Wannock River Hydroacoustic Study, 2002

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WANNOCK RIVER HYDROACOUSTIC STUDY, 2002

by

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ABSTRACT

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We collected acoustic data with a split-beam hydroacoustic system on the Wannock River during the 2002 sockeye salmon migration. Few suitable acoustic sites are available on this river. The site identified and studied was located 750 metres downstream of the outlet of Owikeno Lake, in the Rivers Inlet area. We were able to obtain approximately 70% coverage of the river cross-section and we believe that extrapolation of the known fish densities could be used to estimate the salmon densities in the areas not covered by the acoustic beam. Two types of salmon behaviour were noted. The salmon were either actively migrating or holding stationary in the fast current. This type of holding behaviour is problematic for obtaining population estimates.

RÉSUMÉ

Cronkite, G., P. VanWill, D. Noon, and S. Bachen. 2003. Wannock River Hydroacoustic Study, 2002. Can. Manuscr. Rep. Fish. Aquatic Sci. 2632: 20 p.

À l'aide d'un système hydroacoustique à faisceau divisé, nous avons recueilli des données acoustiques sur la rivière Wannock durant la migration du saumon rouge en 2002. Il y a peu de sites appropriés à la collecte de données acoustiques sur cette rivière. Le site identifié et étudié se trouve à 750 mètres en aval de l'effluent du lac Owikeno, dans la région du bras de mer Rivers. Nous avons pu couvrir environ 70 % de la section de la rivière et croyons que l'extrapolation des densités de poisson connues pourrait être utilisée pour évaluer les densités de saumon dans les zones non couvertes par le faisceau acoustique. Deux types de comportement du saumon ont été observés, nommément une migration active et une position stationnaire dans le courant rapide. Il est difficile d'évaluer les populations avec ce second type de comportement.

1.0 INTRODUCTION

The Owikeno Lake Watershed, located at the head of Rivers Inlet (Figure 1), historically supported large sockeye salmon (*Oncorhynchus nerka*) populations that played an important role in the local First Nation culture (food, social and ceremonial harvest) as well as providing a strong terminal commercial fishery. The tributaries of the glacial Owikeno Lake contribute to the majority of the sockeye salmon production for the Rivers Inlet area.

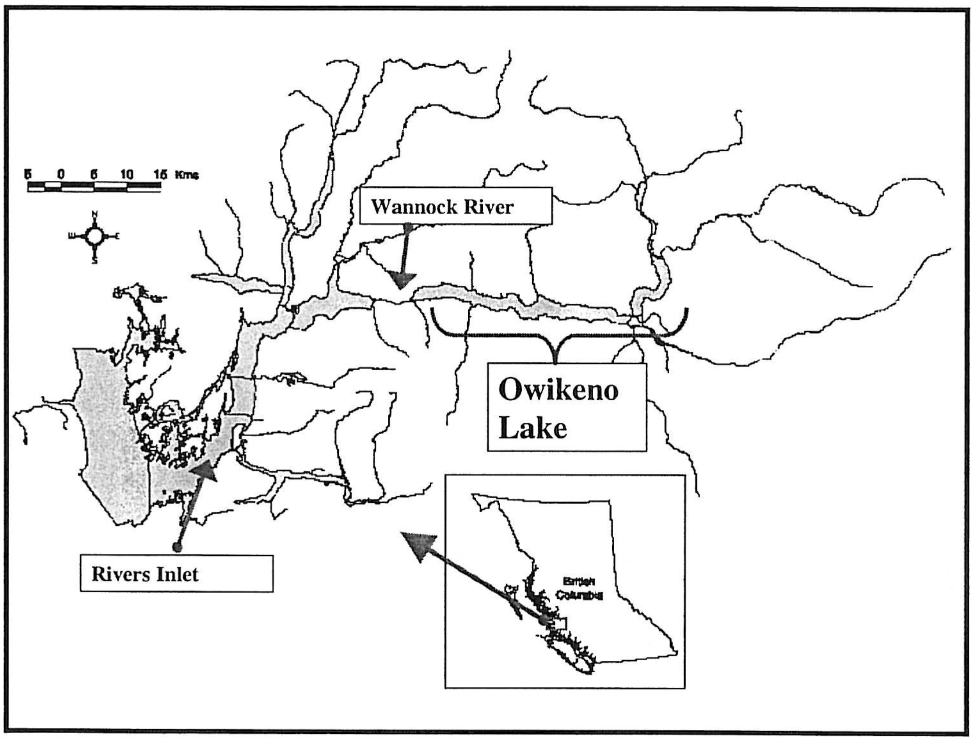

Figure 1. Area map.

In the past 10 years, Rivers Inlet sockeye salmon have endured a dramatic decline in the return of spawning adults to their natal streams (Figure 2). This decline was so significant that Rivers Inlet sockeye salmon were identified as a conservation concern which caused the Department of Fisheries and Oceans (DFO) to enact various area closures for sockeye salmon directed fisheries (Rutherford and Wood, 2000). The magnitude of this decline resulted in the Rivers/Smith Planning Group (RSPG), in conjunction with DFO, to develop and initiate a recovery plan for the sockeye salmon stocks of the Owikeno Lake Watershed. Subsequent evolution of the recovery plan and further support from the Pacific Salmon Endowment Fund Society has provided an even greater focus on the problems associated with the Rivers Inlet and also the Smith Inlet sockeye salmon stocks.

One of the main components of a successful recovery plan is the development of accurate assessment tools to monitor the performance of the plan. Currently, adult sockeye salmon assessment activities in Owikeno Lake have been hampered due to the glacial nature of the main sockeye spawning tributaries and as a consequence, DFO stock assessment have only an index of relative sockeye abundance. In order to satisfy DFO's management and stock rebuilding requirements, a need has been identified to accurately estimate the numbers of migrating adult salmon into Owikeno Lake. In 2002, the RSPG approved a feasibility study on the use of a split-beam acoustic enumeration device (HTI, 1993) in the Wannock River, at the outlet of Owikeno Lake, to determine if this tool can provide accurate and defensible estimates of the total Owikeno Lake sockeye salmon stocks.

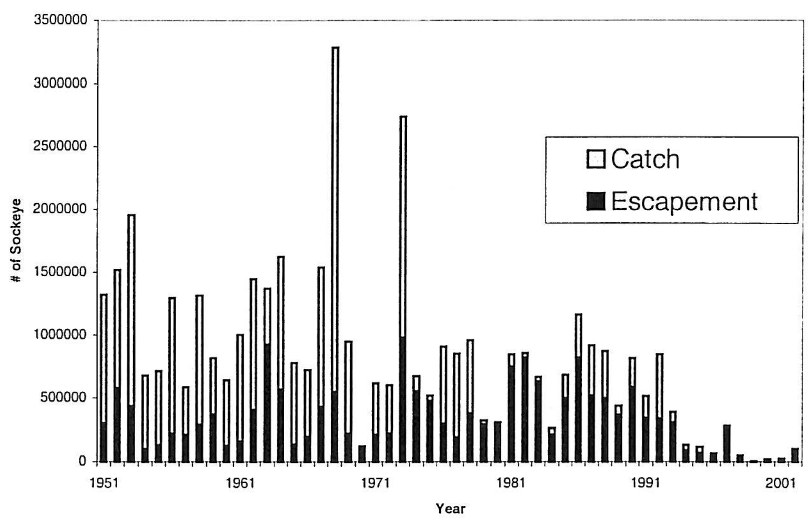

Figure 2. Historical trend in abundance of Rivers Inlet adult sockeye (Statistical Area 9).

This report provides detailed analyses of the split-beam data collected during the 2002 field season.

2.0 MATERIALS AND METHODS

2.1 Site Selection

General criteria for the selection of a hydroacoustic site include (Enzenhofer and Cronkite 2000):

1. A straight channel with laminar water flow. Laminar flows produce less acoustic background noise than turbulent flow, resulting in an increased signal-to-noise ratio and hence, a greater ability to detect fish.

2. A planar bottom profile, rather than shelved or scalloped. A shelved bank creates riverbed zones that are inaccessible to the acoustic beam.

3. Bottom substrate should be free of large boulders, which will interfere with the path of the acoustic beam or create turbulent flow.

4. Human activity on the river should be minimal because propeller wash entrains air bubbles, creating background noise. Activities that may alter fish behaviour such as harvesting should be avoided as this may affect the flux estimate (estimate of fish passage through the beam per unit time).

5. Fish should be actively migrating and not holding or milling. Fish that tend to remain in the sampling area may be counted several times, which would lead to overestimates of flux.

Other criteria such as accessibility and the specific operational requirements of other parties may be relevant on a site-by-site basis.

2.2 Site Location

Since the majority of the sockeye salmon spawn in the tributaries of Owikeno Lake, the most practical way to monitor total escapement of Rivers Inlet sockeye is at an acoustic site on the Wannock River, which drains Owikeno Lake (Fig. 1). Based on field reconnaissance prior to the sockeye migration, a site approximately 750 metres from the outlet of the lake at latitude 51° 40.946' and longitude 127° 10.652' was selected for the acoustic work in 2002.

2.3 Acoustic Data Collection

Measurements from a split-beam echo sounder provide three-dimensional target location in the beam as a function of time and allow target strength estimation (Traynor, 1986; Traynor and Ehrenberg, 1990) and tracking of individual fish in four dimensions (time and 3D space) (Carlson and Jackson, 1980). Using this data, movement (vector direction and velocity) and flux can be estimated, in addition to the traditional fish density measurements (Ehrenberg and Torkelson, 1996). For example, we use split-beam sonar to estimate the number of salmon migrating in the Fraser River (Enzenhofer and Cronkite, 2000).

We used a Hydroacoustic Technology Inc. (HTI) Model 244 Digital Split-Beam Hydroacoustic System (HTI 1998) operating at 200 kHz, and a 4° x 10° elliptical transducer. The echo sounder was operated at 24 dB re 1 W transmit power with a -18 dB total receiver gain. The source level was 211.47 dB and the receive sensitivity was –170.54 dB. The transmitted pulse width was 0.2 ms with a pulse repetition rate of 10 pings per second. The ping rate was dropped to 8 pings per second on aim #1 and #2 as this was found to reduce noise at certain ranges. This acoustic system pings at the set rate and so time and ping are synonymous. Echoes were rejected if they did not meet the minimum amplitude of 200 mV, which was approximately equivalent to a –38 dB target on axis. We used a pulse acceptance window between 0.1 and 0.3 ms for the width of the returned echo. Further analysis of the data using other amplitude and pulse width acceptance criteria is possible by reprocessing the digital audio tape (DAT) data.

The processing computer contained HTI's software TS/INTEGRATION/TRACKER for real-time three-dimensional target tracking and both the ABTrack and Polaris software routines for off-line tracking and editing of data files produced by the acoustic system (Pacific Eumetrics, 2002). The transducer was mounted on a Remote Oceans System dual-axis underwater rotator connected to a shore-based rotator controller. The transducer aims were monitored with an underwater position sensor (Jasco, 1995, Racca, 1999) which gave pitch, roll, magnetic bearing and water temperature information. The electronic components were housed in a small shed mounted on a log raft and were powered by a 2 kW gasoline generator.

The complete system was calibrated in March 2001 at the manufacturer's calibration facility. An *in-situ* target calibration was also performed using a 38.1 mm tungsten carbide sphere, which produces a nominal target strength of –39.5 dB in freshwater (MacLennan and Simmonds, 1992). We obtained the same target strength in our field calibration at the Wannock River site.

2.4 Physical Configuration of the Site

Once a suitable acoustic site was chosen, we began testing various transducer locations at the site. The electronic components, including the split-beam echosounder, digital echo processor and rotator controller, were set-up inside a small cabin built onto a log raft, which allowed reasonable portability and therefore the ability to monitor the left- and right-banks. (By convention, left- and right-banks are identified when facing downstream). We operated one acoustic system and moved it to different locations to get an overview of the properties of the site over the season.

We first located the transducer on a tripod on the right-bank substrate, at about 2 m from the shore and in approximately 1.5 m of water. This location was protected from floating debris by boom-logs that also provided a tie-up point for the log raft. The transducer was located approximately 0.5m below the water surface and was aimed perpendicular to the river flow. The tripod could be moved progressively offshore if the water level receded. The transducer was linked to the echo sounder via underwater cables. The transducer aims were controlled by a dual-axis rotator controller, and monitored with an underwater position sensor. The transducer was later moved to a mounting point on the side of the log raft, which positioned it approximately 22 m from shore on the right-bank. A second location positioned the transducer approximately 12 m from shore on the left-bank. This allowed the collection of data from the three transducer locations needed to cover the river cross section. The log raft proved to be a stable platform even in the presence of boat wakes, due to the large size of the logs used in its construction. (Boat traffic was infrequent at the acoustic site).

Figure 3 presents the three-dimensional co-ordinate system commonly used in riverine acoustics. The Y-axis is the up/down or surface/substrate direction, the X-axis is the upstream/downstream direction and the Z-axis is the range from the transducer perpendicular to the riverbank, i.e., the bank to bank direction. A fish swimming upstream would be travelling in the positive X-direction if the transducer was located on the left bank as shown. Also shown in this figure is the nominal beam width, referred to as the –3dB point, which is the point at which the acoustic power has dropped to half the power available at the beam axis. For the transducer used in this study, this point corresponded to a total beam width of 4° in the vertical axis and 10° in the horizontal axis. Salmon targets can be detected further off-axis than the –3dB point, but the probability of detection is lower compared to detection probabilities within the 4°x 10° ellipse of the acoustic beam.

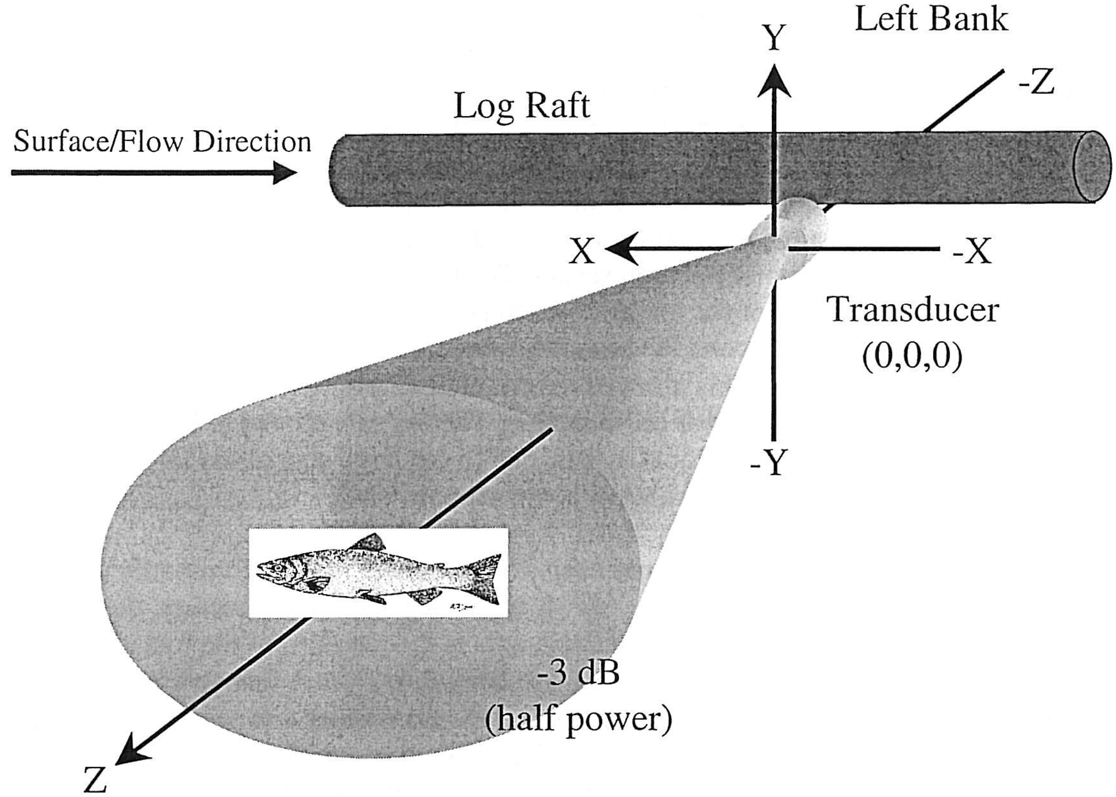

Figure 3. Co-ordinate system commonly used in riverine acoustics.

We used vertical aiming strata to partition the spatial and temporal sampling effort over the entire water column. The sampling plan made use of five to six vertical aims with the 4°x 10° transducer. The transducer was aimed at 4°, 0°, -4°, -8° and -12° relative to horizontal for the near-shore right-bank tripod position. For the right- and left-bank positions when the transducer was mounted on the side of the log raft, aims of -2°, -6°, -10°, -14°, -18° and -22° were used. The first -2° aim put the nominal beam edge parallel to the water's surface. The transducer was located approximately 0.30 m below the water surface, allowing the detection of fish close to the surface while minimising interference from surface noise caused by wind and rain. A complete cycle of aims took one hour, therefore each aim took either 12 minutes for the five-aim set-up or 10 minutes for the six-aim set-up. The data collection ranges (i.e. along the Z-axis) were limited primarily by boundary interactions (bottom or surface) and reverberation noise levels.

3.0 RESULTS AND DISCUSSION

3.1 Site Characteristics

We began setting up the site and acoustic system on July 13 and data collection was initiated on July 17 with the near-shore right-bank transducer. There was negligible fish activity at this near-shore site, making it difficult to determine when the sockeye run began. When we moved from the near-shore position to the right-bank offshore position on the log raft on July 21, we detected increased fish densities and we concluded that fish densities likely had been building prior to this date but were not detected at the near-shore transducer position. The system was moved to the left-bank on July 31 and operated until August 6 at which time the sockeye flux had decreased and remained at a level of approximately 20 fish per hour for several days. Small numbers of sockeye were still being captured at this time by the in-river native food fishery downstream of the acoustic site, so we believe that the sockeye run continued at these low levels for a few days after this study ended.

Based on our reconnaissance survey in the Wannock River, there are few suitable split-beam acoustic sites. Much of the river contains boulder fields with white-water reaches, which are unsuitable for acoustic enumeration. The site chosen was a 120 m wide and approximately 750 m downstream of the outlet of Owikeno Lake. Water levels in the river were unusually high during this study (Environment Canada, 2003), due to a heavy snow pack combined with relatively warm temperatures. Bottom profiles were mapped using a single-beam Lowrance echosounder and the chosen site profile was determined to be V-shaped without large boulders or steps (Figure 4) i.e. meeting criteria 1, 2, and 3 for acoustic site selection in section 2.1. One other potential acoustic site was located approximately 500 m downstream of the selected site, but was approximately 180 m wide and displayed a flat bottom profile that was less suitable for acoustic enumeration than the chosen site.

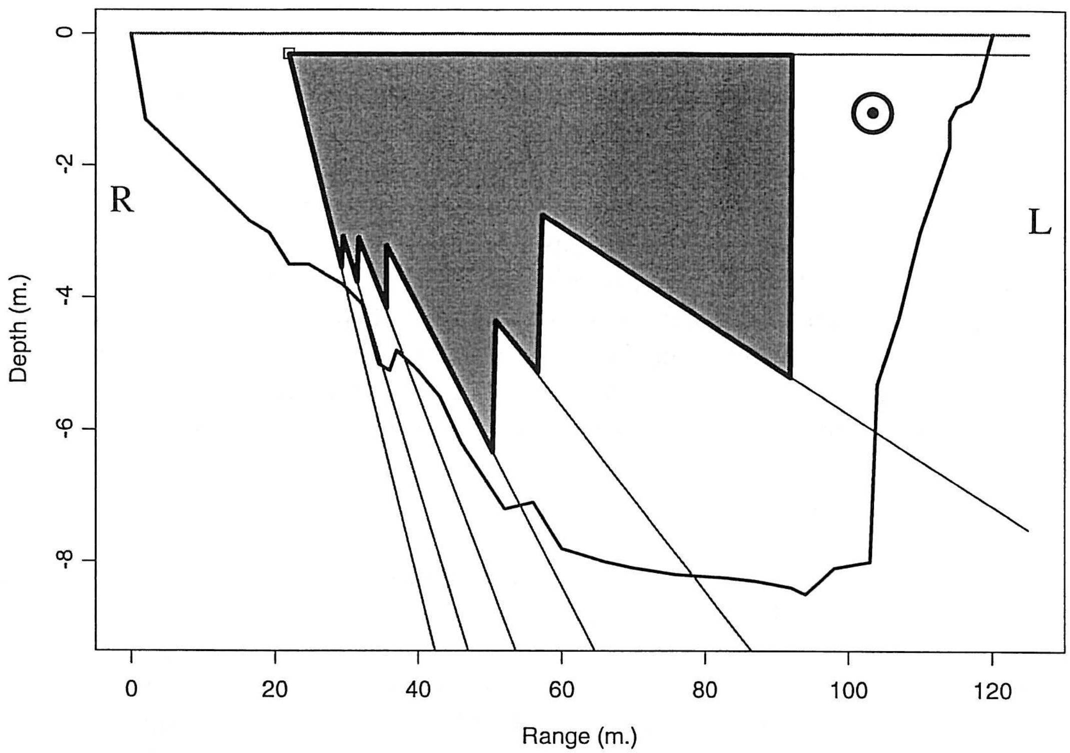

Figure 4. Bottom profile of the Wannock River at the acoustic site. The X-axis is the distance from shore and the Y-axis is the depth below the surface. The 'R' and 'L' refer to the right and left banks, respectively and the river flow is towards the observer as indicated by the circular symbol. The outlined grey area represents the coverage obtained with the right-bank transducer using 6 aims. The vertical lines show the maximum range for data collection that avoided interference with either the bottom or the water surface. The horizontal line at zero depth represents the water's surface. Note: the vertical scale has been significantly exaggerated relative to the horizontal scale.

3.2 River Coverage

Figure 5 presents the acoustic coverage that we were able to obtain at this site with the three-transducer locations. The longest range (i.e. Z-axis) obtained was 70 m, but ranges were usually limited by the substrate, the surface, or by reverberation noise from the deeper, fast flowing water that likely contained debris and entrained air. With this aiming pattern, approximately 70% of the total river cross-section was covered acoustically when all three of the transducer locations were added together and the crossover areas were taken into account. We are currently developing methods to extrapolate the acoustic estimates of known fish density to obtain estimates of density for the areas not covered by the acoustic beam. The fish in the Wannock River were distributed throughout the water column, making extrapolation feasible. We feel that the fish flux in the areas not covered by the acoustic beam can be estimated.

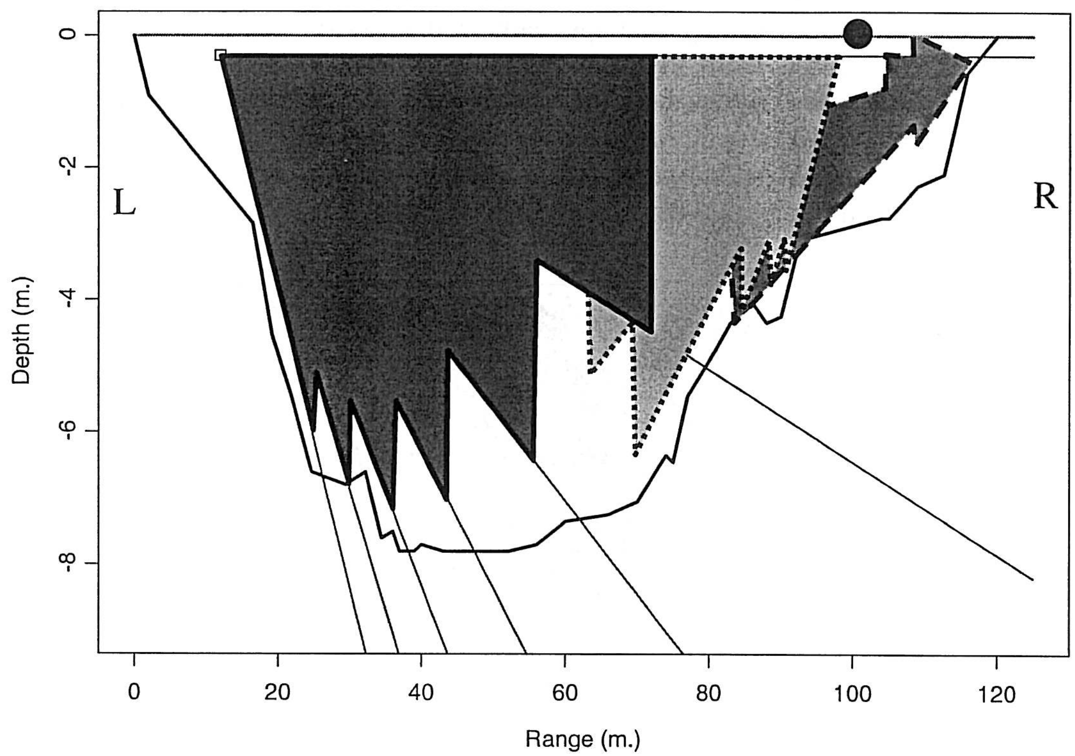

Figure 5. Wannock River cross-section showing the coverage obtained with three transducers over the season. The circular object at the water surface represents the boom-stick log location that limited the range of the second aim of the inshore transducer.

3.3 Salmon Detection

Sockeye salmon were easily detected in the Wannock River, displaying target strengths averaging approximately –27 dB for the duration of the run. In systems such as the Fraser River we routinely obtain smaller TS values of approximately –30 dB for sockeye (Xie et al, 2002). This difference may be due to a difference in the physical size of the fish in the two rivers, or it may be due to a difference in the calibration of the two systems. Based on the consistency of the target strengths over the Wannock salmon run, we believe that few resident fishes or other salmon species differing in size from sockeye salmon were active at the same time and detected acoustically.

3.4 Salmon Behaviour

Figure 6 shows a standard echogram for the –2° aim taken on July 25. Two fish tracks are marked in light grey on the echogram and are numbered as –135 and –142. Figure 7 shows the various views of Fish –142, which was an actively migrating fish. The Y vs. X and Z vs. X plots show the character of the track as Fish –142 moved through the beam. The lines on the plot connect points that are measured with error. Therefore, the fish did not move exactly along this erratic path, rather it moved along a smooth path that passes through the observed points. This fish moved systematically in the X-direction as seen in the X vs. ping plot and migrated upstream, as the transducer was located on the right-bank shore. For comparison, Figure 8 shows the same views of Fish –135, which was not actively migrating but was holding nearly stationary in the upstream-downstream direction, and moving over several metres in range (Z-axis). A track for a fish performing this behaviour has minimal velocity in the X-direction and an equal likelihood of being categorised as an upstream or a downstream track by a tracking algorithm.

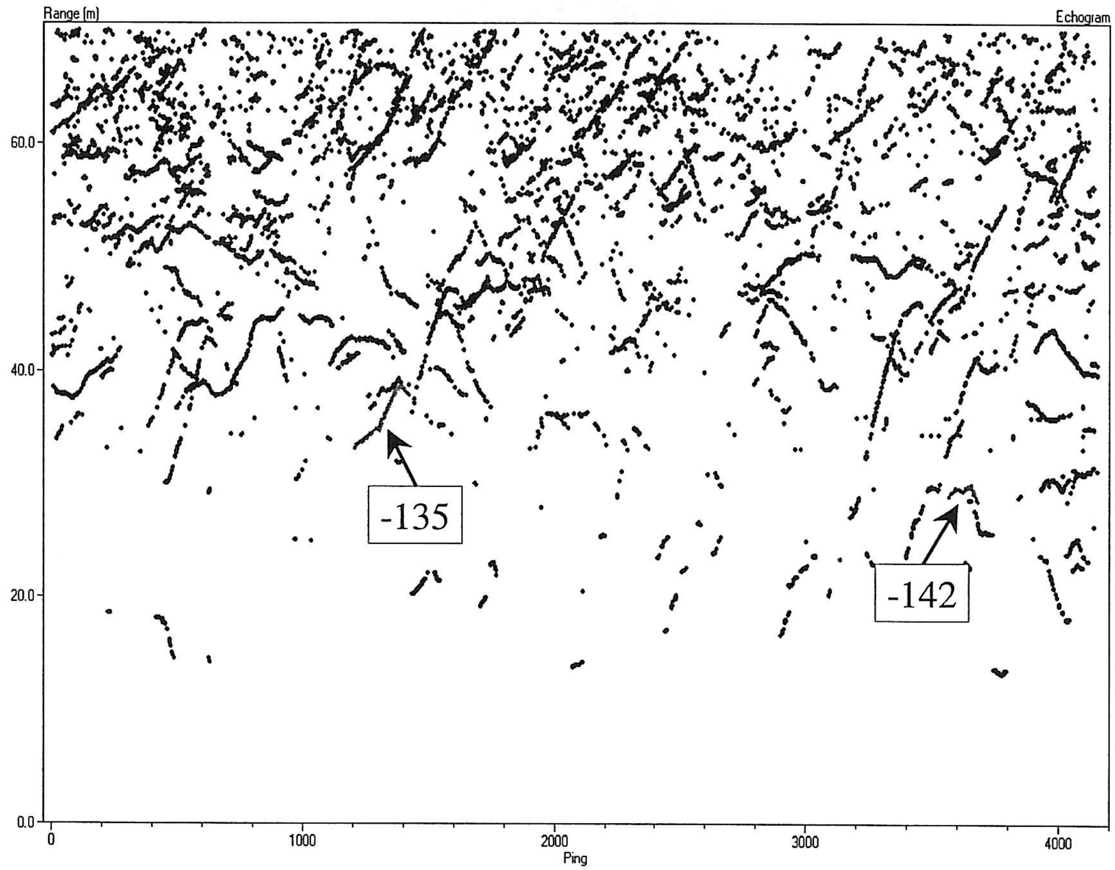

Figure 6. Typical echogram from the Wannock River. The X-axis displays the ping number, which is equivalent to time, and the Y-axis displays the distance from the transducer to the migrating salmon. Most of the tracks are from sockeye travelling through the beam. The smaller, randomly distributed dots are from noise in the river. The two highlighted tracks are displayed in more detail in the following figures.

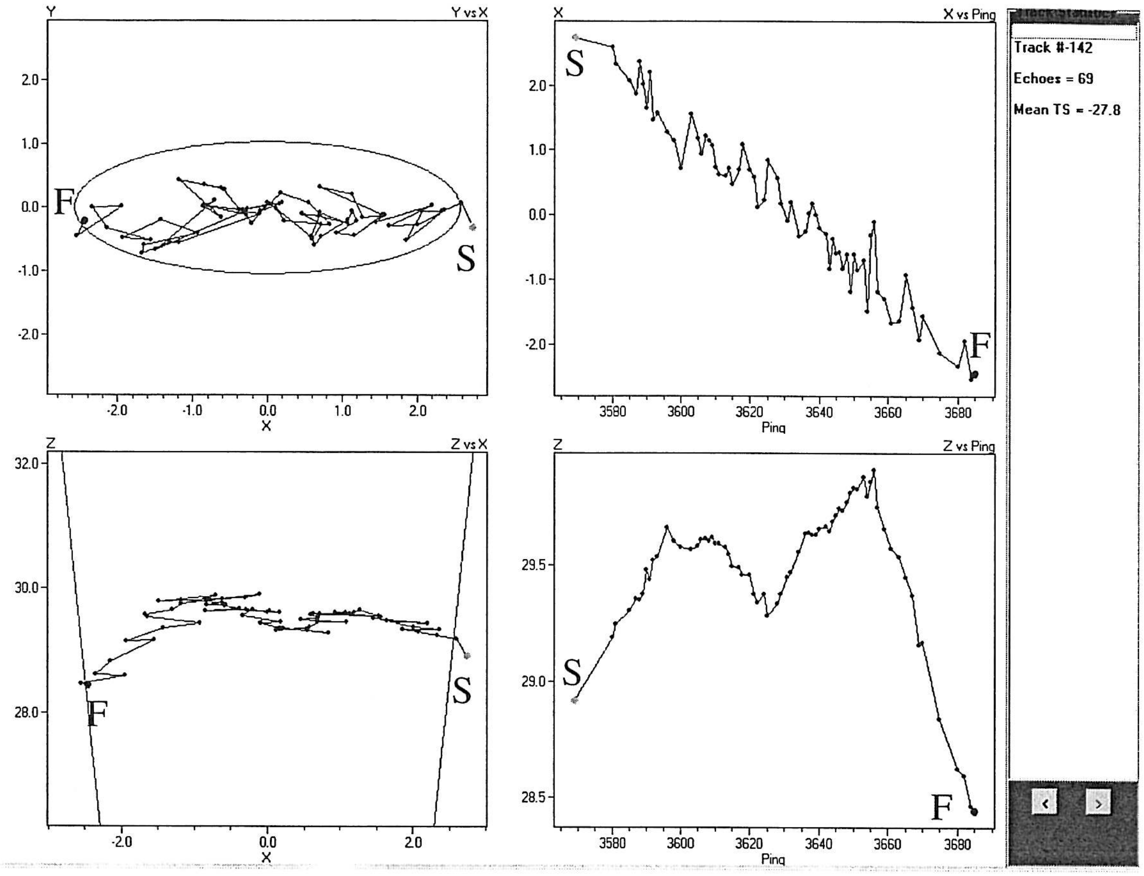

Figure 7. Detailed track projections of track number –142. The plots on the left display the target position in the YX and ZX planes for a single moving fish. The small ellipse represents the size of the sound-beam relative to the fish track. The 'S' and 'F' indicate the start and finish of the track. The plots on the right display the X-co-ordinate and Z-co-ordinate vs. ping number. The statistics on the far right display the fish number, the number of echoes contained in the track and the relative target strength of the fish. These plots show how the fish moved in the X- and Z-directions over time. This fish moved in a systematic fashion through the beam in the X-direction and showed more than 1 m change in its distance from the transducer.

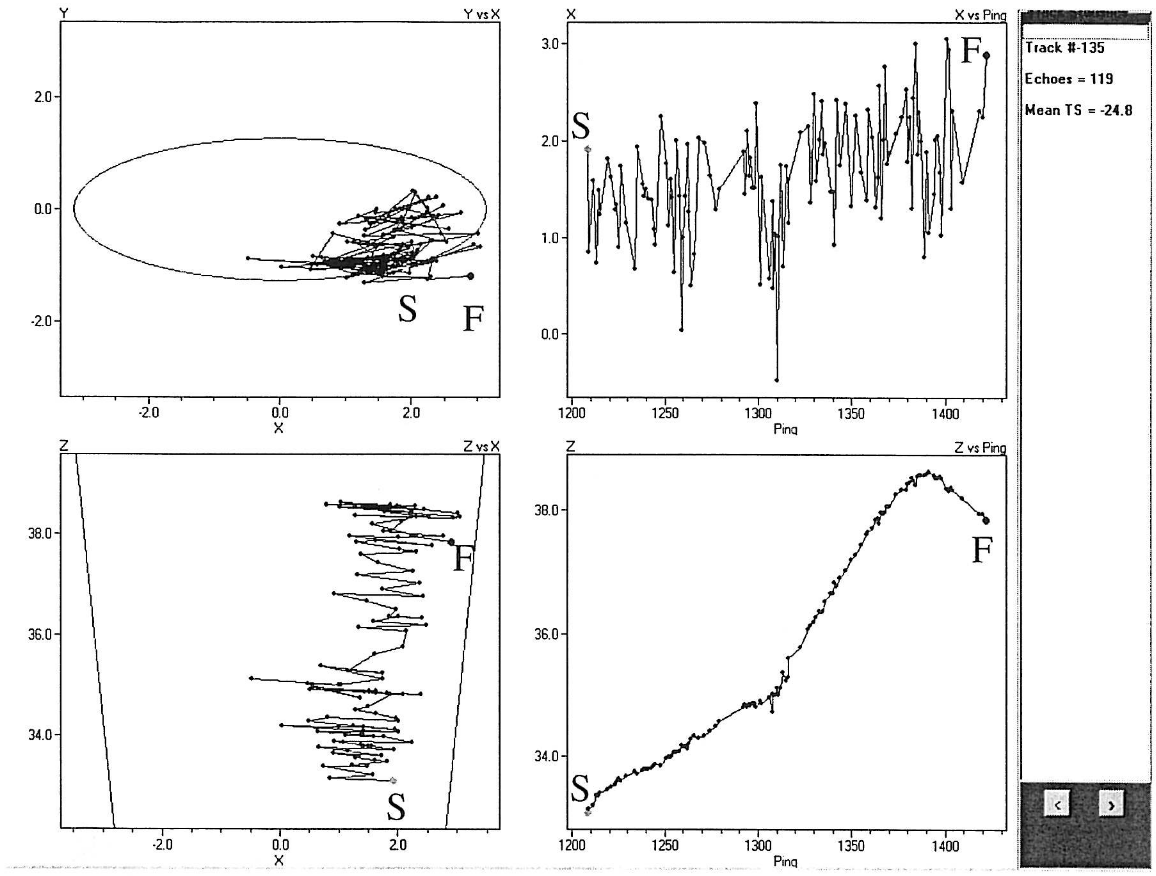

Figure 8. Detailed track projections of track number –135. This fish was nearly stationary in the upstream/downstream (X-) direction but slowly moved more than 2 m away from the transducer (Z-direction).

Figure 9 presents an echogram from July 25. By looking at the track projections for these fish (e.g., Figures 7 and 8), we estimate that 5 fish are actively migrating out of all the fish tracks displayed on this echogram. Most of the fish appeared to be holding in the current. Figure 10 is a magnified view of the area outlined in Figure 9. The predominant features on this echogram are the noise present at approximately 32m range and the dense pattern made by the holding sockeye from 40m to 70m range. Some of the tracks are very long with the same fish remaining in the beam for more than 3 minutes (at 8 pings per second this is equal to approximately 1400 pings). The tracks also become less distinct within this area, due to the acoustic interference between the fish and the acoustic noise present in the river at these longer ranges.

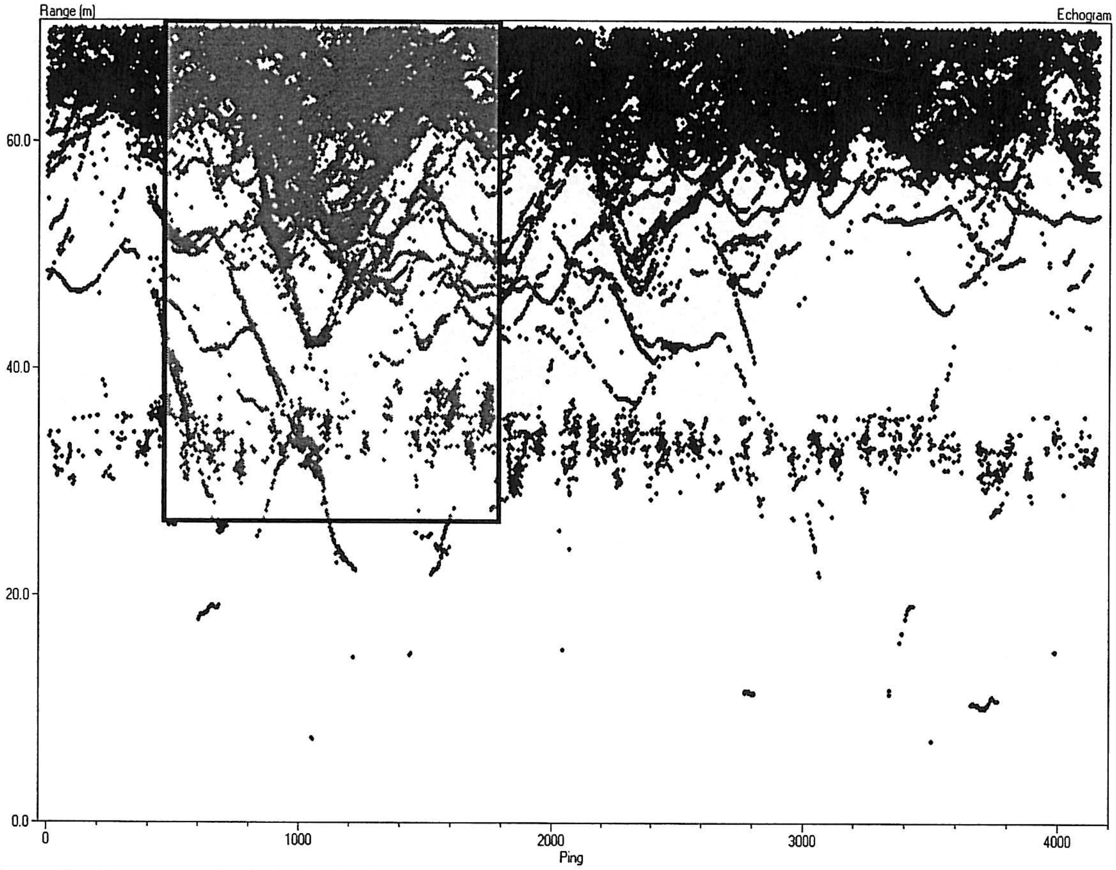

Figure 9. Echogram of relatively high density at the Wannock River acoustic site. Most of these fish are holding in the current. Surface noise is apparent at the 30 to 40 m range. The outlined area is magnified in Figure 10.

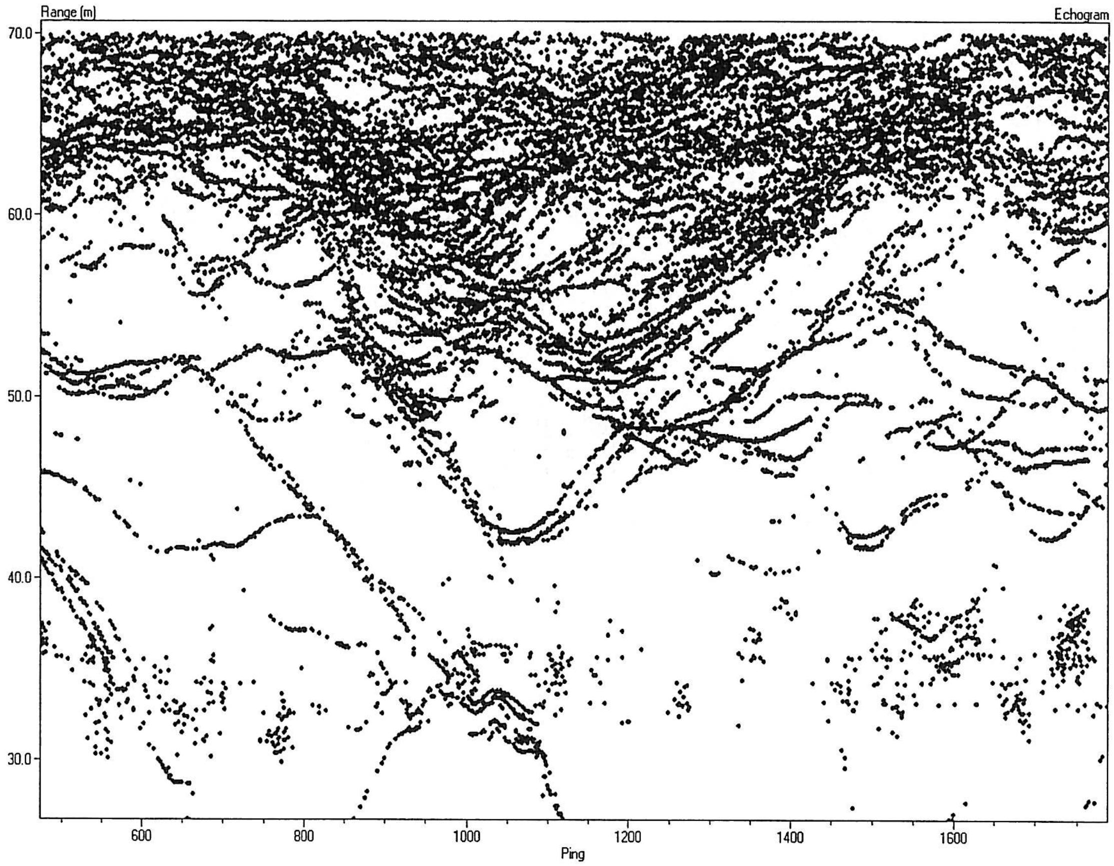

Figure 10. Magnified view of the echogram area outlined in figure 9. Note the extended fish tracks and the occurrence of noise mixed in with the highest density of fish.

Figure 11 (a) presents the cumulative right-bank distribution of upstream migrating fish for 24 hours on July 26 from the perspective of an observer standing downstream of the transducer. Figure 11 (a) also indicates the need for an inshore transducer, as there may have been significant numbers of fish migrating inshore of the coverage of this sequence of aims, as indicated by the abrupt cut-off in density displayed in the lowest aim. Figure 11 (b) presents the distribution for the downstream migrating fish. The upstream fish (Figure 11 (a)) would be travelling away from the observer and the downstream fish would be travelling toward the observer (Figure 11 (b)). The upstream migrating fish tended to migrate near the surface and towards the right-bank of the river channel, but were also distributed throughout the entire river cross-section. The downstream migrating fish tended to be distributed further from the right-bank, in the central area of the channel, in the zone of high current flow (Figure 11 (b)). The holding behaviour was also most predominant in this area. Many of the downstream tracks are holding fish, which are classified as downstream by the tracking algorithm, but in fact have near zero velocities. In addition, temporal patterns were not detected in the migration data with respect to factors such as daylight and darkness or tidal cycles.

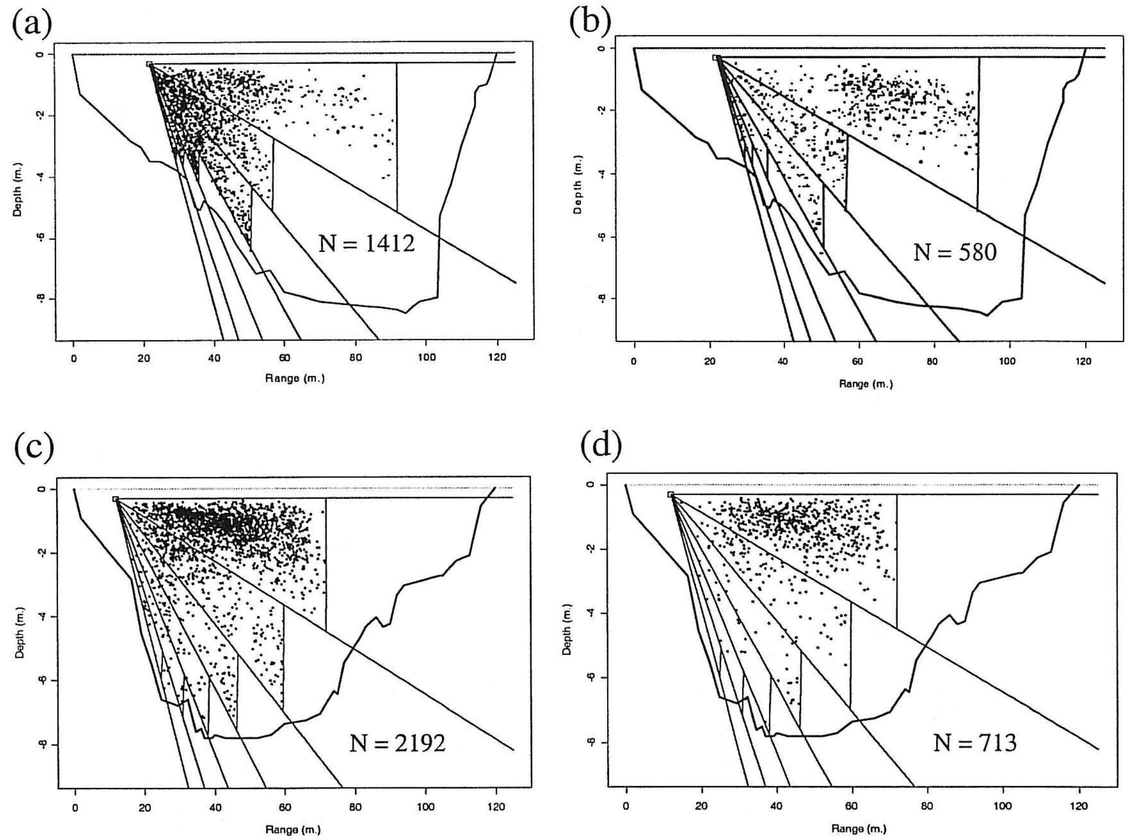

Figure 11. Cumulative spatial distributions of sockeye salmon at the Wannock River acoustic site. These scatter plots display the mean position in a cross-river plane of each fish that passed through the beam over a selected 24-hour period. "N = " refers to the number of tracked fish displayed in each plot. The bottom contour at this cross-river plane is also displayed. (a) and (b) show right-bank upstream and downstream migrating fish respectively and (c) and (d) show the same for the left-bank .

Figure 11 (c) & (d) present the cumulative left-bank distribution of upstream and downstream migrating fish for 24 hours on August 02. The upstream migrating fish (Figure 11 (c)) are travelling towards the observer. The highest density of downstream tracks is located in the same area in which the holding behaviour was observed.

The acoustically observed location of the holding fish was consistent with observations of fish porpoising on the surface of the river. This porpoising behaviour may have been a physical indication of the holding fish. This porpoising behaviour was also observed downstream of the acoustic site, possibly indicating that the fish are holding over a large area, including the only other potential acoustic site on the river.

Figure 12 presents the right-bank speed distributions of migrating sockeye salmon. The data presented are for 48 hours from July 25 and 26 combined, to give a larger sample size. Upstream migrating fish along the right-bank travel faster in the slower current closer to shore and closer to the substrate. Downstream fish travel faster further offshore (Figure 12), as the current may assist their downstream movement.

`Neither of these trends is strong, and there are exceptions to the general patterns as seen by the colours of some of the cells.

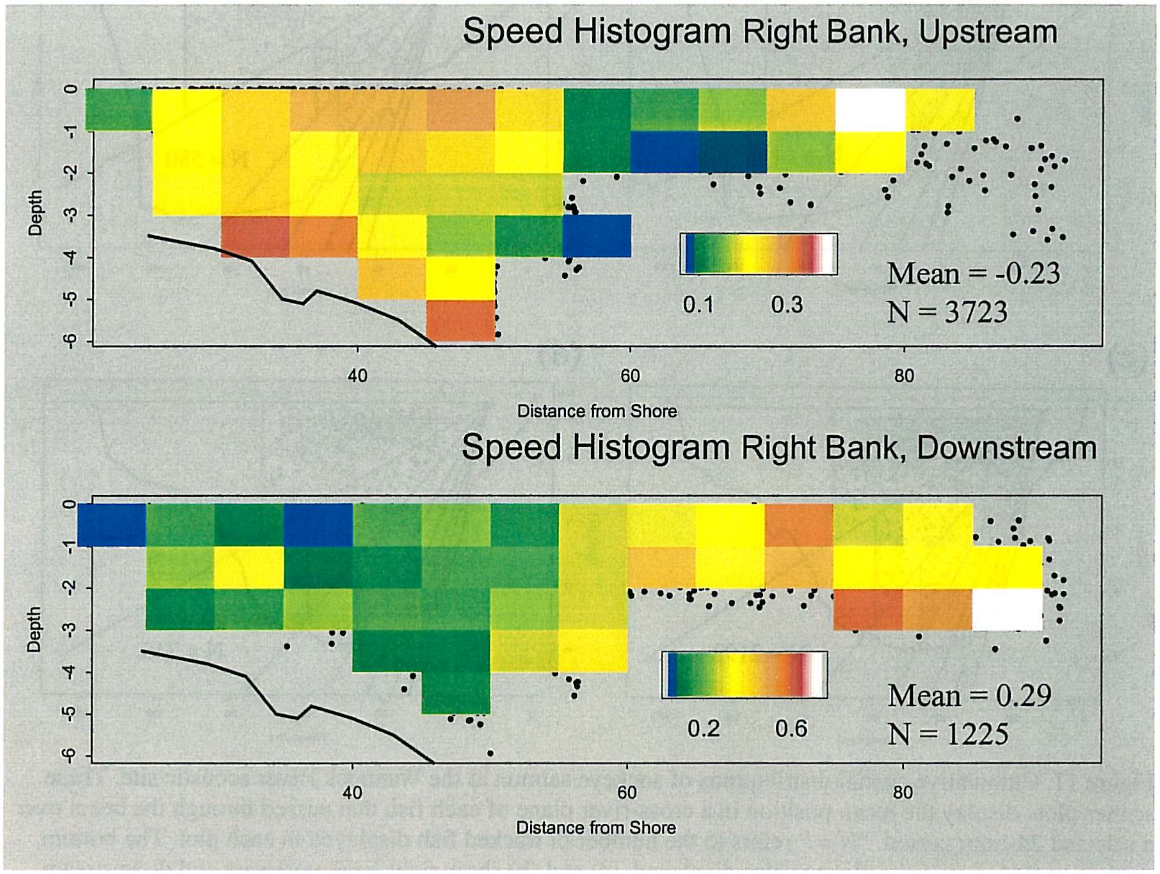

Figure 12. Speed histograms for upstream and downstream moving fish observed with the side-looking split-beam transducer on a cross-river section off the right-bank. Colours represent the various average speeds for each 2-D grid. The size of the grid is 1 m by 5 m, and grids with less that 10 observations are not coloured. The black dots show the average position of individual fish as they passed through the beam. The colours have been added over the top of the plot showing the individual fish positions. The caption "Mean = " shows the mean speed in msec^{-1} for the sample, and the caption "N= " is the total number of samples used in the plot.

Figure 13 presents the speed distributions of the migrating salmon for the left-bank. The data are for 48 hours from August 02 and 05. There is no discernible pattern in migration speed among the upstream migrating fish on the left-bank with respect to the shore or substrate. For the downstream migrating fish, we again note that migration speeds are higher as the distance from shore increases. As with the right-bank, the patterns are not strong and there are exceptions. For example, the dark-blue grid at 65 to 70 m range and 0 to –1 m depth indicates a slow speed further offshore. The mean migration speeds are slower in this river than we have measured in other rivers such as the Fraser, where migrations speeds at Mission BC averaged between 0.5 and 0.8 msec^{-1} depending on the river discharge (Xie et al, 2002).

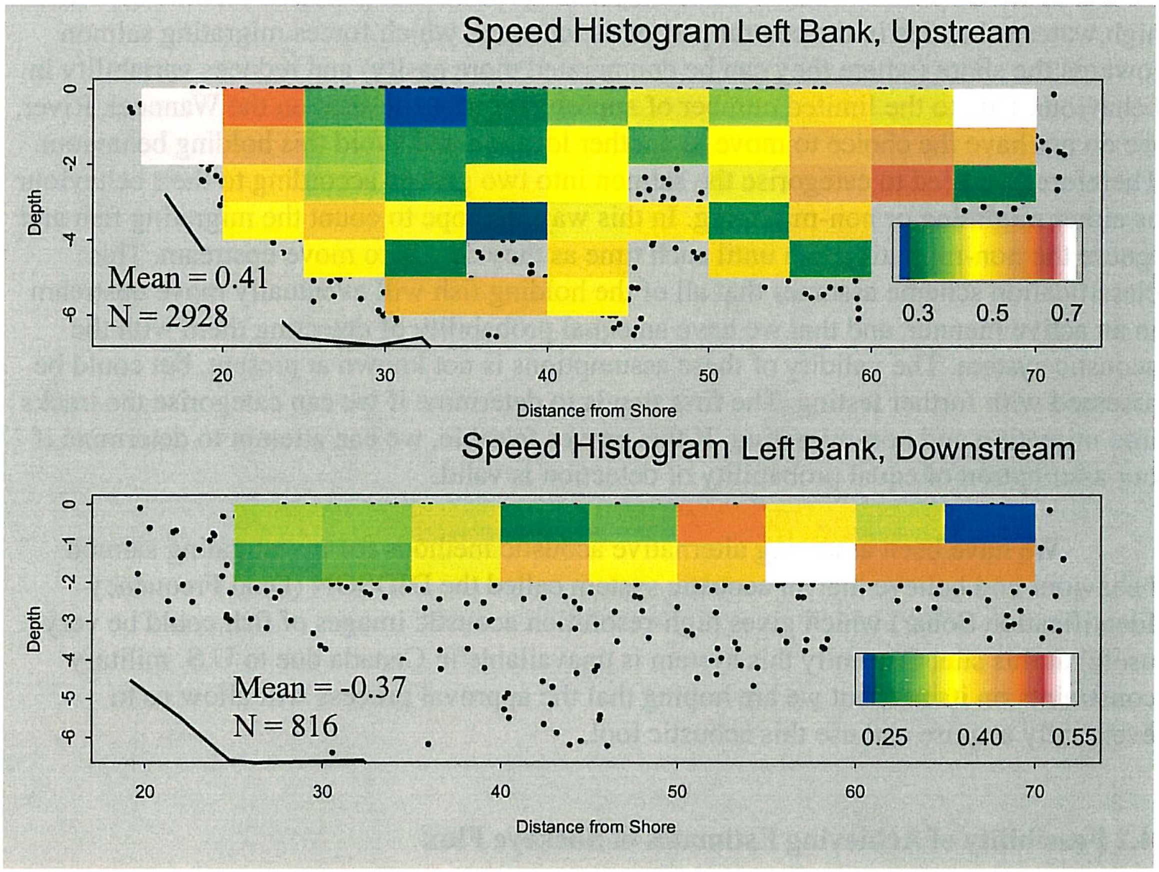

Figure 13. Speed histograms for upstream and downstream moving fish observed by the side-looking split-beam transducer on a cross-river section off the left-bank.

4.0 CONCLUSIONS

4.1 Ramifications of the Observed Salmon Behaviour

We have not observed the salmon holding behaviour documented in the Wannock River at acoustic sites on other rivers. In general, salmon tend to hold or migrate where the current velocity is lower in an attempt to reduce energy consumption, therefore providing energy reserves for long migrations and gonad development (Hinch and Rand, 2000). In the Wannock River we noted that the salmon appear to prefer to hold in the fastest current flows at the acoustic site. We hypothesise that this behaviour may be related to the relatively short migration distances that these sockeye cover, hence a strategy of energy conservation is not critical for the ongoing survival of Owikeno Lake sockeye stocks.

The salmon exhibit two main categories of migration behaviour at the site. These are: 1) active migration, and 2) near stationary or holding. When looking for appropriate acoustic sites we try to choose sites where the salmon are actively migrating and there is little or no incidence of holding or milling behaviour. Typically, these sites have relatively high water velocities in the central part of the channel, which forces migrating salmon towards the shore (where they can be enumerated more easily) and reduces variability in behaviour. Due to the limited number of appropriate acoustic sites on the Wannock River, we do not have the choice to move to another location and avoid this holding behaviour. Therefore, we need to categorise the salmon into two groups according to their behaviour as either migrating or non-migrating. In this way we hope to count the migrating fish and ignore the non-migrating fish until such time as they decide to move upstream. This classification scheme assumes that all of the holding fish will eventually move upstream in an active manner, and that we have an equal probability of detecting them with the acoustic system. The validity of these assumptions is not known at present, but could be assessed with further testing. The first step is to determine if we can categorise the tracks into migrating and non-migrating. If this proves feasible, we can attempt to determine if our assumption of equal probability of detection is valid.

We have been assessing alternative acoustic methods for investigating salmon behaviour and believe that an acoustic system called the DIDSON (Dual Frequency Identification Sonar) which gives high-resolution acoustic images of fish could be very useful at this site. Currently this system is unavailable in Canada due to U.S. military constraints on its use, but we are hoping that the approval process will allow us to eventually acquire and use this acoustic tool.

4.2 Feasibility of Achieving Estimates of Sockeye Flux

The biggest problem with obtaining reliable estimates of sockeye flux in the Wannock River is the holding behaviour that we observed. Because alternative acoustic sites on this river are limited and equally affected by the holding behaviour, we feel that we may be able to address this problem with analysis methods that separate the holding fish from the actively migrating fish. We have begun to develop software tools to accomplish this task and we expect that an initial working system will be available some time in 2003, and we may be able to come up with a working method in the near future. If we are able to do this, then we can apply the technique and count the number of upstream and downstream actively migrating fish and obtain an escapement estimate. Use of other acoustic systems such as the DIDSON, might shed some light on the nature of the holding behaviour and improve the feasibility of achieving an accurate count. On a cautionary note, there is always a chance that this or some other problem may prove insurmountable with the current technology.

The holding behaviour we documented in the Wannock River makes it difficult to obtain acoustic estimates of fish flux. However, this behaviour poses an interesting and important problem that if overcome, would be useful in other river systems as well (e.g. Fraser and Nimpkish Rivers). Recently, we successfully completed a preliminary analysis that separates the holding fish data from the actively migrating fish data. This is the first step in identifying and understanding this type of fish behaviour, allowing us to determine if we can obtain estimates of salmon passage when this behaviour is occurring. Our next step is to develop methods to assess the spatial and temporal extent of this behaviour (e.g., where it occurs and how long on average, a fish engages in this holding behaviour). If this is successful, then we may be able to provide better estimates of upstream fish passage, or at least reduce the uncertainty associated with these estimates. In the absence of this holding behaviour, we believe that acoustic estimates of salmon escapement could be made quite easily for the Wannock River, as other traits of the river are conducive to acoustic enumeration.

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