Feasibility of deploying a dual-frequency identification sonar (DIDSON) imaging system to improve spawning ground escapement estimation in the Fraser River

John Holmes[1], George Cronkite[1], Hermann Enzenhofer[2], Richard Bailey[3], Chuck Parken[1] and Timber Whitehouse[3]

1. Fisheries and Oceans Canada
   Pacific Biological Station
   3190 Hammond Bay Road
   Nanaimo, BC, V9T 6N7

2. Fisheries and Oceans Canada
   Cultus Lake Salmon Research Laboratory
   4222 Columbia Valley Highway
   Cultus Lake, BC, V2R 5B6

3. Fisheries and Oceans Canada
   Stock Assessment Division
   BC Interior
   985 McGill Place
   Kamloops, BC V2C 6X6

2004 Project Completion Report

For

Southern Boundary Restoration and Enhancement Fund
Pacific Salmon Commission
600 - 1155 Robson Street
Vancouver, B.C.
Canada V6E 1B5

31 March 2005

Project Rationale

The Fraser River system supports the largest grouping of sockeye salmon (*Oncorhynchus nerka*) and Chinook salmon (*O. tshawytscha*) stocks along the west coast of North America (Northcote and Larkin 1989). Sockeye and chinook salmon spawn in natal areas ranging from small streams to large rivers and lakes. Spawning ground escapement of sockeye salmon has been estimated in a large proportion of these natal areas since 1938. Mark-recapture programs are used to enumerate large sockeye salmon stocks consisting of ≥ 25,000 spawning fish (this threshold was raised to 75,000 fish in 2004) and are among the most costly enumeration techniques currently in use. The number of sockeye salmon populations on which mark-recapture estimates are conducted has risen over the past decade as a result of stock rebuilding efforts, substantially increasing the pressure on limited resources. The large number and wide-spread distribution of chinook salmon stocks in the upper Fraser River impedes our ability to collect precise and cost-effective escapement data on all or even a few key indicator stocks. The absence of these data is a growing concern to fisheries managers because of the inability to adequately evaluate the effects of the expanded in-river and marine mixed stock fisheries which are impacting these Chinook stocks.

As a result of these pressures, a strategic planning exercise was initiated in 2003 to better align stock assessment resources and priorities with management needs and to investigate new technologies and best practices in an effort to reduce costs while maintaining assessment coverage. The DIDSON (**D**ual-frequency **ID**entification **SON**ar) acoustic imaging system (Sound Metrics 2004) was identified through this process as an acoustic technology with the potential to deliver a cost-effective means of producing escapement estimates with similar levels of precision and accuracy as existing techniques and lower operational costs for some salmon programs in the Fraser River watershed. The DIDSON system produces high resolution near-video quality images of targets in aquatic environments, including fish, and is small, highly portable and does not require extensive sonar expertise to operate. The small portable design and less stringent operating characteristics of the DIDSON system may open up new opportunities to deploy this technology in streams and rivers that have not received much attention previously from a stock assessment or management standpoint, particularly tributaries used by Chinook salmon but not sockeye salmon.

Project Deliverables

In this project we address the following objectives:

1. Identify deployment sites for the DIDSON system in upper Fraser River subwatersheds (Stuart-Nechako, Quesnel-Horsefly and Chilcotin-Chilko) and site features and ancillary equipment (weirs, tripods, pan and tilt capability) that enhance/degrade the performance of a DIDSON system;
2. Assess the accuracy and precision of fish counts made using the DIDSON system;
3. Determine the effects of fish behaviour and fish density distribution within the acoustic beams (i.e., passage rates) on the accuracy and precision of fish counts

produced by the DIDSON system; and

4. Develop software tools (target tracking and editing) that facilitate data analysis and interpretation.

Our findings concerning the efficacy and implementation of the DIDSON system into the salmon stock assessment framework in the Pacific Region are documented in three reports. The first report (Holmes et al. 2005a) describes where the DIDSON system can be used and the accessory equipment required for effective operation, i.e., Objective 1 above. A second report (Holmes et al. 2005b) provides an evaluation of the precision and accuracy of fish counts made with the DIDSON system by comparison with visual counts and counts through a fish enumeration fence (Objective 2). The third report (Cronkite et al. 2005) describes the development and testing of improved target detection and tracking software, which is an important step in the implementation of computer-automated counting and species identification. Although aspects of Objective 3 – the effects of fish behaviour and density on the accuracy and precision of counts – are addressed in Holmes et al. (2005b), we were unable to fully evaluate the effects of variations in fish density on the accuracy and precision of count data because sockeye salmon escapement to natal systems for all four run-timing groups (Early Stuart, early summer, summer, late) was much lower than gross escapement past Mission in 2004.

The site evaluation report (Holmes et al. 2005a) will be submitted for publication in *Canadian Technical Report of Fisheries and Aquatic Sciences* after some minor modifications in the second quarter of 2005. The accuracy and precision report will be submitted to *Canadian Journal of Fisheries and Aquatic Sciences* or *ICES Journal of Marine Science* for review and publication in the second quarter of 2005 as well. The design for an adjustable pole mount and mounting bracket to deploy the DIDSON transducer from a modified step-ladder anchored to the riverbed or a bracket attached to the gunwale of a boat was documented by Enzenhofer and Cronkite (2005).

Project Schedule

Work on the three of the four objectives proceeded according to the schedule originally proposed for our project. Specific dates and timelines for completing our objectives in 2004 are shown below.

Objective 1

Tachie River - 19-23 July
Lower Stuart River - 19-23 July
Horsefly River – 03-16 August
Mitchell River - 11 Aug
Chilko River - 17-28 August
Seymour River – 22 September
Scotch Creek – 22 September
Lower Shuswap – 23 September
Lower Adams River – 24 September

Objective 2 and 3
Chilko River (Henry's Bridge) – 18-20 August
Stellako River fish - 01-10 September

Objective 4
Contract awarded to Pacific Eumetrics – December 2004.
Software, beta version - delivered 01 Mar 2005
Testing – 01-11 Mar
Revised software – delivered 30 Mar 2005

Quality Assurance / Quality Control

Objective 1

The reliable detection and enumeration of fish passage in riverine environments with acoustic systems involves the recognition and solving of problems derived from three sources: (1) physical site characteristics, including bottom profile and water flow; (2) operating characteristics of hydroacoustic systems; and (3) fish behaviour and ecology. An initial list of 22 sites on 10 river systems for evaluation was compiled in collaboration with DFO sockeye and Chinook salmon assessment staff in Kamloops using accepted criteria for acoustic sites as guidelines. Field work to determine where the DIDSON acoustic imaging system could be used to estimate sockeye salmon escapement in the Fraser River watershed and to determine the additional equipment needed (e.g., weirs, mounting system and platform) for effective operation of a DIDSON imaging system was conducted between late July and mid-Sept 2004. Based on a combination of in-stream testing and site visits, we conclude that the DIDSON system could be used to effectively estimate escapement in Scotch Creek, Chilko, Horsefly, Mitchell and Seymour Rivers, and probably the Lower Adams River as well. Additional equipment needed to effectively enumerate populations in these systems is minimal but includes a transducer mounting pole and bracket, a modified step-ladder from which the transducer is deployed and that can be used as a viewing platform for species composition estimates, a secure shed for topside equipment (computer and battery bank), solar panels to provide power, and 5-10 m of weir, depending on the site. Although work is needed on some systems to choose the most appropriate site for deployment (Mitchell River) or to confirm that fish do not exhibit unusual behaviours (e.g., milling, holding) that would degrade the performance of the DIDSON system (Mitchell River, Scotch Creek, Seymour River), we do not believe that the additional time commitment to address these issues is large. The Lower Shuswap, Lower Stuart, and Tachie Rivers were not suitable for deployment of the DIDSON system in our judgement. We suspect that acoustic counting of migrating fish in the Lower Stuart River could be accomplished with shore-based side-looking split-beam systems, but at least one field season of testing would be required to confirm or refute this hypothesis. Neither the Lower Shuswap nor the Tachie were amenable to acoustic counting of migrating salmon because of the high probability of unusual fish behaviour and poor site characteristics, respectively. Our findings concerning physical characteristics, DIDSON operating profile, and fish behaviour at each site are documented in Holmes et al. (2005a) along with recommendations concerning the potential deployment of a DIDSON system for salmon escapement estimation.

Objective 2 and 3

The reliability of fish count data collected by the DIDSON imaging system was evaluated on the basis of accuracy and precision criteria. An errors-in-variables analysis was used to assess accuracy of fish count data from a DIDSON system by comparison with visual counts of unconstrained migrating salmon on the Chilko River and fish counts from an enumeration fence on the Stellako River. Regressions fitted to the DIDSON count data and the enumeration fence count data were statistically indistinguishable from a 45° line passing through the origin (which we interpret as agreement in both counts) whereas the regressions fitted to the DIDSON count data and the visual count data from the Chilko River had slopes that were significantly less than 1.0 ($P < 0.001$), i.e., were not parallel to a 45° line. The precision of manual counts from the DIDSON system among different observers, as measured by the coefficient of variation (CV) and average percent error (APE), improved as the number of fish counted increased. When DIDSON counts were > 50 fish, repeated independent counts of the DIDSON files were observed to produced the same counts 97-99% of the time, meeting our criterion of at least 95% agreement among individuals. We conclude that when migrating fish are shore-oriented or the migration range is restricted by weirs and fish can be ensonified by a DIDSON acoustic imaging system in the high frequency mode, the resulting count data are as accurate as counts of fish from an enumeration fence and that these counts exhibit very high precision among different observers doing the manual counting, especially when the counts exceed 50 fish•event^{-1}. Although similar conclusions may be appropriate for data collected in the low frequency mode of the DIDSON system, a formal assessment of precision and accuracy is needed because the low frequency mode has poorer target resolution than the high frequency mode, which may affect low frequency fish counts. Our findings and conclusions concerning accuracy and precision of the DIDSON data and the effects of fish density on these parameters are documented in Holmes et al. (2005b).

Objective 4

After the 2004 field season was completed, we began developing standalone software to improve and automate the detection, tracking, and identification of moving targets. The design goals of this software are to provide the ability to detect, track and characterize targets with sufficient fidelity to discriminate between fish, debris and spurious targets, and to use shape and behavioural information derived from tracking to identify and accurately count fish species of interest such as sockeye salmon (*Oncorhynchus nerka*). The development of this software was planned in three phases and Pacific Eumetrics Consulting Ltd. was contracted to implement Phases 1 and 2 for our 2004 Southern Boundary Fund proposal.

In Phase 1, additional image filtering and analysis techniques were tested to improve target detection and tracking because all of the anticipated features of the software depend on high fidelity target detection and resolution. During this phase the alpha-beta tracker, developed by the military to track missiles and aircraft, was implemented for tracking fish targets in DIDSON images over time. DIDSON Target

Detection, tracking (ABTrack) and data viewing/editing (Polaris) software was delivered in early March 2005 for testing. Based on comparisons between manually counted files from Henry's Bridge on the Chilko River and counts of these files produced using the software suite delivered by Pacific Eumetrics, we are satisfied that the new software will perform well, with minimal user tweaking. We have asked for some modifications to make the software more user-friendly, particularly the implementation of manual counting on the computer screen, in time for the 2005 field season on the Horsefly River. The outcome of Phase 1 is high fidelity target detection and resolution.

Phase 2 focused on the development and testing of target features such as size, shape (height, width), aspect and mean intensity as tracking variables. Used in addition to position (X – upstream-downstream, Z – range, T – time) data, these variables provide the tracker with the potential to use target characteristics to choose between candidate echoes in dense schools and environments with spurious echoes (e.g., shadows). Implementation of Phase 2 involved three steps: (1) the development of a new export file format for ABTrack and Polaris, (2) modifying the target detector to export new target features, and (3) a redesign of the tracking parameter optimizer in Polaris. The software as delivered for testing in early March used a fixed variable binary file format developed by Hydroacoustic Technology Inc. (HTI) for their split-beam echosounders for transferring data among the DIDSON target detector, ABTrack and Polaris software. Because we are still in the process of determining which target features will be useful for tracking, a new file format is needed that is flexible enough to allow the inclusion or exclusion of features as they become necessary. Furthermore, the target detector must be modified to calculate and export the relevant variables into the new file format. Considerable discussion during our testing has focused on the third step of redesigning the tracking parameter optimizer because of the enormous time and programming commitment required to successfully complete this task, and because of the necessity of the redesign given the enhancements to target detection and tracking implemented in the target detection software. We have concluded that this step is not necessary at this time for accurate tracking and counting at high fish densities and in poor acoustic environments with the DIDSON system. Pacific Eumetrics has delivered the new file format and feature export function in the target detection software.

Our findings with respect to Objectives 1, 2 and 3 have been presented at two salmon assessment staff meetings in Kamloops and to a Salmon Assessment Coordinating Committee (SACC) meeting of managers in the fall of 2004. We have also presented and discussed this work at a joint DFO/PSC Hydroacoustic Working Group meeting and we are preparing a presentation for a session on Riverine Acoustics at the upcoming Acoustical Society of America meeting in Vancouver, 16-20 May 2005.

Monitoring and Evaluation

Long-term success of this project will be measured by the degree of acceptance of our findings and interpretation among Stock Assessment staff within DFO and other agencies such as the Pacific Salmon Commission and ADF&G. We completed our evaluation of the four project objectives in an efficient and timely manner and our results and conclusions are well documented in three separate reports (Holmes et al. 2005a, b; Cronkite et al. 2005), which we will submit for publication in 2005, and these findings have been widely presented to the intended users of this technology. Based on the comments and feedback that we have received from salmon assessment staff and managers, we anticipate that our evaluation and interpretation of the data will guide DFO with respect to the implementation of the DIDSON technology operationally into salmon stock assessment programs in the Fraser River. As a potential measure of long-term success, we note that there is also considerable interest among DFO staff in purchasing additional DIDSON systems for the Fraser River and elsewhere and that we continue to receive informal requests concerning the availability of the current DFO DIDSON system and the potential for conducting a site evaluation on other systems using the site and operational guidelines developed as a result of this project.

Benefits

The DIDSON acoustic imaging system is a visual tool for assessing salmon escapement and migratory behaviour. Because it is visual, interpretation of the data (fish images) is intuitive and does not require specialized training in acoustics, i.e., users can readily see and understand the behaviour of migrating fish. Consequently, demonstrations of the technology to field staff have resulted in support for the integration of this technology into the stock assessment program for Fraser River sockeye salmon. Since the rationale for acquiring the DIDSON technology was as an alternative to MRPs, we suggest that implementation into salmon assessment activities in the Fraser River is likely to improve escapement data quality in terms of accuracy and precision and that this improvement will be achieved at lower cost to existing stock assessment programs since a minimal crew of two individuals can deploy and operate the DIDSON system (Holmes et al. 2005b). The list of deployment sites and operational requirements (e.g., accessory equipment and sampling strategy) documented for each river and site (Holmes et al. 2005a) can be cross-referenced to existing management priorities in order to determine deployment opportunities that best exploit the capabilities of the DIDSON technology within existing programs and as additional DIDSON units are purchased.

Better and more timely knowledge of spawning ground escapements benefits the resource because it allows fisheries managers to adjust in-season management of sockeye salmon to reflect current realities such as in-river mortality in the Fraser Canyon, lower or higher than expected returns and hence changes in opportunities for at-sea or terminal area harvesters. Experience with the DIDSON system in Alaska has shown that field crews can be producing fish counts and upstream flux estimates (net upstream migration) in near real-time using manual counting. We are developing software that will detect, track and characterize targets with sufficient fidelity to discriminate between fish, debris and spurious targets, and to use shape and behavioural information derived from tracking to identify and accurately count fish species of interest such as sockeye salmon. The goal of this software is to assist the user in providing timely fish counts and upstream flux estimates in complex situations in which migrating sockeye salmon must be differentiated from other salmon species, resident non-migratory species, milling fish, debris or other unwanted targets when the density of targets passing through the ensonified area is very high because these conditions are the norm in many of the Fraser River tributaries in which the DIDSON system is likely to be deployed for stock assessment purposes.

The small portable design and less stringent operating characteristics of the DIDSON system has opened up new opportunities to deploy this technology in streams and rivers that have not received much attention previously from a stock assessment or management standpoint, particularly systems that support Chinook salmon but not sockeye salmon. Based on feedback from salmon assessment staff throughout the Pacific and Yukon Region, we believe that the process of identifying and evaluating alternative sites is actively underway.

Budget

The proposed budget for this project was 245K, consisting of 100K from the PSC and $145K of in-kind and cash support from DFO (all figures are in Canadian currency). The summary of expenditures on the next page (which reflects only the 100K requested from the PSC) shows that our project came in on budget, with total expenditures of 79.4K and outstanding commitments of 20.6K as of 31 March 2005. Overall spending in the major budget categories (labour, site/project costs, training, overhead, capital) was consistent with our forecasts, but there were important changes in certain line items within these categories that were necessitated by emerging requirements of the project. For example, 25K was budgeted for a contractor to carry out site identification work. These funds were no committed because we concluded that it was more efficient for the principal collaborators (Cronkite, Enzenhofer, Holmes) to complete this work. This saving was offset by a 13.5K increase in software development costs (Pacific Eumetrics) and slightly higher overtime costs (4K) than anticipated. Similarly, a total of 42K was budgeted for travel expenses but travel expenditures only totalled 21.5K. However, associated costs for tools and equipment, site supplies and materials, and work and safety gear were 12.8K higher than anticipated prior to commencing this project. Lastly, an additional 18.5K was required for capital costs associated with the design and fabrication of equipment in support the DIDSON technology. These costs are in addition to the costs to DFO of the pole mount and step ladder platform described by Enzenhofer and Cronkite (2005).

Budget Summary
(Expenditures + Commitments)
as of 30 March 2005

Labour	**43,372**
Project / Site Costs	**36,457**
Training Costs	
Overhead Costs	**1,610**
Capital Costs	**18,561**
Total	**100,000**

Detailed Expenditure Summary: 01 July 2004 to 31 March 2005

Labour	Budget	Expenditures	Commitments
Wages & Salaries			
Overtime (biologists - 2)	14,000	18,118	
Subcontractors & Consultants			
Pacific Eumetrics	10,000	13,500	10,000
Site Identification contractor	25,000		
Tim Mulligan	7,500	1,088	
Bill Hanot (Sound Metrics)		667	
Total labour costs	56,500	33,372	10,000
Site / Project costs			
Travel	42,000	21,564	
Small Tools & Equipment		9,701	
Site Supplies & Materials		740	
Work & Safety Gear		2,410	
Repairs & Maintenance		342	
Other site costs - Helicopter - Mitchell R		1,700	
Total Site / Project Costs	42,000	36,457	
Training			
Equipment Training			
Field Safety			
Total Training			
Overhead			
Insurance		36	
Office supplies		523	
Telephone & long Distance		767	
Other overhead costs		30	
Publication Costs	1,500	254	
Total Overhead	1,500	1,610	
Capital Costs / Assets			
Weir, solar panel tower, battery box fabrication		8,001	10,560
Total Capital Costs		8,001	10,560
Project Totals	**100,000**	**79,440**	**20,560**

Project Reports

Objective 1

Holmes, J.A., Cronkite, G, and Enzenhofer, H.J. 2005a. Feasibility of implementing a dual-frequency identification sonar (DIDSON) imaging system to estimate sockeye salmon escapement in major tributary systems of the Fraser River, British Columbia. Project Completion Report, Southern Boundary Restoration and Enhancement Fund, Pacific Salmon Commission, Vancouver, B.C., 58 p.

Objective 2 and 3

Holmes, J.A., Cronkite, G.M.W., Enzenhofer, H.J., and Mulligan, T.J. 2005b. Accuracy and precision of fish count data from a dual-frequency identification sonar (DIDSON) imaging system. Project Completion Report, Southern Boundary Restoration and Enhancement Fund, Pacific Salmon Commission, Vancouver, B.C., 47 p.

Objective 4

Cronkite, G., Enzenhofer, H.J., Holmes, J.A., Mulligan, T.J., and Withler, P. 2005. Target detection, tracking and automated counting software development for the dual-frequency identification sonar (DIDSON) imaging system. Project Completion Report, Southern Boundary Restoration and Enhancement Fund, Pacific Salmon Commission, Vancouver, B.C., 19 p.

Literature Cited

Enzenhofer, H.J., and Cronkite, G. 2005. A simple adjustable pole mount for deploying DIDSON and split-beam transducers. Can. Tech. Rep. Fish. Aquat. Sci. 2570: iv + 14 p.

Northcote, T.G., and Larkin, P.A. 1989. The Fraser River: A major salmonine production system. In Proceedings of the International Large River Symposium. Edited by D.P. Dodge. Can. Spec. Publ. Fish. Aquat. Sci. 106. pp. 172-204.

Sound Metrics Corporation. 2004. Dual-frequency identification sonar. DIDSON Operation manual. V4.47.15, Sound Metrics, Seattle, WA, 44 p.