beyond the ramp. In 2018, we used ARIS in 90° rolled orientation to complete bottom profiles at both banks to examine them for features, scalloping or obstructions, that could result in undetected passage.

### RB Bottom Profile





## LB Bottom Profile



## Bottom Mapping Conclusions

- Bottom profiles from each bank reveal no features that will result in fish passing the site undetected.
- Rocks to 40cm in size are evident but do not extend full width of the ensounded bottom (1.5+ m), so while fish can move behind a rock within the acoustic field, they would not be obscured for the entire duration of their trajectory through the bin, and are detectable.
- There are no physical features in the bottom profiles on either bank in Bin 1 that will result in salmon being undetectable for the duration of their transit through the bin. Migration near the bottom in Bin 1, when it extends over natural substrates at low water, can be eliminated as a source of potential negative estimate bias.

### **Summary: Bin 1 Blind Zone**

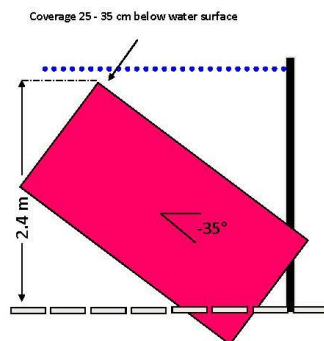
- Direct investigations into two sources of uncertainty potentially responsible for near-bottom blind zones within Qualark's Bin 1 data collection protocol illustrate conclusively that undetected salmon passage is not occurring in this area of the bin.
- Confirmation of acoustic coverage in Bin 1 regardless of water level eliminates concerns over undetected fish passage in the bin and any resultant negative bias in total migration that such fish would represent.
- Consistency in the methodology applied over the program duration means these results can be confidently applied to historic results obtained since 2008.

### **Bin 1 Blind Zone: concluding remark**

- Walters noted (Fig. 7) that the equipment track disappears from the DIDSON image files (particularly) at low water levels. This inability to see the track was interpreted as evidence that the acoustic beam did not extend to the river bottom, thus leaving a blind zone on the bottom for fish to migrate through undetected....
- What Walters noted was not the track becoming invisible to acoustics, what he detected was the acoustic monitoring field extending past the track's end. This was misinterpreted as evidence of a blind zone. There was no blind zone, just acoustics documenting the track's end, and extending beyond to trackless river substrate!

**but wait, there is more on Bin 1  
blind zones....**

### **Coverage with 35° Roll**



What about this gap in  
near surface acoustic  
coverage using the  
rolled aim? No  
undetected migration  
here?

## **2016-2017 Vertical Distribution of Salmon**

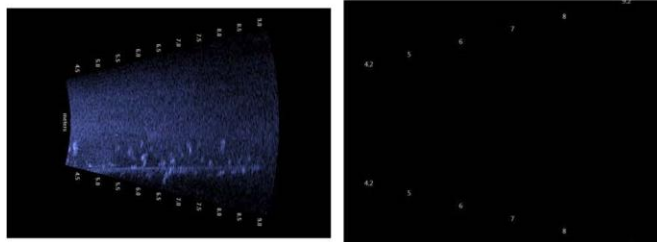
### **Vertical Distribution Data Collection Methods**

- ARIS simultaneously collected files with the same aim and range as DIDSON Bin 1 (35° roll; 4.2-9.2 m) only the ARIS files were collected at a 90° roll.
- Vertical surface coverage was tested over entire Bin 1 range (4.2-9.2m) using a target and determined to be complete.
- ARIS data collected at HF. No crosstalk was observed between the systems at this orientation.

## Vertical Distribution Data Processing

- The ARIS measuring tool was used to measure the distance of salmon sized targets from the bottom.
  - The measurement was made from the bottom perpendicular to the middle of the target.
  - The measurement was made at the middle of the targets trajectory through the beam. For example, if the target was present for 5 frames the measurement would have been made at the 3rd frame.

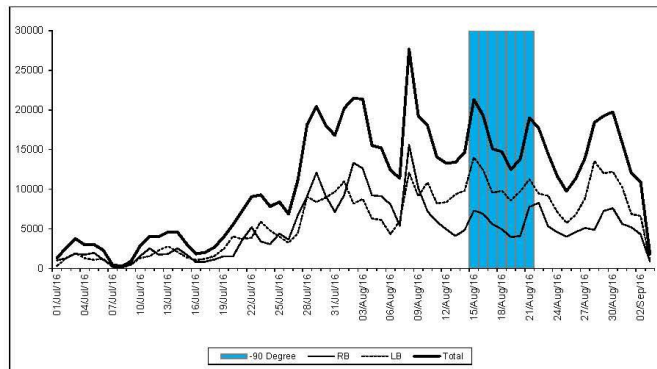
## Simultaneous -35° DIDSON and -90° ARIS File Example



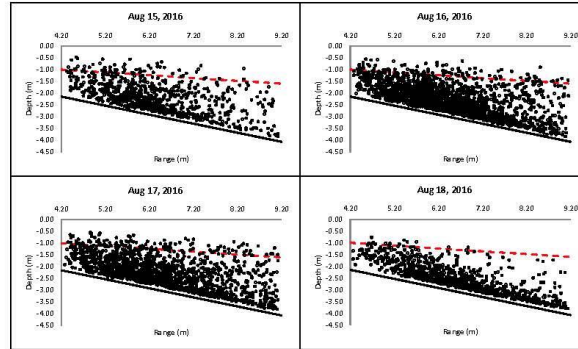
## 2016 Vertical Distribution Data Collection

- From Aug 15-21, -90° ARIS files were recorded with a range of 4.2-9.2 m and duration of 20 minutes.
- The files recorded coincided with two peaks in salmon passage (4-8k RB daily salmon abundance), low water conditions (2500-2900 m<sup>3</sup>/s discharge) and high water temperature (>20°C).
- Sockeye were the dominant species from Aug 15-21 with some Chinook presence.
- No First Nation Fisheries occurred during this period.

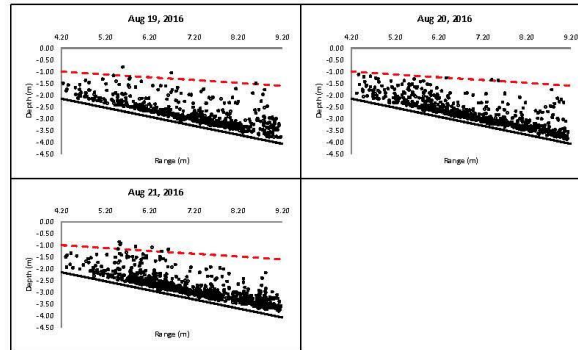
## 2016 Daily Salmon Passage and Periods of 90° Rolled ARIS Data Collection



## 2016 Vertical Distribution Results



## 2016 Vertical Distribution Results



## 2016 Vertical Distribution Results

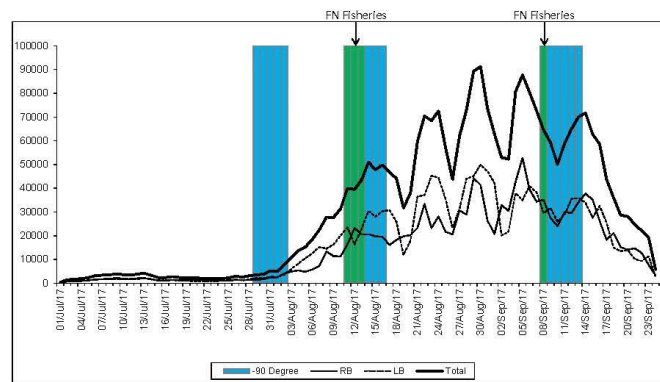
- From Aug 15-21, 142 90° ARIS files were recorded for a total time of 47.3 hours.
- 8151 vertical distribution measurements were completed.
- 81% of total salmon sized targets were detected within 1m of the bottom.
- 17% of total salmon sized targets were detected between 1-2m from the bottom.
- 2% of total salmon sized targets were detected migrating >2m above the bottom.
- 4% of total targets were detected above the coverage of a flat orientation sonar.
- Based on target work early in the season the coverage of the 35° rolled DIDSON is to approximately 0.38m below the surface at a range of 5m. Beam expansion increases vertical coverage as range increases. No targets were detected migrating within 0.38m of the surface.

## 2017 Vertical Distribution Data Collection

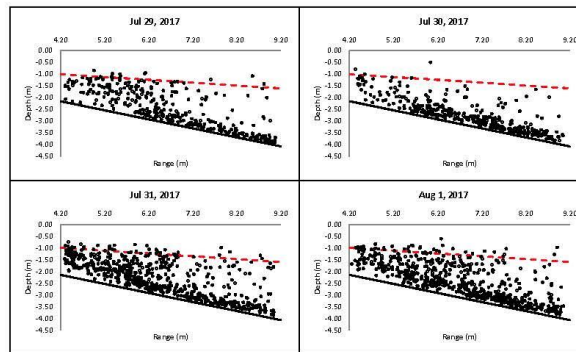
- 90° ARIS files were recorded periodically throughout the season (Jul 29-Aug 2, Aug 11-16 and Sep 8-13) with a range of 4.2-9.2m and duration of 20 minutes.
- The 2017 data set is larger and more robust data than what was collected in 2016, with greater contrast in:
  - water levels (1700-3100 m<sup>3</sup>/s discharge)
  - abundance (1-35k RB daily salmon abundance)
  - species composition (Sockeye/Chinook→Sockeye dominant→Pink dominant)
  - Human activity, Aug 11-13 and Sep 8, First Nation set gill net fisheries



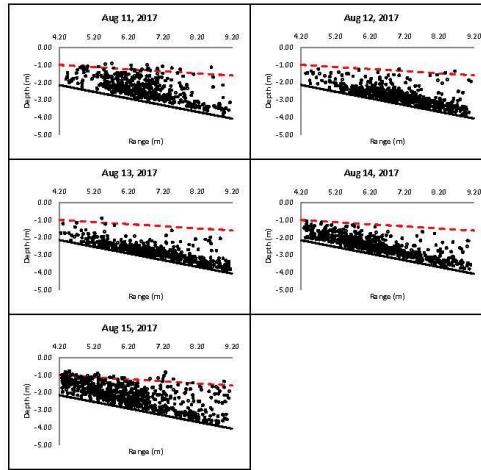
## 2017 Daily Salmon Passage and Periods of 90° Rolled ARIS Data Collection



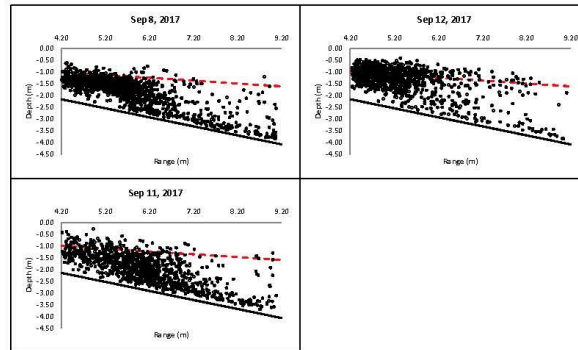
## July 2017 Vertical Distribution Results



## August 2017 Vertical Distribution Results



## September 2017 Vertical Distribution Results



## 2017 Vertical Distribution Results

- A sub-sample of 12 days of 90 degree ARIS files were processed.
- 10% of the targets in each file were measured for vertical orientation in the water column.
- 7740 individual measurements were completed.

### Sockeye Dominant Periods (Jul 29-Aug 1 and Aug 11-15)

- 82% of total salmon sized targets were distributed within 1m of the bottom.
- 17% of total salmon sized targets were distributed between 1-2m above the bottom.
- 1% of total salmon sized targets were detected migrating >2m above the bottom.

- 3% of total targets were detected above the coverage of a flat orientation sonar.

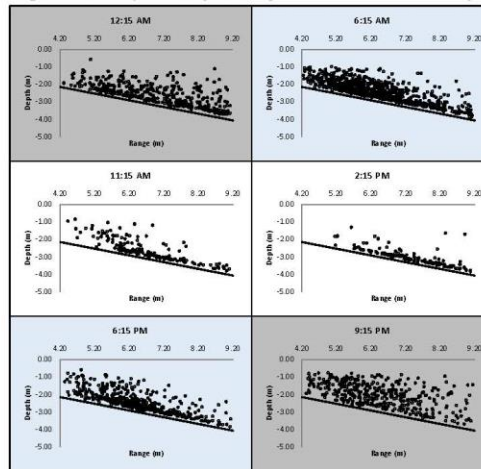
### Pink Dominant Period (Sep 8-12)

- 48% of total salmon sized targets were distributed within 1m of the bottom.
- 49% of total salmon sized targets were distributed between 1-2m above the bottom.
- 3% of total salmon sized targets were detected migrating >2m above the bottom.

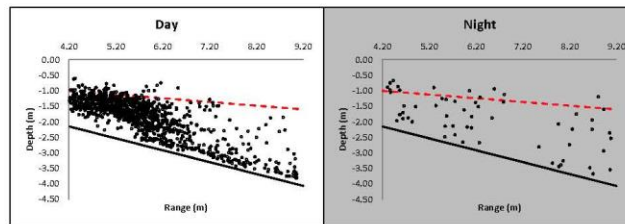
- 20% of total targets were detected above the coverage of a flat orientation sonar.

- Based on target work early in the season the coverage of the 35° rolled DIDSON is to approximately 0.24m below the surface at a range of 5m. Beam expansion increases vertical coverage at range. A single target was detected within 0.24m of the surface.

## Daily Changes in Vertical Migration August 15-21, 2016 (Sockeye Dominant Period)



### Daily Changes in Vertical Migration September 8, 2017 (Pink Dominant Period)



### Vertical Distribution Summary

- A narrow band below the surface in Bin 1 is not sonified using DIDSON in rolled aim, leaving a area where undetected migration could occur.
- Like the offshore area beyond Bin 3 this gap in water column coverage is a blind zone.
- Salmon demonstrate avoidance of the surface during their migration through Qualark's Bin 1, rarely approaching within 0.5m of the surface.

### **Vertical Distribution Conclusion**

- Documentation of vertical target distribution within Bin 1 addresses concerns over undetected fish passage within the bin near the surface. Any resultant negative bias in total migration that such fish represent is very minor, and would not have significant consequence to the utility of Qualark's abundance data as an in-season reference for Mission.

**Moving on to the offshore blind  
zone....**

**2015-2018 Qualark Long Range ARIS  
Counts: investigating salmon passage  
10m beyond the range of DIDSON  
coverage**

**Long Range Monitoring**

- Walters (2015) identified the offshore area, beyond the 29 m monitored on each side of the river with DIDSON, as a blind zone where undetected passage could bias estimates of total abundance.
- Each 29m monitoring zone reflects the maximum extent of coverage that can be achieved with DIDSON. Ensonification of offshore areas beyond 29m is beyond the capacity of the DIDSON gear.
- Flow offshore is too heavy to consider moorings or mobile transecting.

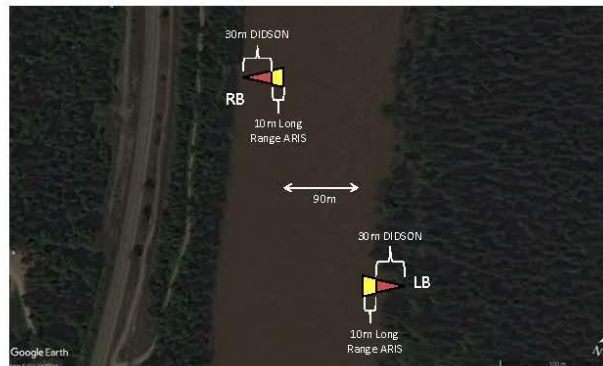
### **Long Range Monitoring**

- Our approach to extending coverage included installation of an additional acoustic system, ARIS, which could extend coverage by up to 20 m based on its enhanced acoustic capacity. (we realized 10m extension)
- Operated simultaneously with DIDSON to collect offshore data.
- Despite enhanced capacity still leaves major portion of the river unassessed due to range limitations.

### **Long Range Data Collection Methods**

- ARIS was mounted to the existing acoustic infrastructure next to the standard DIDSON using a pole mount.
- ARIS was aimed with a bottom priority and deployed with a flat (0° roll) aim. Data files were recorded for 5-20 minute periods.
- ARIS files were recorded in LF during simultaneous operation of DIDSON in HF (Bin 1) data collection to reduce crosstalk between systems.

## Hydroacoustic Coverage at a Discharge of 5500 m<sup>3</sup>/s



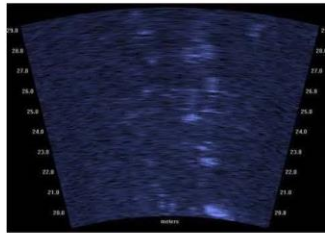
## Hydroacoustic Coverage at a Discharge of 3300 m<sup>3</sup>/s



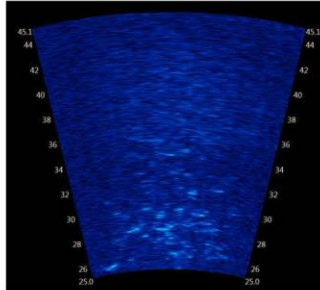


## Comparison of DIDSON Bin 3 and ARIS Long Range Files

DIDSON Bin 3



ARIS Long Range (25-45m)

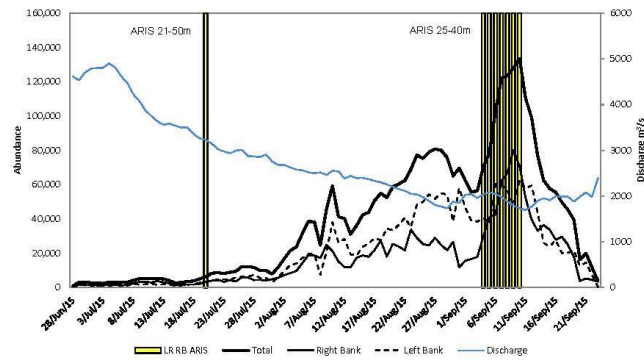


## 2015-2018 Long Range Results

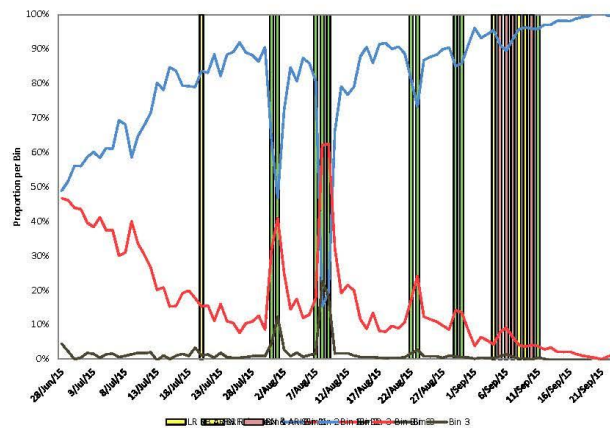
Year	# Days Processed	Bank	Expanded Long Range	Expanded RB Bin 1-3	Expanded LB Bin 1-3	% in Long Range
2015	8	RB	6	450,000		0.001%
2016	19	RB	126	100,000		0.1%
2017	13	RB	156	270,000		0.06%
2018	7	RB	168	370,000		0.05%
2018	12	LB	1269		560,000	0.2%

- Salmon distribution offshore was influenced by the occurrence of First Nations gillnet fisheries with Long Range files accounting for 0.3% of the total passage observed when these fisheries occurred.
- In the absence of fisheries Long Range files accounted for 0.01% of the total salmon passage observed.

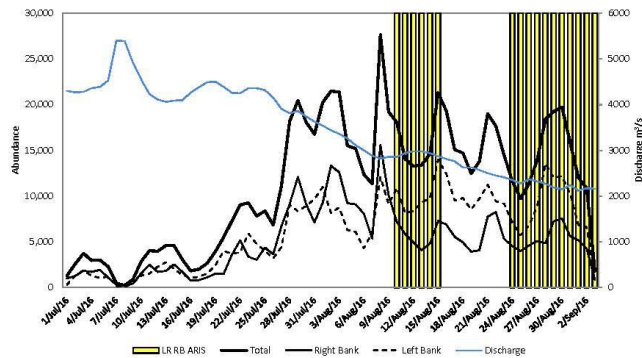
### 2015 Daily Salmon Passage, Discharge and Long Range RB ARIS Data Collection



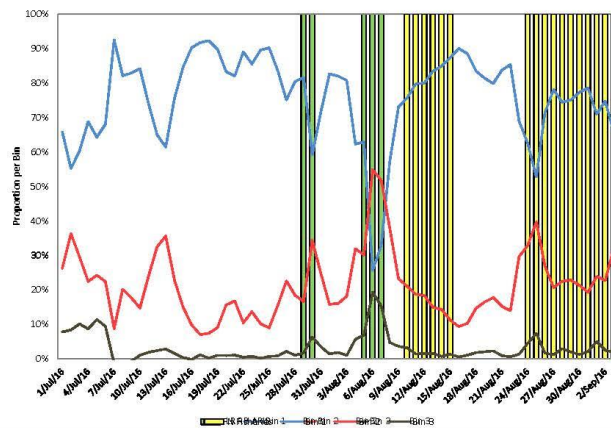
### Percentage of Salmon in 3 Qualark DIDSON Bins During Periods of Long Range RB ARIS Data Collection in 2015



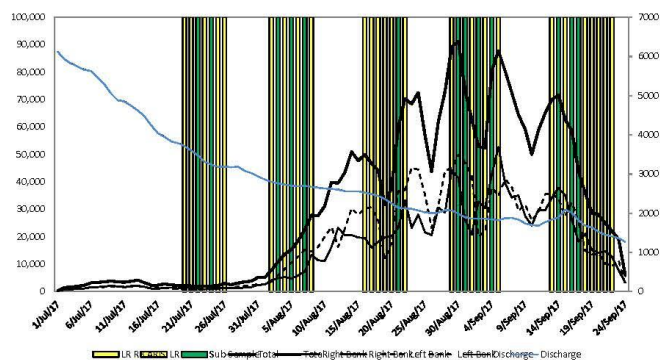
### 2016 Daily Salmon Passage, Discharge and Long Range RB ARIS Data Collection



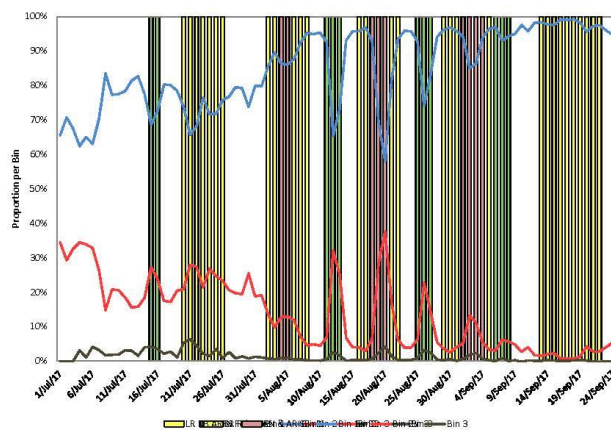
### Percentage of Salmon in 3 Qualark DIDSON Bins During Periods of Long Range RB ARIS Data Collection in 2016



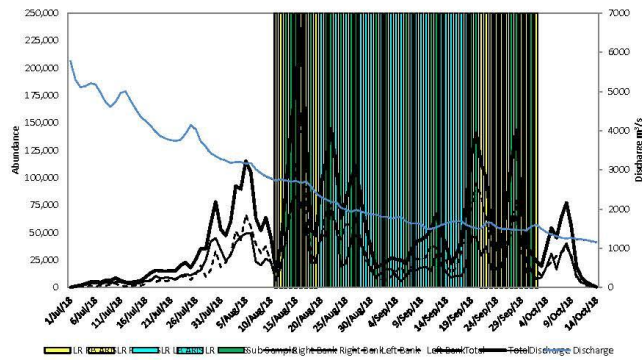
### 2017 Daily Salmon Passage, Discharge and Long Range RB ARIS Data Collection including Sub-Sample



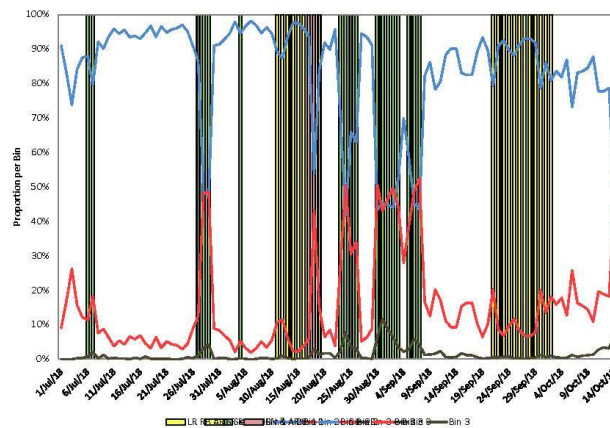
### Percentage of Salmon in 3 Qualark DIDSON Bins During Periods of Long Range RB ARIS Data Collection in 2017



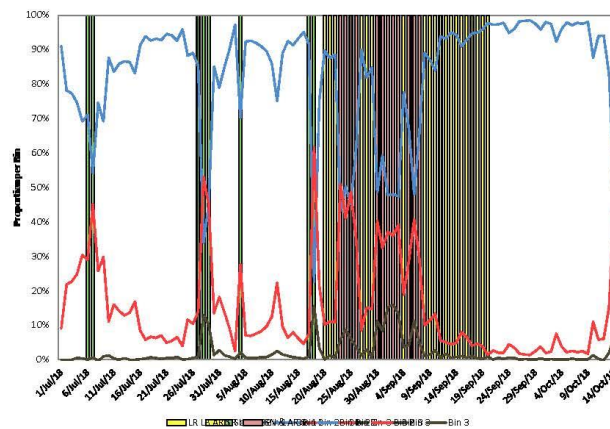
### 2018 Daily Salmon Passage, Discharge and Long Range ARIS Data Collection including Sub-Sample



### Percentage of Salmon in 3 Qualark DIDSON Bins During Periods of Long Range RB ARIS Data Collection in 2018



### Percentage of Salmon in 3 Qualark DIDSON Bins During Periods of Long Range LB ARIS Data Collection in 2018



### Long Range Monitoring Summary

- Salmon exhibit a very high affinity for shore oriented migration in this region of the Fraser River
  - 90+% of migration occurs within 10m of shore (in Bin 1) under most conditions.
  - <10% of migration occurs between 10-20m offshore;
  - <3% of migration occurs between 20-30m offshore;
  - <<0.5% of migration occurs beyond standard DIDSON monitoring at a range of 30-40m offshore.
- This pattern is independent of water level. Offshore shifts are only observed when salmon have been exposed to fishing immediately downstream of Qualark.

## Long Range Monitoring Summary

- When shifts offshore are observed they are generally quite subtle involving a 3-5m shift into Bin 2, and occasionally by 10-12 m into the onshore edge of Bin 3.
- Very few salmon demonstrate offshore movement into the waters beyond Bin 3. The the most dramatic shift into the Long Range monitoring bin we have observed resulted in 0.3% of the total daily migration being accounted for out beyond Bin 3.
- Monitoring in the far offshore reaches, >40m, remains inaccessible due to gear and environmental limitations.

## Long Range Monitoring Summary

- The most pronounced offshore shifts are observed when salmon have encountered fishing activity immediately prior to passing the Qualark site.
- These shifts may see as much as 20% of the daily migration move out into Bin 3. This does not however correspond to a large fraction moving out beyond Bin 3. As noted above, the most severe shift seen in response to fishing pressure during low river discharge yielded only 0.3% of the daily migration in the Long Range file.
- On release of fishing pressure, salmon immediately return to onshore migration.

### **Offshore Migration Conclusions**

- There remains an unmonitored portion of the river in the middle of the Fraser at Qualark, which is beyond reach of the standard DIDSON and the enhanced Long Range ARIS surveys reported here, and as Walters points out this area could represent a source of undetected salmon that would negatively bias Qualarks estimate.
- Enhanced sampling with ARIS at long range has added to our understanding of the local migration dynamics and can be used in a weight-of-evidence review to assess reasonableness of significant offshore migration occurring.

### **Offshore Migration Conclusions**

- Multiple factors indicate that offshore passage is negligible and will not significantly bias Qualark abundance estimates.
  - Previous experimentation done by the Applied Technologies group with split beam acoustics.
  - Bi-weekly offshore gillnet drifts to verify presence of salmon offshore beyond the DIDSON coverage.
  - Observations of fish behavior showing highly shore orientated migration.
  - Dramatic increase in current gradient as you move offshore.



### **Offshore Migration Conclusions**

- Knowledge that the river profile is a uniform unobstructed channel with no velocity barriers that would create eddy conditions mid channel.
- Knowledge of fish behavior related to bioenergetics of migration (high fidelity to nearshore, low current velocity areas reduces energy expenditure).
- This long range ARIS work showing lack of substantial migration occurring into areas 10m beyond normal DIDSON coverage – even during periods with low discharge and fishing influence acting in concert.

### **Offshore Migration Conclusions**

- Collectively, weight of evidence indicates that under the full range of conditions experienced at Qualark there have been no instances where a substantial offshore shift in migration could be supported.
- Qualark abundance estimates are only negligibly biased due to the normal DIDSON coverage implemented, particularly the gap in coverage beyond the DIDSON range capabilities.
- While offshore migration may comprise a tiny fraction of total daily migration, failure to monitor it will not substantively change the utility of Qualark data as an accurate in-season escapement reference for Mission.

### **Concluding Observations**

Investigation undertaken since 2015 supports the validity of the abundance estimates generated using the standard DIDSON protocol at Qualark as accurate in-season references for Mission data, specifically:

- the proposed blind zones do not negatively affect the utility of Qualark's abundance information;
- there is no Bin 1 blind zone due to rolled aim or low water. PSC should consider adopting the rolled aim at Mission to eliminate the sources of estimate bias that sequential vertically stratified aims represent (double counting at strata boundaries and implementation imprecision).

### **Concluding Observations**

- While offshore migration occurs it represents  $\ll 0.5\%$  of the total migration. Excluding this area from the monitoring protocol does not alter the accuracy of the estimates in a manner relevant to explaining large between-site discrepancies.
- Unlike Mission where variable flow conditions regularly result in salmon distributing across the entire channel, at Qualark, under all conditions observed salmon remain highly shore oriented. This makes them consistently vulnerable to being accurately counted with a greatly simplified acoustic system.

### **Concluding Observations**

- Low river discharge does not equate to low offshore flow at Qualark such that salmon shift their migration offshore. At lowest flows monitored (2018 Sept) salmon remained highly shore oriented, avoiding offshore migration, unless driven so in a response to fishing pressure.
- Qualark's protocols can be accurately and reliably implemented to provide an essential, cost effective in-season abundance reference for identifying potential estimate bias developing in Mission data, through comparison of the between-site DBE's.

**Q&A or End**

## **Appendix 4: Edits to Cover Letter Post Submission of Hydroacoustics Technical Summary Document (Part 1, page 2)**



## PACIFIC SALMON COMMISSION

ESTABLISHED BY TREATY BETWEEN CANADA  
AND THE UNITED STATES OF AMERICA  
VANCOUVER, B.C.

600-1155 ROBSON STREET  
VANCOUVER, B.C. V6E 1G5  
TELEPHONE: (604) 684-3081  
FAX: (604) 686-8707

Our File:

September 14, 2017

Your File:

August 15, 2019

Dear ~~members~~Members of the Fraser Strategic Review Committee,

### Re: Hydroacoustics Review

The attached document *Hydroacoustic Technical Review Summary* is presented for your consideration in the current review of the hydroacoustics programs in the Fraser River mainstem. This report summarizes work completed via the Fraser River Panel and Technical Committee as directed by the Fraser Strategic Review Committee (FSRC), and draws upon products of other component projects that formed part of the overall review to provide a synthesis of key findings and associated recommendations. The attached document has been reviewed by the bilateral Fraser River Panel and focuses on how the passage estimate differences (PEDs) between Mission and Qualark can affect assessments of run size and Total Allowable Catch (TAC) of Fraser sockeye. The technical review focused on evaluation of the likely contributing factors driving the PEDs during certain years, as well as whether adjustments to some elements of the current Mission hydroacoustics program are possible. The review does not cover other uses of the hydroacoustics estimates, which include less formalized but technical methods (e.g., quantitative comparison of passage estimates from both sites to verify the Mission estimates that are feeding into run size models) as well as non-technical uses (e.g., general reassurance that Mission estimates being used by run size models and as the measure of beyond in-river escapement are reflected in Qualark estimates), season management decisions.

In conjunction with the hydroacoustics review a separate but related Southern Endowment Fund project titled "Improving Fraser River Test Fisheries and Run Size Estimates" was conducted over the past two years with a final report pending, completed in March 2018 (Nelitz, M., A. Hall, C. Michielsens, B. Connors, M. Lapointe, K. Forrest, and E. Jenkins. 2018. Summary of a Review of Fraser River Test Fisheries. Pacific Salmon Comm. Tech. Rep. No. 40: 155 p.) Information and recommendations from this test fishery project were evaluated in relation to the hydroacoustics review as the test fisheries contribute data for assigning species and stock ID to the estimates of total fish passage generated by the hydroacoustics programs. In addition, the test fisheries are used to generate estimates of in-river

sockeye escapement early and late in the season when the hydroacoustics programs are not operating due to financial constraints or are swamped by pink salmon passage.

Initial Panel recommendations in 2017 included continued operation of the Qualark hydroacoustic site through the 2018 Fraser sockeye season in order to conduct experiments at both Mission and Qualark to further our understanding of potential causes of passage estimate differences (PEDs) between Mission and Qualark, which have been most dramatic during Late Shuswap dominant cycle years of 2010 and 2014. Substantial efforts were made from 2016 to 2018 by both programs in the form of experiments to understand potential causes of PEDs. At Mission these experiments included an examination of offshore fish behaviour, potential biases in estimates using different sonar systems (split-beam vs. imaging sonar), the influence of fishing activity on cross-river fish distributions, left-bank river bottom reprofiling, and the impact of changes to sampling configurations (i.e. six aims vs. 10 aims). At Qualark, experiments included an examination of near bottom blind zones, the vertical distribution of fish, and the presence of fish further offshore than the insonified area. The total PED in 2018 was 4.2% (207,100 sockeye), with the Mission projection being higher than Qualark.

After considering the technical evaluation contained in the attached document ~~and, including the additional work done by both hydroacoustic programs (Mission and Qualark) since 2016 and the~~ non-technical experiential information from our years of serving on the Fraser River Panel, the Panel ~~provides~~provided the following updated recommendations for the Fraser River mainstem hydroacoustics program:

1. Maintain the current hydroacoustics program at Mission that covers the entire cross-section of the river. (Within this recommendation, there is room to further investigate some small cost savings associated with sub-sampling the Mission mobile unit and potentially re-direct the funds to improving sample size of in-river test fisheries. However, there was no hydroacoustics gear configuration examined which would allow assessments to continue at both mainstem hydroacoustic sites for the cost of the current Mission program without severely compromising the data that is used by the Fraser River Panel.)
- ~~2. Continue operating the Qualark hydroacoustics site through the 2018 Fraser Sockeye season in order to conduct experiments at both Mission and Qualark to further our understanding of potential causes of passage estimate differences (PEDs) between Mission and Qualark.~~
- ~~3.2. Depending on the outcomes from the 2017 and 2018 Qualark programs and experiments to address remaining questions, there~~There may be a desire to further evaluate the continuation

of Qualark in ~~future non-dominant Adams~~ years pending available funding. As well, continuation of Qualark needs to be considered in the context of the overall sockeye assessment program and outcomes from the current test fishing review.

~~4-3.~~ Longer term considerations for the continued operation of Qualark will need to incorporate the value of information generated by the site ~~that. At this time, Qualark data (both hydro-acoustic and test fishing data) are not formally utilized for in-season Panel management decisions. The value of these data~~ was not evaluated in this technical review, which focussed on the use of hydroacoustics data used to calculate run size and TAC. In particular, the evaluation of the species and stock composition information used at Mission and Qualark as per deferred workplan items #11 & #12 may help quantify the value of the Qualark dataset during the times when species composition is highly uncertain due to the proportions of co-migrating Chinook and Pink salmon or when sample sizes at Whonnock and Cottonwood are small.

~~5-4.~~ The Panel also supports the suggestions of additional work to ~~evaluate blind-zones, implications of large return years and further examination of~~ examine the impact of hydroacoustic estimate uncertainties on Management Adjustment (MA) models and the Run Size Adjustment (RSA) process.

The Fraser River Panel and Technical Committee are very willing to meet and discuss the findings to date and the recommendations provided above.

Sincerely,

John Field  
Executive Secretary

Ms. Jennifer Nener, Chair

Ms. Lorraine Loomis, Vice-Chair