Evaluation of an up-looking sonar system designed to enumerate sockeye salmon smolts on the Kvichak River, 2008

Prepared for

BBSRI

Bristol Bay Science and Research Institute
Box 1464, Dillingham, AK 99576

March 2010

Evaluation of an up-looking sonar system designed to enumerate sockeye salmon smolts on the Kvichak River, 2008

by

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March 2010

Suggested format for citation:

Wade, G. D., D. J. Degan, M. R. Link, and S. W. Raborn. 2010. Evaluation of an up-looking sonar system designed to enumerate sockeye salmon smolts on the Kvichak River, 2008. Report prepared by LGL Alaska Research Associates, Inc., Anchorage, AK, and Aquacoustics, Inc. Sterling, AK, for the Bristol Bay Science and Research Institute, Dillingham, AK, 45 p + Appendix.

ABSTRACT

We document and evaluate an up-looking sonar system designed to enumerate sockeye salmon (*Oncorhynchus nerka*) smolts in Bristol Bay, Alaska rivers. The sonar system included bottom-founded sonar pods and a shoreside network attached storage device (NAS), and was powered by 12 V batteries. Each sonar pod was a custom-built transducer and sounder that sent a digital data stream to the NAS. Two independent and redundant sonar systems were operated on the Kvichak River during the 2008 sockeye salmon smolt run. Site 1 was operated from 25 May to 15 June and Site 2 from 26 May to 15 June. Eight sonar pods were spaced 10 m apart along the bottom on a line perpendicular to the bank at Site 1 and seven pods were deployed at Site 2. Pod- and depth-specific smolt density estimates were obtained by echo integration. Smolt density for each pod was summed for all depth strata sampled, then multiplied by water velocity to obtain smolt flux. Estimates of smolt flux were then expanded for the unsampled area between pods. A portion of the river closest to each shore was not included in these expansions. At Site 1, 4.0% of the total river width (at the surface) was ensonified and data from 89% of the season was used to develop an abundance estimate for the entire season (shutdowns and environmental noise accounted for the remaining 11% of the operational period). At Site 2, 2.3% of the river width was ensonified and data from 85% of the operational period was used to estimate the abundance. Where data were missed, pod-specific hourly estimates were developed by interpolating between adjacent hours; uncertainty and bias caused by interpolation was considered nominal. The sampling rate of the smolt run was greater than 4% and 2.3% at Sites 1 and 2 because fish do not travel in a good portion of the unsampled width of the river. Sampling error incurred from subsampling the entire cross-sectional area of stream was incorporated into confidence limits around the expanded pod-specific estimates. The seasonal abundance of sockeye salmon smolt was estimated to be 30,786,980 (95% confidence limits = 24,886,708—36,687,251) at Site 1 and 26,965,627 (24,276,255—29,654,999) at Site 2. The most likely explanation accounting for the lower estimate from Site 2 was unrepresentative sampling of the smolt migration. We conclude that the best estimate was from Site 1 and therefore was 30.8 million smolts in 2008.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PHOTOS

LIST OF APPENDICES

INTRODUCTION

This report documents the design and application of an up-looking smolt sonar system to enumerate salmon smolts in rivers in Bristol Bay, Alaska. The sonar system was developed from 2006 through 2008 by the Bristol Bay Science and Research Institute (BBSRI) and Scientific Fisheries Systems, Inc., and was tested on the Kvichak River in 2008. The project represents a re-introduction of a technology and methodology that has a long history in Bristol Bay. In this report, we first provide some background of the Bristol Bay smolt program to put the current effort into perspective and provide rationale for the system we designed, describe the key design features of the new sonar system, and document the testing of two redundant sonar systems on the Kvichak River in May and June 2008.

BACKGROUND

Annual estimates of smolt abundance can improve understanding of the factors affecting the productivity of individual salmon stocks and can be used to forecast adult salmon returns 2 and 3 years from the year smolts migrate to sea. Time series of annual smolt production as a function of parent escapement can track changes in freshwater productivity over time and can be used to develop and/or refine escapement goals that maximize average yield from a stock.

In Bristol Bay, where returns of adult salmon are large (10s of millions of fish) and compressed in time (~ 6 weeks), preseason forecasts of returns are useful to managers and the fishing industry. Preseason forecasts help salmon processors to gauge the amount of effort and material to bring to the fishery before it starts. Once the fishery is underway, processors can do little to add capacity and unnecessarily preparing with excess capacity is costly. With little time to react to large or small runs, preseason forecasts can help managers gauge the degree to which they should manage a stock conservatively or aggressively.

The utility of salmon smolt abundance estimates from Bristol Bay rivers has been long recognized. Researchers funded by salmon processors and employed by the University of Washington began testing approaches to estimating the age, length, and abundance of outmigrating salmon smolts on the Wood River in the early 1950s and the Kvichak River in the mid 1950s (Burgner 1968). After Alaska statehood (1959) these programs were expanded and continued by the Alaska Department of Fish and Game (ADF&G; Crawford 2001) through the end of the 20th century.

Methods to monitor smolt age, abundance, and body size varied over time. In the early years, netting was used to capture fish to index abundance and to provide fish for age and length analyses. In the 1970s an up-looking sonar system was developed by Al Menin (with Bendix Corporation) to index smolt abundance. Netting programs were paired with the acoustics projects in order to obtain estimates of body size and age of smolts. At various times over the next 30 years, the “Bendix smolt counter” and/or netting programs were used on 9 Bristol Bay rivers. The duration and success of these projects varied and data were generally used to characterize stock-specific freshwater productivity and many cases, forecast adult returns. The utility of the smolt programs to improve preseason forecasts of adult returns was difficult to quantify and varied significantly among rivers.

By 2002, Bristol Bay smolt projects had been discontinued on all river systems except the Kvichak River. The demise of the different Bristol Bay smolt projects was due to a combination of several factors. About 20 years of monitoring adult escapement, smolt size, age, and abundance on many river systems in the region had provided researchers a reasonable understanding of the population dynamics of these stocks and escapement goals needed to provide high yields. Budget cuts to ADF&G in the late 1980s and through the 1990s put pressure on regional managers to pare assessment programs to those essential for management.

By the 1990s, the value of the smolt programs had to be increasingly justified on the basis of improving preseason forecasts because the basic understanding of stock and recruitment was being provided by catch and escapement monitoring programs. The smolt programs provided a wealth of information but they were labor intensive and therefore relatively expensive to operate. In the mid-1990s there were some high-profile and large errors in forecasts developed with smolt data, including those developed for the Kvichak River (Ruggerone and Link 2006). Most notable were the erroneous forecasts for the 1997 and 1998 adult salmon returns to the Kvichak River based on smolt estimates obtained in the spring of 1995 and 1996 (Crawford and Fair 2003). Continued pressure to reduce budgets and high-profile errors in forecasts based on smolt data contributed to decisions to discontinue projects to estimate smolt abundance by 2002 (Crawford and Fair 2003).

By the mid-2000s, there was renewed interest in smolt programs in Bristol Bay for two reasons. First, a regular escapement goal analysis suggested that goals to some river systems should be increased (Baker et al. 2006). Local communities and some in the fishing industry opposed this increase without more evidence (through monitoring) that increases would lead to more smolt production and hence be worth the foregone harvest larger escapement goals represented in the short run. Second, economic conditions in the fishery were forcing salmon processors to limit capacity and this limited capacity resulted in some foregone harvests. The amount of capacity processors supply each year is a function of salmon markets, the preseason forecast, and the accuracy of the preseason forecasts. Smolt monitoring has the potential to improve preseason forecasts and hence reduce foregone harvests caused by limited processing capacity.

Before any new smolt monitoring was to be proposed, it was prudent to develop an understanding of what (if anything) might have gone wrong with the previous methods that once appeared to work well.

The Kvichak Smolt Program

The work presented in this report benefited tremendously from the diligent efforts of dozens of researchers and numerous studies before us. Below we briefly review aspects of the more recent research to document how that work led to the sonar system we designed.

Following a "disaster" of unexpectedly poor salmon returns to Bristol Bay and elsewhere in Western Alaska in 1998, a congressional appropriation was provided to ADF&G to assess the causes and mitigate future poor returns. Research to assess the Kvichak smolt program was initiated in 2000 and was partially supported by these disaster funds. Maxwell et al. (2009) built on earlier work using side-looking sonar (Huttunen and Skvorc 1991, 1992) and video technology (Hughes and Kelley 1996) to evaluate how the Bendix smolt counter might have failed, and examined opportunities for replacing the up-looking Bendix system with side-looking sonar.

A key component of the Maxwell et al. (2009) research was to characterize the behavior and vertical distribution of smolts migrating in the Kvichak River. Using 3-dimensional video data they found that smolts migrated primarily in the top 0.3 m of the river, fish traveled a speed similar to the water velocity, and the body aspect varied considerably. The vertical distribution (with depth) of fish changed over the course of each day and combined with close proximity to the surface, made for a challenging environment to estimate abundance with a side-looking system. The Bendix system had been designed to adjust for swimming speed of the fish and an assumption was made that fish traveled at 0.34 m/s faster than river velocity, possibly creating a substantial inflationary bias. The project experienced other changes and the bias could have varied among years depending on the amount of surface disturbance in a given season.

Several changes to the Bendix systems have confounded interpretation of possible causes of an apparent failure in the program. Two models of Bendix sonar systems were used on the Kvichak and the up-looking transducer arrays were modified from 18 degree transducers to 9 degrees (Maxwell et al. 2009). Changes in the sonar sites and the changes to equipment used (1989, 1990, and 1993) coincided with the beginning of suspected large overestimates of smolt abundance based on subsequent returns of adult fish. In addition to these changes to the transducer arrays, the sounders were also switched from the 118 kHz "Model 1976" to the 235 kHz "Model 1982" in 1993, where it operated through 2001.

Maxwell et al. (2009) concluded that the higher frequency Model 1982 may have been more susceptible to reverberation from entrained air from wind, rain, and passing boats. Reverberation from these sources would have led to inflationary biases in the abundance estimates. Maxwell et al. (2009) also suggested that the switch to the new sampling site in 1989 may not have been accounted for in the transducer array design and internal data processing, and this would have also led to biased estimates of smolt passage. The Bendix-based abundance estimate in 2000 was 326 million fish and an independent estimate based on side-looking acoustics and a 3-D video system was 15.3 million (Maxwell et al. 2009).

Maxwell et al. (2009) concluded that side-looking sonar could characterize the lateral distribution of migrating smolts but developing quantitative estimates of smolt passage with side-looking sonar was sensitive to noise from entrained air, variation in the vertical distribution of smolts, and to the tilt angle of the transducer. In addition to sources of biases, these sensitivities associated with side-looking sonar contribute to a labor intensive operation and data analysis. Furthermore, a side-looking system must still be paired with up-looking acoustic or video systems to quantify vertical distribution of fish over the course of each day and across the season.

In 2003, BBSRI obtained support from the North Pacific Research Board (NPRB) to examine several hypotheses to explain the collapse of the Kvichak sockeye salmon (*Oncorhynchus nerka*) stock from brood years 1991 to 1999 (return years 1993 through 2002; Ruggerone and Link 2006). A critical component of that work was to describe changes in the operation and accuracy of Kvichak River smolt sonar program to help determine whether the collapse was related to freshwater or marine factors – the implications for management were profound and different depending on whether the sonar-based abundance estimates were accurate during the 1990s.

With NPRB support, researchers examined the historical sonar hardware and smolt data to characterize the accuracy of smolt estimates in the 1990s and attempt to quantify any error. The Model 1976 and Model 1982 Bendix systems were tested side-by-side in a swimming pool in Soldotna in March 2005. Tests using rafts of simulated smolts (ping pong balls filled with lead shot) confirmed the two Bendix models provided substantially different results but the smolt counts each provided were not well correlated with one another (unpublished data). In general, the Model 1982 provided higher estimates than the 1976 system. Electrical noise from high-efficiency lighting in the swimming pool introduced noise in the acoustic results and precluded the development of a correction factor to use between the two models.

In October 2006, side-by-side bench tests of the two Bendix counters (sounders) used on the Kvichak showed that there were several technical problems with the aging 1976 counter, including a defective transmitter section and bad transducer connections (Russell Thynes, pers. comm., Southeast Instruments, Petersburg, AK). Mr. Thynes suspected that these problems developed in more recent years making accurate comparisons of the Model 1976 and Model 1982 performance during the 1990s difficult. To examine more closely the internal data processing differences in the two models, Mr. Thynes designed and built a sophisticated smolt "simulator" to test the circuitry of both the 1976 and 1982 models.

Tests using the smolt simulator revealed a fault in the Model 1982 that Mr. Thynes believed was in the Bendix counter since it was built. The Bendix system uses a single transmitter that is timeshared (multiplexed) among sets of transducer arrays. The Model 1982 system had 6 arrays, each made up of 5 transducers. Thynes discovered that the "Offshore-Inshore" (i.e., the offshore-near) transducer array was being activated at the wrong interval. Upon closer inspection, he found a very small piece of solder flake under one of the integrated circuit sockets on the main logic board. This solder was shorting the circuit and the Offshore-Inshore array (representing 5 of 30 transducers) was firing on every ping instead of every 6th ping. The solder flake was removed and all the functions appeared normal. The effect of this malfunction would be to significantly inflate abundance estimates compared to the 1976 counter, the magnitude of which would depend on the portion of the smolt run that the Inshore-Offshore array sampled. Also, the bias would likely be a function of the abundance of fish in the river – high abundance years would be over counted to a greater extent than in years of low abundance.

Ruggerone and Link (2006) attempted to test for potential sonar equipment malfunction by examining the historical time series of smolt abundance estimates and adult returns from the Kvichak River and those from the nearby Egegik River. They estimated the smolt abundance in the Kvichak during the 1957-2001 period using the Bendix sonar (and fyke net methods prior to the introduction of sonar) and two statistical models: 1) Kvichak escapement and Illiamna Lake temperature, and 2) correlated smolt-to-adult survival rates from Egegik and Kvichak rivers. They found the relationship between estimates from independent statistical models accounted for 46% of the variability in the sonar/fyke net based estimates during the 1957-1994 period – a comforting result and one that suggested the Bendix system provided a useful index of smolt abundance. However, during the period 1995-2001 sonar-based estimates were consistently greater than modeled estimates (Figure 1; Ruggerone and Link 2006). Of particular importance, they found that the sonar-based estimates from 1995-2001 were highly correlated with the model estimates ($r^2 = 0.88$; Appendix of Ruggerone and Link 2006), indicating that error in the estimates from the Model 1982 system were not random and instead a function of the smolt abundance.

The sonar-based estimates during the 1995-2001 period were 2.6 times greater than those based on the parent year Kvichak escapement and 5.9 times greater than those estimates based on the Egegik smolt-to-adult survival rates. The direction of bias was consistent with the bench and pool tests of the Bendix models. The direction of bias was also consistent with what Maxwell et al. (2009) found for the smolt run in 2000 using an acoustics/video technique, but the magnitude of average bias from 1995-2001 was smaller than the 21 times greater Bendix estimate they saw (15.3 million versus 325.9 million).

An interesting feature of the relationship between smolt abundance estimates from statistical models and the Bendix counter during 1995-2001 (Figure 1) was that the Bendix estimates were highly correlated to independent estimates but that the slope of the line was much steeper than it had been in previous years. This suggested that the Bendix counter continued to index the abundance well but that the relationship between its estimates and actual abundance of smolts changed significantly beginning in 1995. The steep slopes (>1) of the 1995-2001 relationships in Figure 1 were consistent with what we would expect from the problem discovered with the Inshore-Offshore array firing on every ping instead of every 6th ping (due to the solder flake). The significant and non-zero intercepts in these two regressions (99 and 40 million) suggest the Bendix counter might have provided significant estimates in the absence of a smolt run (extrapolating beyond the data). Such a result is consistent with the Maxwell et al. (2009) suggestion that the higher frequency Model 1982 would be more susceptible to including reverberation from entrained air from wind, rain, and passing boats, in the smolt estimate than the 1976 model.

Based on all of the above, the Kvichak sonar program began to provide highly biased estimates of smolt abundance beginning in the early-to-mid 1990s. The potential sources of problems with the up-looking Bendix system included:

1. A change in frequency of the sonar system from 118 kHz to 235 kHz.
2. Changes in transducer beam angle and transducer arrays.
3. Sampling error created by changing river channels, lateral fish distribution, and changing sonar sites.
4. Electrical malfunctions within the Model 1982 Bendix sonar, which was used on the Kvichak River beginning in1993.

As noted by Maxwell et al. (2009), the Bendix system was only validated once (and in the beginning) by comparing its smolt estimates to known numbers of smolt captured downstream in a net. The Bendix system was never tested after changes in the sounder, modifications to transducers and transducer arrays, or after changes to the site. Had one or more forms of validation been a regular part of the smolt program, the apparent problems of the Model 1982 would likely have been detected. Further limiting detection of problems, the Bendix system did not provide a data stream that could be examined for developing problems, nor was sampling error examined by regularly examining cross river distribution of smolts and the effects of wind, rain, and boats on the counts it produced. Essentially all of the data processing in the Bendix counter was hardwired internally and smolt estimates from each array were provided by a printer each minute, multiple minutes, or hour. Again, the data processing algorithms were based on early tests and tuning performed by Al Menin in the 1970s and prior to significant changes in hardware, system configurations, and site changes (Appendix C in Maxwell et al. 2009).

In summary, up-looking sonar systems once provided a useful means of indexing the smolt abundance in the Kvichak River and elsewhere in Bristol Bay. On the Kvichak River, several equipment and site changes were made in the late 1980s and early 1990s and these led to large overestimates of smolt abundance. These problems were not necessarily a failure of the up-looking approach, but a failure to fully test assumptions when the system was moved or modified, and because the data output limited the ability to monitor for developing problems. Side-looking sonar can be used to characterize the cross-river distribution of smolts across the Kvichak River but estimating abundance is sensitive to entrained air, vertical distribution of smolts, and the tilt angle of the transducer (Mueller et al. 2006). Furthermore, the side-looking approach is potentially labor intensive to operate and to process data.

With this knowledge, we set out to design a low-power, easy-to-operate, up-looking sonar system that would also provide a data stream that could be used regularly to test assumptions and monitor performance across a range of conditions. Investments were made in “non-recurring engineering” (NRE) costs to reduce the cost of subsequent units so that it could be affordable to deploy multiple units on a river system to provide redundancy, provide a form of validation, and to characterize measurement error.

OBJECTIVES

1. Design and document an up-looking sonar system to enumerate outmigrating salmon smolts on Bristol Bay rivers.
2. Operate two identical sonar systems on the Kvichak River in 2008 and assess the ability of the sonar system to characterize the hourly, daily, and seasonal abundance of sockeye salmon smolts migrating to sea.

STUDY AREA

The Iliamna watershed, located in southwest Alaska, drains an area of 16,830 km^2 (Figure 2). Within this watershed is Iliamna Lake, the largest lake in Alaska, with an area of 2,622 km^2 and a volume of 115.3 km^3 (Quinn 2005). The Kvichak River connects Iliamna Lake to the ocean and flows southwest for approximately 106 rkm (river kilometer) where it enters Kvichak Bay, which is located in the northeastern corner of Bristol Bay. Lake Clark (267 km^2) is located north of Iliamna Lake and this flows into Iliamna Lake via the Newhalen River. Lake Clark is glacially fed causing turbidity at the head of the lake, lessening as it reaches the Newhalen River. The Kvichak River is a clear-water stream beginning at the western end of Illiamna Lake near the village of Igiugig, which is approximately 14 m above sea level.

Discharge measurements for the Kvichak River collected near Igiugig for 1968 to 1986 ranged from 361 m^3/s to 729 m^3/s annual mean discharge, with an average of 503 m^3/s (USGS 2008). Peak discharge occurs during August, September, and October; the lowest discharge typically occurs during March, April, and May. Total duration of ice coverage for Lake Illiamna varied from 39 d to 161 d, with break up date averaging 13 May for the years 1970 to 2001 (Crawford and Fair 2001).

In the initial 1.2 km below Illiamna Lake, the Kvichak River is contained within a single channel; beyond this section, the river is braided and comes together into a single channel in only a few places (Figure 3). Two places where the river forms a single channel, at 3.5 and 7.0 rkm, have been the locations of smolt studies from 1976 to present (Maxwell et al. 2009).

METHODS

Sonar Design

A concept of operation for the smolt sonar is provided in Figure 4. Each up-looking sonar node (pod) was joined through a “daisy chain” where each pod was connected to the next in line. The number of pods in a system can vary from 1 to 10. Pods were mounted on a sled (76 cm long, 30 cm wide and 10 cm in height; Photo 1) and all sleds were tethered together by wire rope. The sleds were equipped with attachment points at each end and designed to remain upright while perpendicular to the current. The pods were connected to a shoreside control box by a cable for power and data transmission. Data storage was provided by a Network Attached Storage (NAS) unit linked to the control box. Power was provided by 12-V DC batteries located next to the NAS. The control box provided connectivity to a notebook computer, which was used during operation to set data collection parameters and diagnose system performance.

Sonar Pod

Each sonar pod was essentially a 24 v low-power acoustic sounder and transducer contained within a machined aluminum housing (22 cm diameter x 19 cm high) and designed to send a data stream back to shore via an Ethernet cable. A functional overview of the sonar pod is provided in Appendix A. The transducer transmitted 0.064 msec pulses at 120 kHz. Carrier removal was provided to reduce the bandwidth needed for digitization. Analog-Digital conversion was done with a 50 kHz A/D converter to produce a stream of 16-bit sample values. The data conversion control was programmed using a Field Programmable Gate Array (FPGA). Digital sample values were exported into a data stream in Simrad EK60 sonar format. The export operation was programmed using a FPGA. Standard Ethernet protocol (TCP/IP) was used to transmit data from each pod to the NAS on shore. Each pod was outfitted with a 7.5^{o} (at -3 dB) single beam transducer, model # 1111, manufactured by BioSonics (Seattle, Washington).

Control Box

The function of the control box was to provide an interface for powering and communicating with the sonar pods, manage the stored data, and monitor the input voltage. Power from the battery bank was converted from 12 V to 24 V within the control box and then provided to the pods with an underwater cable. The same connection communicated with the pods allowing the operator to start and stop the sonar and apply data collection parameters using a laptop computer. The technicians could also use the computer to review files in season for quality control. As the raw data were received from the pods they were transferred to a NAS via a gigabit network switch. A volt meter located on the control box allowed the technicians to monitor the input and power level from the battery bank.

Sonar Systems

Two multi-pod systems were deployed on the Kvichak River in 2008 (Photo 2). Each system consisted of an array of pods daisy chained end to end at 10 m intervals. All transducers were calibrated using a 36 mm tungsten carbide sphere prior to deployment. All pods were configured to collect acoustic data using the following parameters: 0–7 m sample range, 0.06 second ping interval, and 0.064 msec transmitted pulse duration. Data files were collected continuously and then stored in 10 minute blocks on the NAS. All data collected at each site were stored in a 1 terabyte NAS configured with two 500 gigabyte hard drives. Power to the sonar was supplied by two 70-W solar panels, one 2 kW generator and a bank of 12 v, 100 AH absorbed glass mat (AGM) batteries connected in parallel. These batteries were recharged by the solar panels and gas-powered generator. The control box, NAS, and power source for each system were housed on the river's west shore in WeatherPORT tents (Photo 3).

Sonar Site Selection

A key feature of a suitable site to place the sonar system was a location where the river was confined to a single channel. Bottom profile also influenced site selection and we sought areas where the bottom gradient was gradual and suitable to towing the sled-equipped daisy chained pods across the river. To best characterize the measurement error between sonar systems, we sought two sites sufficiently far apart to allow mixing and redistribution of smolts between sites.

Two sites that have been used in previous smolt sonar projects were deemed suitable for our requirements (Figure 3). Site 1 was 103 m wide and located 3.5 rkm downstream of the outlet from Lake Illiamna. This was approximately the same place as the smolt sonar studies conducted by Maxwell et al. (2009) in 2002 through 2004. Site 1 was on a slight bend in the river with the steeper east bank being the outside bend. The bottom profile of Site 1 was characterized by a gently sloping west bank to a maximum depth of 4.3 m, 69 m off shore, followed by a steep incline to the opposite bank (Figure 5). Site 2 was located 7.0 rkm downstream of the outlet of Iliamna Lake and was 130 m wide. This was the site for earlier Bendix and side looking sonar studies (Crawford and Fair 2003; Mueller et al. 2006; Maxwell et al. 2009). The west bank of Site 2 had been an island before the river channel changed but now the narrow channel on the north side of the island becomes flooded only during periods of very high water and not typically in the spring. Site 2 was located along a fairly straight stretch of river, with the west bank being flat and the east bank having a steep slope to a plateau above. The bottom profile of Site 2 was more uniform across the entire river bottom than Site 1 and had a maximum depth of 2.9 m (Figure 6).

Sonar Deployment and Operation

The two sonar systems were deployed in the same manner. The pods were attached to each other by a 10 m long, 7.9 mm (5/16 in) diameter wire rope (cable) so as not to put any stress on the power and data cable (Photo 1). The first sled had a 6.1 m section of 6.4 mm (1/4 in) chain attached to the leading end that acted as an anchor while being towed. Once the set up was completed, the system was staged on the west bank (Photo 3). Prior to deployment, the 7.9 mm cable had been laid on the river bottom at a right angle to the staging site to be used as a tow line. This tow line was attached to the chain on the first sled and a chain saw winch was used to pull the entire array across the river bottom. Once in a suitable location, the ends of the sonar array were anchored to each bank.

The sonar systems operated 24 hours per day except for stoppages for repositioning. Each system was checked twice daily, generally at 0800 and 2300 hours, to ensure adequate power supply and operation. Data were downloaded onto a portable computer from the NAS each day and examined visually using specialized software (EchoView® 4.5 by Myriax Software Pty. Ltd., Tasmania, Australia) to ensure the sonar was operating correctly and useful data were being collected.

Deployment of the sonar array was dependant on ice break up of Iliamna Lake and absence of ice in the Kvichak River. Through communication with air taxi operators in the area, we determined the lake ice began breaking up on 10 May and was mostly clear by 18 May (Table 1). Crews arrived in the village of Igiugig on 19 May to begin mobilization. Iliamna Lake was mostly clear of ice at this time except for the southwest section near the outlet where prevailing winds had pushed the remaining ice. The Kvichak River was clear of fast ice but would become intermittently congested with ice trickling in from the lake. Crews were able to navigate the river and began setting up the shore-based facilities at Sites 1 and 2 on 20 May. Once WeatherPORT tents were in place, sonar equipment was moved to each site and the control box, NAS, and power supply were assembled (Photo 2). On 24 May, as ice conditions began to lighten and Site 1 sonar was assembled and staged on shore (Photo 3).

Sites 1 and 2 were powered by six and four 12v AGM batteries, respectively. Each site was charged by two 70 W solar panels and one 2 kW generator. Each sonar system required 110 watts for operation, half of which was devoted to the NAS. The solar panels at each site were unable to keep the batteries fully charged and therefore the generator was used for 2 to 3 hours each day in order to keep the system operating.

On 25 May, the Site 1 sonar was deployed and began operating at 1700 hours. A total of eight transducers (S^1–T1 through S^1–T8) were set at 10 m intervals with S^1-T1 located 19 m off the west bank and S^1-T8 located 14 m off the east bank. Depth of each transducer varied from 1.8 m for S^1-T8 to 4.3 m for S^1-T7 (Table 2). Site 2 sonar was deployed 26 May and began operating at 1730 hours. Due to a broken coupling on one of the housings only 7 transducers (S^2-T1 through S^2-T7) were deployed. As with Site 1, each transducer was spaced at 10 m intervals with S^2-T1 located 42 m off the west bank and S^2-T7 located 28 m off the east bank. Depth of all transducers at Site 2 was approximately 2.7 m (Table 2).

The Site 1 sonar operated from 25 May to 2 June at 1300 hours when it was shut down to be pulled out and re-set due to S^1-T8 being tilted. Once re-set, pinging resumed the same day at 1700 hours, and it ran continually to season end on 15 June at 1200 hours. Site 2 operated continually from 26 May at 1200 hours to 15 June at 1500 hours.

Water velocity was measured using a Model 622 Gurley Price meter made by Gurley Precision Instruments (GPI; Troy, NY). A boat was anchored 2 to 3 m downstream of each transducer and velocity measurements were taken at a depth of 1 m at each location. Measurements were taken for one minute, three times at each transducer to give an arithmetic mean. Velocities were then calculated based on the GPI conversion table.

Water velocity was measured a total of three times at each site, roughly at the beginning, middle, and end of the sonar operating dates (Table 3). Stage height was not measured, however little change in water level was observed during the study. Water velocities differed across the river channel at both sites, with the near shore velocity being lower than the mid river velocity. Ranges varied from 0.93 m/sec at S^1-T1 to 1.83 m/sec at S^1-T6, and from 0.97 m/sec at S^2-T1 to 1.47 m/sec at S^2-T4.

Climate and hydrologic data were recorded at the boat launch near the ADF&G facilities in Igiugig (Table 4). Observations of sky conditions and measurements of wind direction, wind velocity (mph/h), daily precipitation (in), air and water temperature (^{o}C) were recorded at 0800 and 2000 hours daily. Wind direction, wind velocity, and air temperature were measured with a West Marine, Model 332356 weather monitor. Precipitation data were collected with a direct-read rain gauge graduated from 0.1 to 1.0 in. Water temperatures were collected at the ADF&G boat launch with a mercury pocket thermometer graduated in 1^{o} increments from -10 to +110 ^{o}C.

Sampling Smolt for Age, Weight, and Length

During the time the 2008 smolt sonar was operating, BBSRI worked cooperatively with ADF&G to sample smolts at a location on the river between the two sonar sites (Figure 3). This was the same general area where ADF&G had been sampling smolts since 1956 (Crawford and West 2001). The purpose of this sampling was to collect age, body size, and run timing information of the smolt run and to aid with interpretation of smolt sonar data. In 2008, a fyke net and incline plane trap were used each night (weather permitting) to capture smolts. Once the nightly sampling goal was met the fish were then measured, weighed, and scales were taken to determine age (Baker et al. 2008).

To keep the data together from each nightly sampling session, all fishing times, fish catches, and age-length-weight sampling data were logged by smolt day. A smolt day was a 24-h sampling period that started at 1200 hours and ended at 1159 hours the next calendar day.

Data Analysis

Pre-processing

Prior to data analysis, the individual data files from each transducer were processed to remove internal system noise spikes, and then merged from all transducers at each location to provide a single EchoView® compatible data file for each 10-min period. These data files were then pre-processed (using EchoView® 4.5 software) by removing noise events generated by boat passage through the sample area, wind/rain events which injected bubbles into the water column, and any cross-talk among transducers. Given that 10-min periods were grouped and reported in hourly bins, if a noise event occupied the majority of an hourly bin then that entire hour was removed.

Smolt Abundance Estimate

<u>Requirements for a Reliable Abundance Estimate</u>

Several assumptions concerning smolt behavior must be met in order to produce a reliable abundance estimate across years. The assumptions required are based on the specific design of the sonar and the methods of generating the abundance estimates. Violations of these assumptions could introduce a bias to the final estimate.

(1) Smolts travel at or near the same speed as the river water velocity.

In order to obtain an estimate of smolt flux, the density of smolt at a given time must be multiplied by the velocity of the smolt through the sonar beam. For this project the velocity of the smolt was assumed to be equivalent to the velocity of the water, which was measured three times over the course of our study. This assumption was based on the work of Maxwell et al. (2009), who used 3-D video techniques estimate that smolt speed (over the ground) was near the current velocity. If smolts swim faster than the water velocity, our estimates will be biased low.

(2) The majority of smolts travel in the upper portion of the water column.

Transducers produce a “near field” effect that is unique to the beam angle and frequency for each unit. Pressure waves created by the sounder must travel a sufficient distance from the face of the transducer before they become parallel; within this region fish can be detected but echo strength varies so quantitative data cannot be calculated. If smolts travel low in the water column (i.e., close to the transducer face) then these fish would not be included in the estimate therefore biasing the estimate low. Vertical distribution of smolt does vary with time but it has been found that the majority utilizes the upper 1 m and the bulk of those are found in the upper 30 cm (Maxwell et al. 2009).

(3) Vertical distribution of smolts within the water column does not vary among years.

There has not been a specific study to test the assumption that vertical distribution is the similar among years but this could be, at least in part, monitored with the system we have developed and it should be examined on an annual basis. Of particular concern is whether the portion of the run that travels within 2-3 cm of the surface (and therefore cannot be separated from the surface echo) changes as a function of the abundance of smolts. This could happen if in large run years the smolts distribute themselves deeper rather than across the river and across days. If the fish distribute themselves deeper in the water in large run years compared to small run years, then a smaller fraction of the run will be unaccounted for at the surface. In such a circumstance, estimates from small run years could be biased low. If fish from large runs spread out across nights, we should expect to see abundance from the nights of peak migration to represent smaller portions of the total migration in large run years compared to small run years. Metrics characterizing the vertical distribution across nights and for each season could be compared to see whether changes are correlated with annual abundance.

<u>Abundance Estimates</u>

The majority of the time sockeye salmon smolts outmigrate they tend to aggregate in schools too dense for the sonar to detect single targets accurately, therefore abundance estimates cannot be calculated by counting individual fish. In order to obtain abundance estimates in this study we employed a technique called echo integration, this method has been used since the mid 1960s as an acceptable means for estimating abundance from high density fish schools (Simmonds and MacLennan 2005). Echo integration uses the summed energy from multiple targets in a given sample volume (echo integral) and from this echo integral extrapolates the numbers of fish based on individual target strength (TS).

After excluding noise events from the data, the files were processed with Echoview® 4.5 to export echo integration values by 1-min intervals and 0.5 meter depth strata below surface for the top 2 meters of the water column (Table 5). Additionally, single target detections from each transducer were exported to obtain uncorrected TS values. These uncorrected TS values were processed with a deconvolution algorithm (Hedgepeth et al. 1999) to provide a scaling factor for the echo integration values. The sum voltage for each analysis cell (1-min x 0.5 m depth interval) was corrected for the unsampled portion of the cell and then divided by the mean voltage for an individual smolt (scaling factor) to obtain the fish density for each cell. The smolt density for each cell was summed for all depth strata to obtain smolt/m^2 and then multiplied by the water velocity to obtain the smolt flux (smolt/minute/meter of river channel cross section) for each pod.

Several models were considered for expanding the pod estimates to the entire cross section of river. We chose to linearly interpolate between pods to estimate the smolt passage for the area not sampled. Likewise, we interpolated over the distance between the end pods and the river banks, which were assigned values of zero passage. This method yielded a river-wide estimate of smolt passage at each site.

Smolt passage was not subsampled through time as counts were continuous from beginning to end of the enumeration project. A small portion of the total season was missed due to shutdowns and environmental noise. For these periods, the missing hours for each transducer were filled via linear interpolation between adjacent hours. A plot of these missing hours reveals they occurred during periods of extremely low passage (Figures 7, 8), and any uncertainty and bias incurred due to interpolation was considered nominal. The season total abundance and variance of the mean for each site were estimated by the following:

$$SA = \sum_{j=1}^{K} HA_j \tag{1}$$

$$HA_j = \frac{\sum_{i=1}^{n} T_{ij}}{n} \times ES_j \tag{2}$$

$$ES_j = \sum_{i=1}^{n}\sum_{m=0}^{d} T_{ij} + \left(T_{i+1,j} - T_{ij}\right)\frac{m}{d} \tag{3}$$

$$Var(SA) = \sum_{j=1}^{K}\left[Var\left(HA_j\right)\right] \tag{4}$$

$$Var\left(HA_j\right) = \frac{\sum_{i=1}^{n}\left(T_{ij} - \overline{T}_{.j}\right)^2}{n-1} \cdot \frac{fpc}{n} \times ES_j^{\ 2} \tag{5}$$

$$fpc = \frac{A-a}{A-1} \tag{6}$$

where, *SA*=smolt abundance, HA_j=smolt abundance for the j^{th} hour, ES_j=scalar that expands each hourly average across transducers to the entire stream, *m*=number of meters after the i^{th} transducer for which the interpolation was being generated, d=number of meters between transducer *i* and *i+1* (*i* and *i+1* could also represent either bank for which smolt passage was assigned a value of zero), *K*=number of hours for which counts were estimated over the entire season, *n*=number of transducers across the river, T_{ij}=count for the i^{th} transducer in the j^{th} hour, *Var(SA)*= variance of *SA*, $\bar{T}_{.j}$ =average count across all *i* transducers for the j^{th} hour, *fpc*=finite population correction, *a*=cross sectional area ensonified by all transducers, and *A*=total cross sectional area for which the estimate was expanded. Normal 95% confidence intervals were produced for *SA* estimated at each site. It should be noted that our estimates of variance include uncertainty due to subsampling the water column only and do not include uncertainty from estimating the scaling factor during echo integration. In the future, we will investigate methods for propagating uncertainty from all inputs.

RESULTS

Sonar Performance

Sonar Calibration

A pool calibration test of each sonar pod was performed prior to deployment in the field. Each pod was independently tested with a 36 mm tungsten carbide sphere with known target strength of -40 dB. Once the measured target strength for each transducer was determined, an offset was calculated for data processing (Table 6).

Transducer Operation

All transducers were tested and beam patterns measured by the manufacturer (BioSonics) prior to purchase. Based on the beam patterns the side lobes were relatively low averaging ~ -30 dB. Calculated near field zone was 0.71 m from the face of the transducer and dead zone began at 0.049 m (4.9 cm or ~ 2 in) from the surface. During post season calibrations the actual dead zone at the surface was tested using the calibration sphere. Results from this test revealed that the sphere could be detected ~ 0.005 m from the surface. The average distance from the top of the transducer to the surface was approximately 3.0 m; with the 7.5 degree beam at this range the diameter of the beam covered by each pod was 0.39 m.

Power Requirements

Power consumption for each sonar site was approximately 110 W; the NAS required approximately 60% of this power. Site 1 operated with six 12-V, 100AH batteries and Site 2 operated with 4 (two were damaged in shipping). Each system required charging with the generator at least once every 24 h. Solar panels could maintain the charge on batteries during periods of clear sunny weather, but for the majority of the time the solar radiation levels were not high enough to use solar as a reliable source of power.

Data Analysis

Pre-processing

Site 1 analysis included data from 25 May through 12 June 2008 for a total of 438 h of processed data. Site 2 data were analyzed from the period 26 May to 6 June 2008 (271 h). Wind events made up the majority of environmental noise. In total, 11% and 15% of data collected at sites 1 and 2, respectively, were removed due to wind-generated noise. Although the two sites were close enough together to experience the same wind events, Site 2 was located in an area that allowed more fetch for the wind to generate additional wave action than Site 1.

Due to time constraints, a smaller portion of Site 2 data were pre-processed and analyzed to estimate abundance. The final analysis of Site 1 data indicated that 98% of all smolts detected at Site 1 had passed between 25 May and 6 June (Figures 7, 9). By comparing the hourly and daily smolt flux between each site, it was thought that the analysis of Site 2 data through 6 June would be adequate to produce a reliable and comparable estimate (Figure 8).

For both sonar sites, single target detections were obtained from each transducer (by sample week) in order to obtain a scaling factor for echo integration. Contamination of single targets occurred frequently, and can be observed for several transducers during both the first and second week of sampling. Contamination of single targets from multiple targets occurred when densities were high and resulted in a secondary peak in the TS distribution plot as observed for S^1-T6 during week one (Figure 10). These multiple targets were removed by selecting sample periods for analysis when the smolt densities were lower or from transducers with low densities to estimate the scaling factor. EMS deconvolution method developed by Hedgepeth (1994, 1999) was used to estimate the mean TS used to scale the echo integration values (Figures 11, 12).

Abundance Estimate and Smolt Distribution

The estimated abundance of sockeye salmon smolts from 25 May to 12 June at Site 1 was 30,786,980 (95% confidence limits = 24,886,708 - 36,687,251; Figure 13). For Site 2, the estimated abundance was 26,965,627 (24,276,255 - 29,654,999; Figure 14) from 26 May to 6 June.

Smolt passage by hour of day was the highest after sunset and remained high until sunrise. The peak hours for smolt passage were 0100 hours through 0300 hours for Site 1 (30% of the total run) and 03:00 through 05:00 for Site 2 (22%). Smolts continued to migrate during all hours of the day, with daylight hours accounting for about 50% of the total run (Figure 15). There was approximately 330 h of daylight (75% of each day) and 108 h (25%) of dark over the course of the study.

Smolts were detected at all depth strata sampled at each site. For both sites, vertical distribution varied between daylight and dark hours. During the hours of darkness over 95% of smolts at each site traveled in the upper 1.0 m, with the majority in the upper 0.5 m (Figures 16, 17).

Smolts traveling in the day tended to move a little deeper in the water column, particularly at Site 1 where ~ 25% were detected below 1.0 m during daylight (Figure 16).

Cross-river distribution was characterized by the percentage of total smolt detected at each transducer. Smolts were detected by all transducers at each site, but were disproportionate across them. The majority of smolts at Site 1 were detected at T6 (38.8%), with numbers dropping off towards the shores on both sides (Figure 5). Site 2 had two peaks in total distribution with a small peak at T2 that accounted for 13.2% of smolts and another at T6 with 31.4% of the total (Figure 6).

DISCUSSION

Abundance Estimates

Daily abundance estimates from the two sites and sonar systems were remarkably consistent with the exception of 27-28 May (between 21:00 and 05:00 hrs) when the Site 1 estimate was ~ 4 million fish greater than Site 2. This difference accounted for most of the discrepancy between the estimates for the entire run from the two sites (30.79 million from Site 1 and 26.97 million from Site 2). Given that the two sites were in substantially different bottom profiles, had different cross-sectional areas, and were 3.5 rkm apart, the similarity of almost all daily estimates suggest that the sonar systems worked well to estimate actual fish passage. The differences in daily and annual estimates from the two sites likely had more to do with sampling error than any systematic bias in the echo integration or operation of the acoustics equipment.

Site 2 was less intensively sampled than Site 1 and this limited our confidence in the full-season (i.e., annual) abundance estimate from Site 2. Originally, we planned to operate two identical sonar systems on the Kvichak River in 2008. However, due to a broken coupling on one of the systems, Site 2 had to be operated with only seven pods compared to the full eight pods used at Site 1. Our method of extrapolating for unsampled area did not go beyond 5 m from each side of each pod and therefore a narrower area was used to develop an estimate for Site 2 than Site 1 (70 m of 130 m of river width compared to 80 m of 103 m). It appeared that the lower sampling rate at Site 2 did not fully capture or account for what was an obviously a very large pulse of fish on the night of 27-28 May at Site 1 where we were able to better sample the “river of fish”. However, more confidence can be placed in the results from Site 1 than Site 2.

There was evidence of less effective coverage from Site 2. River depth at Site 2 was relatively constant across the channel, which promoted a more uniform distribution of smolts across the river whereas the thalweg was more pronounced at Site 1 (Figures 5, 6). Average night time passage rates at the distal transducers for Site 1 were T1 = 1.4 smolts/min and T8 = 0.5 smolts/min, whereas at Site 2 they were T1 = 5.5 smolts/min and T7 = 32.8 smolts/min (Figures 17, 18). Because a greater number of smolts were estimated at the margins of the sonar array for Site 2, it follows there was a greater chance for smolts to pass unaccounted beyond either end of the array.

Echo integration did not appear appreciably influenced by entrained air caused from wind, rain, and boats because we expected these to be different between the two sites. Site 2 was located in an area that allowed more fetch for the wind to generate additional wave action than Site 1. Any differences in the daily vertical distribution of fish between the two sites appear to have been accounted for by the acoustics and data processing methods used.

During the 2009 field season all precautions will be taken to ensure that each sonar system is operated with eight pods. However, even if the Site 2 sonar is operated with a full complement of pods, the sampling width may not be sufficiently wide for this site. Other features equal, it would be beneficial to move the Site 2 sonar system to a narrower section of river in 2009.

It would also be helpful to use a side-looking sonar system in 2009 to characterize and quantify the cross-river distribution of smolts so that our assumption of uniform distribution around each pod can be tested. It may be possible to use side-looking distribution to weight the pod-specific estimates in the future.

Distribution

Vertical distribution of smolts was primarily in the upper portion of the water column and these results are consistent with previous studies. By examining video data from 2000 and acoustic data from 2000 and 2001, Maxwell et al. (2009) found that all smolts travelled in the top 100 cm and the majority in the top 30 cm. They also found a diel pattern of vertical distribution, with smolts nearer the surface in the late evening and early morning hours and deeper during the daylight hours. In our study, the majority of smolts were detected in the upper 1.0 m of water, with only 27% and 15% (Sites 1 and 2) between 1.0 and 2.0 m of depth. The majority of smolts between the 1.0 to 2.0 m depth strata were detected during the daylight hours.

Cross-river distribution of smolts varied with highest concentrations located in areas of higher water velocity: Site 1 distribution was highly skewed toward T6 (deepest portion of the river) and Site 2 had a more uniform distribution (Figures 5, 6). Bue et al. (1988) used side-looking sonar and found the majority of smolts were detected 6.4 to 74.4 m from the shore in a 100-m wide section of the river [*and in a fairly uniform distribution with range?*]. A later study with side-looking sonar indicated that nightly distribution of smolts tended to be more dynamic, with peak passage detected at different ranges across the river across nights within a year (Huttenen and Skvorc 1991, 1992). Mueller and Degan (2006) used side looking sonar on the Kvichak River in 2001, partly because it could better detect changes in cross-river distribution than the upward looking Bendix sonar.

There also appeared to be diel fluctuation in the cross-river distribution of smolts where fish were more shore-orientated during the day. At both sites, detections tended to increase during daylight hours on the nearshore transducers (Figures 18, 19).

Although side-looking sonar data is problematic with respect to estimating abundance, it appears to be an effective way of characterizing smolt cross-river distribution. In future studies it may be beneficial to combine a side-looking sonar system with the up-looking arrays to help better describe cross-river smolt distribution than the up-looking array can alone.

Data Processing

Distinguishing between environmental noise and smolts is essential to produce reliable abundance estimates. As noted earlier, the Bendix smolt counter did not provide a means of visually analyzing the data to manually separate the noise events. For this study, all data collected could be manually analyzed for noise events post season via EchoView® 4.5 software. This software allowed the processor to visually inspect files and assign noise events to "bad data" regions, which were excluded from the abundance estimate (Figure 20). Wind, rain, and boat traffic affected all transducers during a given event, so data from all transducers were removed during these periods. Cross talk affected a single transducer at each site for a given time period, therefore only the data on that single transducer were excluded. The distinction between noise events and smolts was clear the majority of the time (Figure 21). In the event that the technician could not make a distinction between smolts and noise, that region of data were assigned to bad data.

As mentioned earlier, noise generated by wind accounted for the majority of data removed. In most cases wind speeds had to be approximately 20 mph or higher before it affected data analysis, but this varied with wind direction and site location (Figure 22). Rain accounted for a portion of the data to be assigned to bad data; rain visually appeared similar to wind on EchoView® files. Intermittent or light rain did not affect data analysis, only a constant heavy rain-fall, like that experienced on 5 May created noise sufficient to cause analysis problems. Boat noise occurred more during the day light hours and increased once the sport fishing season began (Figure 20). A boat passing the sonar site would typically require a 2- to 4-min block of data to be removed. Cross talk occurred at both sonar sites and was caused by one transducer being tilted enough for the next transducer to receive its signal (Figure 23). These events lasted about 1 to 2 min and occurred 0 to 3 times each hour for both sites. This noise can be reduced or eliminated during the 2009 field season by ensuring the transducers are not at an angle.

CONCLUSION

This was the first year of a project to evaluate the efficacy of a newly designed up-looking sonar to enumerate sockeye salmon smolts on the Kvichak River. The design and operation of the sonar met the project's objectives and our expectations. We were successful in developing abundance estimates from two independent and redundant sonar systems. The estimate from Site 2 was 12% lower, which is a modest difference and we suspect that this may have been due to a lower and less effective sampling at Site 2. We offer the Site 1 estimate of 30.8 million (30,786,980; 95% confidence limits = 24,886,708—36,687,251) as the best estimate for sockeye salmon smolt abundance in the Kvichak River in 2008.

RECOMMENDATIONS FOR 2009

Based on the results above and lessons learned from the 2008 project, the following are recommended improvements for the 2009 program:

1. Operate a side-looking sonar system to characterize horizontal (cross-river) distribution of smolt.
2. Provide for in-season data processing by on-site technicians to remove noise spikes and concatenate data files in real time.
3. Operate Site 1 sonar in the same location as in 2008.
4. Explore the feasibility of operating the second sonar system at a new location where the river is narrower than the site it was used at in 2008.
5. Explore the feasibility of using alternative energy sources in order to reduce the dependence on maintaining gas generators at each site.
6. Create a more robust data back-up system than was used in 2009.
7. Incorporate uncertainty from all inputs into the abundance estimate.

ACKNOWLEGEMENTS

This work was the culmination of many years of research and development by numerous people beginning in the 1950s. Ole Mathisen, whose work on the Kvichak began 50 years earlier, was instrumental in securing funding in 1999 to examine the Bendix sonar system and smolt behavior in the Kvichak in 2000 and 2001. Ole's efforts in 1998/99 provided the seeds of a new smolt program for Bristol Bay. Nick Hughes' enthusiasm and intellect was instrumental in making the most of those funds by helping to critically examining smolt behavior in the Kvichak. Ole and Nick will be missed.

Dave Gaudet patiently waded through Bristol Bay smolt reports from three decades to document the changes to the Kvichak smolt program and pinpoint potential sources of problems. Greg Ruggerone's work with the smolt dataset helped to quantify Gaudet's hunch. Greg Buck and Fred Tilley worked with Don Degan to conduct side-by-side comparisons of the two models of Bendix smolt counter in a Soldotna swimming pool. Russell Thynes of Southeast Instruments and his ingenious sleuthing of the problems with the Bendix smolt counters helped put to rest a decade-long debate. Russell also provided us the confidence that up-looking sonar itself was not fatally flawed and that it was worthwhile to pursue the development of a modern version. Mike Daigneault conducted much of the review of the Bristol Bay smolt program and the initial scoping of hardware vendors, alternative designs, and approaches to field sampling.

Patrick Simpson, Alex Kulinchenko, and Ja-Byung Jung of Scientific Fisheries Systems, Inc. capably designed the hardware and software for the sonar system, and did so on time and to the specifications envisioned.

BBSRI technicians Pamela Edwards, Leilani Luhrs, and Shelly Woods assisted with deploying and maintaining the sonar systems, and conducted fish sampling. The people from the Village of

Igiugig provided invaluable assistance with all aspects of the field project. Janelle Mueller and Fred West (ADF&G) assisted with the deployment and maintenance of the smolt sonar. ADF&G supplied housing and equipment (boats, generators, etc.) that was essential to the project. Anna-Maria Mueller assisted with the processing of the acoustic data.

This project was a cooperative effort among BBSRI, ADF&G, and Aquacoustics. Funding was provided by BBSRI, the North Pacific Research Board (Project R0321), the Southeast Sustainable Salmon Fund (SSSF Project 45632), and BBSRI benefactors American Seafoods, Bristol Leader Fisheries, and Alaskan Leader Fisheries.

The report Evaluation of an up-looking sonar system designed to enumerate sockeye salmon smolts on the Kvichak River, 2008 was prepared by the Bristol Bay Science and Research Institute by Guy Wade, Don Degan, Michael Link, and Scott Raborn under award 45632 from the National Oceanic and Atmospheric Administration, U.S. Department of Commerce. The statements, findings, conclusions, and recommendations are those of the author(s) and do not necessarily reflect the views of the National Oceanic and Atmospheric Administration or the Department of Commerce.

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TABLES

Table 1. Ice cover dates for Iliamna Lake, 2008.

Winter of	Freeze-up Date	Break-up Date	Total Days of Ice Coverage
1969 - 1970	1-Jan		
1970 - 1971	1-Jul	16-Jun	161
1971 - 1972		5-Jun	
1972 - 1973		25-May	
1973 - 1974		21-May	
1974 - 1975	26-Dec	4-Jun	161
1975 - 1976		7-Jun	
1976 - 1977	4-Feb	2-May	88
1977 - 1978		11-May	
1978 - 1979		3-May	
1979 - 1980		3-May	
1980 - 1981			
1981 - 1982	9-Jan	25-May	137
1982 - 1983			
1983 - 1984			
1984 - 1985	11-Feb	5-Jun	115
1985 - 1986	18-Jan	12-May	115
1986 - 1987	13-Feb	23-May	39
1987 - 1988	26-Jan		
1988 - 1989	13-Jan		
1989 - 1990	9-Jan	22-May	134
1990 - 1991	7-Jan		
1991 - 1992	27-Jan	4-May	98
1992 - 1993	22-Jan	3-May	102
1993 - 1994	16-Feb	5-May	79
1994 - 1995	11-Jan	22-May	132
1995 - 1996	12-Jan	5-May	114
1996 - 1997	23-Dec	8-May	137
1997 - 1998	5-Jan	26-Apr	112
1998 - 1999	30-Dec	28-May	150
1999 - 2000	30-Dec	6-May	128
2000 - 2001			
2001 - 2002		20-May	
2002 - 2003		11-Apr	
2003 - 2004			
2004 - 2005		12-May	
2005 - 2006		19-May	
2006 - 2007		17-May	
2007 - 2008		15-May	

[a]Data provided by ADF&G, most information was provided by local air charter companies and considered anecdotal.

Table 2. Range and depth for pods at Site 1 and Site 2, 2008.

Transducer	Depth (m)	Range[a] (m)
S[1]-T1	2.4	19
S[1]-T2	2.5	29
S[1]-T3	3	39
S[1]-T4	3.6	49
S[1]-T5	4	59
S[1]-T6	4.3	69
S[1]-T7	3	79
S[1]-T8	1.9	89
S[2]-T1	2.9	42
S[2]-T2	2.7	52
S[2]-T3	2.7	62
S[2]-T4	2.7	72
S[2]-T5	2.6	82
S[2]-T6	2.5	92
S[2]-T7	2.6	102

[a]Range based on distance from west shore to transducer.

Table 3. Water velocity (m/sec) measurements taken at sonar sites 1 and 2 on the Kvichak River, 2008.

Site 1				
Transducer	27-May	3-Jun	18-Jun	Average
T1	0.93	1.09	1.24	1.09
T2	1.31	1.27	1.43	1.34
T3	1.54	1.47	1.67	1.56
T4	1.52	1.65	1.70	1.63
T5	1.60	1.60	1.74	1.64
T6	1.60	1.70	1.83	1.71
T7	1.58	1.65	1.76	1.66
T8	1.09	1.17	1.31	1.19
Site 2				
Transducer	29-May	3-Jun	17-Jun	Average
T1	0.97	1.29	1.08	1.11
T2	1.10	1.31	1.24	1.22
T3		1.38	1.42	1.40
T4	1.29	1.29	1.47	1.35
T5		1.35	1.45	1.40
T6	1.24	1.15	1.29	1.23
T7	1.08	1.17	1.15	1.13

Table 4. Daily climate and hydrologic observations made at 0800 and 2000 hours near Igiugig on the Kvichak River, 2008.

Date	Sky[a]		Precipitation[b] (in)			Dir./Vel. (mph)		Air Temp. C^0		Water Temp. C^0		Water Color[c]	
(mm/dd)	8:00	20:00	8:00	20:00	Total	8:00	20:00	8:00	20:00	8:00	20:00	8:00	20:00
5/21	1	2	0	0	0	Calm	NE 7	10	12	3	3	1	1
5/22	2	4	0	0	0	Calm	NE 15	5	7	3	4	1	1
5/23	3	1	0	0	0	SW 30	SE 10	5	15	3	4	5	5
5/24	2	2	0	0	0	Calm	W 10	7	9	1	3	5	5
5/25	3	3	0	A	0	Calm	W 5	3	11	5	5	5	5
5/26	4	2	Tr	A	0	W 5	W 5	4	11	4	5	1	1
5/27	4	1	0	0	0	Calm	Calm	5	15	4	5	1	1
5/28	1	1	0	0	0	Calm	Calm	6	16	4	6	1	1
5/29	2	1	0	0	0	Calm	Calm	11	13	5	7	1	1
5/30	1	4	0	0	0	Calm	N 10	7	9	5	6	1	5
5/31	2	3	0	0	0	NE 10	NE 40	6	10	5	8	5	5
6/1	2	3	0	A	0	NE 25	NE 30	7	6	5	6	5	5
6/2	4	3	0	0	0	E 10	E 10	7	14	5	8	1	1
6/3	4	3	A	0	0	E 10	E 15	7	12	5	7	1	1
6/4	3	3	A	A	0.02	Calm	Calm	7	14	7	8	1	5
6/5	4	4	B	A	0	E 10	Calm	7	5	7	7	5	5
6/6	2	3	0	B	0.01	Calm	Calm	5	14	6	9	5	1
6/7	3	2	A	0	0	W 5	W 5	10	15	8	8	1	1
6/8	4	3	0	0	0	Calm	W 5	10	13	7	8	1	1
6/9	4	2	0	0	0	Calm	Calm	10	10	7	7	1	1
6/10	4	3	0	0	0	W 5	W 10	10	8	6	6	1	1
6/11	4	4	0	0	0	Calm	Calm	8	10	6	7	1	1
6/12	4	4	0	A	0	W 10	Calm	6	5	6	6	1	1
6/13	3	2	0	0	0	Calm	Calm	10	17	6	9	1	1
6/14	1	2	0	0	0	Calm	S 5	9	11	6	7	1	1
6/15	4	4	0	0	0	SW 10	Calm	9	9	7	7	1	1
6/16	4	2	0	0	0	Calm	Calm	9	8	7	7	1	1
6/17	1	1	0	0	0	Calm	Calm	n	17	8	8	1	1

[a] Sky Codes
n - No observation
1 - Clear sky, < 1/10 cloud cover
2 - Cloud cover , 1/2 sky
3 - Cloud cover > 1/2 sky
4 - Completely overcast
5 - For or thick haze

[b] Precipitation Codes
n - No observation
0 - No precipitation
Tr - Trace
A - Intermittent rain
B - Continuous rain
C - Snow
D - Snow and rain
E - Hail
F - Thunderstorm

[c] Water Color Codes
n - No observation
1 - Clear
2 - Light Brown
3 - Brown
4 - Dark brown
5 - Murky or glacial

Table 5. EchoView® data processing parameters used for the site 1 and 2 analysis, 2008.

Echo integration settings	
Data analysis threshold	-40 dB
Analysis range	Suface to 2.0 m below surface
Analysis cell size	0.5 m depth by 1 minute intervals
Single target settings	
Data analysis threshold	-60 dB
Analysis range	Surface to 2.0 m below surface
Pulse length determination level	9 dB below peak
Minimum normalized pulse length	50%
Maximum normalized pulse length	150%

Table 6. Transducer pool calibration and offset used for data processing, 2008.

Transducer	Measured	Expected	Offset	EV Gain
S^1-T1	-27.9	-40.0	12.1	41.2
S^1-T2	-27.6	-40.0	12.4	41.3
S^1-T3	-25.5	-40.0	14.5	42.4
S^1-T4	-26.2	-40.0	13.8	42.0
S^1-T5	-30.1	-40.0	9.9	40.1
S^1-T6	-26.4	-40.0	13.6	41.9
S^1-T7	-25.8	-40.0	14.2	42.2
S^1-T8	-27.1	-40.0	12.9	41.6
S^2-T1	-27.2	-40.0	12.8	41.5
S^2-T2	-26.8	-40.0	13.2	41.7
S^2-T3	-29.3	-40.0	10.7	40.5
S^2-T4	-24.9	-40.0	15.1	42.7
S^2-T5	-27.2	-40.0	12.8	41.5
S^2-T6	-26.2	-40.0	13.8	42.0
S^2-T7	-39.3	-40.0	0.7	35.5

FIGURES

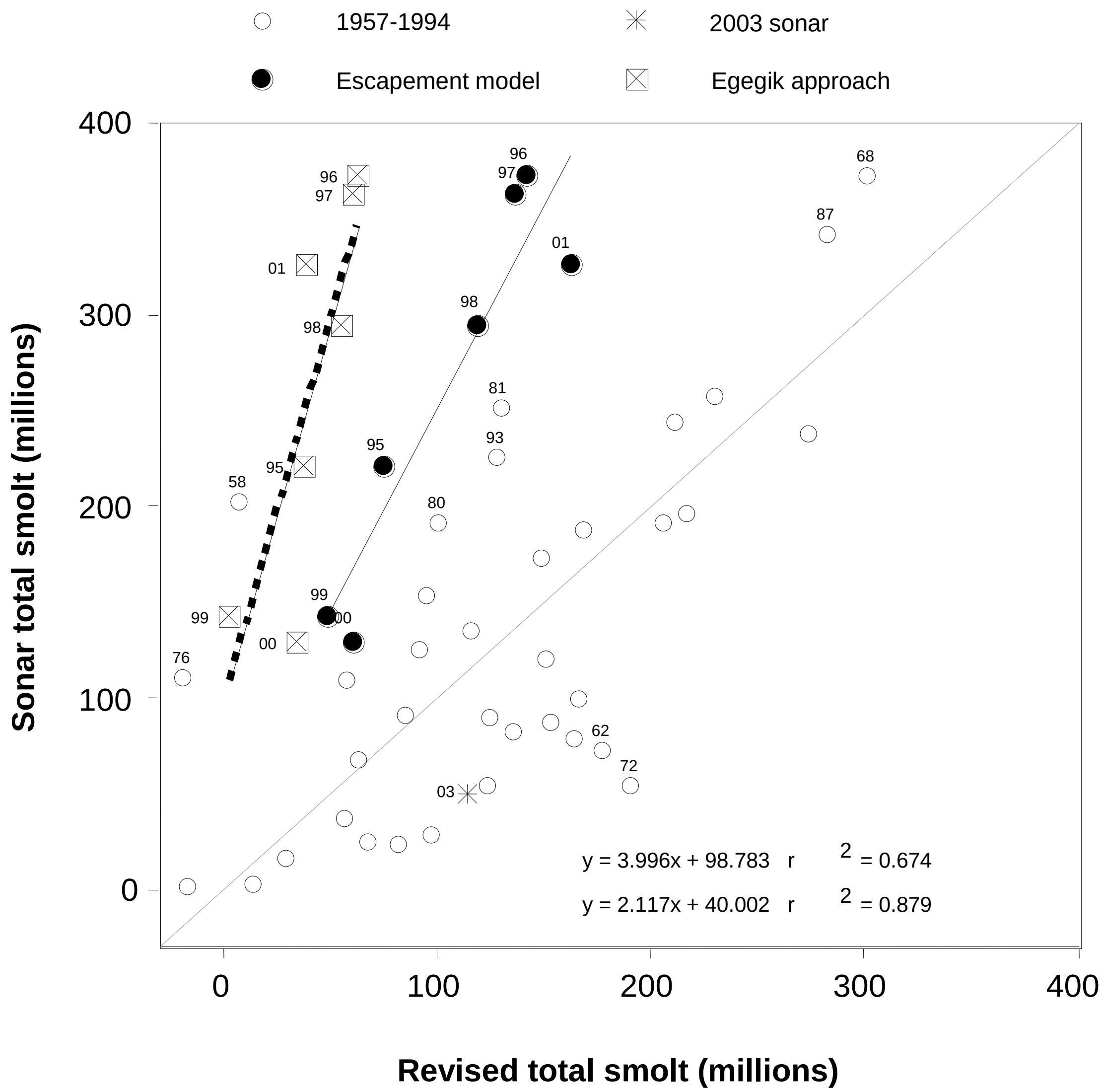

Figure 1. Relationship between total smolts estimated by Bendix sonar and two statistical models (adult escapement and lake temperature, and Egegik smolt-to-adult survival rates). The two regression lines are fits to the 1995-2001 Bendix estimates to the two model results for those years. Open circles represent abundance estimates from 1957-1994 developed from the Bendix sonar and fyke net catches (y-axis) compared to the modeled abundance (using the Egegik model). Figure taken directly from (and the methods described in) the Appendix of Ruggerone and Link (2006).

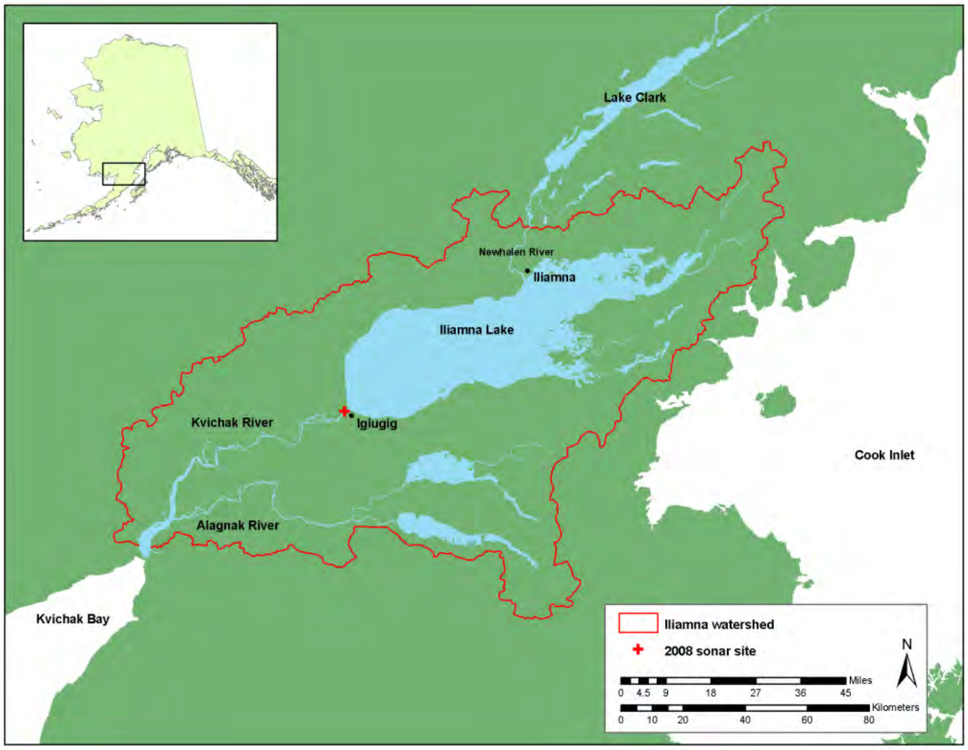

Figure 2. Map of the Iliamna watershed in Southwestern Alaska showing the location where sonar systems operated near the village of Iguigig, 2008.

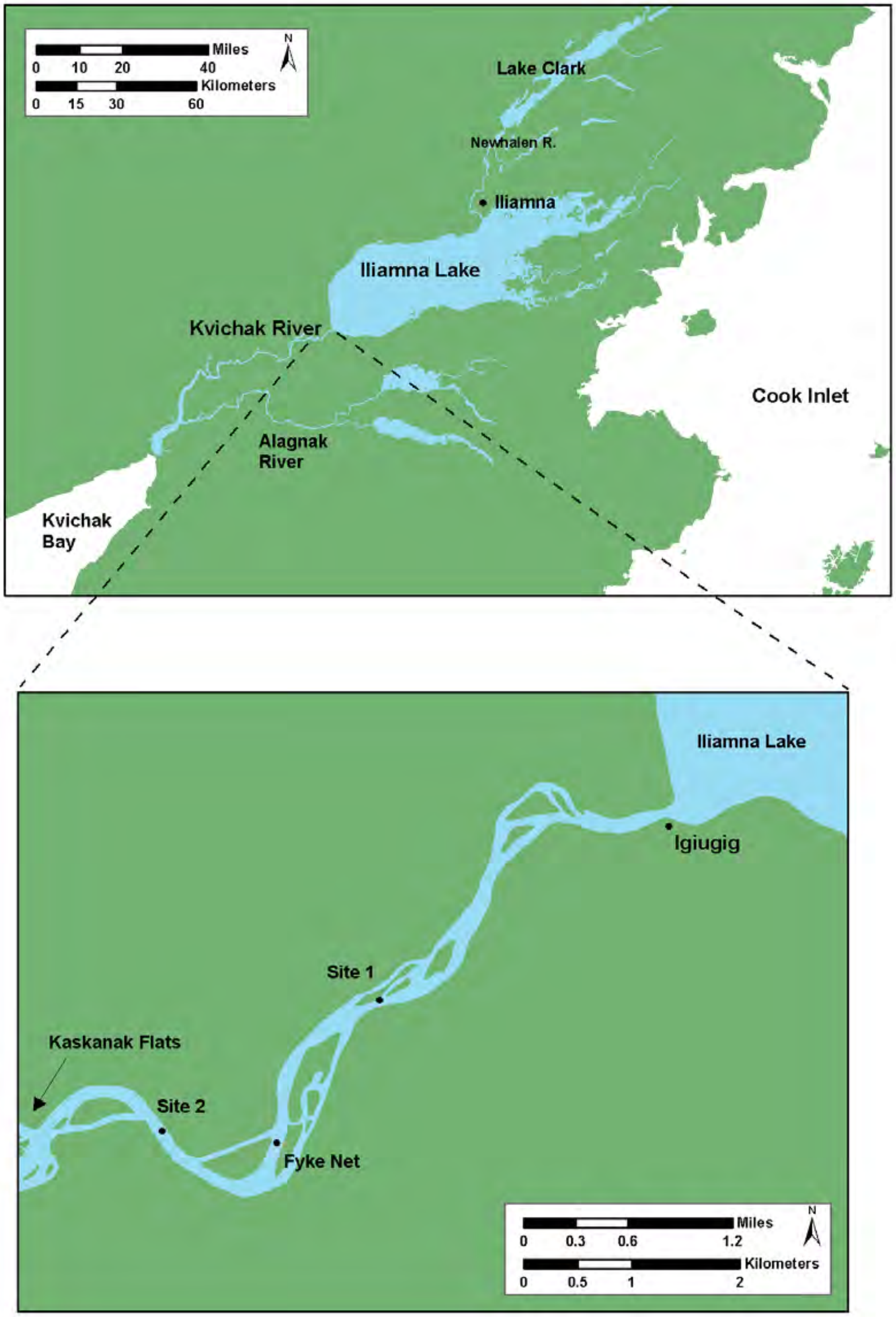

Figure 3. Map of study site on the Kvichak River showing locations of sonar sites 1 and 2, plus the fyke net location used for smolt sampling, 2008.

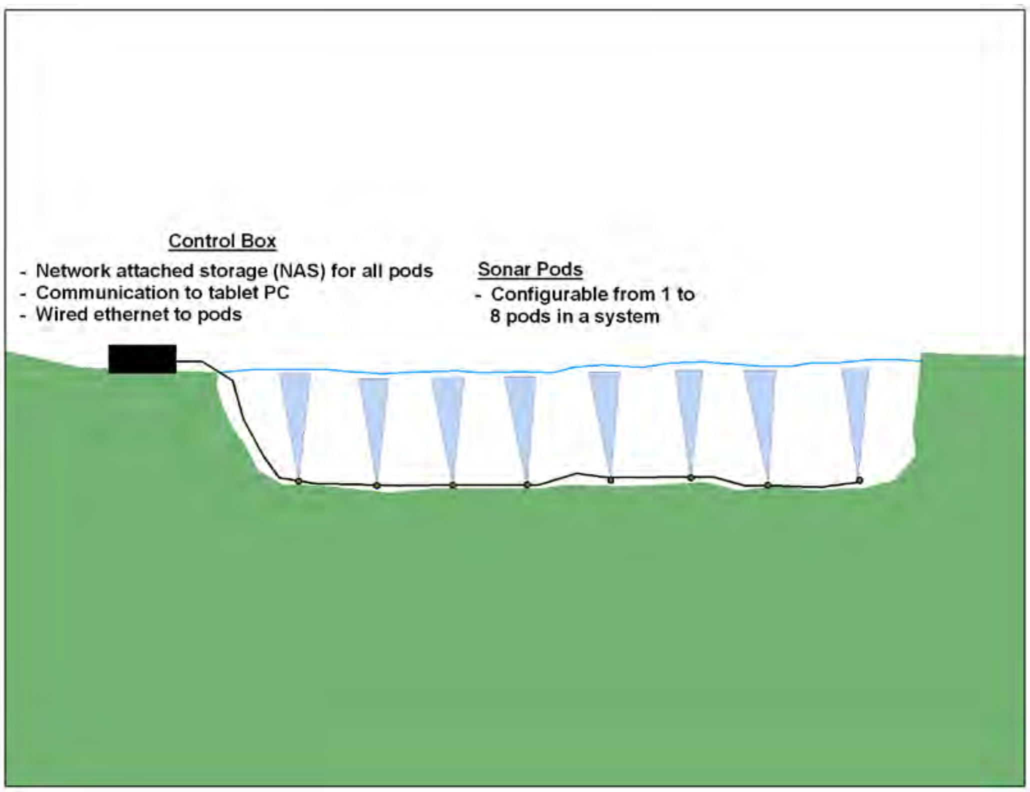

Figure 4. Conceptual drawing of smolt sonar designed for rivers in the Bristol Bay region, 2008.

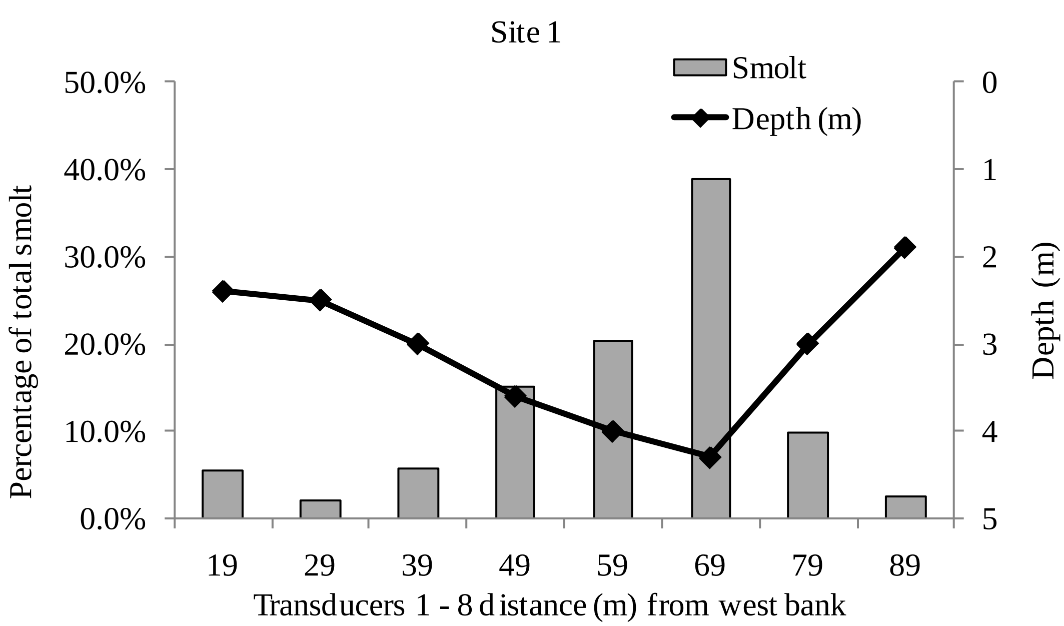

Figure 5. Site 1 bottom profile (based on transducer depth) plus cross river distribution of smolt detected, 2008.

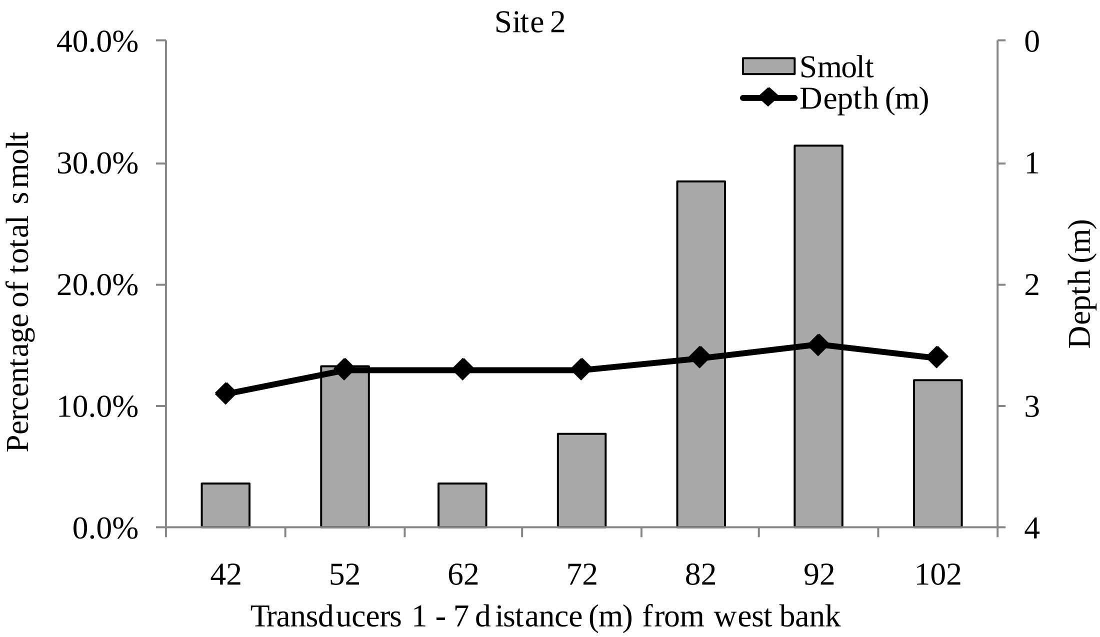

Figure 6. Site 2 bottom profile (based on transducer depth) plus cross river distribution of smolt detected, 2008.

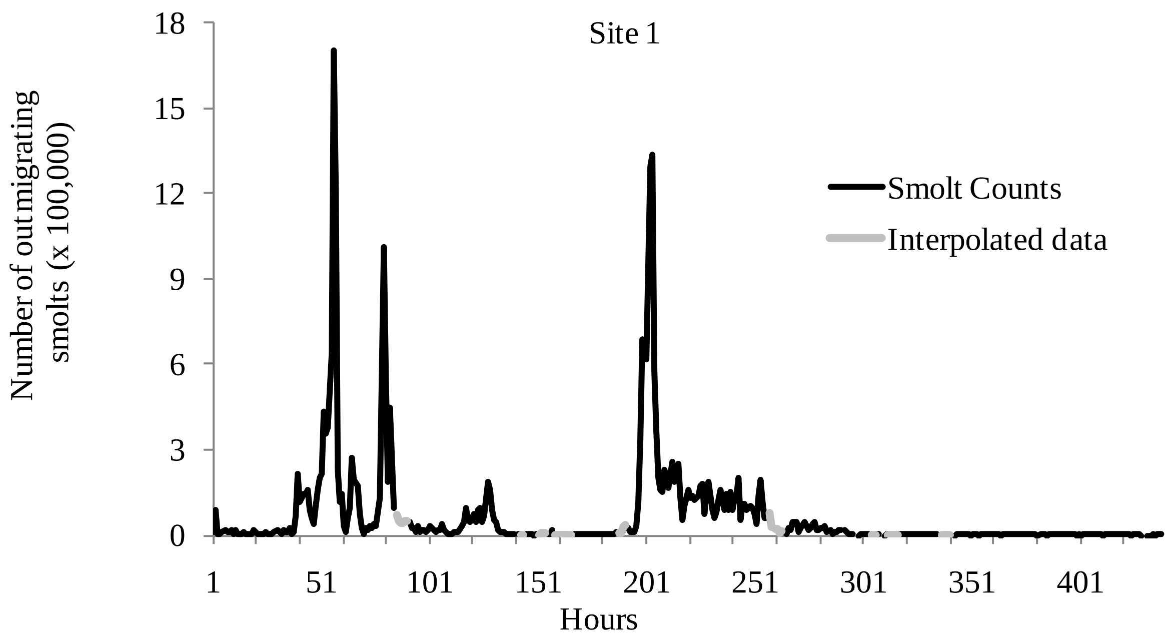

Figure 7. Hourly smolt estimates at Site 1 showing periods of missing data via linear interpolation, 2008.

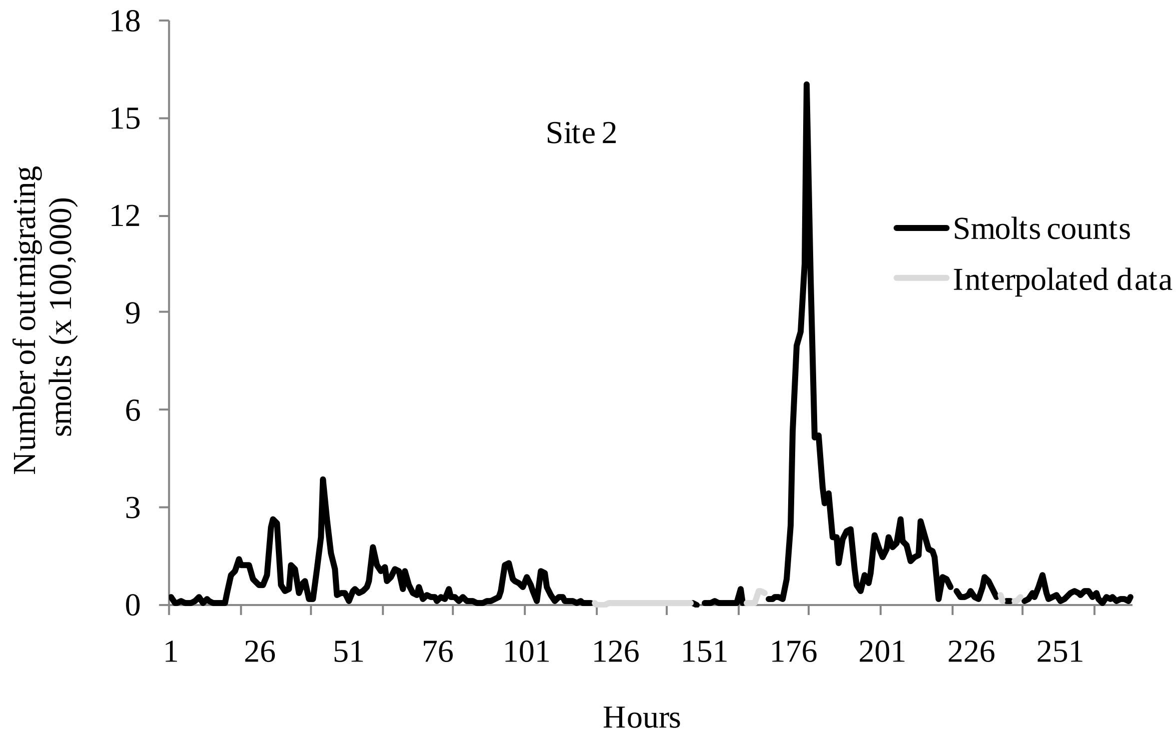

Figure 8. Hourly smolt estimates at Site 2 showing periods of missing data via linear interpolation, 2008.

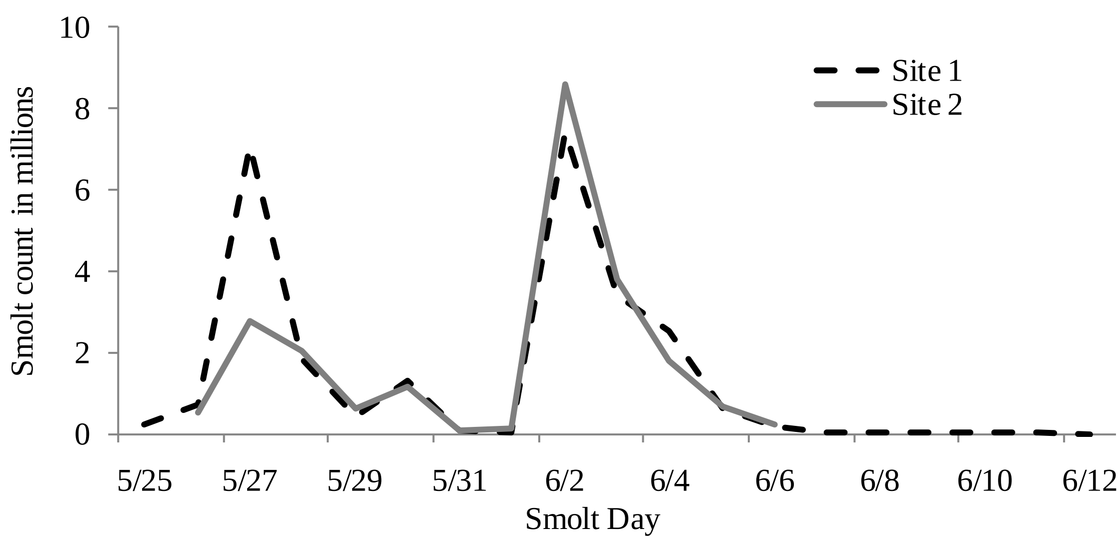

Figure 9. Estimated daily smolt abundance at sonar sites 1 and 2 on the Kvichak River, 2008.

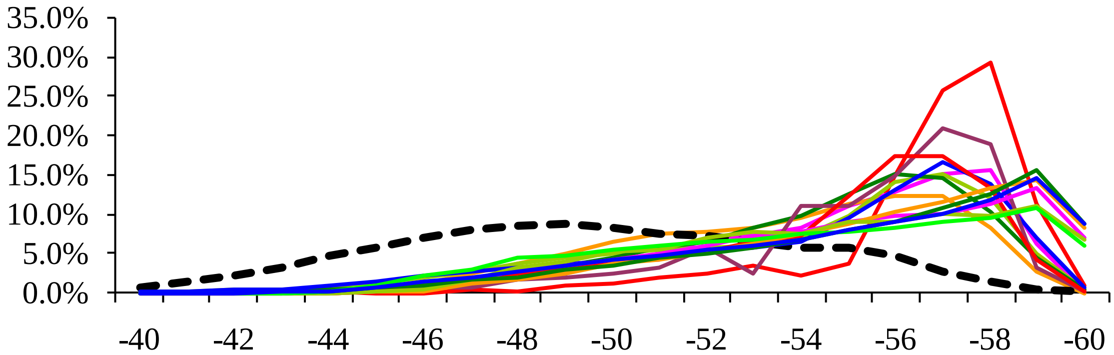

Figure 10. TS distribution of single targets from each transducer (dashed line is transducer 6 at site 1) for the first week of sampling, 2008.

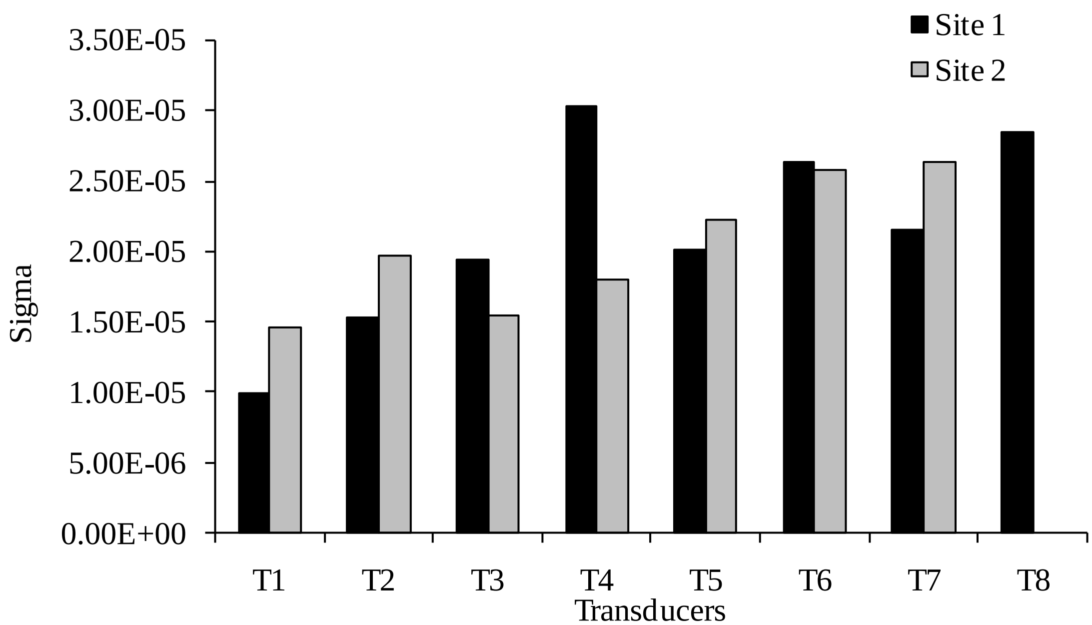

Figure 11. EMS deconvolution estimates of sigma by transducer, 2008.

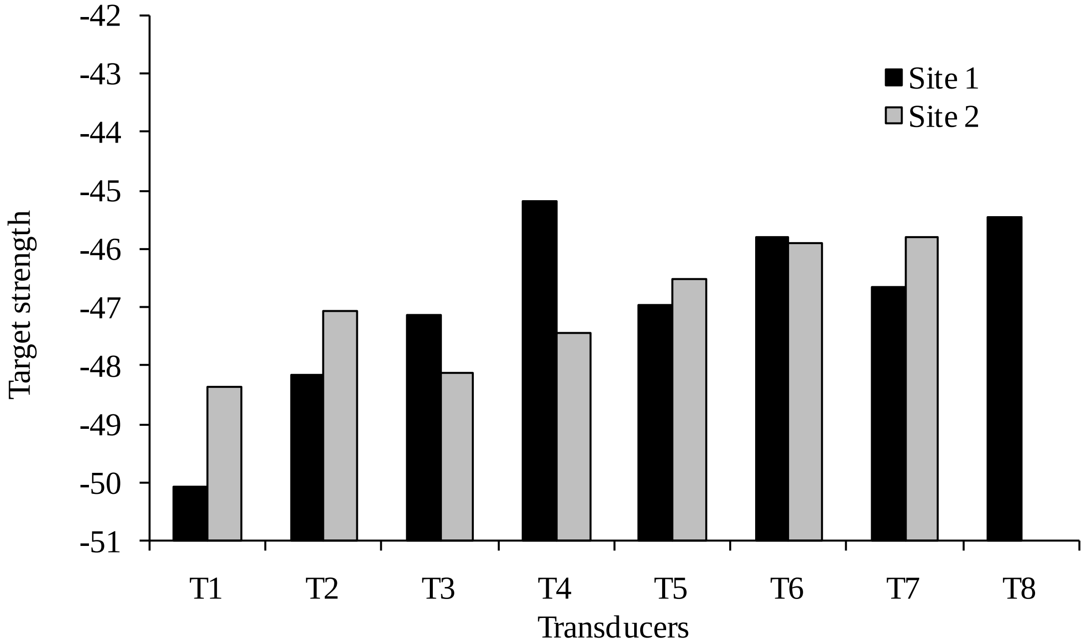

Figure 12. EMS deconvolution estimates of TS by transducer, 2008.

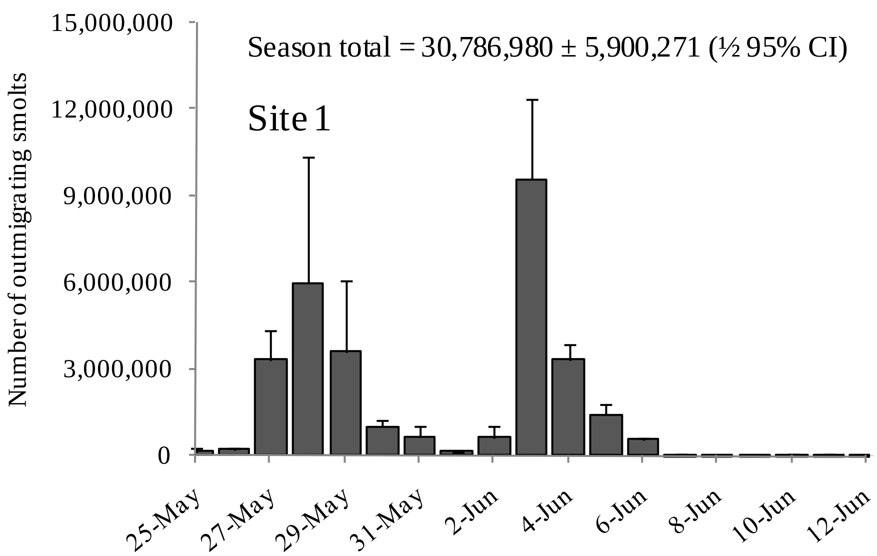

Figure 13. Estimated daily and annual abundance of smolt at Site 1 on the Kvichak River, 2008.

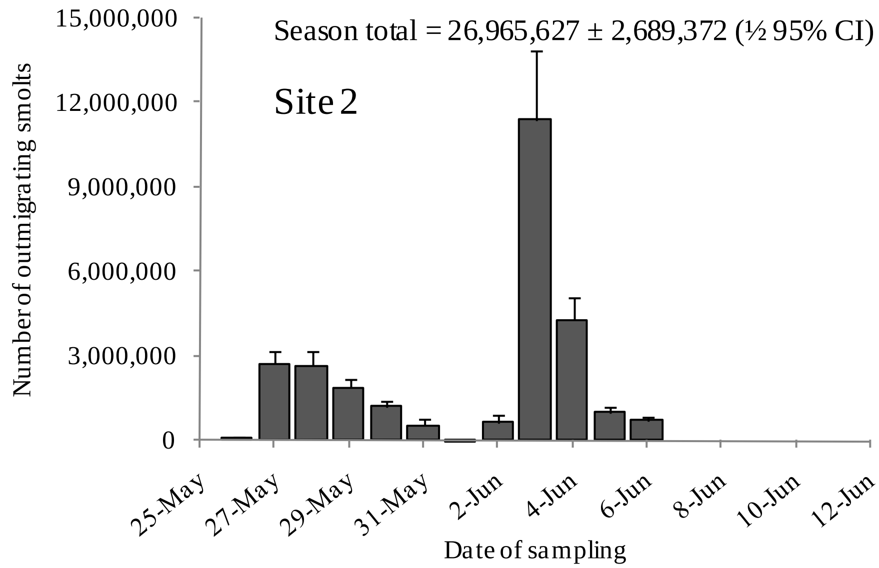

Figure 14. Estimated daily and annual abundance of smolt at Site 2 on the Kvichak River, 2008.

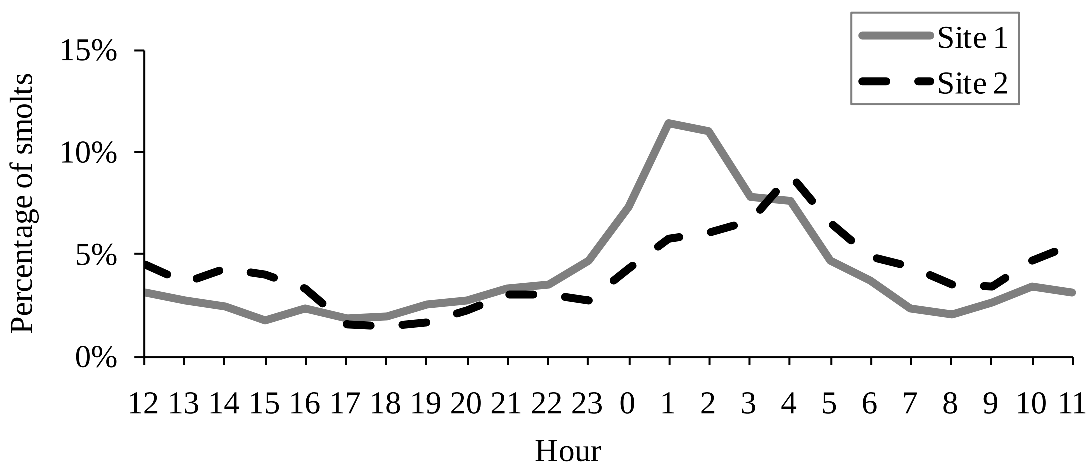

Figure 15. Percentage of total smolt detected by hour at sonar sites 1 and 2 on the Kvichak River, 2008.

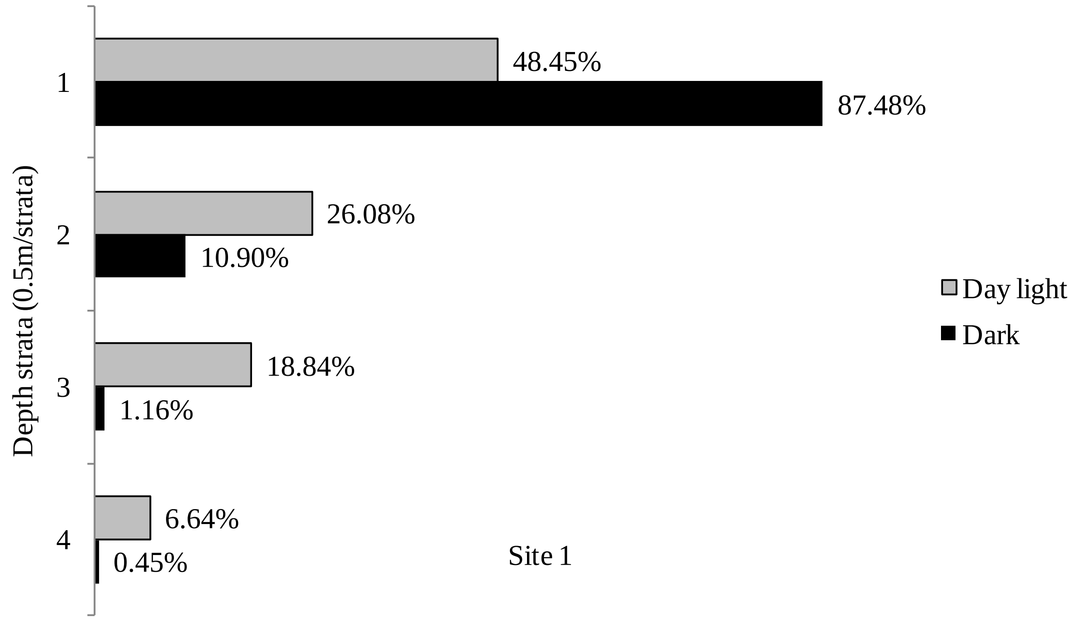

Figure 16. Site 1 vertical smolt distribution by 0.5 m strata for daylight and dark hours on the Kvichak River, 2008.

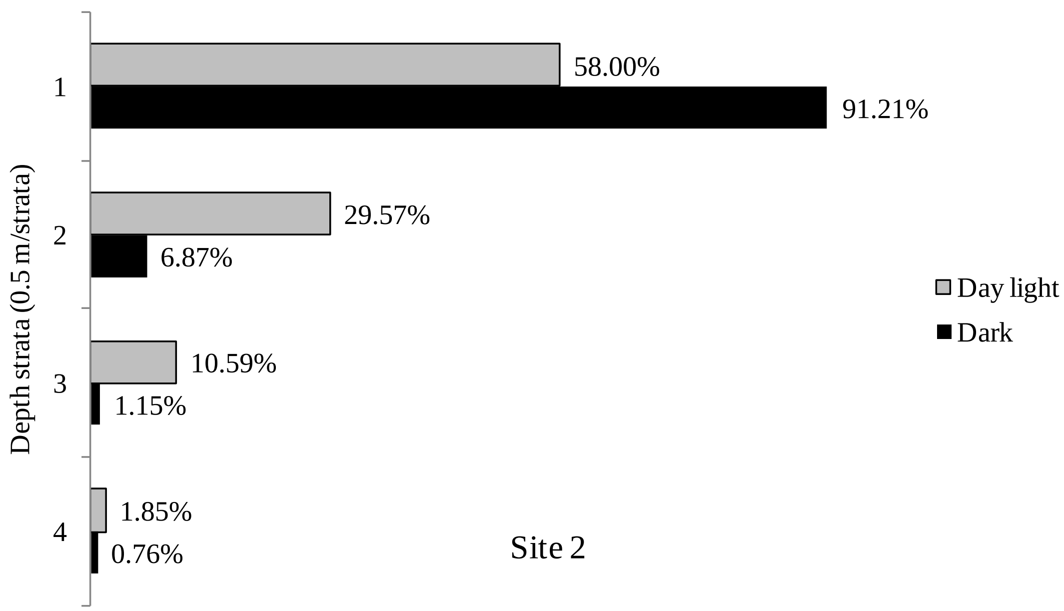

Figure 17. Site 2 vertical smolt distribution by 0.5 m strata for daylight and dark hours on the Kvichak River, 2008.

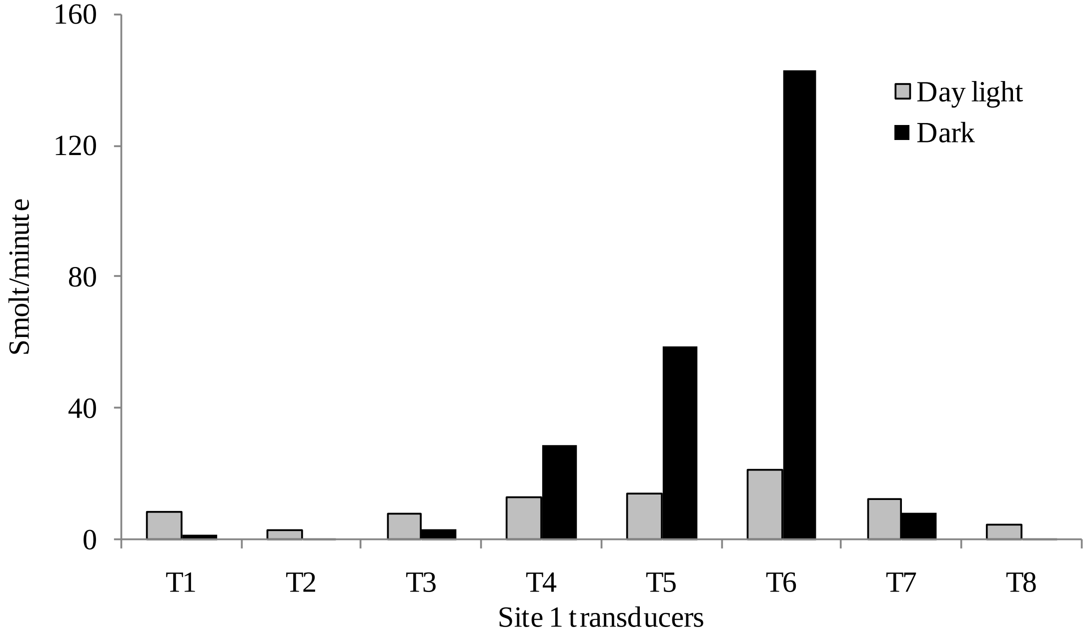

Figure 18. Smolt passage/minute at each transducer for Site 1 during daylight and dark hours on the Kvichak River, 2008.

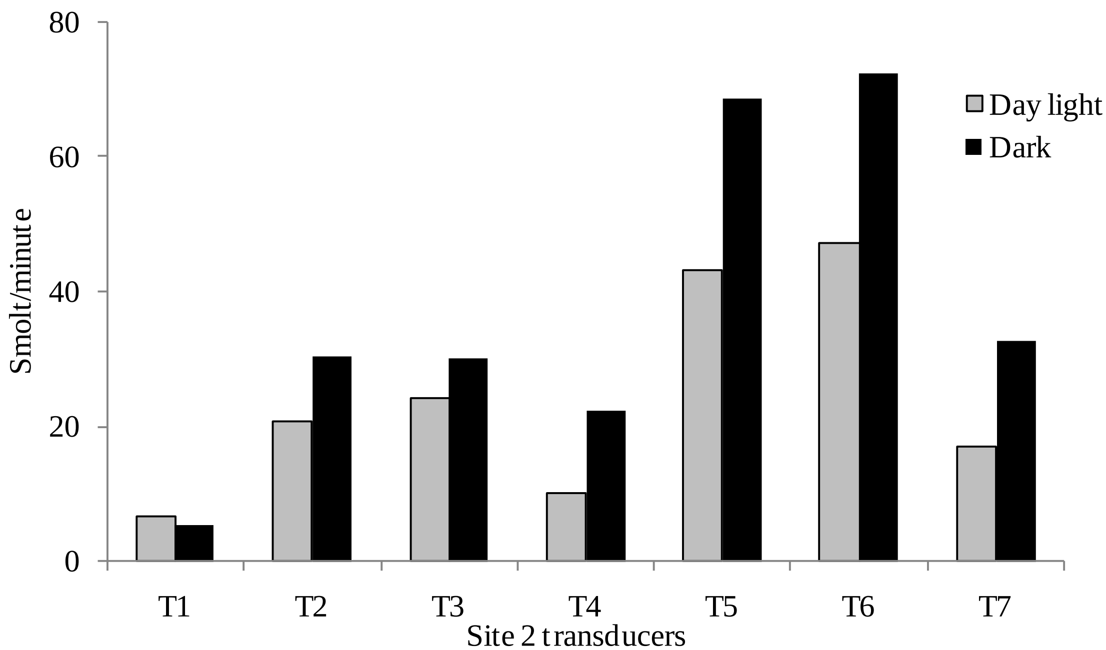

Figure 19. Smolt passage/minute at each transducer for Site 2 during daylight and dark hours on the Kvichak River, 2008.

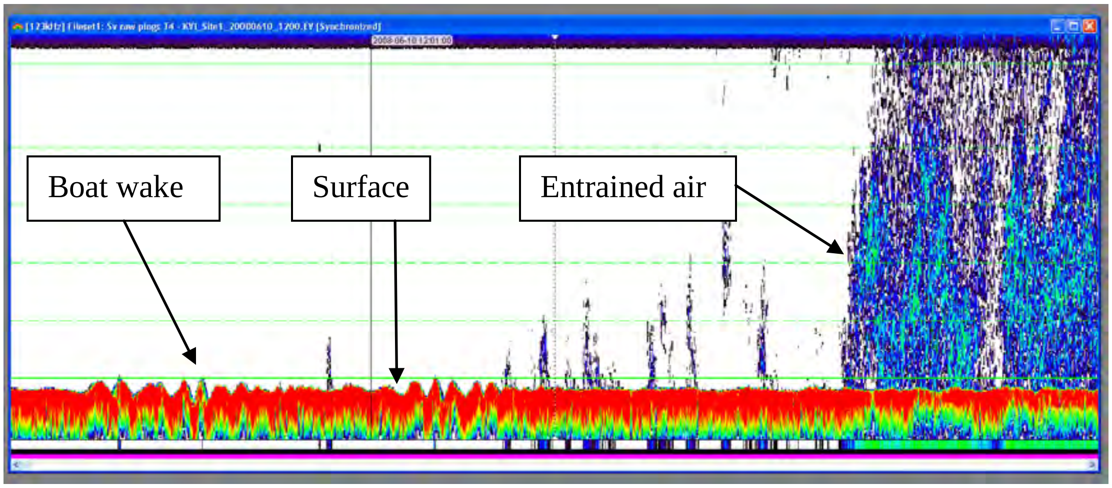

Figure 20. Echogram of noise generated by boat passage on 10 June, 2008 at Site 1, note the boat wake that precedes the noise created by entrained air from the propeller. (EchoView® 4.5 software displays echogram of smolt data as “upside down” due to up-looking transducers.)

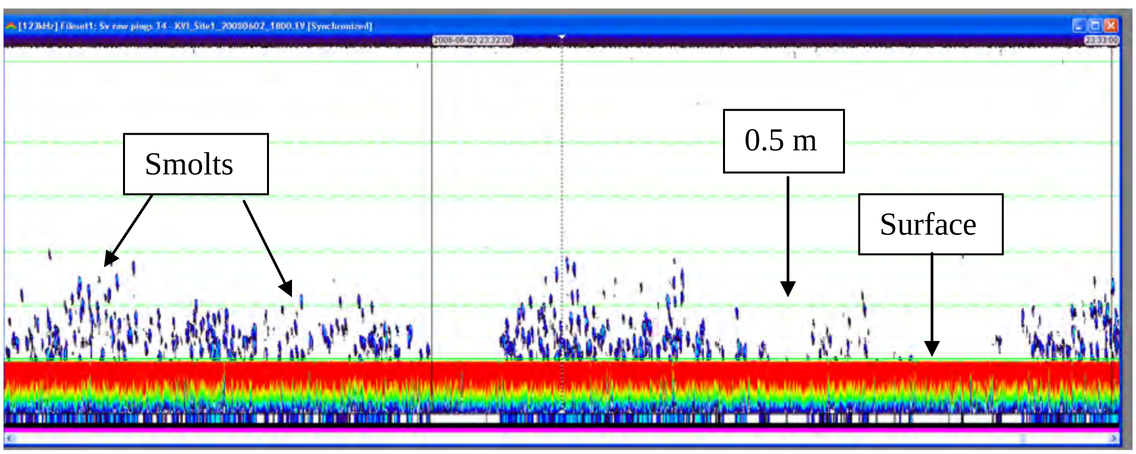

Figure 21. Echogram of smolt detected 2 May, 2008 at Site 1. Dashed green lines signify 0.5 m depth strata and show majority of smolts are in the upper 1.0 m. (EchoView® 4.5 software displays echogram of smolt data as “upside down” due to up-looking transducers.)

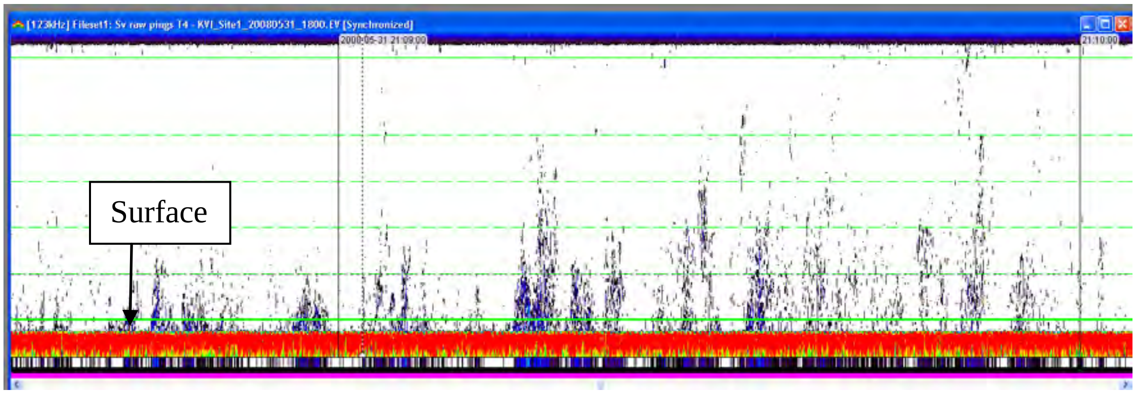

Figure 22. Echogram of a wind event (~ 40 mph) detected on 31 May, 2008 at Site 1. (EchoView® 4.5 software displays echogram of smolt data as "upside down" due to up-looking transducers.)

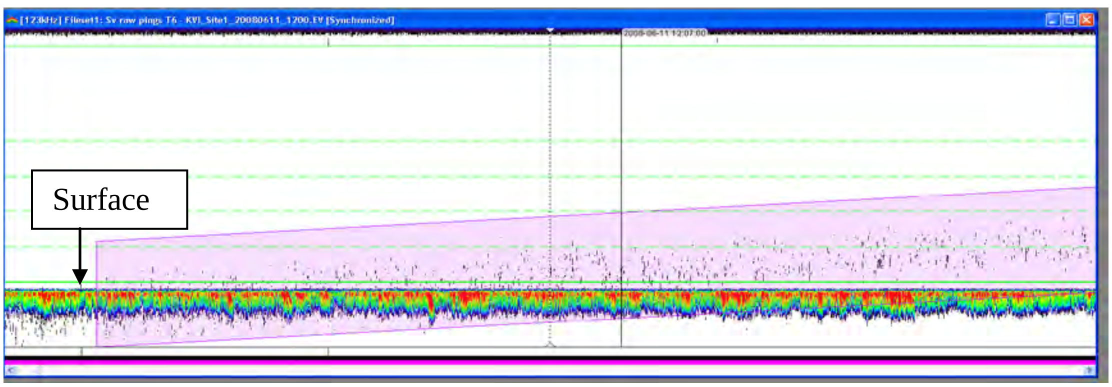

Figure 23. Echogram of cross-talk (shown in highlighted purple region) between transducer six and seven, 2008. (EchoView® 4.5 software displays echogram of smolt data as "upside down" due to up-looking transducers.)

PHOTO PLATES

Photo 1. Up looking transducer mounted on sled with attached power and tow cables used in the Kvichak River, 2008.

Photo 2. Sonar array of 8 pods staged at Site 1 on the river's west bank with the WeatherPORT tent in the background, 2008.

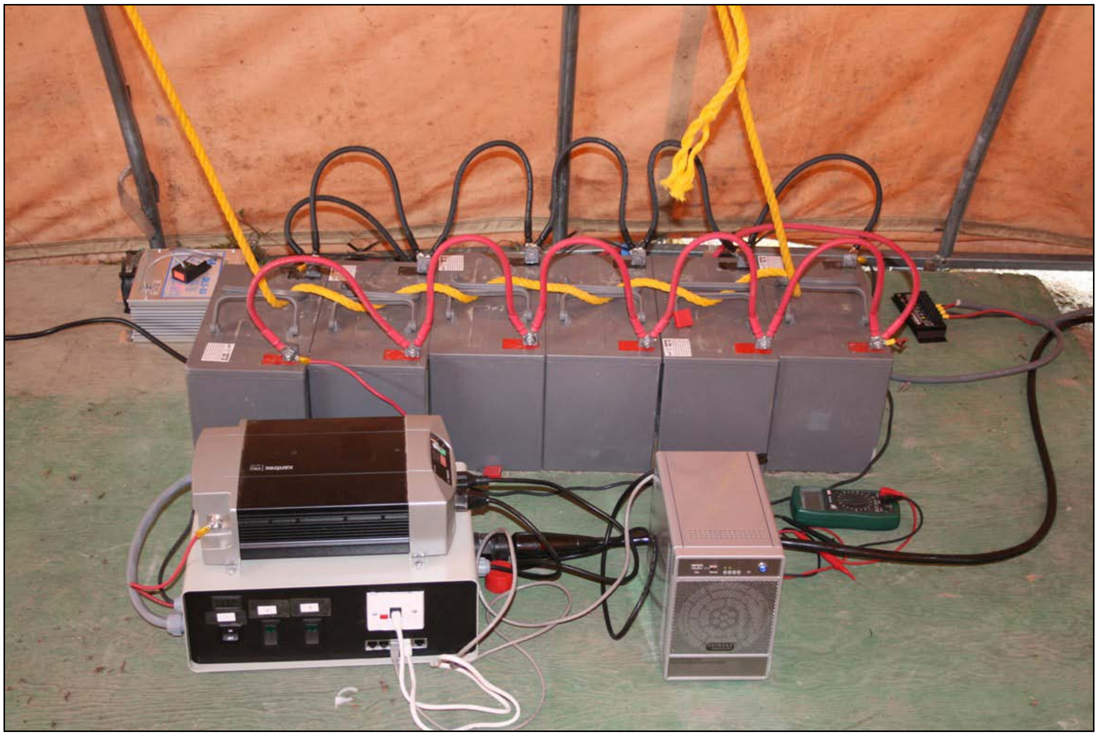

Photo 3. Control box, NAS and power source for the site 1 sonar system housed in Weather Port tent, 2008.

APPENDIX A

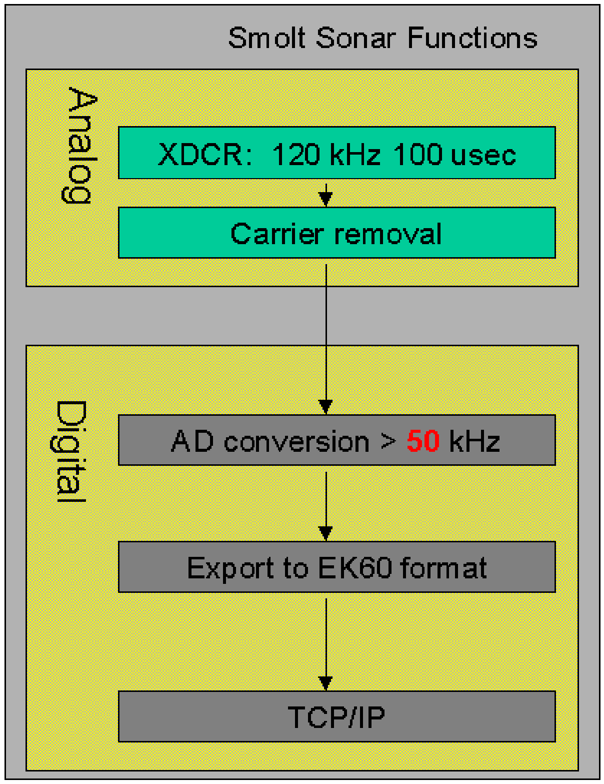

Figure A-1. Functional overview of a sonar pod used on the Kvichak River in 2008.