An Evaluation of Methods Used by the Freshwater Ecosystems Section for Pelagic Fish Surveys of Sockeye Rearing Lakes in British Columbia

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AN EVALUATION OF METHODS USED BY THE FRESHWATER ECOSYSTEMS SECTION FOR PELAGIC FISH SURVEYS OF SOCKEYE REARING LAKES IN BRITISH COLUMBIA

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ABSTRACT

MacLellan, S.G. and Hume, J.M.B. 2010. An evaluation of methods used by the freshwater ecosystems section for pelagic fish surveys of sockeye rearing lakes in British Columbia. Can. Tech. Rep. Fish. Aquat. Sci. 2886: v + 67 p.

We describe the methods the Freshwater Ecosystems Section used to determine the species, density, and biomass of pelagic fish assemblages in juvenile sockeye salmon (*Oncorhynchus nerka*) rearing lakes. The primary methods used were mobile hydroacoustic and midwater trawl surveys, which we describe in detail, including survey design and analytical details. Acoustic equipment has developed and evolved over the course of 34 years of data collection and we compare and discuss the differences this has made. Trawl systems suitable for small boats were developed early on and have changed little, yet their capture efficiencies are still not well known. We have also adopted sampling with fine mesh Nordic gill nets to partially compensate for known trawl catch bias, particularly when using a small 2x2 m trawl and when surveying small lakes with a complex mix of fish species . We describe these systems, compare and discuss their characteristics, and make recommendations for future work.

RÉSUMÉ

MacLellan, S.G. and Hume, J.M.B. 2010. An evaluation of methods used by the freshwater ecosystems section for pelagic fish surveys of sockeye rearing lakes in British Columbia. Can. Tech. Rep. Fish. Aquat. Sci. 2886: v + 67p.

Nous décrivons les méthodes utilisées par la Section d’étude des habitats dulcicoles pour déterminer les espèces, et la densité et la biomasse des assemblages de poissons pélagiques dans des lacs servant d’habitat de grossissement de saumons rouges (*Oncorhynchus nerka*) juvéniles. Les principales méthodes utilisées étaient les relevés au chalut pélagique et les relevés hydroacoustique mobiles, que nous décrivons avec précision. Le plan d’étude et les détails de l’analyse sont également présentés. Le matériel acoustique a évolué au cours des 34 années de collecte de données, et nous comparons et analysons les différences que cette amélioration a apportées. Bien que les systèmes de chalutage adaptés aux petits bateaux aient été mis au point il y a longtemps et aient peu changé depuis, on en sait très peu sur leur efficacité de capture. Nous avons également adopté la méthode d’échantillonnage au moyen de filets maillants à mailles fines Nordic pour compenser partiellement les biais connus dans les captures au chalut, particulièrement lorsqu’on utilise un petit chalut de 2 × 2 m pour réaliser des relevés dans de petits lacs abritant un mélange complexe d’espèces de poissons. Nous décrivons ces systèmes, comparons et analysons leurs caractéristiques, et formulons des recommandations pour les travaux à venir.

INTRODUCTION

Pelagic surveys of juvenile sockeye salmon (*Oncorhynchus nerka*) and their competitors have been commonly used to assess the health and abundance of sockeye stocks in British Columbia lakes for over 50 years (Johnson 1956; Simpson et al. 1981; Mathisen and Smith 1982; McDonald and Hume 1984; Hume et al. 1996; Shortreed et al. 1998; Hume and MacLellan 2000; Hyatt et al. 2000; Hume and MacLellan 2008). Normal diel vertical migration patterns make juvenile lake-resident sockeye ideal for pelagic surveys. Juvenile sockeye salmon typically spend at least one year of their life in the pelagic region of lakes before migrating to the ocean (Narver 1970; Burgner 1991). In most lakes, particularly in the summer and early fall when light levels are high and a thermocline is present, they undergo a daily vertical migration, spending the day in schools as deep as 80 m, coming to the surface waters to feed at dusk, dispersing to slightly deeper depths during the night, before feeding again at dawn, and migrating, mainly in schools, back to deeper depths (Narver 1970; McDonald 1973; Levy 1990). During the night, their dispersion and distribution in near surface waters (often just below the thermocline) facilitates the capture and enumeration of juvenile sockeye using hydroacoustics and various types of nets.

Sockeye rearing lakes are found in most British Columbia watersheds draining into the Pacific Ocean. There are large variations in many of the physical characteristics of the rearing lakes that will affect the methodology and success of a pelagic fish survey, including lake size, depth, elevation, water clarity, and access (Shortreed et al. 1998, 2001, 2007). Size of the rearing lakes in British Columbia varies by three orders of magnitude, ranging from <25 ha to > 460 km². Mean depths vary from 3 m to 172 m while euphotic zone depth ranges from 2 to 23 m. Elevations range from near sea level to 1,450 m. Many of the lakes are extremely remote, only accessible by float plane, while many others are road accessible, often with large communities nearby. Although the basic survey methods are the same on all surveys, these large variations in sockeye rearing lakes often require different sampling equipment, platforms, and gear which are discussed in the following sections.

Capture methods for pelagic juvenile sockeye salmon have included circular nets towed from two boats (Johnson 1956), small mesh purse seines (Scarsbrook and McDonald 1970), small beam trawls towed from a single boat (Gjernes 1979), relatively large Otter trawls (Parkinson et al. 1994), and closing trawls capable of targeting a particular depth strata (Enzenhofer and Hume 1989). This freshwater gear, is much smaller than the typical marine counterpart with trawl openings ranging from 4 to 21 m². Distribution and indices of abundance (rarely absolute estimates of abundance) were originally determined using data from trawl or seine catches (Johnson 1956, 1958; McDonald and Hume 1984).

The development of calibrated hydroacoustic systems enabled direct estimates of abundance and distribution to be made beginning in the 1970's (Nunnallee and

Mathisen 1972, 1974). Reliable estimates of age-0 sockeye abundance exist from about 1974 onwards (Nunnallee and Mathisen 1974; Mathisen and Smith 1982; Hyatt et al. 1984; Burczynski and Johnson 1986; Hume et al. 1996; Shortreed et al. 1998; Hume and MacLellan 2000, 2008; Hyatt et al. 2000).

In many cases stock abundance of Pacific salmon is estimated by enumerating the spawning escapement in natal streams (Roos 1989; Schubert 1998), but as spawning often occurs over large areas and extended periods of time, great effort is required for accurate assessments, even for a single lake system. Under appropriate circumstances, acoustic and trawl surveys have proven to provide accurate and relatively precise estimates of juvenile abundance, comparable to the more traditional adult enumeration surveys but usually in a more cost effective manner (Cox-Rodgers et al. 2004).

In this paper we describe the methods currently in use within the Freshwater Ecosystem Section of Fisheries & Oceans Canada (DFO) to conduct pelagic fish surveys of juvenile sockeye rearing lakes. We use data from Hume and MacLellan 2008 and additional data in our databases (Data on file) to compare and discuss some of the advantages and problems with the current methodology.

This paper starts with a detailed description of the current methods used in conducting a survey and then is followed by a description of the methods used in a number of comparative studies. The following Results and Discussion touches on some aspects of current methods but focuses mainly on the comparative studies. Most of our hydroacoustic methodology is similar to the current standard operating procedures developed recently by The Great Lakes Fisheries Commission (Parker-Stetter et al. 2009). We use their work as part of the basis for our discussion and examine the differences.

CURRENT METHODS FOR FIELDWORK AND DATA ANALYSIS

FIELD DATA COLLECTION

Survey Design

We enumerated and sampled populations of *O. nerka* and other pelagic fish using hydroacoustic and midwater trawling techniques developed for juvenile sockeye salmon (Hyatt et al. 1984; Burczynski and Johnson 1986; Hume et al. 1996). In smaller lakes where the littoral and slope zones comprised a larger portion of the total lake area, we also collected additional fish samples with gill nets and occasionally with minnow traps.

Prior to each survey we divided the lake into one or more sections for population analysis and fish collection. The number of sections chosen depended on lake size, basin morphometry, and complexity, and the expected distribution of fish. Section boundaries usually corresponded to shallows between major basins or ends of arms within the lake. Within each section we usually established a minimum of three hydroacoustic transects (Fig. 1), although we are still using some historical sample designs that employ two, or in some instances, a single transect within a small section. Transects were normally perpendicular to the long axis of the lake and generally parallel to each other. We did not use zigzag transects to avoid over sampling of the shore areas where the transects started and ended (Simmonds and MacLennan 2005).

Transects were spaced more or less evenly within a section but were also placed, when lake depth was relatively shallow (<80m), to sample the deepest part of each basin where sockeye tended to occur (Narver 1970; Hume and MacLellan 2000). In the past, we normally established a minimum of five transects for each lake but have used as few as three for some very small lakes (<30 ha, Hume and MacLellan 2008). Since 2005, we have been using a minimum of seven transects per lake when designing new surveys. Using digitized Natural Resources Canada 1:50,000 topographic maps (Spectrum Digital Imaging, www.mapsdigital.com) and Oziexplorer mapping software (www.oziexplorer.com) we established GPS waypoints at the ends of each transect for navigation during the survey. One or more trawls were planned for each section, but actual number, duration, and depth depended on fish abundance, vertical distribution, and amount of time available.

Environmental considerations for acoustic data collection

The technical characteristics of acoustic equipment combined with juvenile sockeye behaviour and environmental conditions dictate suitable circumstances for conducting acoustic surveys of pelagic juvenile sockeye salmon. Approximately the first meter in front of the transducer (the near field) has a complicated unfocused wave front pattern and is not useful for enumerating objects in the water (Simmonds and MacLennan 2005). After this first meter, the area of acoustic detection widens linearly with depth (e.g. at 5 m a nominal 6.6° beam is only 0.58 m wide while it is 1.3 m at 10 m). As well, fish in shallow water near the boat may be frightened and thus avoid the area of the transducer beam. Therefore, with the transducer deployed from 0.4 to 1.0 m below the lake surface, the first 2 to 3 m are not effectively sampled by acoustics. As well, echosounders are not effective at measuring backscattering from fish near the bottom. Thus, lakes that have mean depths of 5 m or less and maximum depths of less than 10 m, such as some found in the Skeena and coastal watersheds, are poor candidates for hydroacoustic surveys (Hume and MacLellan 2008).

Other factors that restrict fish (particularly *O. nerka*) to either the near surface depths or near the bottom also adversely affect the success of an acoustic survey. High turbidity levels will often restrict juvenile *O. nerka* to the upper 2 m of the water column (e.g. Motase Lake, Hume and MacLellan 2009). We have worked on relatively few glacially turbid lakes but our existing data indicates that age-0 sockeye are surface oriented at turbidity NTUs >5 and Secchi depths <3 m. High epilimnion temperatures often restrict fish to waters below the thermocline and in shallow lakes sockeye fry may be restricted to the waters near the bottom for all but a brief feeding period. The most suitable lakes for acoustic surveys tend to be relatively deep (>40 m max depth, >20 m mean depth) and clear.

Diel migration and day-time schooling of age-0 sockeye meant that all hydroacoustic sampling and trawling for estimating abundance was done at night after fish schools had dispersed and fish tended to be closer to the surface, and more accessible to both hydroacoustics and trawling (Burczynski and Johnson 1986; Narver 1970). Surveys were conducted between civil sunset and civil sunrise using tables supplied by the National Research Council, Canada (http://www.hia-iha.nrc-cnrc.gc.ca/sunrise_adv _e.html). We attempted to only survey in a two week period centered on the new moon of each lunar month although other requirements and work load often extended the sampling period. The moon did not affect fish behaviour on heavily overcast nights, but even partial moonlight on a clear night often caused *O. nerka* to school and commence feeding near the surface, lowering both the precision and accuracy of the acoustic estimate (Personal observations; Luecke and Wurtsbaugh 1993). Trawl catch is also decreased by the moon due to both changes in distribution and net avoidance (Data on file, and P. Rankin, DFO Nanaimo).

Sampling Platforms

The sampling equipment was deployed from one of two boats depending on road access to the study lake. The preferred boat was an aluminum 7.3 m cabin cruiser, the "Night Echo", powered by a 385 HP inboard/outboard motor (Mercruiser 502 MAG MPI). From this boat, we deployed the echosounder's transducer mounted on a towed body, suspended by a cable off the side of the boat, to partially isolate the transducer from the effects of ship pitch and roll (Enzenhofer and Cronkite 2003, Fig. 2). With this large boat we could deploy the large (3x7 m) closing midwater trawl. Given its large size, this boat could only be used on lakes with suitable road access and launching sites.

On lakes without road access, we flew our equipment in by float plane and operated from a 4.3 m inflatable boat , the "Little Echo", which was powered by a 25 HP outboard motor. Pelagic fish sampling was done with a smaller (2x2 m) midwater trawl (Gjernes 1979). The winch for the trawl was mounted amidships on a plywood platform while the sounder was protected from the elements by a canvas cover mounted on a plywood platform on the bow (Fig. 3). The transducer was deployed from the bow platform using a pole mount. All the gear for the “fly-in” lake surveys weighed about 800 kg and was usually transported by a de Havilland Beaver floatplane in two flights.

Fish Sampling

The large midwater “3x7” beam trawl used on the 7 m boat was 18 m long with a 3 m wide by 7 m deep mouth opening (Enzenhofer and Hume 1989). The net was constructed with a graded series of meshes, decreasing in size from the mouth (10.2 cm stretch mesh) to codend (3 mm bobbin or 6mm stretched mesh knotless nylon). A plastic PVC (75 mm diameter) tube was used to collect fish at the codend and was closed by a threaded perforated cap lined with plankton netting. The mouth was kept open by top and bottom spreader bars and two 22.7 kg (50 lb) lead balls hung from the ends of the bottom bar, which was a solid metal rod providing additional weight.

The trawl net was operated using separate 4.8 mm (3/16”) wire cables to the top and bottom bars, each operated by a separate hydraulic powered winch. This provided the capability of opening and closing the trawl, by varying cable length, enabling us to sample at discrete depths without contaminating the catch from fish in shallower depths (Enzenhofer and Hume 1989). Mean towing speed was approximately 0.7 m/s (2.5 km/h, Table 1). This net was considered relatively unbiased in its ability to catch fish up to about 150 mm (Hume et al. 1996; Parkinson et al. 1994). Standard practice was to deploy and retrieve with the net closed, only opening while at the fishing depth. This appeared to decrease the loss of larger fish but no comparisons were conducted.

The smaller “2x2” midwater trawl used on the inflatable was 7.5 m long and had a 2x2 m mouth opening (Gjernes 1979; Hyatt et al. 1984). The mouth was kept open by top and bottom aluminium spreader bars and two 11.3 kg (25 lb) or two 6.8 (15 lb) lead balls hung from the ends of the bottom bar. The net was constructed with a graded series of meshes from the mouth (5.0 cm stretch mesh) to the codend (3 mm bobbin) with a screw capped PVC tube to collect fish at the codend. Mean towing speed was approximately 1.0 m/s (3.6 km/h). The net was towed by a single 6.35 mm double braid low stretch rope (Samson Warp Speed) attached to bridles from the top and bottom bars. Unlike the 3x7 trawl, this system did not have the ability to close. The winch was custom made and freewheeled out with a friction brake control and was retrieved using a 4 hp gas powered 4-stroke engine (Honda GX120) connected to the winch by a chain drive.

Prior to use during surveys, the 3x7m trawl system was depth calibrated by establishing the relationship between net depth and cable length at known engine revolutions (rpm). Depth was measured with a VEMCO Minilog depth recorder calibrated to 35m, and rated to 50m (www.vemco.com) attached to the lower spreader bar. This enabled us to later determine the true trawling depth ±1 m. We found that for a given combination of boat, motor, motor revolutions, and trawl gear, there was a linear relationship between deployed cable length and measured net depth. A typical relationship for the 3x7 trawl system on the 7 m boat was: Mid-net depth = 0.35•length-3.24 (at 1000 rpm, r^2=0.99).

Engine revolution was more difficult to determine for the outboard motor on the 2x2 m trawl boat. For this system we adjusted the boat speed until the trawl cable was at 15º from the horizontal. We used engine revolutions and boat speed from the GPS to verify settings but found these to be either unreliable or too slow to respond to be used as primary tools. A typical relationship for the 2x2 trawl system on the 4 m inflatable boat was: Mid-net depth = 0.24•length-0.054 (with a 15º cable angle, at 2500 rpm, r^2=0.99). With both trawls we found that the calibrations were specific to a given combination of net and motor and the calibrations needed to be reestablished whenever a new net or motor was used. With the cable capacity of the winch drums on our boats, we were able to fish to depths of about 55 m with the 3x7 trawl and to 32 m with the 2x2 trawl. Deeper depths could be fished using larger winch drums or a thinner cable, but we have found that thinner cables (4.0 mm, 5/32”) overstretch and twist with continued use.

We conducted one or more midwater trawls in each lake section, in order to apportion the acoustic estimate by species and to collect biological samples. We mainly targeted observed layers of fish-sized acoustic targets, as trawling was intended to catch an adequate sample for species composition of fish observed with the hydroacoustics, not as a random sample of the whole lake. After capture, most fish were anaesthetized with a lethal dose of clove oil solution (Anderson et al. 1997) to prevent regurgitation of stomach contents prior to preserving them in either 10% formalin or 85% ethanol. Fish too large for easy storage were identified, measured, and released alive without anaesthetizing. After 30 days or more, preserved fish were identified, measured to the nearest mm, and weighed to the nearest 0.01g. Total length of sculpins and fork length of other fish was measured.

In many smaller lakes we also sampled fish using "Swedish" style gill nets, but using only the smaller mesh sizes (Appleberg 2000, www.lundgrensfiske.com). The mesh size of these nets increase in geometric increments with a ratio of about 1.25 between mesh openings and were designed so that there was overlapping catch between the meshes (Appleberg 2000). We used the smaller mesh sizes only, as we were mainly interested in competitors of age-0 sockeye and wished to avoid catching migrating salmon or adult sport fish. The Swedish gill nets we used were made with a small diameter (<0.13 mm) uncoloured nylon monofilament thread and were 1.5 m deep by 16 m long. They consisted of four 4 m long panels with stretched mesh sizes of 12.5, 16, 20, and 25 mm. Although poorly documented, deployment of the gill nets changed over time, in the early years we tended to be set gill nets on the surface close to shore in the epilimnion but in more recent years we have set much further offshore in the metalimnion. We usually used an overnight set of 1 or 2 nets in each lake for about 14 hours fishing time on average.

Hydroacoustic Sampling

From 1974 to 1984, we conducted acoustic surveys using a Simrad EY-M single beam echosounder with a 70 kHz transducer producing an 11° beam (at –3dB) and recorded to analog reel to reel audiotapes and later to Beta video tapes for processing in the lab (Hume et al. 1996). Since 1985 we have used four models of Biosonics scientific echosounders. Prior to 2002 we used a Biosonics 105 echosounder using a 420 kHz dual beam (6° narrow beam 15° wide beam) transducer saving data to a Sony model D-10 audio tape recorder. A comparison was made between the Simrad EY-M and Biosonics 105 sounders and is presented later. In 2001, small north coast lakes were surveyed with a rented Biosonics DT6000 echosounder using a 208 kHz 6.6° split beam transducer. In 2002 and 2003, all lakes were surveyed with a Biosonics DE6000 echosounder using a 201 kHz, 6.4 by 6.4 degree split beam transducer. In 2004 and 2005 we used a Biosonics DE-X model echosounder and a 201 kHz, 6.4 by 6.4 degree split beam transducer (same transducer as used by the DE6000 system). Since the spring of 2006 we have used a Biosonics DT-X model echosounder using 208 kHz, 6.6 by 6.6 degree split beam transducer. All four DT and DE sounders are similar in design with the main difference being where digitizing of the signal takes place and there is no significant difference in the data collected by these systems (Tim Acker, Biosonics Incorporated, Personal communications). All four DT and DE sounders save data to a computer hard drive, all collect and digitize the raw acoustic echoes, calculate the position of the echo within the beam, and record GPS coordinates of where the acoustic sample was taken. Appropriate TVG and target strength calculations are applied later in the processing phase. A comparison was made between the Biosonics 105 and the DE6000 sounders and is presented later.

Electrical noise abatement: All electrical devices produce electrical noise at some level and this noise may be detected by the echo sounder, displayed on echograms and become part of the acoustic data. Sources can be almost any electrical device but are commonly internal combustion engines, small electric motors, and inverters. The sounder system itself generates some noise, but the systems we used were designed so the noise they produced was at a very low level. Whether or not electrical noise was detected depended on its intensity, the detection threshold employed, and magnitude of the TVG applied at the time of the noise event. We obtained the best results (least noise) by powering the sounder system through the DC connector, directly from an isolated 12 volt battery and not using an inverter for either the sounder or computer. If supplementary power is required for the computer, we used an auto style 12 volt adaptor connected to boat batteries. Standard operating procedure for the Great Lakes is to collect passive data during the conditions of the survey to measure noise levels (Parker-Stetter et al. 2009).

On the Little Echo we use a stand alone 12 volt battery, used solely for powering the acoustic system (computer included when necessary). On the Night Echo we use a dedicated commercial duty deep cycle 12 volt battery (~230 Amp/Hours) to power the echo sounder system. This battery was also connected to the boats charging system to allow charging in the field, but could be isolated from the charging system by disengaging two solenoid switches when collecting hydroacoustic data.

Transducer deployment: Transducers were deployed 1.0 m below the water surface when using the towed body and 0.4 m below the surface when using the pole mount. The sounder transmitted at a pulse width of 0.4 ms. Until 2008, data was collected above a lower threshold of -70 dB, since then we have collected data above a lower threshold of -100 dB. The standard sampling range was set to a maximum of 80 m in deep lakes and just beyond the maximum depth of shallower lakes. Pulse rate, which normally ranged from about 3 to 10 pings/s, was optimized for maximum ensonifications per target and the least interference from false bottom echoes.

In order for the towed transducer to track correctly, we needed to maintain a minimum speed of around 2.3 m/s (8.3 km/h @ 800 rpm in the Night Echo, Table 1). There was more flexibility with transecting speed when using the pole mounted transducer and typically, we transected at approximately 1.5m/s with the pole mount. However, recently we transected at slower speeds when using the pole mount of around 1 m/s to maximize the number of ensonifications per fish. Faster transecting speeds were sometimes required to maintain steerage when encountering winds or when surveying larger lakes. Modifications to these procedures when *Chaoborus* were present are described later.

Bathymetric charts: Charts were required for navigation, determination of the survey design, and for determining lake volumes in the post-survey hydroacoustic analysis. Charts were available for many of the lakes on the British Columbia Ministry of Environment’s “Fisheries inventory data queries” website: (http://a100.gov.bc.ca/pub/fidq/main.do). There were no charts available for many other lakes and we used survey data to draw new bathymetric charts for these lakes (Hume and MacLellan 2008). These charts were based on positional and depth data from the fish transects, from additional transects between the fish transects, from 1 to 3 transects along the length of the lake where practical, and from soundings in shallow areas not otherwise surveyed. We found that the transects along the length of the lake were particularly useful in eliminating “scalloping effects” around transect data when constructing the charts using mapping software. Water levels were noted but not formally benchmarked. Base maps were taken from digitized Natural Resources Canada 1:50,000 topographic maps (Spectrum Digital Imaging, www.mapsdigital.com) using Oziexplorer mapping software (www.oziexplorer.com). Final bathymetric charts were constructed using Golden Software's "Surfer" surface mapping software ((Version 8, www.goldensoftware.com). Typically the maps were constructed using the Krigging algorithm with anisotropy set at 2:1 along the long axis of the lake and a grid spacing of 5-10 m for small lakes.

Field instructions: The goals, methodology and equipment requirements of a field survey are often complex. In order to ensure that all goals were met, the field crew was provided with detailed instructions, while at the same time we tried to maintain flexibility to accommodate local conditions and challenges. A typical set of field instructions are shown in Appendix 1.

SAMPLE AND DATA PROCESSING

Standard Hydroacoustic Methods

Since juvenile sockeye salmon are often found in very high densities in B.C. rearing lakes, we have most frequently used echo integration techniques as our primary method of processing hydroacoustic data for fish abundance estimates (Nunnallee and Mathisen 1972; Nunnallee and Mathisen 1974; Mathisen and Smith 1982; Burczynski and Johnson 1986; Hume et al. 1996). However, with the low densities often found in many lakes and the development of more capable post processing software (Echoview), the alternative echo counting methods of data analysis; counting of single and tracked targets have become more useful and practical.

Data collected from 1974 to 1984 with the Simrad EYM were analyzed by using the duration-in-beam technique to determine fish density on a subset of transects and then using these estimates to calibrate the echo integrated data. First, the number of times each fish in a given depth range was ensonified was counted on an oscilloscope from selected transects in each lake. This information along with boat speed and ping rate was used to calculate the true beam width at depth and subsequently the fish density (fish/m^3) (Thorne 1988). Second, recorded voltages were integrated with a Biosonics 121 echo integrator to give the relative uncalibrated density of fish in each transect. These counts were then regressed against the integrated data from the same transect. The regression line was then used to calibrate all of the integrated transects to provide an integrated density estimate for each transect.

Data collected using the Biosonics 105 sounder was essentially processed as described by Burczynski and Johnson (1986). In 1985, target strengths and mean backscattering cross sections were determined for each transect with a Biosonics 181 Dual-Beam Processor, then data were echo integrated with the Biosonics 121 Echo Integrator to give the relative density of targets. From 1986 to 2001, the Biosonics 105 data were analyzed using a Biosonics 281 Dual-Beam Processor and 221 Echo Integrator. Also in 2001, we used Biosonics' Visual Analyzer (www.biosonicsinc.com) to process data collected with the DT6000. Since 2002 we have used Myriax's Echoview software (www.echoview.com).

Estimating juvenile sockeye populations using a dual beam system and the echo integration technique is described in Burczynski and Johnson (1986). Although the equipment has changed from dual beam to split beam transducers and from analog to digital sounders, the process has remained the same. In general, backscatter energy from targets at the depths of interest was integrated by the software over discrete distance and depth intervals to provide relative estimates of fish density. These relative estimates were then scaled with the average target strength (TS) for that layer to produce an absolute estimate of fish density. Unlike the dual beam system used prior to 2001, the split beam systems allowed us to determine *in situ* TS from the same data set we integrated, and to produce a more accurate estimate of TS by compensating for target position within the sound beam (Ehrenberg and Torkelson 1996).

In single target echo counting analysis (ST) the water column was sampled ping by ping (Simmonds and MacLennan 2005). However, instead of measuring the total energy returning to the transducer, the software counted the number of single targets detected as described in Myriax's Echoview help file (www.echoview.com/WebHelp /Echoview.htm). A single target was an echo that both exceeded minimum TS threshold requirements and met pulse width requirements before it was accepted as a target. We normally used a TS threshold of -65 dB and a pulse width of ± 50% (0.2 to 0.6 ms) of transmitted pulse width (0.4 ms) measured at the -6 dB (1/2 amplitude) point of the echo envelope. As a result, poorly formed echoes, which may have been from noise sources, or overlapping echoes from multiple targets were filtered from the data. For each transect interval, the number of single target detections was divided by the sum of the individual ping sample volumes to produce an absolute fish density for the interval.

Echo counting using tracked target analysis (TT) approached sampling in a different manner (Keiser and Mulligan 1984). Fish counts were based not on single targets by themselves, but on fish tracks, which were made up of a series of single targets grouped together to form a track of a single fish (www.echoview.com/WebHelp /Echoview.htm). Single targets were determined as above, and we used the standard algorithms in Echoview to determine if a series of single targets comprised a tracked target. Tracked targets were then visually examined and, where necessary, edited to correct tracking errors using the editing tools in Echoview. Rather than using each ping as a sample, tracked target analysis used the entire length and depth of an interval as a sample. As a result, sample volume was the product of the physical length and depth of the interval and the width dimensions of the acoustic beam. Fish density for the interval was determined by dividing the number of tracked fish by the interval sample volume. A special modification to data collection and tracked target analysis used when *Chaoborus* was present in higher densities is discussed in the next section.

Certain survey or population conditions may mean that only one method is suitable for deriving an acoustic estimate. We discuss the validity and use of these three methods in the Results and Discussion Section.

***Chaoborus* Tracked Target Method**

The larval form of the phantom midge (*Chaoborus* spp.) was present in the midwater of a number of our study lakes. *Chaoborus* have been found in many of the smaller sockeye rearing lakes, including high densities in three lakes of the Skeena and northern coastal lakes, and in moderate densities of six more lakes in the same region (Shortreed et al. 2007; Hume and MacLellan 2008). *Chaoborus* contain two pairs of air sacs that are used to regulate their buoyancy (Teraguchi 1975). These air sacs are effective reflectors of acoustic energy. Consequently, *Chaoborus* has a TS in the range of -60 to -70 dB with a 200 kHz sounder (Jones and Xie 1994; Knudsen et al. 2006). This overlaps with the lower end of age-0 *O. nerka* TS which ranges from -45 to -64 dB using Love's (1977) ±45º formula. Besides having a TS similar to smaller age-0 *O. nerka*, *Chaoborus* has a similar vertical diel distribution, migrating from deep waters during the day to midwater at night (Northcote 1964; Teraguchi and Northcote 1966; Voss and Mumm 1999, data on file). Thus, their diel behaviour, their acoustic signature and their potentially high densities can create considerable interference with the detection and abundance estimation of juvenile sockeye salmon.

When *Chaoborus* were present, we attempted to separate the fish and *Chaoborus* signal through a combination of changes in data collection and in signal processing. While *Chaoborus* are capable of reflecting sound energy at intensities similar to those of juvenile sockeye (and similar size fish of other species), individual *Chaoborus* do not appear to do so consistently, and therefore usually fail to produce clean unbroken echo traces as fish usually do at the analysis TS thresholds normally used for age-0 sized O. nerka (-63 dB to -65 db). The echo returns from *Chaoborus*, while they may represent the majority of reflected sound energy, tend to be scattered and unorganized in comparison to multiple reflections from a fish target; i.e., they rarely meet the criteria for a fish track, particularly if slightly stricter criteria were used. This difference is what we focused on to separate *Chaoborus* echoes from fish echoes.

We modified both our survey collection methods in order to maximize the quality of fish detections and our data processing to minimize the interference created by *Chaoborus.* During the survey data collection, we enhanced the formation of echo traces (fish tracks) from fish by increasing the ping rate and decreasing the transecting speed. We increased the ping rate from the usual 3-5 p/s to as high as 10 or 12 p/s. The maximum rate used was dependent on the lake's depth, as increasing the ping rate will often create interference from false bottom echoes. If necessary we would adjust the ping rate, and repeat the transect, so the false bottom (if present) did not center in the depths with fish. We decreased transecting speed from our normal speed of 1.5 m/s to as low as possible, about 1.0 m/s (using the pole mounted transducer in the 4 m boat). By increasing the ping rate and decreasing the transecting speed we increased the number of times a fish was ensonified thereby providing more data for tracking individual fish. We attempted to only collect data during calm lake conditions, as the transducer needed to be steady and stable during transecting. These slow transecting speeds required the use of a pole mounted transducer as the towed transducer does not track properly at slow speeds.

We used a modified tracked target analysis to process transects with *Chaoborus* present. We made adjustments to the single echo and tracked target acceptance parameters and occasionally to minimum TS threshold settings to filter out many of the *Chaoborus* echoes. This was followed by a visual check and editing of the echogram to correct obvious errors made by the tracking algorithm. The processing consisted of firstly filtering single echoes more stringently by using tighter acceptance values for the pulse width of the wave form of the returning echo. Whereas with regular processing we normally accepted echoes with ±50% of the transmitted pulse width (0.2 to 0.6 ms), we narrowed the acceptable range by using pulse width acceptance values of 80% to 110% (0.30 - 0.44 ms). This ensured only the best quality echoes (those that more closely resembled the transmitted pulse) were accepted for processing, resulting in the elimination of a large proportion of the *Chaoborus* echoes while accepting most of the echoes from fish targets.

Secondly, we set the tracking algorithm in the software to accept only fish tracks with at least two consecutive single targets (no ping gaps). Normally we accepted single hits on fish as valid fish detections, especially in the shallower depth layers, where the beam width is very narrow and the probability of multiple pings per fish is low. This would theoretically result in a decrease in the number of targets that would be accepted as fish but this loss is compensated for by the modified survey collection methods which increase the potential ensonification rate for a given fish.

Thirdly, as most of the returns from *Chaoborus* were below the normal sockeye threshold we raised the threshold slightly to -63 dB. If enumerating a fish population of relatively large fish, the threshold could be raised still further, to eliminate more of the *Chaoborus* returns in the processed data.

Finally, the echograms were visually examined to detect and correct fragmented fish tracks. Single hits in the upper layers would be accepted if they exceeded the TS range of Chaoborus. When specifying fish tracks with no gaps between single targets, some tracks that were obviously from one fish were broken into two or more fish tracks and these tracks were manually joined into one track.

It should be noted, that when attempting to separate an acoustical signal (i.e. fish) from background noise (i.e. Chaoborus, mysids, electrical) within the same depth layers, there is always a compromise between loosing some of the fish signal and filtering out the noise. The challenge is in determining the desired balance between the two and in achieving it by setting the appropriate filters (thresholds, single target criteria) and applying the appropriate manual edits.

Mysids

Two species of mysids, the native freshwater shrimp (*Neomysis mercedis)*, and the introduced species (*Mysis relicta*) are occasionally found in BC sockeye and kokanee rearing lakes (Data on file; Lasenby et al. 1986). Unlike Chaoborus they do not have acoustically reflective air sacs and consequently have lower TS values. Literature values of *M. relicta* TS measurements vary from a range of -76 to -74.6 (Gal et al. 1999) to a mean of -82 dB (Rudstam et al. 2008), much less than the minimum -65 dB threshold used for sockeye. *N. mercedis* is smaller than *M. relicta* which should therefore result in a lower TS values. A survey of Lakelse Lake in September 2003 indicated that the maximum TS for *N. mercedis* at that time was -77dB (data on file). Aggregations of mysids can, on the other hand, exceed fish analysis thresholds and need to be dealt with. Normally, the mysids don't exceed the fish threshold by much and simply raising the threshold to -63 dB will eliminate most of the mysid signal with minimal loss of fish signal. Any remaining mysid signal can usually be handled by editing it out.

Hydroacoustic Analytical and Summary Procedures

For all methods, we divided each transect vertically into depth strata from surface to bottom. The strata were usually 2 m deep but were 1 or even 0.5 m deep in shallow lakes. These strata were then divided horizontally into 100 m long intervals (or 1 minute intervals prior to using Echoview), to form a grid of cells that covered the length and depth of each transect. We analyzed data from each transect separately. The volume of each stratum was calculated by determining the surface area of the mid depth of the stratum within the region of the lake represented by the transect and then multiplying by the stratum depth (usually 2m). We determined the strata area by measuring the areas delineated by contour lines on bathymetric charts and then interpolating between contours to estimate the area covered by the strata.

At the start of processing, we normally eliminated acoustic targets that we considered too small to be fish by using a lower cutoff threshold of -65 dB. We used a

-63 dB threshold if the trawl caught fish were large or if there was considerable low threshold noise present in the data (mysids, suspended sediments or dense plankton were possible causes). Primary analysis outputs from both Echoview and Visual Analyzer included the mean volume backscattering strength (*S*v) of the detected targets, single target counts, the TS of single targets, and, if tracking was possible (Echoview only), TS and counts of tracked targets, for each cell. This data was averaged and summarized using custom SAS programs (www.sas.com) to produce total fish density and TS estimates for each stratum within a transect. In the case of integration, the mean Sv of each cell within the stratum was averaged. It was then scaled with the mean TS of all the single targets in that strata to produce a volumetric fish density for the stratum (n/m^3).

The total fish abundance (n) in each strata was determined by multiplying the strata fish density by the strata volume. Total fish abundance was apportioned into large fish, age-0 *O. nerka*, and other small fish through the use of stratum specific TS data and the trawl catch. Because of the bias of the trawl towards small fish we used TS to apportion the total fish estimate into small and large fish. We preferred to use TS from tracked targets but if tracking was not possible, we used TS from single targets. We used a TS value of -45 db to determine the proportion of large and small fish. This value was originally arrived at by examining TS frequency plots from high density years on Quesnel Lake. Over 99% of the trawl catch in Quesnel is age-0 *O. nerka* and densities in these years exceeded 2,000 fish/ha. In most years there was a definite break at -45 dB with abundance of TS values dropping drastically after this point. A TS value of -45 dB is approximately equivalent to a 135 mm fish using Love's (1977) formula, assuming a ±45 degree fish tilt.

We applied these proportions to the total fish estimate to determine the number of large and small fish in each stratum. We then applied the proportion of *O. nerka* in the trawl catch (fish <135 mm only) to the small fish estimate to derive an estimate of juvenile sockeye and of other small fish. These various estimates for each stratum were then summed to provide an abundance estimate of total fish, juvenile *O. nerka*, other small fish and large fish for the region represented by each transect. We then divided by the surface area represented by each transect to produce an estimate of fish densities (n/ha) for each transect.

Based on the stratified systematic design, density results from each transect in a lake section were averaged to provide an estimate of density relative to surface area (n/ha) for the section. The mean density was then multiplied by the surface area of the section to provide a population estimate for the section. The section population estimates were summed to provide a total population estimate for the lake. Mean lake density was calculated by dividing the lake population estimate by the total surface area. Variances were calculated for the density of each section from the transect densities and were then weighted by the square of the section area. The sum of the weighted variances was divided by the square of the lake area to provide a variance for the lake population estimate.

The variance calculated by our methods reflects the statistical confidence in the precision of the population estimate and is largely driven by fish distribution throughout the lake. Due to many factors such as food and currents, fish frequently have a highly patchy distribution, resulting in a large variance. Thus a wide confidence interval does not necessarily mean a hydroacoustic survey is unreliable, simply imprecise. However, technical and environmental factors that may affect the quality or reliability of the estimate are not necessarily reflected in the variance estimate. We therefore developed a four step rating system for survey quality to convey the degree to which the survey successfully detected and enumerated the target population. The quality ratings and their associated criteria are:

1. High - no significant issues with the survey and the quality of the survey was excellent: the sounder system operated correctly; weather was favourable; fish distribution allowed for a complete assessment of the target population; target population was adequately sampled by trawling and; there was no serious acoustic noise to adversely affect fish detection.
2. Medium - some minor issue(s) with the survey, but the impact on the survey is relatively minor and the survey results are a reasonable estimate of the target population; the issue(s) may involve one or more of the factors affecting survey quality; sounder operation, weather, fish distribution, trawl sampling or noise.

3. Low - relatively major issue(s) with the survey, possibly having a significant impact on survey results; generally, the population estimate should be looked on as a “ball park” estimate, with only its order of magnitude having any significance.
4. Very low - a major problem with the survey exists and any population estimate derived from the survey is likely very inaccurate, although in some circumstances, the determination of minimum densities may be possible. This is usually the result of the complete failure in one of the factors affecting survey quality, such as a defective echosounder; wave action too rough making the transducer unstable; fish distribution was such that most of the target population was not detected by the sounder; insufficient biological samples were acquired (trawls or gill nets); or very high noise levels caused excessive interference with the fish signal.

Fish Samples

Trawl, gill net and trap catches were used to determine species composition, size and age structure, and diet. We preserved most fish in formalin, but some *O. nerka* (usually 20) from each lake section were preserved in 85% ethanol. These alcohol preserved fish were processed in a similar manner to the formalin preserved fish and then archived for possible otolith or DNA analysis. Fish were kept in formalin or ethanol for at least one month until weight had stabilized before lengths and weights were recorded (Parker 1963; Rogers 1964).

After a minimum of 30 days, we identified, weighed and measured all fish in each sample. A random subsample of 20 *O. nerka* juveniles was selected for diet and scale age analysis. Up to 30 more juveniles were sampled for scales, if needed, to clarify the age and size structure found in the trawl/gill net sample. Scales were removed and sent to the Scale Ageing Lab at the Pacific Biological Station in Nanaimo, B.C. for aging.

Preservation of fish affects both their length and weight and different methods have different effects. We typically report summary statistics and preservation method of preserved fish without converting to live size. There has been considerable work done on the effects of preservation enabling conversions to be made if desired. Formalin preservation causes a consistent shrinkage in length enabling a simple conversion back to live length, although, various relationships have been established with somewhat different results. Rogers (1964) estimated a factor of +4% for sockeye up to 70 mm and +5% for sockeye smolts 70 to 120 mm. Shields and Carlson (1996) established a formalin length to live length conversion equation ($L=0.744+0.998(FL)$).

Effects on weight are more complex and are dependent on fish size, original state, and the ionic concentration of the formalin when fish were preserved (Parker 1963). Changes in weight from live to preserved fish ranged from -11% to +6% according to Rogers (1964) and from +5% to +12% as reported by Parker (1963). Shields and Carlson (1996) produced the conversion equation $W=0.939(FW)-0.048$.

Conversion factors for fish preserved with alcohol or freezing have been researched by Shields and Carlson (1996), DiStefano et al. (1994), and Macdonald et al. (1997). These studies have shown that appropriate conversion factors not only vary between species, but between watersheds and between years within species. Unless researchers are willing to develop and update conversion factors on a study and site specific basis, conversion factors should be used only to roughly estimate live measurements (Shields and Carlson 1996)

Diet Sampling

When the trawl catch was adequate, we took stomachs from up to 20 fish/trawl of each captured species. To minimize bias caused by different digestion rates of prey, we attempted to only sample fish collected within three hours of the onset of civil dusk. Samples consisting of the contents of up to 10 pooled stomachs (2 samples/tow) were subsampled with a Folsom plankton splitter and enumerated with a computerized video measuring system (MacLellan et al. 1993). Diet analysis included a visual estimate of stomach fullness, identification and counts to genus or species, and, if possible, length measurements. Length was then used to estimate biomass of the stomach contents (dry weight) using taxa specific length-weight regressions adapted from the literature (See Table 2 for formulas and sources). Due to the digestive process, it was often not possible to get direct measurements of all organisms. In these cases we used the mean length of each measurable taxon to estimate length, providing we were able to measure at least 5% of the taxa in the sample. If we were not able to measure 5% of the taxa, we used an average length from all measurements of that taxa from all stomach analysis done by our work group since the early 1990s. This strategy worked well for zooplankton, which are the main food items of most *O. nerka* populations. Insects, however, when present in the diet, were often difficult to identify, measure and to determine biomass. This is due in part to the wide variety of insects, of varying shapes and sizes, that were consumed by the fish. Also, larger insects tended to be broken up when consumed, making measurements difficult and of doubtful accuracy. The end result was poor estimates of length and biomass for insects. Most measurements from insects found in *O. nerka* stomachs probably came from insects that were small enough to be ingested whole, while partial remains would not be measured. This may lead to an underestimate of the average length and biomass of insects taken by these fish. Investigations into the magnitude of this problem are needed particularly in studies where the data is used for estimating food resource portioning by sockeye and competitor species.

METHODS for the EVALUATION STUDIES

EFFECTS OF HYDROACOUSTIC SURVEY DESIGN

We investigated how the precision and accuracy of abundance and density estimates were affected by increasing the transect density on Quesnel Lake (N52.53°, W121.05°). This is a large (270 km^2) deep (mean depth 151m) multibasin fjord lake in the middle Fraser River watershed and has been surveyed regularly for many years (Hume et al. 1996). The pelagic zone is almost exclusively occupied by *O. nerka* of which juvenile sockeye dominate in most years. Our regular (original) survey design had 16 transects in 6 sections of the lake (Fig. 1). We conducted intensive surveys of the lake by approximately doubling the number of transects to 33. This was accomplished by placing new transects between the existing transects and by adding transects at the ends of the three arms. We analysed the collected data using only the regular 16 transects and using the intensive 33 transect design. We also added extra transects to the relatively shallow Hagen Arm but these are not included in this comparison.

VARIABILITY IN ACOUSTIC ESTIMATES

We examined the variability of the acoustic data by repeatedly sampling acoustic transects over the course of three nights on Cultus Lake (N49.05°, W121.99°). Cultus Lake is a relatively small (630 ha) single basin lake with a mean depth of 33 m and our standard survey consists of seven transects (Burczynski and Johnson 1986), approximately evenly spaced along the length of the lake. In 1989 we conducted 4 full surveys of the lake, one each on December 4, 5 and two on December 6. We also conducted a survey of transect 5 an additional five times on Dec 5. In total we conducted nine replicates of transect 5 and four replicates each of the other six transects. We compared results though the use of ANOVA and graphical examination.

COMPARISONS BETWEEN HYDROACOUSTICS ANALYSIS TECHNIQUES

While the three standard analysis techniques ST, TT and integration all are derived from the same acoustic data, their methods of deriving fish abundance and density are quite different and can potentially result in large differences in the final estimates. We compared the results from all three methods (where appropriate) in surveys conducted from 2004 to 2007. In total we compared acoustic density data from 312 transects completed during 34 surveys on 18 lakes. In lieu of knowledge of the true density, we compared the results of the ST and the TT analysis to the integration analysis by least squares regression and examination of the residuals.

COMPARISONS BETWEEN ECHOSOUNDER HARDWARE

Simrad-EYM, single beam vs. Biosonics-105, dual beam

In August 1986 we conducted concurrent surveys on a major juvenile sockeye rearing area, Quesnel Lake, using the Simrad EY-M (70 kHz) and the Biosonics 105 (420 kHz) dual beam sounder to compare the results obtained with the two sounders and data processing methods. Both sounders surveyed the same 16 transects from

Aug 24 - 27, but not always consecutively as the boat with the Simrad also conducted midwater trawls during the course of the acoustic survey.

Although analysis of the data from both sounders was done using integration, scaling of the integration results was done very differently. The Simrad EY-M data were analyzed in two stages using the duration in beam technique to calibrate the integration estimates while analysis of the Biosonics 105 integration results used insitu TS data (see the Sample and Data Processing section). We compared density and population estimates from the two sounders though the use of ANOVA and graphical examination.

Biosonics 105 dual beam vs. Biosonics DE6000 split beam

While surveying Quesnel Lake in August 2002 and 2003 we collected replicate data on selected transects using the Biosonics 105 (420 kHz) and DE6000 (200 kHz) echosounders. To avoid sound interference between the sounders, transects were sampled consecutively by each sounder. The procedure was: transect with the DE6000; reverse course and transect with the Biosonics 105, collecting data at 20 log R for integration; reverse course again and transect with the Biosonics 105, collecting data at 40 log R for TS determination. A total of 16 transects over a wide range of densities were completed. Data from the Biosonics 105 was analysed with the Biosonics 221 Echo Integrator and 281 Dual-Beam Processor. Data from the Biosonics DE6000 was analysed with Echoview. We compared the linear forms of TS (σ_{bs}), Sv (E), and fish density estimates from the two sounders though the use of ANOVA and graphical examination. We eliminated all estimates that used 20 or fewer fish for determining σ_{bs} as typically TS is not reliably estimated with small sample sizes.

RESULTS AND DISCUSSION

Recently "best practices" for fisheries acoustics in lakes have been published by a number of organizations involved with the assessment, management and conservation of lacustrine fish stocks. The Great Lakes Fishery Commission organized a study group on fisheries acoustics in the Great Lakes which resulted in a report describing standard operating procedures (SOP) for data collection and analysis (Parker-Stetter et al. 2009). Researchers at Cornell University used this work as the basis of an online acoustics methodology website "Acoustics Unpacked - A General Guide for Deriving Abundance Estimates from Hydroacoustic Data" (Rudstam and Sullivan 2008). The American Fisheries Society in conjunction with a non-governmental organization "State of the Salmon" (http://www.stateofthesalmon.org/) has also published a comprehensive salmonid field protocols manual with a chapter on hydroacoustics in lakes and reservoirs (Johnson et al. 2007). Our procedures generally followed those suggested in these publications but differ in some cases due to the nature of juvenile sockeye and their rearing lakes. In the following sections we discuss the observations and investigations we made into potential areas of concern in equipment usage, survey design and data analysis.

SAMPLING METHODOLOGY

Transducer Mounts

When wave height was low (≤ 0.2 m), transecting with the transducer mounted on either the towed body or the pole mount produced good quality data. As wave height increased, the quality of the data collected decreased because of both undetected ping returns and the variable distance to the acoustic target when the transducer moved from the perpendicular. When we used the pole mount, data quality decreased quickly as wave heights increased above 0.2 m and usable data could not be collected at heights ≥0.4 m. Pitch and roll was dampened when transecting with the towed body, and data could be collected with wave heights up to about 0.7 m. Transecting with the transducer on the lee side of the boat further reduced the transmission of the boat's roll to the towed body and resulted in the collection of better quality data.

When wave height was very low, the pole mount provided a more stable transducer platform than did the towed body which fluttered minimally under all conditions. As well, the towed body required a speed of ≥2 m/s in order to maintain stability. Thus, under some circumstances, the pole mount can collect better quality data than can the towed body. Only the pole mount was suitable for collecting data for *Chaoborus* analysis because of the desired slow transecting speed.

Size bias of trawl catch

Most sampling gear is known to be size selective and trawls tend to biased against larger fish which may be able to escape the net because of their faster swimming speeds (Simmonds et al. 1992). The bias of the 2x2 trawl has been estimated by Hyatt et al. (2004) and McQueen et al. (2007) in different lakes by comparing the trawl catch with fish caught in downstream smolt traps at about the same time (making the assumptions that the captured fish represent smolts about to leave the lake and the smolt trap is unbiased). The resulting analysis found the size selectivity of the trawl to be a power relationship of the form ($S = a(T)^b$) for fish over 40 mm where S = length in smolt trap and T = length in trawl (McQueen et al. 2007).

The authors reported two trawling bias studies on trawl caught fish ranging in size from 50 to 85 mm. Using data from 4 coastal lakes, Hyatt et al. (2004) found the

2x2 trawl to be highly size selective for length ($S = 0.542 \cdot T^{1.196}$, where $T > 40$mm). This meant that an average trawl catch length of 70 mm would be increased by 25% to 87 mm. This is equivalent to a 95% increase in weight (about 3.6 g to 7.0 g, based on our length-weight relationship). A later study by McQueen et al. (2007) on Woss and Vernon lakes found a much smaller bias ($S = 0.629 \cdot T^{1.125}$, where $T > 40$mm). Using this relationship a mean length in the trawl catch of 70 mm would increase only 7% to 75 mm, equivalent to a 23% increase in weight (about 3.6 g to 4.4 g).

The size range of age-1 sockeye captured by the 2x2 and 3x7 midwater trawls in the spring of 2008 and by the 3x7 trawl alone in 2009 on Cultus Lake were compared to those captured at the smolt fence. In the 2008 study (unpublished data), age-1 smolt samples were collected at the same time and location with both the 2x2 and 3x7 trawl on March 26, 2008 and compared to smolt samples collected at a downstream fence 13 days later and then once a week for five subsequent weeks. From the fence data, there was a strong relationship between date of capture and size ($R^2 = 0.94$, $P<0.01$) with an apparent smolt growth rate of about 2.3 mm /day (Fig. 4). Projected backwards the predicted smolt size on March 26 would have been 99.2 mm. Mean size of pre-smolts in the trawls on that date was 95.4mm in the 2x2 and 94.4 mm in the 3x7 trawl. This was 4-5 mm smaller (4 - 5%) than expected and significantly smaller than the smolt size on April 8 in the fence catch (ANOVA $P<0.05$).

In the 2009 study, trawls were conducted near the beginning and end of the smolt run. In this year, there was no indication of apparent growth in the fence caught smolts and we found that the size range of age-1 sockeye captured in the trawls overlapped with but were smaller than the age-1 sockeye captured at the fence. The results of these two preliminary studies indicate that the trawls do show size bias but perhaps not as large as found in previous studies.

There are however potential problems with this type of study. The difference between years in apparent growth the smolts and pre-smolts implies an essential problem with interpretation of the data. The trawls and the smolt fence may not be sampling the same population, as not all trawl caught *O. nerka* may migrate (they may be resident kokanee or may not migrate until the next year as age-2 smolts), or trawl capture date may not be related to fence capture date. More extensive tests of trawl size bias need to be conducted and we feel until these biases can be more rigorously defined they should be noted, but corrections, if used, should be applied only with caution.

We can also use the 2008 sampling on Cultus Lake to compare the trawling efficiencies of the two different midwater trawls. There were a number of similarities and differences between the two trawling systems that may have affected their sampling abilities and catch efficiencies. The 3x7 trawl had a fishing area 5.25 times larger and a towing speed 0.7 times slower than the 2x2 trawl. Both trawls (as do most trawls) had large sized mesh near the front of the net, designed to guide the fish into the finer mesh at the codend but due to the differences in trawl length, the maximum mesh size of the two trawls differed (10.2 vs. 5.2 cm) suggesting the possibility of different size selectivities. These trawls are size selective due to the conflicting requirements of small mesh sizes to retain small fish and large mesh sizes to limit trawl avoidance by large fish (Harrison 1967). As fish do not react to rapidly approaching trawl gear at night, a consequence of this design is to allow a proportion of the smaller fish to pass through the larger meshes (Glass and Wardle 1989; Parkinson et al. 1994).

In 2008, sample sizes were small as we only completed two trawls each for a total of 50 min with the 3x7 trawl and 65 min with the 2x2 trawl (Table 3). The 3x7 trawl caught both age-1 sockeye and threespine stickleback (*Gasterosteus aculeatus*) at the same rate of 2.0 fish/min, while the 2x2 trawl caught them both at <0.5 fish/min. Overall the 3x7 trawl caught fish at a rate 4-6 times higher than the 2x2 trawl. However when scaled to total water sampled (volume swept by the nets = area•velocity•time) there were much smaller differences between the two trawls, and the 3x7 trawl was only 1.1-1.6 times more effective than the 2x2 trawl. Perhaps the faster towing speed of the small trawl (1.0 m/s compared to the large trawl's 0.7 m/s) partially compensated for its smaller mouth opening. While these data are suggestive of similar trawling efficiencies of the two trawls, more side by side trawl comparisons need to be conducted in locations with fish of different sizes and densities.

We did not find any differences in size selectivity between the two trawls when comparing the length distribution of either age-1 sockeye or the much smaller threespine stickleback. The range and median, size of both taxa were very similar in both trawls and the means were not significantly different (T-test P>0.05, Fig. 5).

These results are indicative that the two trawls have similar selectivities for sockeye and stickleback less than 120 mm. Similarly, Hume et al. (1996) in an analysis of Parkinson et al. (1994), which compared the catch of kokanee from fast Otter trawls to a beam trawl similar to ours, concluded there was little difference between trawls in the length-frequency distributions of the catch of age-0 and -1 kokanee up to 155 mm in length, but the beam trawl caught fewer larger fish (age-2 and -3 kokanee) than the two fast otter trawls. Parkinson et al. (1994) concluded that the bias in their trawl data was restricted to underestimates of proportions of older kokanee (age-2 and -3) but that estimates of mean size of each age-class appeared to be unbiased. Gjernes (1979) compared the catch of age-0 sockeye in a 3x6 m trawl to that of a 2x2m trawl and also found no significant difference in mean size. Cultus Lake has very few kokanee (data on file) and so the lack of larger *O. nerka* is not unexpected. As trawl efficiency of the 2x2 trawl only appears to be only slightly less than the 3x7 trawl, the similarity in size of captured age-0 sockeye between the two trawls is also not unexpected. Differences between trawls in size bias, if present, may only be apparent when sampling a midwater population with a significant population of larger fish. It appears with the limited comparisons done to date that there is little difference in trawl efficiency or size bias between the two trawls when sampling age-1 and smaller sized fish, but that both provide size estimates that are smaller than that of the true population, though perhaps by not as much as previously suggested.

Size bias of gill nets

The subset of Swedish gillnets we used were selected to specifically sample smaller fish (age-0 and -1 *O. nerka* and other similar sized fish) and to avoid catching sport fish and spawning adult salmon. They were utilized to supplement trawl catch information and to expose any bias in the small, 2x2 trawl catch. Hume and MacLellan (2008) reported on the catch of these nets in surveys from 2001 to 2005. Unlike recent practice where netting is targeted at the pelagic zone in the metalimnion, the sets in this report tended to be fished closer to shore and at shallower depths than were the trawls.

Using the data from multiple lakes in Hume and MacLellan (2008) we compared the lengths of the catch in the Swedish gill nets and the 2x2 trawl. The gill nets were mostly fished on the surface (until 2005) and closer to shore than the trawl. Starting in 2005 we tended to fish the nets in deeper metalimnion waters. The Swedish gill nets caught fish considerably larger than those caught in the 2x2 trawl during the same surveys (Fig. 6). *O. nerka* caught in the gill nets ranged from 57 to 147 mm with two modes at 75 mm and 87 mm, O nerka caught in the 2x2 trawl ranged from 27 to 108 mm with a modal size of 51 mm, at least 24 mm smaller than the modal sizes in the gill nets. Overall the trawl caught much smaller *O. nerka* than did the gill nets. Similar patterns and differences between the two gear types were found in the size distribution of other species (Fig. 6). Indeed, while many species were caught in both gear types, a few were only caught in one or the other (Hume and MacLellan 2008).

Part of the catch bias in the data presented here is due to the somewhat different habitat types where the two gears were fished. Other reasons for the differences include the different encounter rates caused by the passive (gill nets) and active (trawl) nature of the fishing gears and to a reduced retention rate of the smaller fish in the gill net after being caught (Appleberg 2000). The catch in each gear type included a size range not represented in the other net showing that even though there are difficulties in comparing and interpreting their catches, more than one gear type is necessary for a complete characterization of the fish community.

Hume and MacLellan (2008) conducted 137 overnight gill net sets for a total of 668 hrs of fishing and caught a total of 595 fish of all species for a mean catch rate of 0.89 fish/hr or about 25 fish/survey. In spite of low catches, these nets were an useful supplement to the mid water trawl as they provided evidence of the presence of larger and older *O. nerka* not caught by the trawl. In many lakes they also provided evidence of other fish species that may be either competitors or predators of age-0 sockeye. Hume and MacLellan (2008) found that gill nets captured 7 species other than salmon in the smaller lakes of the Skeena and north coastal watersheds. They were particularly useful in sampling small shallow lakes (e.g. Azuklotz Lake), where trawling is difficult and often ineffective and in glacial lakes (e.g. Motase Lake) where *O. nerka* were located within a few meters of the water surface. As the nets were only 1.5 m deep, they only sampled the near surface waters. Deeper nets could also be used and set lower in the water column in clear water lakes, to obtain a more representative catch of the full epilimnion or deeper thermal layers (Beauchamp et al. 2009, Stables and Perrin 2009).

RELATIONSHIP BETWEEN TS AND FISH LENGTH

TS was used in the analysis process for three purposes: to determine the smallest targets of interest; to provide an abundance estimate by scaling the integration data; and to separate fish into size categories. We used Love's (1971; 1977) formula for ± 45º fish orientation to relate TS and fish length: $TS_{45} = 18.4\log(L)-1.61\log(f)-61.6$, where L=length (cm) and f =transmission frequency. For a 208 dB sounder this simplifies to TS45 = 18.4Log(L) – 65.3. This is only a rough approximation of sockeye length as TS varies considerably with fish orientation (Kang 2009) and fish species (Simmonds and MacLennan 2005). Because sockeye are physostomes, depth in the water column will affect the air bladder and consequently TS (Mukai and Iida 1996, Zhao et al. 2008).

A few other attempts have been made to estimate TS of small fish and the results have been expressed in the form of a "standard" equation with the slope fixed at 20: $TS=20\log(L)-b_{20}$ where b has been found to vary from -65.4 to -68.0 (Simmonds and MacLennan 2005). Kang et al. (2009) collected extensive TS data on tethered Japanese anchovy (*Engraulis japonicus*) which were a similar size to juvenile sockeye (48 to 122 mm) using a Biosonics 200 kHz DTX sounder. They fitted two models; a least squares best fit of TS=15.1log(L)-64.7, (R^2=0.79) and a "standard" model TS=20log(L)-69.1, (R^2=0.71). While length explained a considerable amount of the variation in TS over a wide range in lengths there was a considerable range in TS for an individual fish. For example a 98 mm fish with a mean TS of -49 db had a flat distribution of individual TS measurements (n= 1252 pings) ranging from – 42 to -64 dB. Therefore, any single TS measurement on the same fish could indicate a length ranging from about 20 to 220 mm.

HYDROACOUSTIC SURVEY DESIGN

On most lakes we used a stratified systematic transect design with the transects perpendicular to the shore and usually parallel to each other. Sockeye distribution is often constrained by lake morphometric features such as narrows and shallow sills between basins, or simply long distances between spawning areas and available rearing habitats. In these cases we expected that the mean density may vary from region to region and we stratified our survey in order to reduce the overall variance, usually into a separate section for each basin (Parker-Stetter et al. 2009; Simmonds and MacLennan 2005).

When a lake was surveyed for the first time we typically divided it into one or more sections based on lake morphology and/or distances. After deciding on the number of transects for the lake and lake sections, we divided each section into a number of transect areas, usually of similar size and/or width with respect to the long axis of the lake. Placement of transects was usually through the center of the transect area, perpendicular to the long axis of the lake, except when lake depth was relatively shallow (<80m) or the lake outline did not lend itself to such placement. When the lake depth in a transect area was shallow, which typically occurs towards the ends of lakes, the transect would be off-set towards the deeper portion of the transect area to ensure hydroacoustic sampling of the deeper portions of the area. Islands, shoals, bays, points and other features can also influence the off center placement of a transect. When the width of the lake was particularly narrow, the transect was often placed more diagonally within the area to maximize acoustic sampling. The number of transects used was based on the expected variance (from surveys on other lakes), time and cost constraints, and a minimal coverage. Parker-Stetter et al. (2009) deemed this systematic design appropriate as any periodicity in fish distribution is highly unlikely to be on the same scale as the distance between transects, and it guarantees better coverage than randomly allocated transects.

Effects of transect density on survey results

The appropriate number of transects to use depends on the purpose of the survey (mapping distribution vs. estimating abundance), the desired coverage of potential habitat and the desired confidence in the abundance estimate. Increasing the number of transects will always improve the results but the time and cost involved are also an important consideration. In most of our studies we were interested in both the distribution and abundance of juvenile sockeye, so we tried to maximize both the coverage and the number of transects subject to time and cost constraints.

The degree of coverage (DoC) has been defined as $\Lambda = T/A^{0.5}$ where, T = length of the transect (km), and A = surface area (km^2), Λ = DoC (unitless) (Aglen 1983 in Simmonds and MacLennan 2005). We determined the DoC for many of our survey lakes (n= 28) ranging in size from 1.3 to 338 km^2 with 5 to 24 transects and total transect lengths ranging from 2.4 to 51.8 km (Fig. 7A). The DoC for these lakes averaged 2.6, ranging from 1.2 to 4.0.

We used the acoustic estimate of density (n/ha) for each transect from a recent survey to determine the coefficient of variation (CV) for each study lake using Aglen's

(1989) definition (CV= SE/mean density). We compared the results to Aglen's (1989) empirical study of a wide variety of marine stocks and locations. He found the CV of the mean acoustic estimate decreased as a power function of DoC ($CV=a/\Lambda^{b}$). In Aglen's study "b" was 0.5 but "a" ranged from 0.4 to 0.8 indicating increasing "contagion" (patchiness) in the fish distribution (Simmonds and MacLennan 2005). If we assume that sockeye fry have a somewhat uniform distribution with an "a" of 0.4, Aglen's relationship would predict CV's ranging from 20% at a DoC of 4.0 to 37% at a DoC of 1.2. Our results were similar to these expected values, ranging from 10 to 46% and averaging 23%, but we did not find a significant relationship between CV and DoC (Fig. 7, R^2= 0.00, P=0.5). It appears that the *O. nerka* fry showed relatively little patchiness compared to marine stocks as the survey data is scattered around or below the Aglen line with an "a" value of 0.4 (Fig. 7B).

With our survey design, the length of the transect and consequently the DoC is not as important to our analysis as is the number of transects, as our methodology uses each transect as a single data point to estimate density. In theory, a single transect randomly placed with respect to fish distribution should provide an accurate but imprecise estimate of the true abundance (Parker-Stetter et al. 2009; Simmonds and MacLennan 2005). Precision will increase as the number of transects increases but at an ever decreasing rate and a balance needs to be achieved between precision and the time and effort required to conduct the survey (Simmonds and MacLennan 2005). A theoretical analysis of a sockeye population (mean density = 2000 fish/ha, standard deviation = 2200) shows that increasing from 3 to 7 transects decreases the CV by 22 percentage points (from 64% to 42%) while a similar increase from 13 to 17 transects decreases the CV only four percentage points (from 31% to 27%) (Brock Stables, Shuksan Fisheries Consulting, personal communications).

We empirically tested these results by conducting six intensive surveys (33 transects) on Quesnel Lake from 1998 to 2003. These intensive surveys included our regular survey (16 transects), which were analysed separately, as well as an additional 17 transects dispersed among the original 16. The 33 transects of the intensive survey covered a total distance of 58 000 m and had a DoC of 3.5 while the 16 transects of the regular survey totaled a distance of 26 800 m and a had DoC of 1.6 (Fig. 1).

We found that the intensive surveys provided slightly higher estimates of fish density (0 to 23% higher, mean = 8%) than did the regular survey but the differences were not significant, either for individual surveys or overall (Table 4, Fig. 8, ANOVA, P>0.05). The higher estimates in the intensive surveys can be partly explained by the slightly greater coverage at the outer ends of the three arms provided by this design. We also found that the intensive surveys had somewhat tighter variance estimates than did the regular surveys (CV was 7 to 15% lower, mean = 8%), but again these differences were not significant, either for individual surveys or overall (Fig. 8, ANOVA, P>0.05).

In a broader context, beyond estimation of abundance as a stock assessment tool, we often wish to map the distribution of fish abundance to determine their ecological impact on other components of the lakes biota, such as their primary food source, zooplankton. A good map requires the samples (transects or portions of transects) to be at intervals less than the range of spatial correlation, but sampling at more than the minimum level results in a more accurate distribution map (Simmonds and MacLennan, 2005). On Quesnel Lake the transect spacing on the regular surveys averaged 6.1 km apart, while on the intensive surveys they averaged nearly half that at 3.7 km apart. Distribution maps determined from the intensive surveys would provide considerable more detail although the precise gain in detail is unknown. In the fall a regular survey of 16 transects would usually be accomplished in 2.5 nights while an intensive survey would usually take an extra night's work (3.5 nights). Thus for about an extra 40% increase in field time we only gained possibly 8% in the precision of the abundance estimate but probably considerably more in mapping precision.

Variability in Acoustic Estimates

In Cultus Lake, we examined the variation in the estimates of density within individual transects over the course of three nights and within a single night. Each transect was surveyed at least 4 times, once each on December 4 and 5 and twice on December 6, 1989. Transect 5 was surveyed an additional 5 times (6 times within 3 hours) on Dec 5 for a total of 9 replicates. Overall there was little variation within transects from survey to survey (Fig. 9B). Transects 2 and 4 had very little variability with 95% CI's <10% of mean. The rest were somewhat larger ranging from 19 to 44%. Transect 5 showed less variability within replicates conducted on Dec 5 than it did between survey days.

The four replicate hydroacoustic surveys (7 transects each) conducted over the course of three consecutive nights in December 1989 provided estimates of the age-0 population that ranged from 4 227 to 4 875 fish/ha (Fig. 9A). These estimates were not significantly different between surveys (ANOVA, F=0.820, P=0.495) with 95% CI for each survey ranging from 9 to 20% of the estimates. Overall we found that the hydroacoustic surveys provided repeatable estimates of juvenile sockeye salmon in Cultus Lake within useful confidence limits. Cultus is a relatively small lake with few morphometric impediments to fry dispersal throughout the lake. As well, the DoC of 3.7 was one of the highest recorded for our lakes. These results should be applied with caution to larger lakes, to lakes with more complicated morphometry, and to lakes with a lower DoC.

HYDROACOUSTIC ANALYSIS TECHNIQUES

Standard Techniques

Overall there was a very strong relationship between the results of the single target analysis and the integration analysis ($R^2 = 0.95$, Fig. 10). The single target results were closely related to integration estimates with a slope close to but significantly lower than a one to one relationship (ST = 0.98•Int; T test of slope =1.0, P=0.03). Visual examination of the data and of the residuals shows that for densities >4 000 fish/ha, the variability in the relationship between ST and integration increases considerably indicating that ST and integration analysis methods appear to be less likely to estimate the same density when true densities are high. A number of factors may be affecting the results at higher densities including an increase in single echo rejections due to overlapping echoes from multiple fish. This would decrease the proportion of single targets detected, relative to the true number of fish targets and thereby reduce the ST estimated density. Echo shadowing, where dense aggregations of fish in upper layers (nearest the transducer) diminish the detectable signal from lower layers, may also play a role (Appenzeller and Leggett 1992, Simmonds and MacLennan 2005). However, shadowing affects both integration and ST analysis, resulting in under estimates by both methods, and its difficult to say which would be impacted more. The ST analysis could suffer losses both from shadowing and single target rejection due to overlapping echoes. Potential shadowing can be observed by a decrease in the bottom signal and would possibly only play a role in the very highest observed densities of age-0 sockeye. It should be kept in mind when analyzing high densities but, is unlikely to be a significant problem on most surveys.

Tracked target (TT) analysis had an equally strong relationship with integration estimates of density ($R^2 = 0.95$, Fig. 10), but in this case TT estimates tended to estimate higher densities than did the integration analysis (TT = 1.17•Int, T-test of slope = 1.0, $P < 0.001$). Unlike the single target analysis the variation was about equal over the whole data set. We expected tracked targets to provide lower estimates than the integration method at higher densities when tracks would be difficult to detect. Instead TT estimates were consistently higher than integration estimates at all densities. We speculate that the root cause of this discrepancy involves the calculation of sample volume since TT sample volume is calculated in a fundamentally different way than for ST and integration analyses. In integration and ST analysis the total number of single target detections was divided by the sum of the sample volumes for each individual ping to produce an absolute fish density for the interval. While in TT analysis the total number of tracked targets was divided by the total sample volume which was the product of the physical length and height of the interval and the width dimensions of the acoustic beam.

Based on these comparisons and on our own experience we make the following recommendations for the suitability of each method under varying survey or population conditions. In some cases only one method is suitable for deriving an acoustic estimate. Often, however, more than one method may be suitable (Table 5). In these cases, we conducted analyses using all suitable methods and compared results as an internal check for processing and computational errors. For presentation simplicity, and as differences were low compared to estimated precision, we usually followed the guidelines in Table 5 and only reported one. Given the high densities typically encountered on Fraser system sockeye lakes and the equipment available, integration was the only consistently viable analysis methodology from 1975 to 2001 and was therefore the default method reported. Since then, analysis techniques and software have evolved considerably making other methods easier to use. Under some circumstances, such as high noise levels, very low densities or in the presence of Chaoborus, these other methods may provide a more accurate estimate and should be the ones reported.

Note that we use surface densities as a guide only. The choice of the appropriate methodology for analysis is dependent on the maximum volume density at the ensonified depth, not surface area density. While a high surface area density often indicates a high volume density, the fish may be distributed over a wide depth range and the actual fish volume density is quite low, allowing other methods to be used. For example, a survey of Johnston Lake in 2005 produced a surface area fish density of over 6 000 fish/ha (Hume and MacLellan 2008), which in many instances would indicate integration as the only viable method of analysis. However, this population was distributed over 60-80 m of depth, allowing for reliable single target detection and tracking of targets. The population estimates using the three techniques were closely matched in this lake. This is often the case in fall surveys when, in the absence of a strong thermocline, fish can be widely dispersed vertically. Conversely a low surface density may result from a compact layer of fish with a high volume density which may make the integration result the preferred reporting method and may even preclude any processing method except for integration.

When fish densities are high, echo traces frequently overlap and fish echoes are often superimposed on one another. This leads to a high proportion of fish echoes rejected as single targets, which would lead to an under-estimate using the single target count method. Similarly, with missing single targets, the ability to track individual fish from ping to ping is severely compromised and this can lead to either an under or an over estimate. Underestimates result from missing fish tracks all together and over estimates stem from fish tracks that are broken up and perceived as two or more fish. These situations arise when volume densities are high enough that tracking errors are frequent, despite which tracking criteria is used, resulting in the operator frequently being unable to perceive the real fish track and make the appropriate edits. In these circumstances, echo integration is the preferred, and in extreme cases, the only, viable method.

When data has been collected during poor weather conditions causing excessive transducer movement due to vessel pitch and roll, some of the successive pings comprising a fish trace may not be received by the transducer, thus breaking up the fish traces, and making fish tracking difficult. In this case, echo integration and single target analysis are preferred.

When the fish density is very low, tracked target analysis is often preferred due to its ability to ignore most background noise in the acoustic data. This background noise, which is present in most acoustic data, is usually insignificant relative to a large fish population signal. However, at very low fish densities, this noise may contribute significantly to the population estimate if integration is used. When there is more than the usual background noise in the acoustic data, whether it's from a biological source such as *Chaoborus*, or system generated noise, tracked target analysis allows one to use the coherent and recognizable pattern of echoes in fish tracks to extract them from the noise. If the noise is extreme, then the *Chaoborus* TT method may be of use but more likely no methodology will work. TT analysis is also useful for mapping fish distribution as it directly allows for the elimination of selected size ranges of fish targets based on TS, enabling the distribution of only the fish of a selected size to be mapped.

When integration and one or more other techniques are suitable we have estimated the population with all suitable techniques but have chosen to use the integration technique for further analysis and reporting. Since developing the *Chaoborus* TT method, we have reported it in preference to the standard TT method when Chaoborus are present in significant numbers. To date, we have not used ST in our reports. As shown earlier it generally appears to provide estimates very similar to those produced by integration but with some significant exceptions. Thus for consistency with the historical database we currently report integration results. However, ST could be used for reporting purposes in a situation where densities are high enough to make tracking targets difficult and there is noise in the data, provided that noise can be reliably rejected by the single target algorithms (i.e. electrically generated noise). ST estimates can also serve as a check on integration estimates and have been helpful in tracking down erroneous integration of the bottom and other inclusions of noise in the acoustic data.

***Chaoborus* Techniques**

Two hydroacoustic analytical techniques have been published in recent years to determine fish abundance in the presence of *Chaoborus*. Eckmann (1998) plotted the area backscattering strength (s_a) against decreasing volume backscattering thresholds (s_v) in 1 dB steps. If the slope of the resulting curve decreases at some intermediate threshold and then increases again before the final plateau is reached, different portions of the integrator output can be allocated to two groups of targets (i.e. fish and *Chaoborus*) according to the linearity principle in acoustics (Simmonds and MacLennan 2005). The portion represented by the fish can be described by an asymptotic Von Bertalanffy growth function and the asymptote (equivalent to L_∞) will be an estimate of S_a due to fish (Eckmann 1998). In order for this technique to be successfully applied, the relative abundance and size of fish compared to *Chaoborus* must be sufficiently large that the intermediate change in slopes is detectable. We found that this was not the case in the lakes we have studied and that the intermediate change in slope did not occur and thus no separate estimate of fish could be made (data on file). Similarly, Malinen et al. (2005) also failed to detect intermediate slopes in studies on lakes with populations of both smelt (*Osmerus eperlanus*) and *Chaoborus*.

Malinen et al. (2005) developed a related method by determining the relationship between the area backscattering coefficient (s_a) of a fish population and the backscattering threshold (s_v) in a location or depth range of the lake that did not have *Chaoborus*. They then analyzed the rest of the acoustic data with a threshold high enough to eliminate the acoustic signal due to *Chaoborus* and applied the *Chaoborus*-free relationship to determine the result that would have been achieved with a lower threshold containing all backscattering from fish. As the relationship between s_a and s_v depends on fish size, abundance and behaviour, and varies from lake to lake, season to season and possibly depth to depth, it needs to be determined for each lake under study and requires data to be collected with the fish and *Chaoborus* occupying separate portions of the water column. In sockeye rearing lakes containing *Chaoborus* there is often complete overlap of the two species and this process is therefore not applicable in most lakes.

The third *Chaoborus* TT method that we developed (see Methods) using a modified tracked target analysis requires further testing, but an initial subjective analysis indicates it works well if the data are of high quality and the densities of *Chaoborus* are not extremely high. If *Chaoborus* is very abundant, the distinction between the fish and the *Chaoborus* signal becomes less clear and our confidence in the fish estimate drops below acceptable levels. Hume and MacLellan (2008) used a modified TT method that incorporated the analysis techniques but did not incorporate the field methods of the *Chaoborus* TT method. They found the modified TT method worked well in four lakes where the *Chaoborus* densities were moderate and the fish to *Chaoborus* ratio was relatively high but not in another lake with very high *Chaoborus* densities.

COMPARISONS BETWEEN ECHOSOUNDER HARDWARE

We have used many different sounders, data processors, software, and analysis techniques over the course of this program. Many of these changes were relatively minor, often involving only greater ease in data collection or processing. Some changes, particularly in echo sounders required comparisons to be made between old and new systems. It is however, often difficult to compare intermediate analysis variables between differing systems because the changing technology often introduced new variables not produced by the older system. In the end it was the fish density estimate that was the important result to compare between systems and that is what is concentrated on in the following studies.

Simrad-EYM, single beam vs. Biosonics-105, dual beam

Before switching from a single bean sounder to the dual beam sounder we compared results in a survey of Quesnel Lake in 1986. The same 16 transects on Quesnel Lake were surveyed using Simrad-EYM (70 kHz) and Biosonics 105 (420 kHz) sounders. Surveys were conducted over the course of three nights but transects were not always consecutively sampled by the two sounders. Thus it is possible that there was lateral fish movements between transects which may have resulted in changes in the true fish density between transecting times. Examination of the density estimate for each transect shows that the between sounder 95% CI on the acoustic estimates overlapped for the majority of transects (11 of 16, Fig. 11a) and there was no significant relationship between the Simrad and Biosonics density estimates (Fig. 11b, $r^2_{adj} = 0.19$, $P>0.05$).

While there did appear to be considerable variation between sounders for many transects, these differences were not significant when the data was summed by individual arms or for the whole lake. There was no significant difference between the two sounder estimates for each arm although the Simrad-EYM estimate did tend to be higher (T-tests, $P>0.05$, Fig. 11c). When applied to the whole lake, the Simrad whole lake density and population estimate was only 4% larger than the Biosonics estimate (T-test, $P>0.05$). Given the close correspondence between the sounders within larger lake areas we have not made any corrections to the data when working with whole lake or whole arm time series data using the different sounding systems.

Biosonics 105 dual beam vs. Biosonics DE6000 split beam: σ_{bs}

We found no difference between TS estimates using either sounder. The mean σ_{bs} (linear form of TS) determined using the dual beam Biosonics 105 (420 kHz) sounder was not significantly different from that produced by the split beam Biosonics DE6000 (200 kHz) sounder (Fig. 12a, ANOVA, F = 1.24, P = 0.27). Variability of σ_{bs} was about the same for both sounders with coefficients of variation ranging from 37% to 39% for the two sounders. There was very little relationship in between the two sources of σ_{bs} ($R^2_{adj} = 0.01$, P = 0.19). This can perhaps be explained by the very small range in body length (mean = 51± 0.5 mm) encountered during these summer surveys, resulting in insufficient TS variation to observe a relationship in σ_{bs} between the sounders.

Biosonics 105 dual beam vs. Biosonics DE6000 split beam: (E) and density

There was good correspondence between the returned energy (E) and estimates of fish density made by the two systems (Fig. 12b,c). Regressing the split beam against the dual beam resulted in a significant relationship which explained much of the variance in the data ($P < 0.001$, $R^2_{adj} \geq 0.84$). The slope in both cases was >1.0 indicating that there was a tendency for density estimates from the split beam sounder to be higher than those from the dual beam sounder. Two strata in the data set were considerably higher than the rest of the data and the regressions were rerun excluding these two strata. Highly significant relationships still existed but they explained somewhat less of the variance and had lower slopes ($P < 0.001$, $R^2_{adj} \geq 0.67$).

RECOMMENDATIONS FOR FUTURE IMPROVEMENTS

In this report we described the equipment and methods we used for conducting, analyzing, and reporting of pelagic fish surveys of sockeye nursery lakes. We also reported on various tests and comparisons we made to investigate the validity of our survey designs and assumptions. In this section we describe some of the known weaknesses in our methodology and make some suggestions for further work to address these areas of concern.

TARGET STRENGTH AND TS LENGTH RELATIONSHIPS

Much of the analysis and interpretation of hydroacoustic data depends on accurate relationships between fish size and acoustic target strength. Small errors in this relationship can result in large errors of interpretation. While the target strength of marine fish has undergone considerable investigation (see Simmonds and McLennan 2005 for a summary) there is only a little TS information for juvenile salmonids (Burczynski and Johnson 1986; Iida et al. 1991) and none for any of the fish we commonly find co-habiting with juvenile sockeye. The lack of TS information on other fish was not of much concern in large deep fjord style sockeye rearing lakes where *O. nerka* dominated the midwater fish community, making them effectively the only species present. However, many of the smaller, shallower lakes have a much more diverse pelagic fish community. Common species found in these lakes are threespine stickleback, redside shiner (*Richardsonius balteatus*) and various sculpins (*Cottus sp.*) and whitefishes (*Coregonus sp*). None of these are reported on in the hydroacoustic literature but of particular interest are threespine stickleback and sculpins. The very different body shapes, the lack of a swim bladder (sculpin) and the closed (physoclist) swim bladder of threespine sticklebacks suggest that the relationship between size and TS may be quite different for these species. Better knowledge of the TS range for these species would help in the interpretation of our hydroacoustic data and ultimately provide better population estimates.

DATA NEEDED FOR ECOSYSTEM STUDIES

In many of our study lakes, particularly large lakes in the Fraser River system, age-0 sockeye are the dominant fish species in terms of both abundance and biomass. In these lakes midwater trawling alone often provides adequate sampling of the fish community. In many other lakes the fish community is often more complex with multiple species and multiple age and size groups of *O. nerka* occurring. Few investigations of the species and size selectivity of midwater trawls in freshwater have been conducted and the little work that has been done has concentrated on *O. nerka* (Parkinson et al. 1994; Hyatt et al. 2004; McQueen et al. 2007). Further work is needed to better define the extent of the bias, particularly for older *O. nerka* age classes and for other midwater species.

In many lakes, trawling does not adequately sample the complete pelagic fish community and multiple sampling methods are needed due to the size and species bias of individual gear types. Gill nets seem to hold the most promise for capturing size and species not fully vulnerable to trawling and we have initiated their use in some of our surveys. Considerable work needs to be done to fully document the relative efficiency and selectivity of these techniques so that the results can be fully integrated with those from trawling and acoustics.

SEPARATING AGE-0 SOCKEYE AND KOKANEE

The non-anadromous form of *O. nerka* (kokanee) often cohabit the same lakes as juvenile sockeye. Morphologically they are indistinguishable from each other, although in many lakes age-0 kokanee tend to be smaller than sockeye (Hume et al. 2003). The strontium/calcium ratios in the core of the otolith is a proven technique for separating the offspring of anadromous and non-anadromous *O. nerka* in kokanee bearing lakes where the strontium content of the lake water is significantly lower than the marine environment (Rieman et al. 1994; Volk et al. 2000). Lower strontium levels are typically the case in our study lakes and we have successfully used the technique in the past (MacLellan and Hume 2002; Hume et al. 2003). Unfortunately processing of the otoliths requires specialized equipment, not always readily available and can be quite expensive even though required sample sizes are often not large for exploratory surveys. For example, in an *O. nerka* population that is 20% kokanee a sample of 30 fish would provide an estimate ranging from 7.5 to 30% while a sample of 100 would be only slightly better ranging from 13 to 26%. A sample of 30 would be precise enough to detect the presence of kokanee but it would require considerably more sampling to detect small changes from survey to survey. Alternative methods of detecting the different *O. nerka* taxa such as through the comparison of genetic loci may prove to be more cost effective (e.g. Foote et al. 1989)

THRESHOLDING THE SV ECHOGRAM WITH TS INSTEAD OF SV

Recent advances in hydroacoustic analysis software (i.e. Echoview) allow for the possibility of thresholding the Sv echogram with TS instead of Sv. The software works by filtering each data point in the Sv echogram using the results of the TS echogram, When a TS value exceeds the threshold value, the corresponding Sv value is allowed through to the Sv echogram. Thresholding based on TS makes a great deal of sense because TS is used as the acoustic estimate of fish size and we typically eliminate low level echoes from the data by thresholding based on the smallest fish size of interest. Setting of the TS threshold could be based on either a modeled or an observed TS for the smallest fish of interest. Parker-Stetter et al (2009) suggest setting the threshold an additional 6 dB lower to allow for the inclusion of targets that are sub threshold (TS), but will exceed the threshold once compensation for their off axis in-beam position is applied. While its clear we would want to include these sub threshold targets in our data, its also clear that not all will be elevated above threshold after compensating for off axis position. Unfortunately, we can’t determine which targets will be raised above the smallest fish threshold with compensation and which will fall short, but it does suggest that something less than the full 6 dB drop from the smallest fish size may appropriate to avoid an over estimate.

Determining a TS threshold level is our current challenge. Setting it based on above criteria is an option, however, we hope to be able to set it at a level that will produce similar results to estimates made with our traditional thresholding methods and levels so that future data can be reasonably compared to our 30+ years of historical hydroacoustic data.

SAMPLING THE NON-ENSONIFIABLE SURFACE REGIONS

In some lakes sockeye fry are often found in water less than 5 m due to lake depth, turbidity or behavioural propensity (Hume and MacLellan 2008). As mentioned earlier, fish found in <2 m of water are not ensonifiable by a downward facing transducer and fish as deep as 5 m may be sampled poorly. Hyatt et al. (1989) tackled this problem in Owikeno Lake by using corresponding acoustic and trawl density estimates from deeper depths to calibrate surface trawls, thereby deriving density estimates for the whole water column. While this is a workable solution it is labour intensive and dependent on a possible weak correlation. They also found a temporal solution to the problem by acoustically sampling at a different time of the year (late winter) when the lake was not as turbid and the fish were found deeper in the water column and thus better suited to hydroacoustic surveying (Paul Rankin, DFO, Personal communications)

Two possible purely acoustic solutions to this problem have been investigated. Enzenhofer and Hume (1992) developed a towed body for deploying an upward facing transducer. It was deployed from a 3.5 m boom off the side of the boat at a depth of 40 m and 90 m aft of the stern and successfully detected fish in the 10 m of water near the surface. Due to its displacement off to the side of the boat, there was little boat noise detected but rough water made the transducer difficult to deploy and created considerable surface noise. Directing the acoustic beam in a horizontal direction from the boat is an alternative way of sampling the surface waters of a lake (Yule 2000; Gangl and Whaley 2004). When used to enumerate the density of rainbow trout and cutthroat trout populations, the side looking transducer produced repeatable fish density estimates (Gangl and Whaley 2004) except when windy. When windy, the aiming angle was decreased and estimates were lower, causing the authors to speculate that it was the aiming angle rather than the changes in fish behaviour that caused the decreased estimate. All three techniques described here are worthy of further investigation and will be particularly useful in lakes with fish oriented to the surface waters due to decreased light transmission (Hume and MacLellan 2008).

ACKNOWLEDGEMENTS

This program was first initiated in the early 1970's by the International Pacific Salmon Fisheries Commission. Many fine researchers were responsible for the early development of the program including Hermann Enzenhofer, Terry Gjernes, Bob Johnston, and Ian Williams. Many of the their pioneering techniques are still in use today. Biosonics, Inc. has supplied most of our echosounding equipment along with much helpful and timely advice and service. Brock Stables (Shuksan Fisheries Consulting) has provided valuable assistance in many aspects of this program. Field assistance has been ably provided by Steve McDonald, particularly for the remote fly-in surveys, and by many others over the 30 years of hydroacoustic work carried out by the Cultus Lake Research Lab. The closing midwater trawl was initially designed by Hermann Enzenhofer. The small boat sampling platform was modified by Paul Rankin and Barry Hanslit from an initial design by Terry Gjernes and was again modified by us with the assistance of Brock Stables. Peter Hall, Paul Rankin, and Brock Stables provided valuable reviews of earlier drafts.

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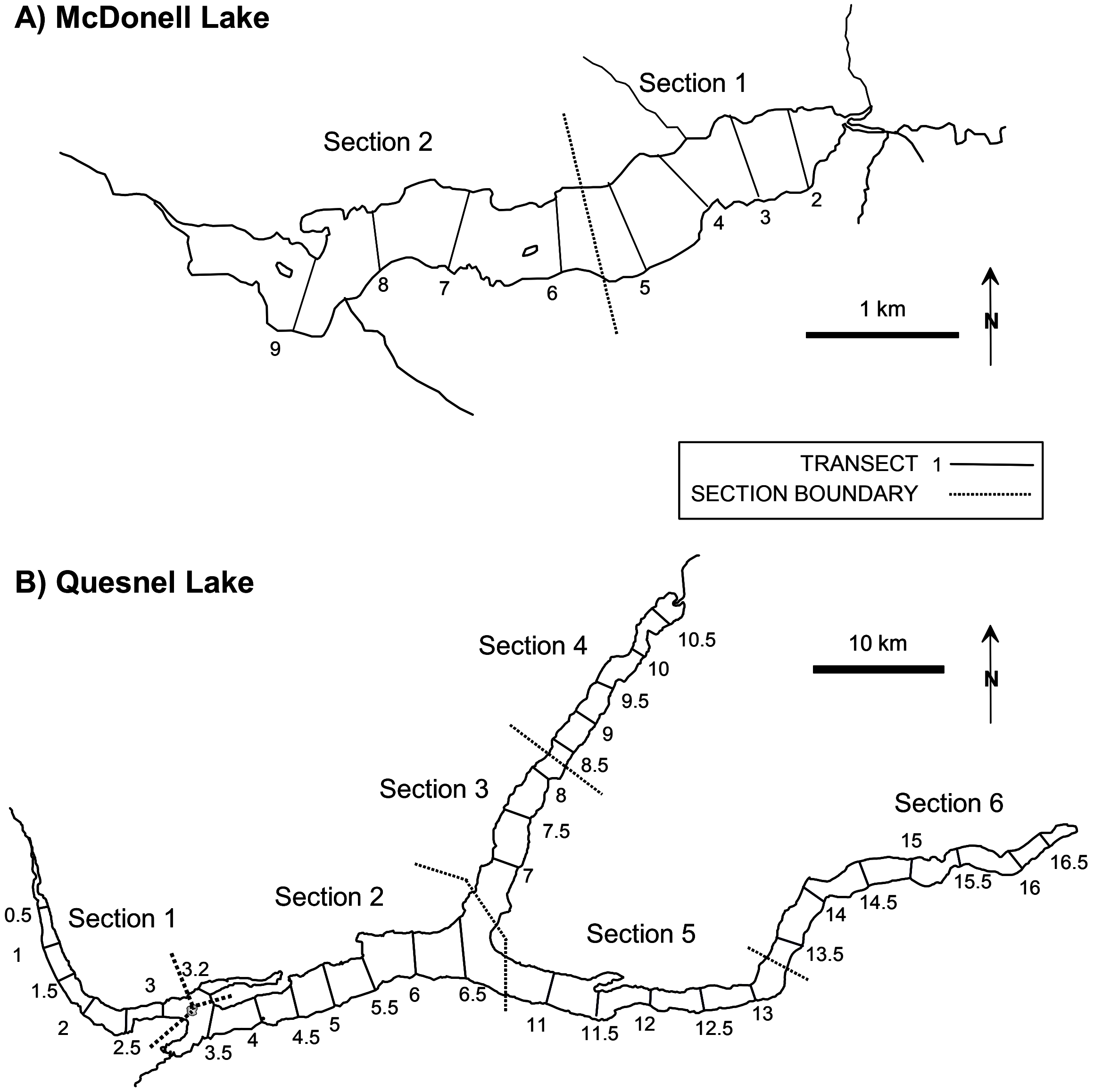


Fig 1. Examples of survey designs for A) McDonell Lake, a small (2.3 km²) lake and B) Quesnel Lake, a large (279 km²) complex lake basin. The McDonell design has a degree of coverage (DoC, see text) of 2.6 with an average spacing of 0.49 km between transects. In Quesnel Lake transects labelled with whole numbers only (1, 2,…16) were used in the original “regular” surveys. Intensive surveys used all transects. The regular survey had a DoC of 1.6 with an average of 7.3 km between transects. The intensive survey had a DoC of 3.6 with 3.5 km between transects.

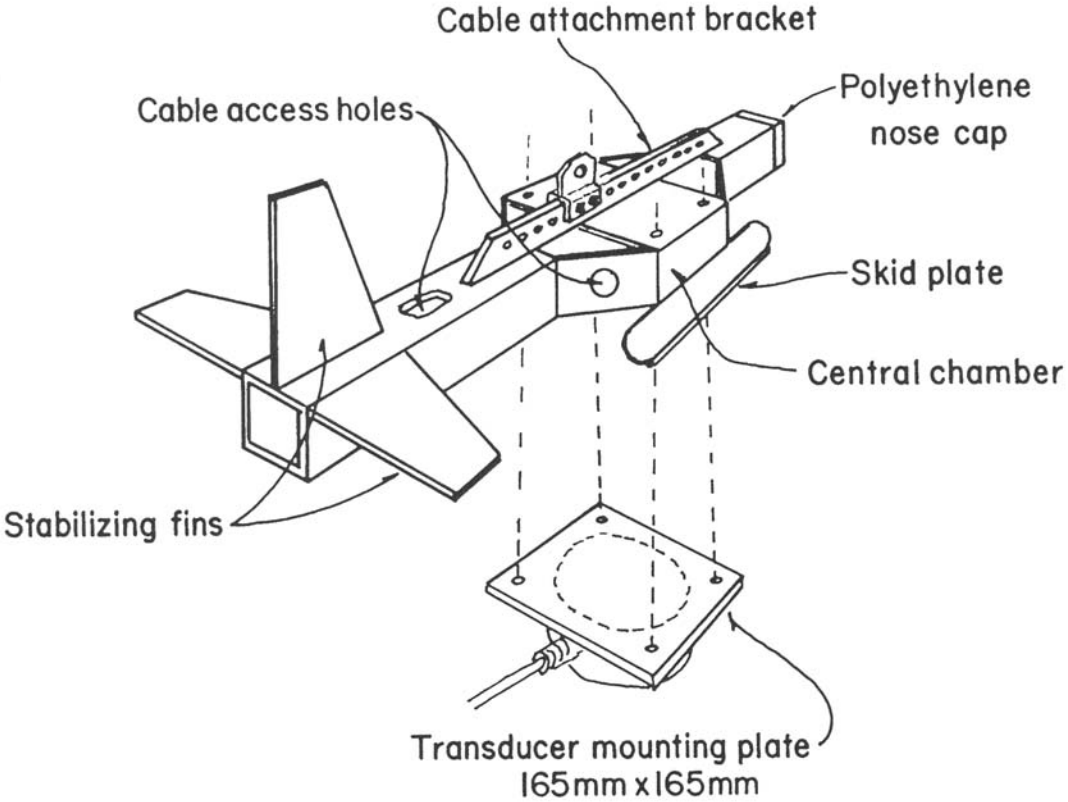


Fig. 2. Towed body for deploying the acoustic transducer from a boat (from Enzenhofer and Cronkite 2003). Suspending the towed body by cable from a davit on the boats gunnel reduces the effects of boat pitch due to wave action.

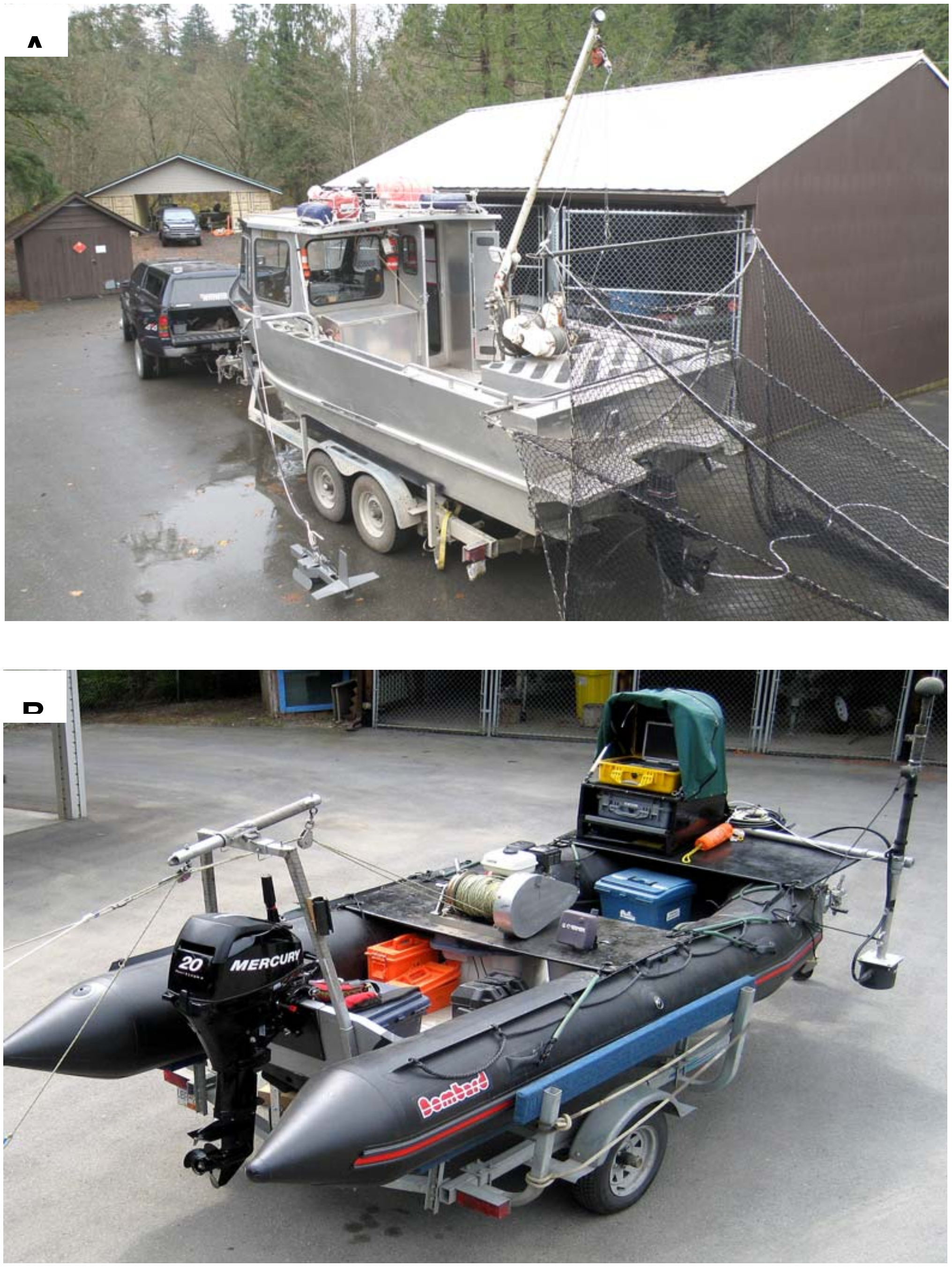


Fig. 3. Field setups: A) the Night Echo showing the towed body and davit with the trawl boom and winches, the trawl is in position for deploying and B) the Little Echo showing the trawl winch, A-frame and trawl cables with the sounder housing and pole mount for the transducer and GPS receiver.

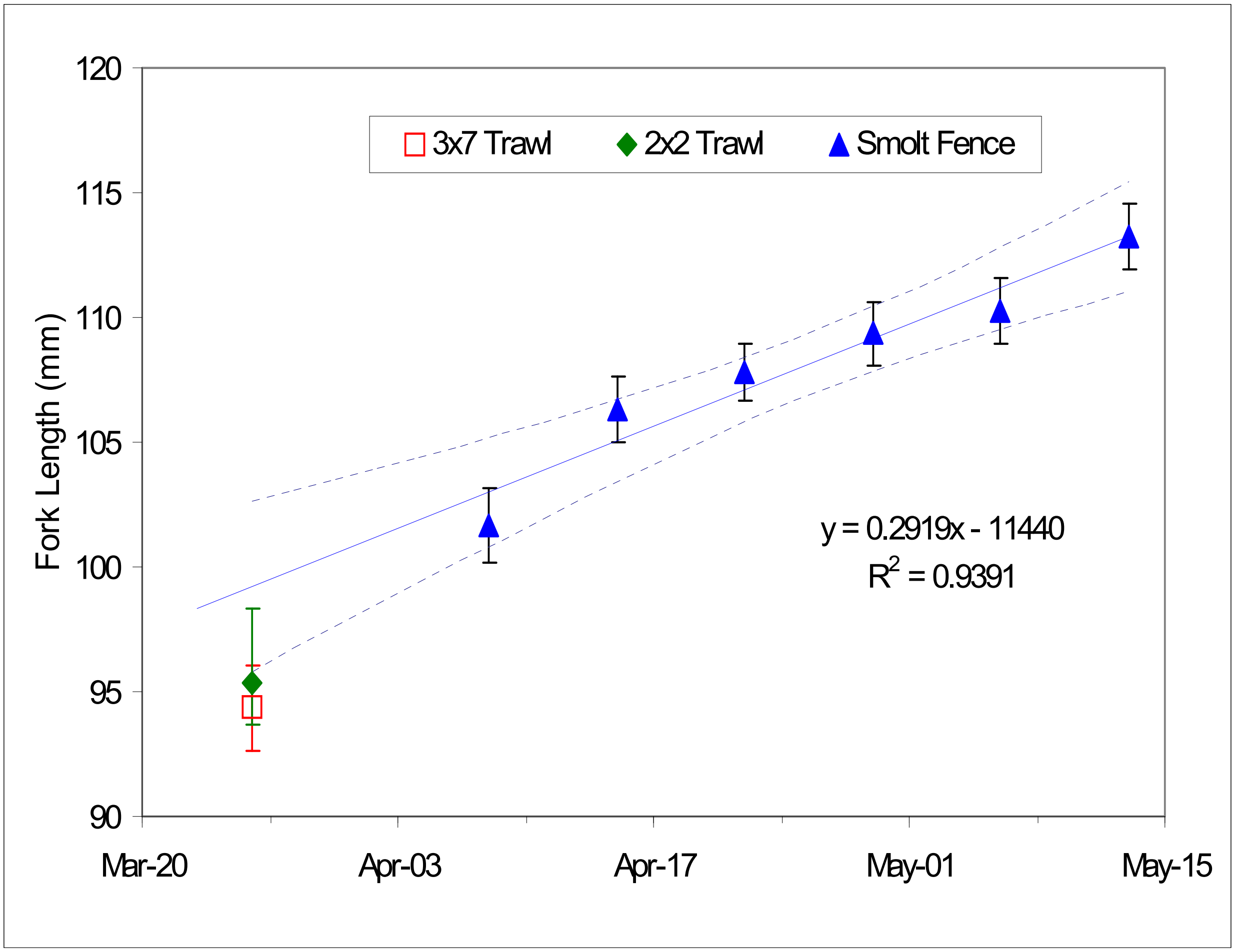
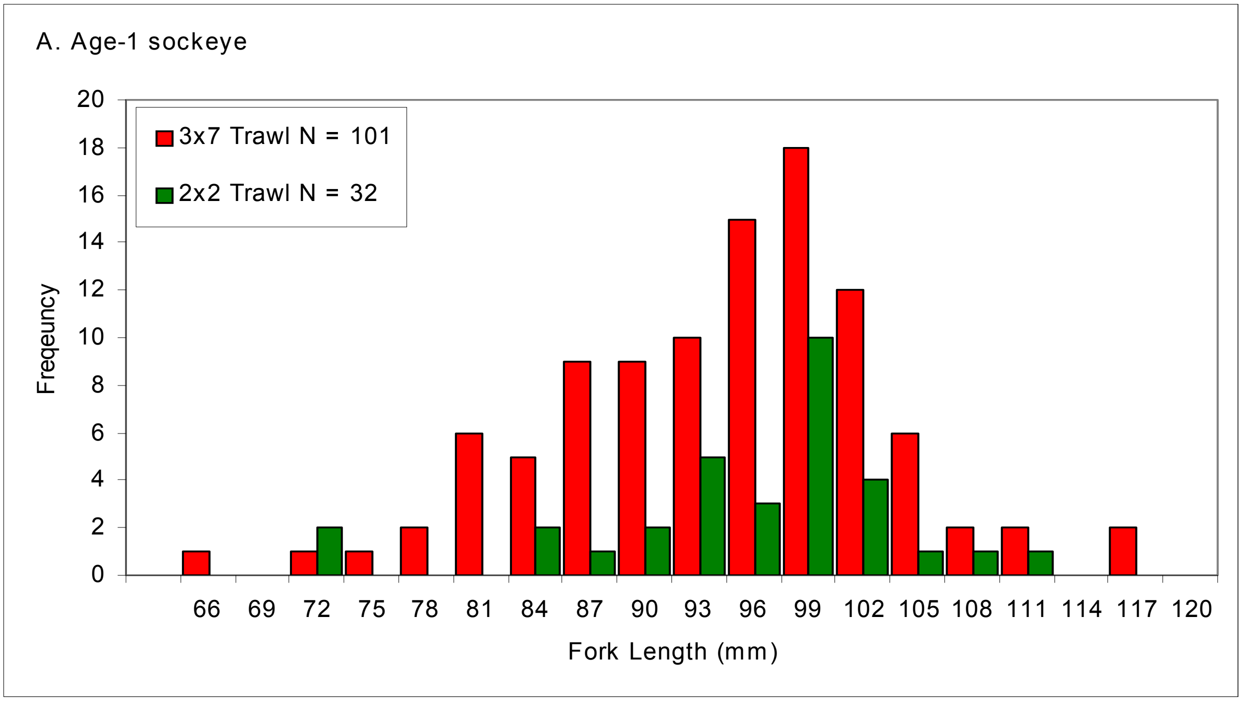


Fig 4. Size of Cultus Lake smolts caught in the 2x2 and 3x7 trawls and at the smolt fence. Vertical bars indicate 95% confidence intervals. Regression (solid line) and 95% confidence intervals (dashed lines) are fitted to smolt fence data only.



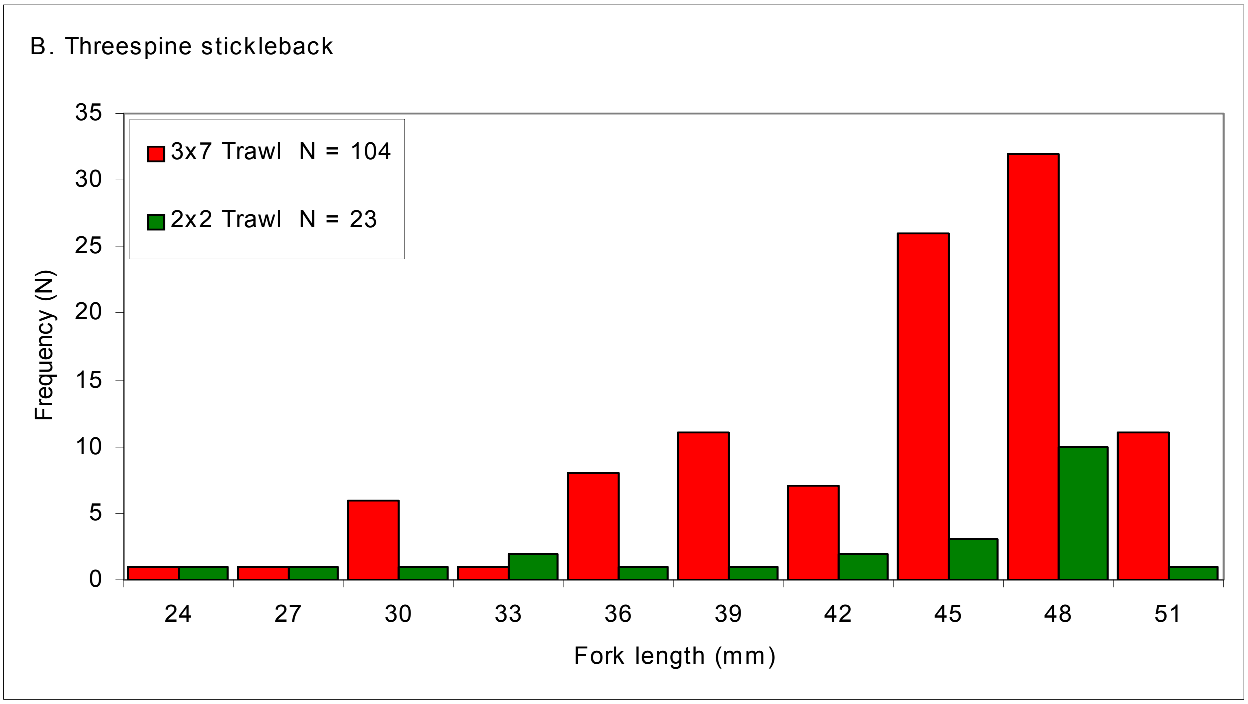


Fig 5. Length frequency of A) Age-1 sockeye and B) threespine stickleback caught in the 2x2 and 3x7 trawls fished on March 26, 2008 in Cultus Lake.

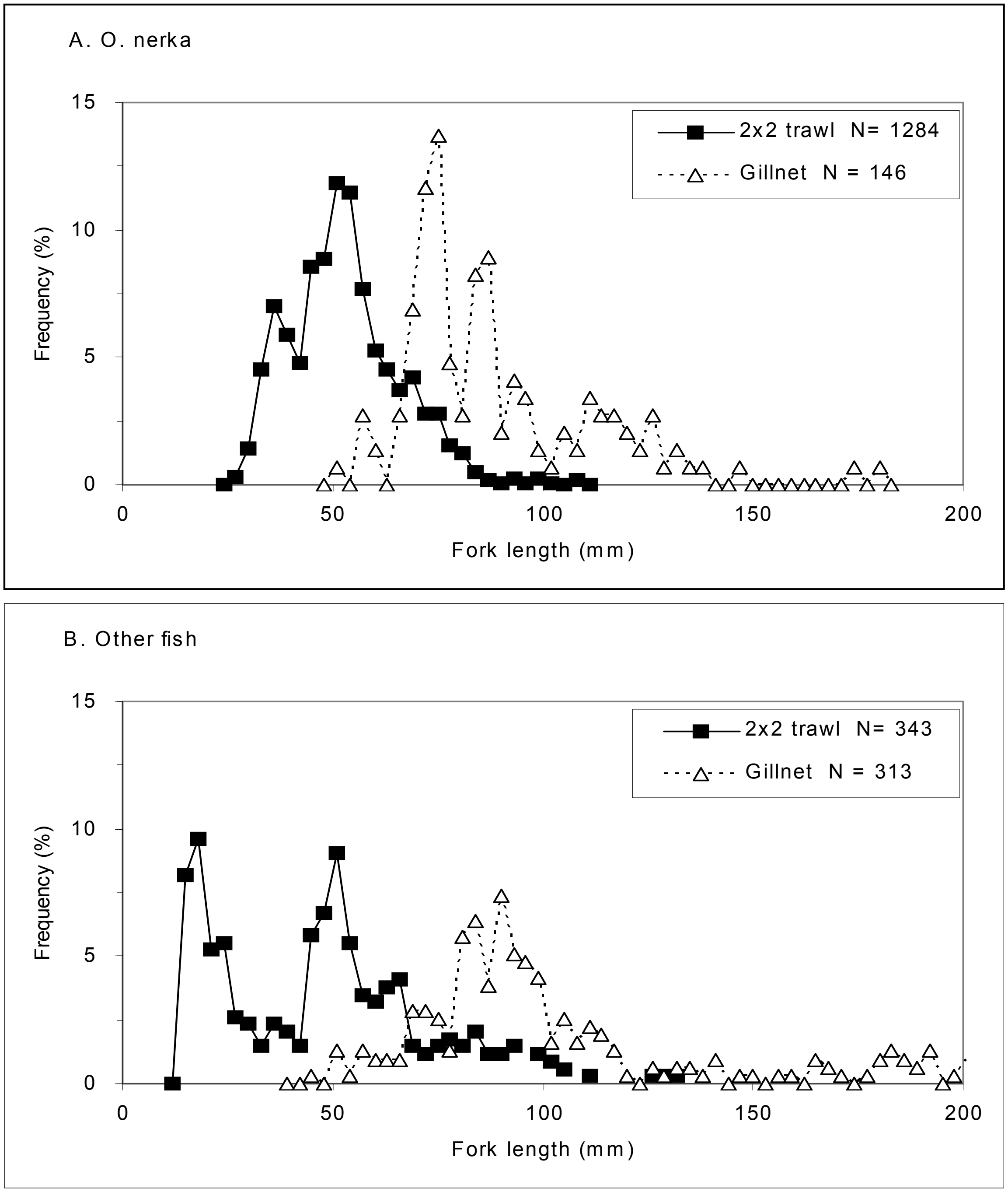


Fig. 6. Length frequency of all (A) *O. nerka* and (B) all other fish caught in the 2x2 trawl and the Swedish gillnets. Data only includes lakes where both gears were used on the same survey and was grouped into 3 mm length bins for plotting. Fish >200 mm are not shown

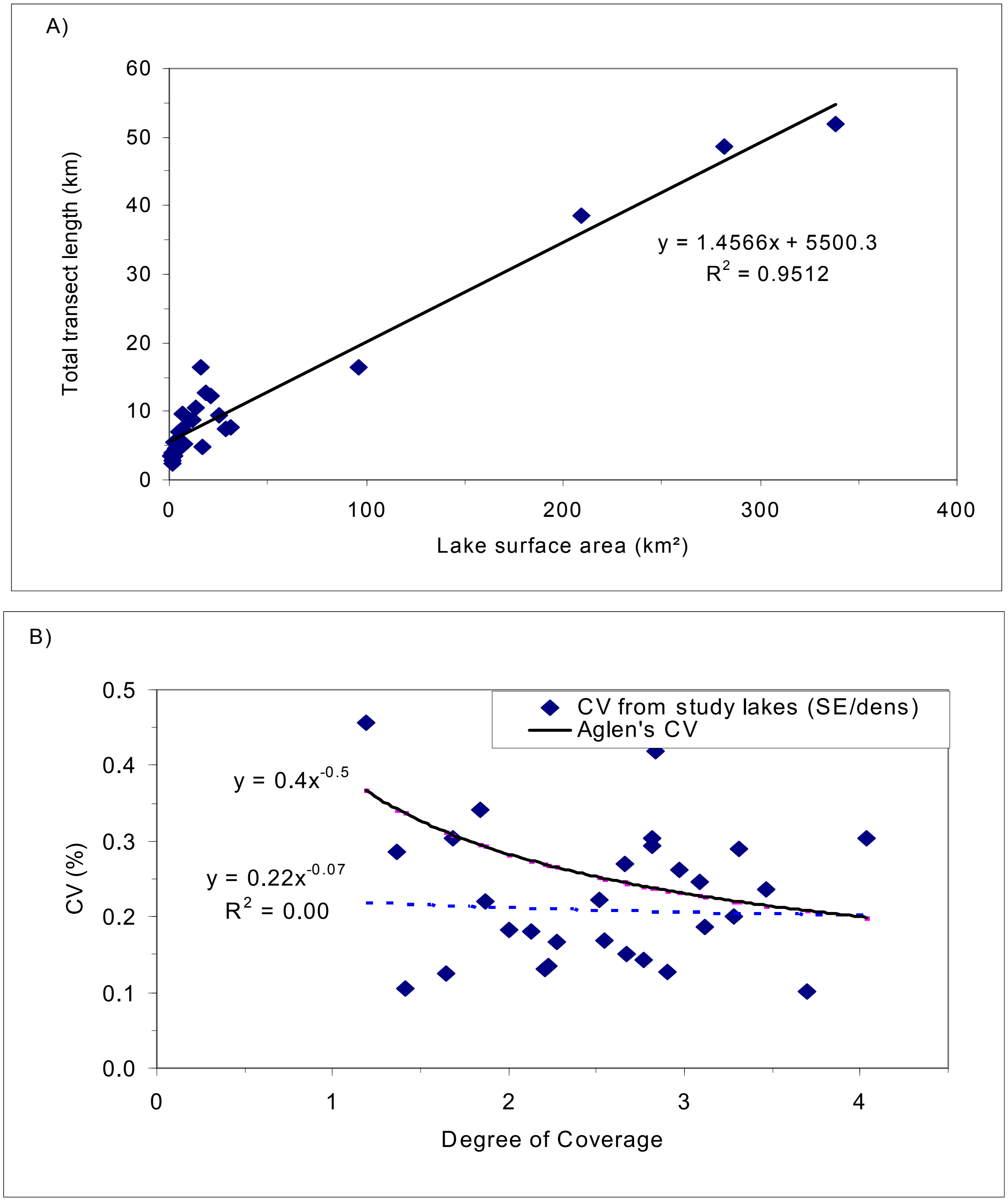


Fig 7.A) Relationship between hydroacoustic transect length and lake area for surveyed lakes. B) Relationship between the coefficient of variation (SE/dens) and the degree of coverage (transect length/area$^{0.5}$).The relationship found by Aglen (1989) for a wide variety of marine surveys is

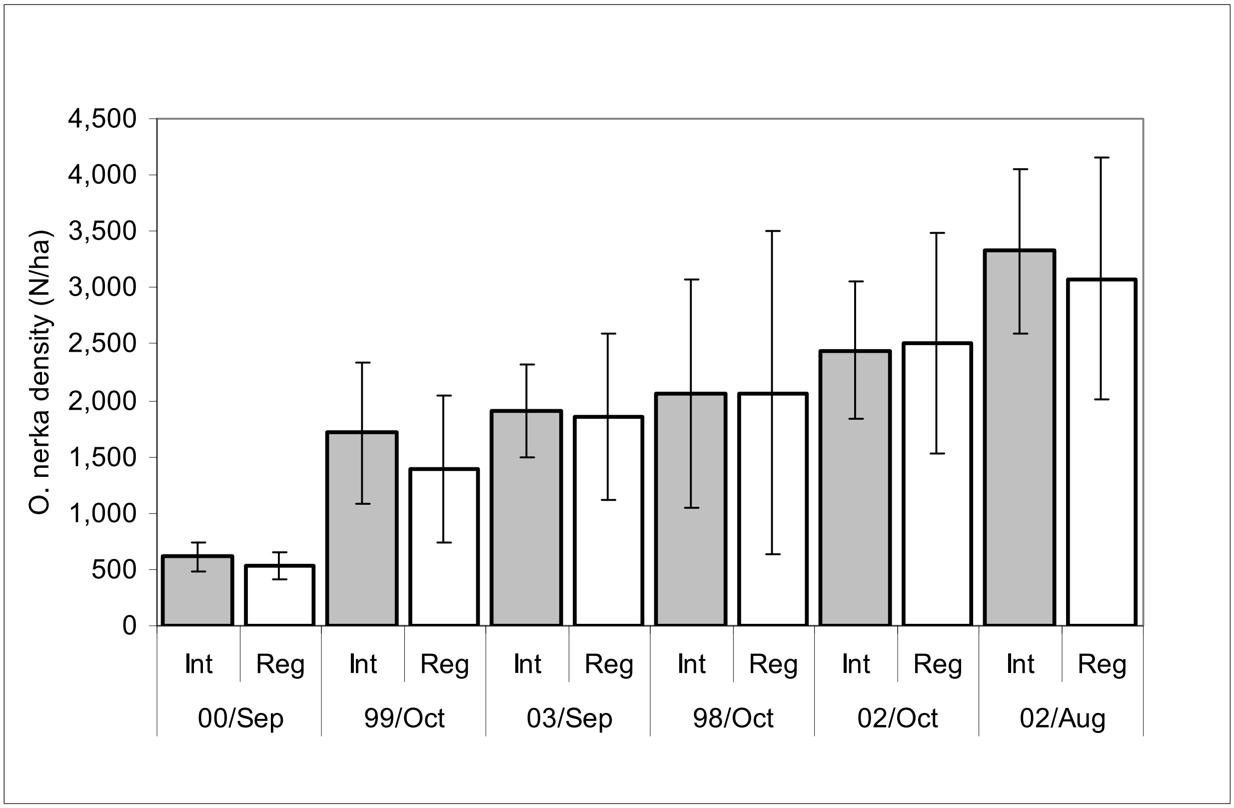
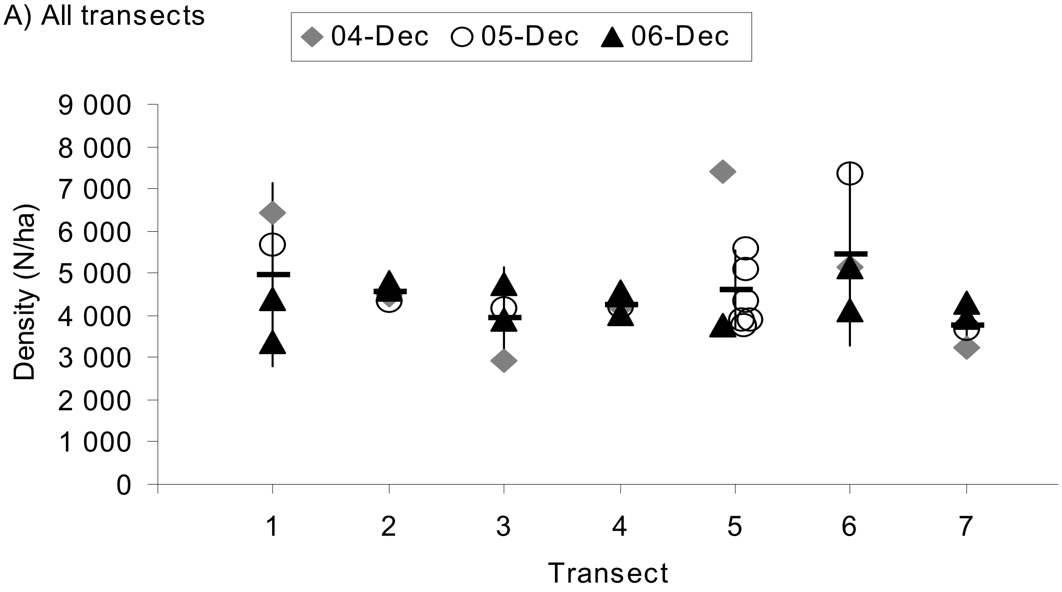


Fig 8. Whole lake estimates of age-0 O. nerka density made from intensive (32 transects, grey bars) and regular (16 transects) surveys of Quesnel Lake. 95% confidence intervals are shown. Surveys are arranged by increasing density.

A) All transects



B) Full survey transects only (whole lake estimate)

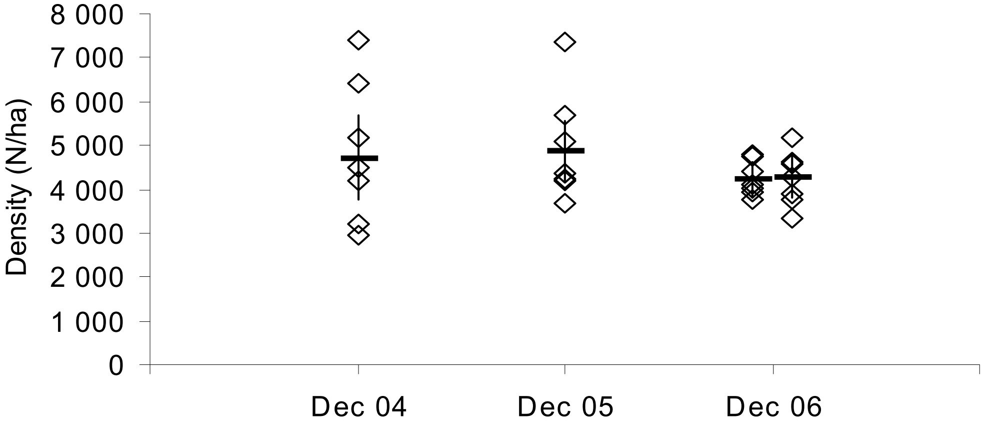


Fig. 9. Comparison of densities from replicate hydroacoustic surveys on Cultus Lake. A) all transects surveyed, mean transect density (horizontal lines) and 95% CI (vertical lines) are shown and B) transects used in estimating the total lake population, mean lake density (horizontal lines) and 95% CI (vertical lines) are shown.

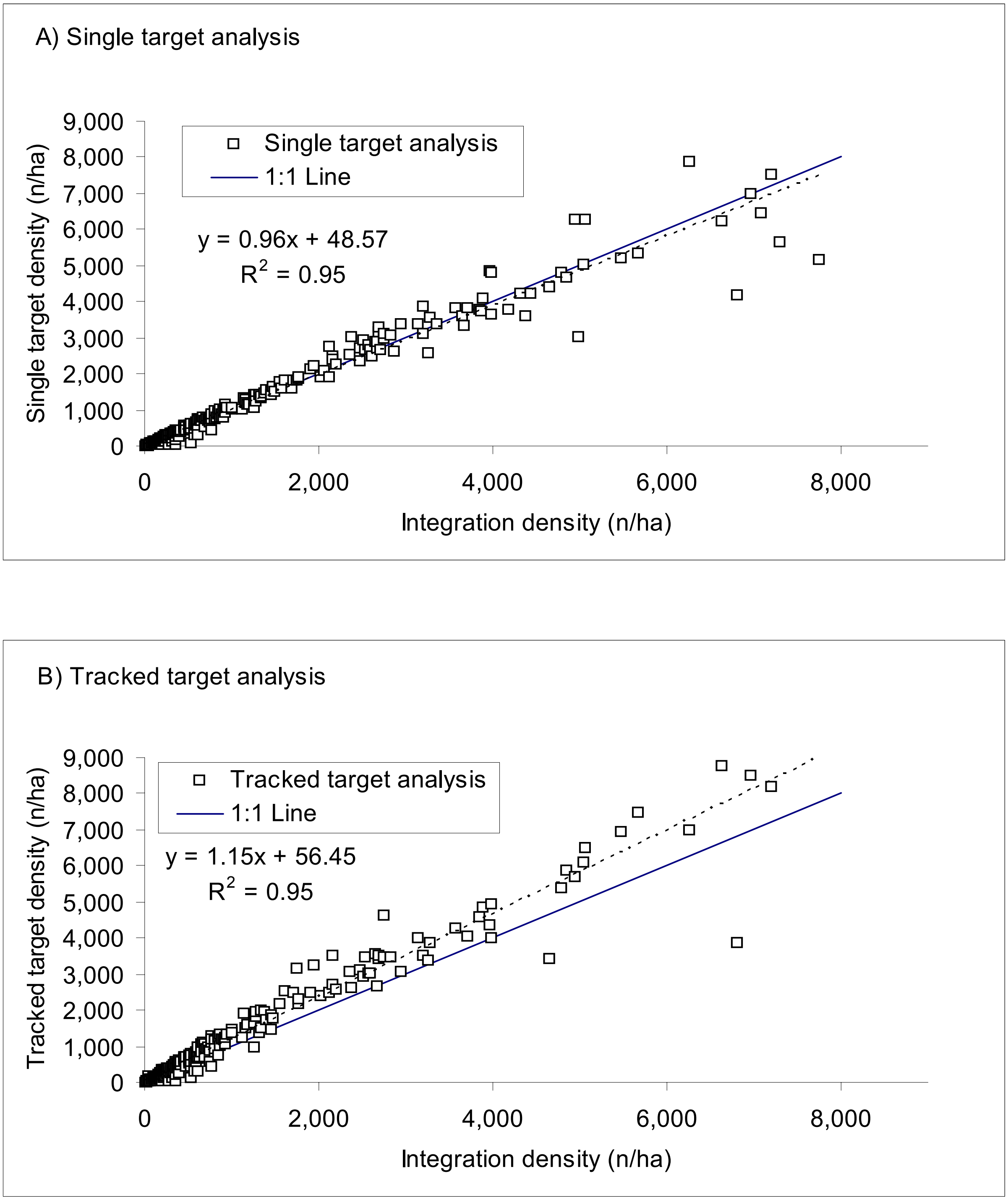


Fig. 10. Comparison of density estimates of age-0 sockeye salmon using three standard hydroacoustic estimates. Data are from 312 transects completed during 34 surveys on 18 lakes.

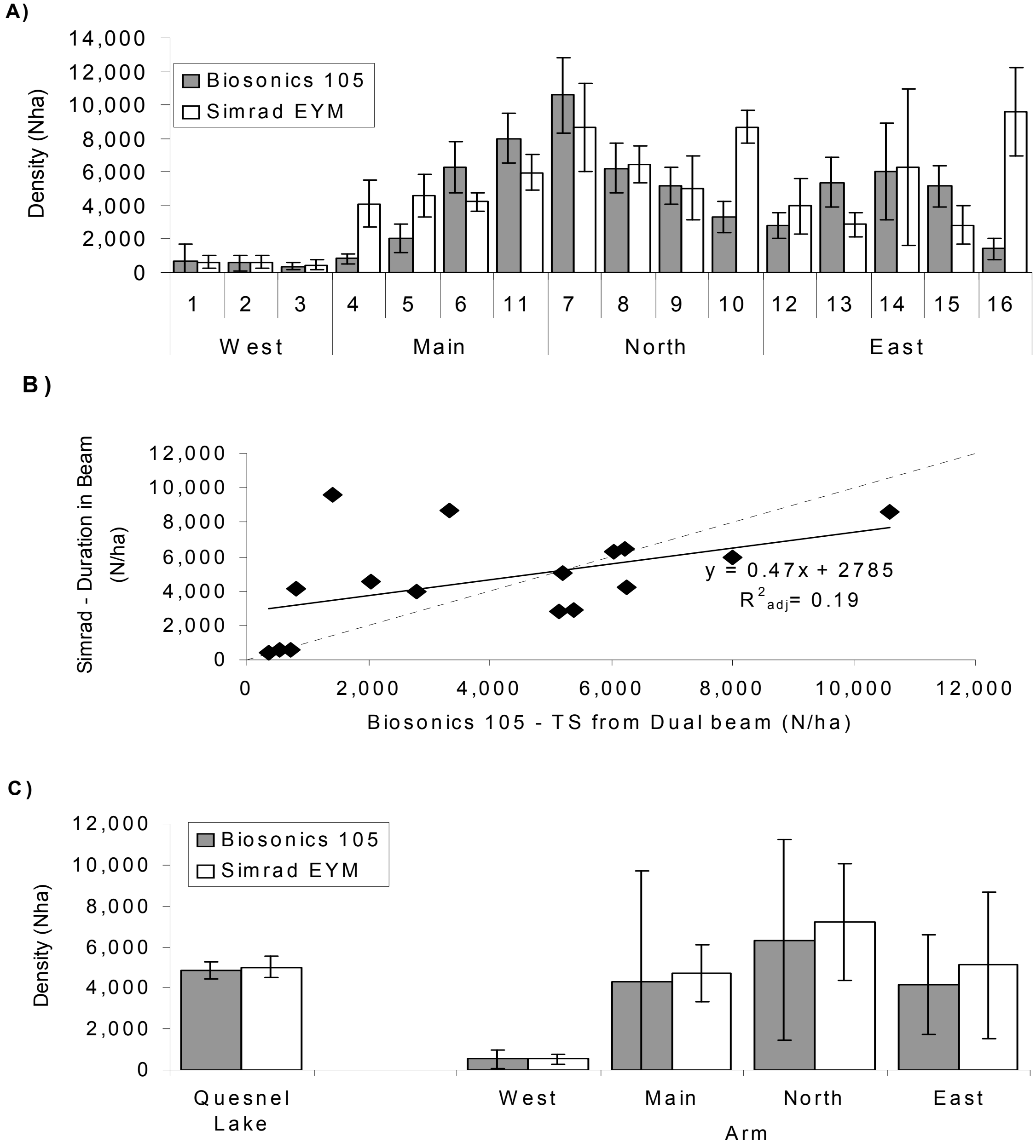
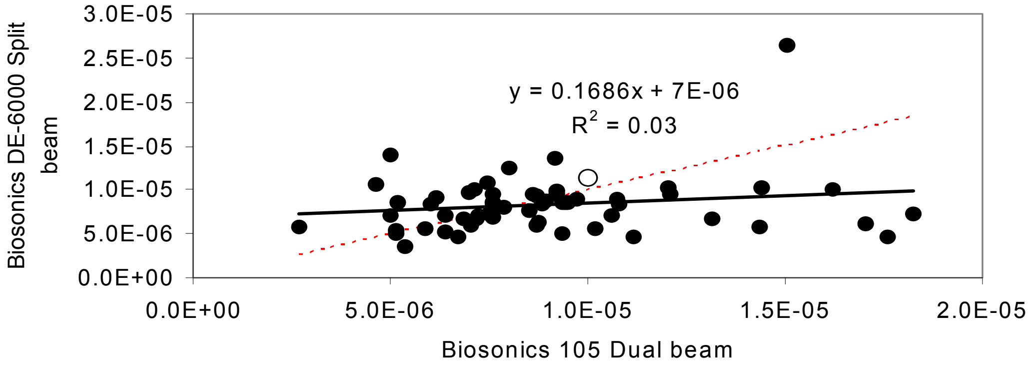
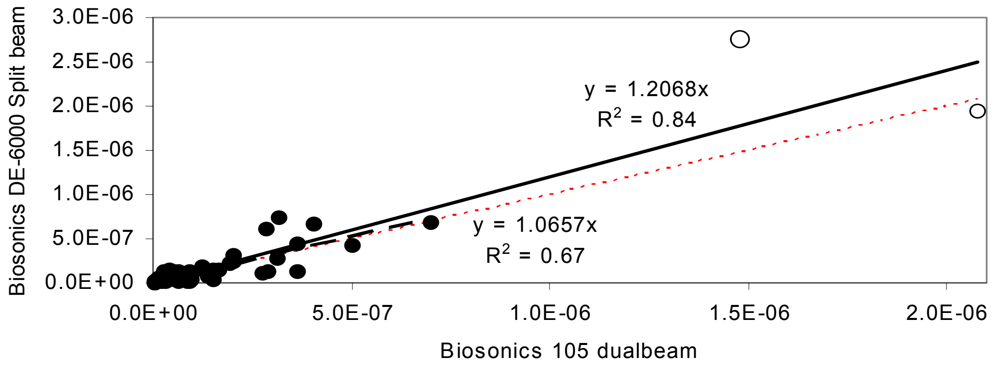


Fig 11. Comparison of integration results of concurrent hydroacoustic transects conducted on Quesnel Lake in August 1986 using a single beam Simrad EY-M (duration in beam analysis) and a dual beam Biosonics 105 (insitu TS analysis); A) individual transects and 95% confidence intervals; B) density from the Simrad EY-M vs. the Biosonics 105, the 1:1 line (dotted) is shown; and C) overall results for the whole lake and for the 4 arms.

A) Mean sigma



B) Mean E



c) Mean density

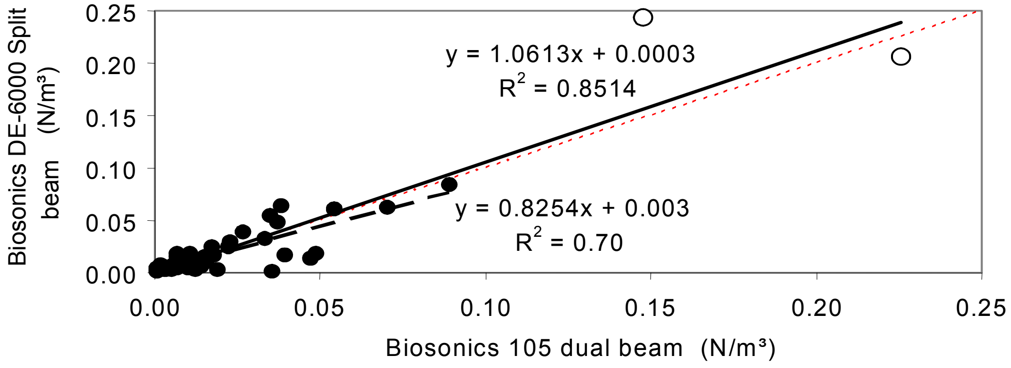


Fig 12. Comparison of mean sigma, E, and fish density (individual depth strata data, N/m³) from concurrent hydroacoustic transects conducted on Quesnel Lake using Biosonics dual beam and split beam sounders. The solid line shows the linear regression using all data, the dashed line excludes the two extreme data points (open circles) and the red dotted line is the 1:1 relationship.

Table 1. Typical sampling velocities used for midwater trawling and for hydroacoustic transects.

			Velocity	
Boat	Gear	Conditions	km/h	m/s
Night Echo	3x7 m trawl	50 lb weights on bottom bar	2.5	0.7
	acoustics	towed body, standard	8.3	2.3
Little Echo	2x2 m trawl	25 lb weights on bottom bar	3.6	1.0
		15 lb weights on bottom bar	3.0	0.8
	acoustics	pole mount, standard acoustics	5.4	1.5
		pole mount, Chaoborus present	3.6	1.0

Table 2. Theoretical length (µm) and weight (mg) relationships used to determine the biomass of common items found in the diet of pelagic fish. Formulas are presented in MS Excel© coding format for ease of use.

Taxa	Length-weight relationship	Source
Daphnia	W=(7.5673*((L/1000)^1.5664))/1000	1,2
Eubosmina, Bosmina longirostris, Eubosmina coregoni, Chydorus, Alona	W=(17.7529*((L/1000)^2.2291))/1000	1,2
Leptodiaptomus	W=(5.8865*((L/1000)^3.8498))/1000	1,2
Skistodiaptomus, Epischura, Calanoid copepidite, *Temoridae* Copepidite	W=(6.2006*((L/1000)^1.9604))/1000	1,2
Diaptomidae copepidite, *Epischura,* unidentified copepidids	W=(4.6008*((L/1000)^1.7064))/1000	1,2
Cyclopoid copepod, *Diacyclops, Tropocyclops, Cyclops scutifer, Macrocyclops*	W=(5.6900*((L/1000)^1.9347))/1000	1,2
Nauplii, Acari	W=(2.6153*((L/1000)^1.6349))/1000	1,2
Leptodora kindtii	W=(1.5634*((L/1000)^1.8730))/1000	1,2
Ceriodaphnia	W=(4.0349*((L/1000)^1.9763))/1000	1,2
Sida crystallina, Diaphanosoma, Polyphemus pediculus	W=(1.76E-6*(L**2.11))/1000	3
Schapholoberis	W=(8.9E-8*(L**2.70))/1000	3
Acanthocyclops vernalis	W=(1.7E-4*(L**1.39))/1000	3
Alona	W=(15.92*((L/1000)^3.84))/1000	3
Chaoborus larvae	W=.0062*((L/1000)^1.9778)	4
Holopedium	W=((EXP(3.21*(LOG(L/1000))+2.36))*1.025828)/1000	5, 2
Heterocope	W=(9.99150707E-12)*(L^2.938072)	4
Neomysis	W=EXP(LOG(L/1000)*2.57-5.02)	6
Chironomid	W=EXP(-5.279+(2.32*(LOG(L/1000))))	7
Ceratopognid	W=EXP(-9.3774+(3.7948*(LOG(L/1000))))	8
Insects	W=.030*((L/1000)^2.62)	9
Amphipods	W=.0029*((L/1000)^2.88)	10
Worms	W=(EXP((2.2853*(LOG(L/1000)))-11.9047))*1000	11

1 - Culver et al. (1985); 2 - Bird and Prairie (1985); 3 - Dumont 1975; 4 - DFO, data on file; 5 - Yan (1987); 6 - Chigbu and Sibley (1996); 7 - Smock (1980); 8 - Meyer (1989); 9 - Rogers et al (1976) in Smock (1980); 10 - Wang and Zauke (2002); 11 - Hale et al. (2004).

Table 3. Catch of age-1 sockeye and threespine stickleback in the 2x2-m and 3x7-m trawls fished on March 26, 2008 in Cultus Lake.

	2x2 m trawl	3x7 m trawl	Ratio (2x2 / 3x7)
Trawl characteristics			
Area of trawl (m²)	4.0	21.0	0.19
Velocity (km/h)	3.6	2.5	1.45
Velocity (m/s)	0.99	0.68	
Duration (min towed)	65.0	50.0	1.30
Distance towed (km)	3.9	2.0	1.89
Volume swept (m3)	15.5	43.0	0.36
Age-1 sockeye catch	32	101	
N/min	0.49	2.02	4.10
N/m^3	2.07	2.35	1.14
Stickleback	23	104	
N/min	0.35	2.08	5.88
N/m^3	1.49	2.42	1.63
Size (mm)			
Age-1 sockeye catch	95.4	94.4	
(+-95% /CI)	(2.96)	(1.72)	
Stickleback	42.2	43.5	
(+-95% /CI)	(3.01)	(1.16)	

Table 4. Comparison of mean fish density and standard error for six hydroacoustic surveys of Quesnel Lake, using the regular survey design (16 transects) and the intensive survey design (32 transects).

Date	Coverage	Mean Fish Density (N/ha)	SE	CV (SE/density)
1998 Oct	Intense	1,614	497	31%
	Regular	1,702	780	46%
1999, Oct	Intense	1,317	336	26%
	Regular	1,230	419	34%
2000, Sep	Intense	525	104	20%
	Regular	503	130	26%
2002, Aug	Intense	2,889	427	15%
	Regular	2,702	590	22%
2002, Oct	Intense	2,161	382	18%
	Regular	2,175	538	25%
2003 Sep	Intense	1,912	249	13%
	Regular	1,823	383	21%
Mean	Intense	2,277	428	20%
	Regular	2,175	429	29%

Table 5. Suitable hydroacoustic analysis methods for specific biological and environmental conditions. Methods typically used for reporting are noted.

Condition	Integration	Single target	Tracked target	Chaoborus TT
Extreme high densities (>4 000 /ha) & most fish in narrow layer (≤20m)	X (report)			
High Densities (2 000-4 000 /ha) & most fish in narrow layer (≤20m)	X (report)	X		
Moderate, to low densities (500 - 2 000 /ha) or high densities with fish dispersed	X (report)	X	X	
Wave induced pitch and roll	X (report)	X		
Very low densities (<500 /ha) & high ping rate			X (report)	
Noise: system, environmental, or biological including *Chaoborus*			X	X (report)
Extreme noise or high density *Chaoborus*				possibly

Appendix 1. Typical set of instructions given to field crew working on the small, floatplane access, lakes.

North Coast Lakes Fish Program - 2008

Lakes: Kooryet - Survey **200871** Keecha – Survey **200872** Moore –Survey **200873**
Note: - Start tow numbers at **2008<u>7101</u>** for Kooryet, **2008<u>7201</u>** for Keecha, **2008<u>7301</u>** for Moore and run consecutively (includes trawls and gill nets). Tow logs and acoustic logs are already started in the lakes folders.

Tasks:

<u>Hydroacoustics:</u>

Fish Survey:

- use Hydroacoustic Field log provided to record details
- transects 1, 2, 3, … x
  - transects are generally short, use as slow a transecting speed as is practical. If conditions are good and you have no time or battery constraints, dead slow would be appropriate, **<u>particularly if Chaoborus are present</u>**.
- repeat at least one transect (preferably one with higher fish densities)during the day at the same settings used at night to demonstrate day time fish distribution.
- Settings
  - <u>Pulse width</u> - **0.4 ms**
  - <u>Threshold</u> - **-100 dB** for data collection, view at ~-70 dB
  - <u>Range</u> - max lake depth or 80 meters (if lake is only slightly deeper than 80 meters, say ~100 meters, and you need to collect bathymetric data as well, its ok to collect at a slightly deeper range setting to accommodate the full water column).
  - <u>Pulse rate</u> - as high as possible without getting false bottom interference in the fish layer(s). Some testing over deep water during the day is useful to get this set up before the survey at night
  - Power Level – leave on high
  - No temperature or calibration correction
  - File naming – use the prefix <date/time stamp>suffix method. Prefix = lake name or abbreviation. Suffix identifies the survey and transect in the form of YYSSTTTx. YY is the year = 08, SS is the survey i.e. 71, TTT is the transect i.e. 040, x (optional) is the replicate or special transect designator(a-z). Thus the suffix “0871040” would translate to survey 200871, transect 04.0 (note the implied decimal following the 4). A ‘d’ in the x (last) position usually refers to a daytime transect. To identify a recording of a tow the suffix would be YYSSt### where ‘t’ identifies it as a tow and the ### indicates the tow number.

EXAMPLE: (Cultus survey 200801, transect 3, day)
User created Computer **User created**
Prefix Generated Date/time **Suffix**
____|___ _________|__________ _______|_
CULTUS20080426_2022240601030**0801030d**

- **back up data** at end of day/night to flash drive.
- **Note** – Moore Lake begins to turn salty at about 12m depth. This may affect the acoustic signal and produce some unusual markings on the echogram. It will be interesting to see if fresh water fish venture into this salty water.

Chaoborus Acoustic Survey:

- fish transects will be used for Chaoborus analysis.

Trawling:

- Use Tow Net Log provided to record details
- At least 1 tow through the fish layer in each lake section is required.
- If a Chaoborus layer is present, at least one tow should target the middle of that layer to help determine if small fish are among the Chaoborus.
- At least 1 surface tow (use floats and small lead balls) is needed to determine if fish are using the top 2 meters of the water column (not seen by the sounder).
- Additional tows if multiple fish layers are seen or more tows are needed to increase fish sample size (we would like to see ~30+ fish from each lake section if possible….more is better).

Standard Target:

- needs to be done when waters are calm (or if you can tie up somewhere) and you need at least 7 meters lake depth under the boat.
- deploy the standard target using the monofilament fishing line attached by **securing the line** to holes at opposite corners in the pole mount plate with the clips provided. Then carefully lower the ball to depth. (**note: be careful, the ball costs over $400**)
- Amplitude on the oscilloscope in Visual Acquisition should be just over -40 dB. The new Acquisition software has a position display for the oscilloscope that you can use to help you position the target in the center of the beam. By slightly moving the pole mount for and aft and shifting weight distribution in the boat can move the target around in the beam.
- Record ~5 minutes with the target in the center of the beam.
- Settings - Pulse width **0.5 ms**
    - Threshold -70 dB
    - Range - 10 meters
    - Pulse rate – 5 pings/sec
    - Power Level – **leave on high**

- No temperature or calibration correction
- File naming – Prefix = lake name or abbreviation. Suffix = YYSSstd.

Bathymetric Survey:

- **Benchmark** – if possible place a benchmark (large spike) on shore in prominent spot, otherwise pick a prominent object (very large rock is good) – measure/estimate height to water line, record on acoustic log.
- Run a series of day transects half way between survey transects (bathymetry transects 0.5, 1.5, 2.5…..x.5)
- Redo any night transects (1,2…x) where lake bottom depth exceeded the collection depth for the population survey (usually 80 meters).
- Pay special attention to ends of the lake and around shoal or bay areas
- if time permits, 1 to 3 transects along the length of the lake, perpendicular to survey transects. Some of this can be done whenever you're traveling up and down the lake throughout your stay.
- Boat speed = transect speed (~2m/sec) +, as long as you are able to get a steady strong bottom signal.
- Bathymetric soundings – priorities:
    1. Transects (0.5, 1.0, 1.5, ……x.5)
    2. Fish Transects (1,2..) **if** bottom not reached on acoustic survey
    3. Lake ends, shoals and bays
    4. Length of the lake – mid lake
    5. Length of the lake – 1/3 off shores (optional – if time permits)
- Settings
    - Pulse width 0.4 ms
    - Threshold -70 dB
    - Range - max lake depth, up to 150 meters. Note: If the lake is greater 150 meters deep you will need to increase the collection range appropriately and increase the collection threshold to eliminate system noise. Also for very deep lakes (>248 meters) you will need to change to single beam mode.
    - Pulse rate – 1 pings/sec
    - Power Level – leave on high (transmit power=0)
    - No temperature or calibration correction
    - **File naming – Prefix** = lake name or abbreviation. For cross lake transects between survey transects use the same format for the **suffix**, YYSSTTTx. For example, 0871045 for a transect (tr 4.5) half way between tr 4 and tr 5. For misc. bathymetric soundings (along shore, at the ends of the lake, bays, along the length of the lake, just use a **suffix** like BATHY1, BATHY2….etc.

Swedish Gill nets:

- these are mainly for sampling the pelagic zone, so try to fish them in as deep water as practical, anywhere from the surface down to the thermocline area (where ever fish densities appear greatest)
- spread the sets around the lake as much as possible to sample various sections of the lake.
- be sure to record GPS co-ordinates, nearest transect, and set/pull times in the tow log.

Fish processing:

- For the most part, preserve all fish in sample bottles.
- **Nerka** - preserve up to 20 in **alcohol** from each lake, or, if nerka are plentiful, 20 from each lake section; remaining nerka and other species should be preserved in formalin.
- A note on the Tow Log that x number of fish by species (a quick count) were preserved in x sample bottles is all that's needed.
- Fill out sample labels and insert them in the bottle with the fish.
- For larger fish that won't fit in sample bottles, record species and length in the Tow Log and release the fish. If there are many, use a separate data sheet.

Other sampling:

- Chaoborus (and other large invertebrates) sampling. Use a SCOR net at 1 location in each lake section, on a transect, about mid lake. Note the transect number and GPS reading on the field log and label. If time permits, more samples on additional transects would be helpful. Take samples after dark.
- at one location (at a limnology station seems appropriate):
  - STD drop
  - Dissolved Oxygen/temperature profile
- Macrophyte samples. Collect and preserve specimens of dominant water vegetation in the sample bottles provided. Make general notes on abundance and distribution in the lake.

Sampling Equipment:

1. Sounder System
2. 2mx2m midwater trawl
3. 3 Swedish Gill nets …each…
   - 2 main float
   - 2 anchor lines
   - 2 sandbags (anchors)
3. SCOR Net
4. STD
5. DO/temperature meter

Suggested timetable at each lake:

Due to the complex nature of the lakes this year we have scheduled an extra day at each lake.

Day 1:
- Fly in and unload
- Set up camp
- Set up boat and equipment
- Do standard target and preliminary sounding (max depth, ping rates etc.)
- Do Std drop and DO/temperature profiles
- Get a start on the bathymetric survey if time permits.
- Set Swedish gill nets
- After Dark - sample for Chaoborus with SCOR Net
  - do a portion of hydroacoustic survey and trawling

Day 2:
- Pull and process gill nets
- Continue bathymetric survey
- Reset gill nets
- After Dark – finish up Chaoborus sampling with SCOR Net if needed
  - finish hydroacoustic survey and trawling

Day 3:
- Pull and process gill nets
- Repeat at least one transect (1, 2 … x) during the day (one where you found significant numbers of fish) for comparison of day/night fish distribution. (Same settings & boat speed you used at night).
- Complete bathymetric survey
- IF NEEDED - reset gill nets
  - SCOR sampling for Chaoborus
  - complete hydroacoustic surveys and trawling
- Pack up hydro acoustics and trawl unless you need to finish off hydroacoustic survey tonight.

Day 4:
- Pull and process gill nets (if deployed)
- Pack up boat and gear
- Pack up camp
- Fly out

Problems/ Questions: Place contact information here for key office personal

Task & Check List - North coast Surveys 2008

Task	Kooryet	Keecha	Moore
Survey #	**200871**	**200872**	**200873**

Bathymetric survey (priority 1-5)	Required	Required	Required
On transect boundaries (.5 transects)	1	1	1
On fish transects (if not fully covered during survey)	2	2	2
Lake ends, bays and shoals	3	3	3
Length of Lake (mid lake)	4	4	4
Length of Lake (1/4 off shore)	5	5	5
Benchmark			

Hydroacoustic Fish Survey	Required	Required	Required
acoustic transects			
Standard Target			

Biological Sampling	Required	Required	Required
Fish			
Midwater trawl			
Swedish Gill nets			
Macro Inv (Chaoborus)			
SCOR net			

Macrophytes			

Lake Physics			
Temperate Profile			
Dissolved Oxygen Profile			
STD Profile			