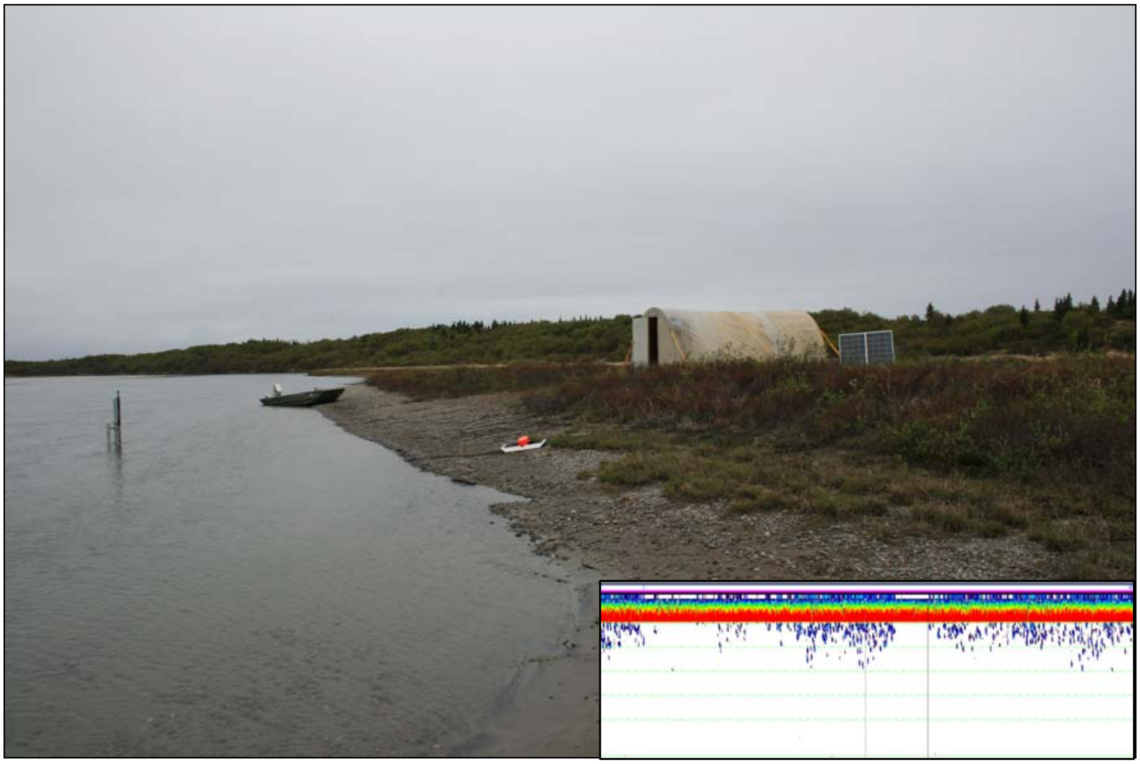
Estimates of hourly, daily, and seasonal sockeye salmon smolt abundance on the Kvichak River in 2009



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Estimates of hourly, daily, and seasonal sockeye salmon smolt abundance on the Kvichak River in 2009

by

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ABSTRACT

We estimate the hourly, daily, and seasonal abundance of sockeye salmon (*Oncorhynchus nerka*) smolts on the Kvichak River in 2009. Two independent up-looking sonar arrays were operated on the Kvichak River during the 2009 sockeye salmon smolt run. Site 1 was operated from 26 May to 14 June and Site 2 from 26 May to 13 June. At Site 1, 7 sonar pods were spaced at 10 m intervals along the bottom in a row perpendicular to the bank and 8 sonar pods were placed in a similar configuration 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 by linear interpolation for the unsampled area between pods. Likewise, we interpolated over the distance between the end pods and the river banks, which were assigned values of zero passage. At Site 1, 3.0% total river width (at the surface) was ensonified and data from 90% of the season were used to develop an abundance estimate for the entire season, (ice and environmental noise accounted for the remaining 10% of the operational period). At Site 2, 2.1% of the river surface was ensonified and data from 89% of the operational period were used to estimate the abundance. Where data were missed, pod-specific hourly estimates were developed by linear interpolation between adjacent hours; uncertainty and bias caused by interpolation was considered nominal. The actual sampling rate of the smolt run was greater than 3.0% and 2.1% at sites 1 and 2 respectively, because fish do not travel in a large portion of the unsampled river width. 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 smolts was estimated to be 35,247,209 (95% confidence limits = 32,164,876—38,329,542) at Site 1 and 38,755,938 (33,677,223—43,834,653) at Site 2. We concluded that the Site 1 estimate of 35.2 million (32,164,876 – 38,329,542) was the best estimate for sockeye salmon smolt abundance in the Kvichak River in 2009. This is 13% higher than the previous year's abundance estimate of 30.8 million obtained on the Kvichak River using the same methods.

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INTRODUCTION

This report documents the ongoing testing of an up-looking sonar system used to enumerate salmon smolts in rivers of 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 and 2009. The smolt sonar represents a re-introduction of a technology and methodology that has a long history in Bristol Bay. Wade et. al. (2010) provides background on the history of the Bristol Bay smolt program as well as offers some insight into the rationale behind the design of the current system. They also documented the design of the new sonar system, testing of it on the Kvichak River in 2008, and provided hourly, daily, and seasonal abundance estimates for the 2008 smolt run from two independent but identical sonar systems.

In this report, we document the ongoing testing and operation of the two sonar systems on the Kvichak in 2009 and provide two sets of hourly, daily, and seasonal abundance estimates of sockeye salmon smolts. The data collected during the first two years of this project will function as a foundation that can be built upon to broaden our understanding of both the fresh and saltwater stages of the sockeye salmon life history. As the adults begin to return over the next several years we will begin to develop a smolt/adult relationship that can improve our understanding of what the actual smolt estimates mean in terms of adult returns. Long term monitoring of smolt production on the Kvichak River could also provide a means of tracking changes in freshwater productivity and ocean survival.

OBJECTIVES

The objectives of the 2009 study were to:

1. Operate two identical sonar systems on the Kvichak River and assess the ability of the systems to characterize the hourly, daily, and seasonal abundance of sockeye salmon smolts migrating to sea; and
2. Operate side-looking and up looking split-beam sonar to verify data collected by the sonar.

STUDY AREA

The Iliamna watershed, located in southwest Alaska, drains an area of 16,830 km^2 (Figure 1). This watershed includes Lake Clark and Iliamna Lake which is the largest lake in Alaska, with an area of 2,622 km^2 and a volume of 115.3 km^3 (Quinn 2005). 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 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. 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.

Mean annual discharge for the Kvichak River collected near Igiugig from 1968 to 1986 ranged from 361 m^3/s to 729 m^3/s and averaged 503 m^3/s (USGS 2008). Peak discharge occurs during August, September, and October; and 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 breakup date averaging 13 May for the years 1970 to 2001 (Table 1, Crawford and Fair 2001).

In the initial 1.2 rkm 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 1). 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). This study will utilize the upper site for one sonar location and operate the second sonar 2.4 rkm from the outlet of the lake.

METHODS

Sonar Design

A concept of operation for the smolt sonar is provided in Figure 2. Each up-looking sonar node (pod) was joined through a “daisy chain” where each pod is 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 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,WA).

Control Box

The control box provided an interface for powering and communicating with the sonar pods, managed the stored data, and monitored 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 through 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 raw data were received from the pods, it was 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 sonar systems were deployed on the Kvichak River in 2009 (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. Data files were collected continuously and then stored in 10 minute blocks on the NAS. All data collected at each site were stored in 1 terabyte NAS configured 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 shore in WeatherPort tents (Photo 3).

In addition to the up-looking sonar array, two other sonar configurations were operated at Site 1 for a portion of the season. In order to verify individual smolt target strength (TS) obtained through the single beam transducers, one split-beam sonar was operated at Site 1 for the first few days of the smolt outmigration. For verification of smolt cross-river distribution a side-looking sonar was operated at Site 1 for the entirety of the run (Photo 4).

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.

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 diameter wire rope so as not to put any stress on the power and data cable (Photo 1). The first sled had a 6.1 m long section of 6.4 mm diameter 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 2). Prior to deployment, a 7.9 mm diameter 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.

After the sonar systems were set up and operating, data were collected 24 hours per day for the entire season. Each system was checked twice daily, generally at 0800 hours 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.

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.

Climate and hydrologic data were recorded at the boat launch near the ADF&G facilities in Igiugig (Table 2). 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 hours 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 2009 smolt sonar was operating, BBSRI worked cooperatively with ADF&G to sample smolts at a location on the river just below the two sonar sites (Figure 1). 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 2009, an incline plane trap was 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

In 2009, the data collection scheme was updated so that the individual data files from each transducer were concatenated as they were being processed 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 ice, boat passage through the sample area, wind/rain events which injected bubbles into the water column, and any cross-talk among transducers. Data were processed in 1-h intervals; therefore, if noise occupied greater than 10% of an hourly bin, then the entire hour of data were removed from analysis. For the regions where data were removed, the estimates were linearly interpolated based on the values prior to and following these events.

Smolt Abundance Estimate

Requirements for a Reliable Abundance Estimate

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 smolts at a given time must be multiplied by the velocity of the smolts through the sonar beam. For this project the velocity of the smolts was assumed to be equivalent to the velocity of the water, which was measured three times over the course of the study. This assumption was based on the work of Maxwell et al. (2009), who used 3-D video techniques to estimate that smolt speed (over the ground) was near the current velocity. If smolts swam faster than the water velocity, then our estimates would 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 and thus it would be biased low. The vertical distribution of smolts varies with time, but it has been found that the majority of fish utilize the upper 1 m of water, and the bulk of those fish 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 of smolts is similar among years. However, this could be monitored, at least in part, using the system we 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 would 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.

Abundance Estimates

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. Because of the dense schooling behavior we observed in this study we used echo integration to obtain the abundance estimates. Echo integration 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 TS.

After excluding noise events from the data, the files were processed with EchoView® 4.5 to export echo integration values by 1-h intervals and 0.5 m depth strata below surface for the top 2.5 m of the water column (Table 3). Additionally, single target detections from each transducer were exported to obtain uncorrected TS values. For both sonar sites, single target detections were obtained from each transducer in order to obtain a scaling factor for echo integration. Contamination of single targets occurred frequently, and could 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, which resulted in a secondary peak in the TS distribution plot. These multiple targets were removed by selecting sample periods for analysis when smolt densities were lower (e.g., 0500-0800 hours) or from transducers with low densities to estimate the scaling factor. 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-h 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, 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, $\overline{T}_{.j}$ =

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. Note that the estimates of variance include uncertainty due to subsampling the water column, but not the 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 4).

Sonar Specifications for up-looking sonar pods

All transducers were tested and beam patterns measured by the manufacturer prior to purchase. Based on the beam patterns, the side lobes were relatively low averaging approximately -30 dB. The calculated near field zone was 0.71 m from the face of the transducer, and the dead zone began 4.9 cm from the surface of the water. 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 approximately 0.5 cm from the surface. The average depth from the transducer to the surface was approximately 3.0 m. With the 7.5 degree beam at this range, the diameter of the beam was 0.39 m. All sonars were configured to collect acoustic data using the following parameters: 0–5 m sample range, 0.06 s ping interval, and 0.064 msec transmitted pulse duration.

Secondary Sonar Equipment

In order to verify data collected by the up-looking sonar, both a single-beam, side-looking and split-beam, up-looking sonar were operated at Site 1. The single-beam sonar, used to asses cross-river distribution, was a Simrad® (Lynnwood,WA) model ES60 200 kHz GPT with a 3 degree beam angle. The sampling parameters for this sonar were set at a ping interval of 0.14 s and pulse duration of 0.256 msec. The split-beam sonar was used to verify the TS collected from the single beam up-looking sonar pods. This sonar was a Simrad® EK60, 120 kHz GPT with a 4 x 10 degree beam angle operated at a 0.06 s ping interval and 0.064 msec pulse duration.

Power Requirements

Each sonar required approximately 65 W to operate; with the NAS requiring ~ 40% of this power. The overall power requirement for Site 1 was increased due to the side-looking and split-beam sonars operating off the same energy source. For Site 1 a total of 10, 12 V 100AH batteries were used and Site 2 was operated with six batteries. Each system required charging with the generator at least once every 24 h. Solar panels maintained the 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.

Sonar Site Selection

Based on recommendations made after the 2008 smolt season, Site 1 remained in the same place and Site 2 was moved upriver in 2009 (Figure 1). Site 1 was 103 m wide and located 3.5 rkm downstream of the outlet from Lake Iliamna. This was approximately the same site used for the smolt sonar studies conducted by Maxwell et al. (2009) from 2002 to 2004. Site 1 was on a slight bend in the river with the steeper east bank being the outside bend. The WeatherPort that housed the power and control box for Site 1 was located on the west bank. The bottom profile of Site 1 was characterized by a gently sloping west bank to a maximum depth of 4.3 m, 69 m offshore, followed by a steep incline to a 2.0 m deep bench at 89 m offshore then a gradual incline to the opposite bank (Figure 3).

Site 2 was 119 m wide and located 2.4 rkm downstream of the outlet of Iliamna Lake. This was approximately the same location where ADF&G placed their towers used for counting adult sockeye salmon. The east bank of Site 2 had been an island before the river channel changed, but now the narrow channel on the east side of the island floods only during periods of very high water (and not typically in the spring). The WeatherPort that housed the power and control box for Site 2 was located on the east bank. The bottom profile of Site 2 was characterized by a gently sloping east bank that dropped off around 20 m offshore to a maximum depth of 4.3 m, where it remained around 4.0 m until approximately 20 m from the west bank where it rose quickly (Figure 4).

The secondary sonars (side-looking and split beam) were set at the Site 1 location. The side-looking sonar was placed 10 m off the west bank approximately 20 m upriver of the up-looking sonar array. The split-beam sonar was placed 10 m upstream of the up-looking array between the first two sonar pods. The secondary sonars began operation on 28 May. The side-looking sonar operated for the duration of the study and the split-beam sonar operated until 31 May. During the ice flow event on the evening of 31 May, the side-looking sonar was knocked out of alignment for roughly 12 hours.

Sonar Deployment and Operation

Deployment of the sonar array was dependant on ice break up of Iliamna Lake and the absence of ice in the Kvichak River. Reports from air taxi operators indicated that the ice was starting to break up on 15 May (Table 1). Crews were mobilized on 17 May from Anchorage to King Salmon. During the flight the plane crossed Lake Iliamna and it was observed that 75% of the lake was still covered with ice. Equipment and crews were flown from King Salmon into Igiugig on 18 May and the sonars and smolt nets were prepared for deployment. As the ice began to lighten, WeatherPort tents were put in place and sonars were staged for deployment (Photo 2). On 23 May the ice appeared to have stopped and the Site 1 sonar was deployed at 1830 hours. On the morning of 24 May ice began to flow again and the Site 1 sonar was pulled to avoid being damaged. Ice continued to consistently flow until 26 May, when on this date both sonars were deployed.

On 26 May, the Site 2 sonar was deployed first and began operating at 1400 hours. A total of eight transducers [Sonar Site^2–T1 (T1 = 1st transducer from control box) through S^2–T8] were set at 10 m intervals with S^2-T1, 22 m off the east bank and S^2-T8, 27 m off the west bank. Depth of each transducer varied from 1.4 m for S^2-T1 to 4.3 m for S^2-T3 and T4 (Table 5).

The Site 1 sonar was deployed 26 May and began operating at 1730 hours. After retrieval of this sonar on 24 May it was found that the housing of one of the sonar pods had flooded and no longer operated, therefore only 7 transducers (S^1-T1 through S^1-T7) were deployed. At Site1, each transducer was spaced at 10 m intervals with S^2-T1 located 29 m off the west bank and S^2-T7 located 14 m off the east bank. Depth of each transducer varied from 2.2 m for S^1-T7 to 4.4 m for S^1-T5 (Table 5).

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 6). Stage height was not measured; but, 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 at Site1 from 1.28 m/s at S^1-T1 to 1.95 m/s at S^1-T5 and at Site2 from 0.68 m/s at S^2-T1 to 2.02 m/s at S^2-T5.

Data Analysis

Pre-processing

Site 1 analysis included data from 26 May (2100 hours) through 14 June (1400 hours) for a total of 449 h of processed data. Site 2 data were analyzed from the period 26 May (1400 hours) to 13 June (0500 hours) for a total of 408 h of processed data. At Site 2, a total of 8 sonar pods were deployed. Unfortunately, once the sonar began operating communications could not be established with the sonar pod closest to the west bank (S^2-T8). The problem with this pod could not be remedied in the field; therefore, the array remained in place and operated with 7 pods. At 0600 hours on 2 June, sonar pod S^2-T7 tipped over. The crew did not realize this had happened and as a result the Site 2 array operated for the remainder of the season with 6 functioning pods.

Prior to abundance estimates being calculated, the data were reviewed and noise events due to environmental factors were removed. The distinction between noise events and smolts was clear the majority of the time (Figure 5). In the event that the technician could not make a distinction between smolts and noise, that region of data were assigned to bad data. Environmental noise accounted for 10% of the data collected at Site 1 and 11% at Site 2 with the majority of environmental noise being from an ice flow event that occurred at the beginning of the season. The lake was believed to be clear of ice when the sonars were deployed, but late on the evening of 30 May, the river filled with heavy ice flow that continued until the early morning. Data from both sites were contaminated and therefore smolt estimates were linearly interpolated during the flow (Figures 6 and 7). Boat traffic was highest during the first two weeks in May and occurred mostly during the daylight hours. Boat traffic accounted for roughly 3% of the data missed at each site (Figure 8). Wind events made up the majority of environmental noise for the remainder of the season (Figure 9). Slightly more data were removed at Site 2 (6%) due to wind-generated noise than at Site 1 (5%). Although the sites were close enough together to experience the same wind events, Site 2 was located in a portion of the river that did not provide as much protection from wind blowing off the lake as the Site 1 location.

Target Strength

Smolt TS was estimated at each of the individual up-looking sonars at both sites. A sample of targets was filtered to select only individual targets, and then a distribution was generated with 1 dB increments. From the distribution of targets the values were input into the EMS program along with the slope of the beam plot to generate a new distribution of TS and the mean. Due to the slight differences in each transducer the abundance estimates were generated based on the TS of each sonar pod. Target strength was also estimated using the split-beam sonar. Individual smolt TS values obtained by the split-beam were used only for validation and not included in the calculation of the abundance estimate.

Abundance Estimate and Smolt Distribution

The estimated abundance of sockeye salmon smolts from 26 May to 14 June at Site 1 was 35,247,209 (95% confidence limits = 32,164,876 – 38,329,542; Table 7, Figure 10). For Site 2, the estimated abundance from 26 May to 13 June was 38,755,938 (33,677,223 - 43,834,653; Table 8, Figure 10).

Smolt passage by hour of day was the highest after sunset, and remained high until sunrise (Figure 11). For the purpose of this study, daylight was defined as the hours from 0500 to 2259 hours and dark from 2300 to 0459 hours. The peak time of smolt passage for both sites was midnight through 0300 hours; during this period approximately 40% of the total smolt run was accounted for. Smolts migrated during all hours of the day, with daylight hours accounting for about 60% of the total run. There was approximately 321 h of daylight (75% of each day) and 103 h (25%) of dark over the course of the study.

Smolts were detected at all depth strata (2.5 m) sampled at each site. For both sites, vertical distribution varied between daylight and dark hours. During the hours of darkness over 90% of smolts at each site traveled in the upper 1.0 m of water, with 80% and 69% in the upper 0.5 m at sites 1 and 2, respectively (Figures 12 and 13). Smolts traveling during the day tended to move a little deeper in the water column. The proportion of smolts detected 1-2 m deep was higher at Site 2 (41%) than at Site 1 (26%). Few smolts traveled below 2 m deep (< 3% at Site 1 and < 6% at Site 2).

Cross-river distribution was characterized by the percentage of all smolt detected at each transducer. Smolts were detected by all transducers at each site, but were disproportionately distributed across them. At Site 1, roughly 55% of all smolts were detected at two pods (S^1-T4 and S^1-T5) that were located in the deepest portion of the river with higher water velocities (Table 6, Figure 3). Smolts at Site 2 were most abundant in the middle portion of the river, with roughly 55% of them detected on a single pod (S^2-T5) where the highest velocity for that site was measured (1.94 ms^{-1}, Table 6, Figure 4).

DISCUSSION

Distribution

As in 2008, the vertical distribution of smolts in 2009 was primarily in the upper 1.0 m of the water column, and these results were consistent with previous studies (Figures 12-15). For example, video data from 2000 and acoustic data from 2000 and 2001, Maxwell et al. (2009) found that all smolts traveled in the top 1.0 m of water, and the majority of smolts were in the top 0.3 m. Although > 90% of smolts detected at night were in the upper 1.0 m for both years of this study, the overall proportion of smolts in the upper 0.5 m for 2009 was lower than in 2008. In 2008, 87% and 91% were detected in the upper 0.5 m at sites 1 and 2, respectively. This is higher than was observed in 2009 where 79% and 69% were detected at sites 1 and 2, respectively. This may have something to do with the total run being larger in 2009 and as a result the upper portion of the water column could have become overcrowded during times of high passage forcing more smolts to utilize the deeper water.

In both years of this study a diel pattern of vertical distribution was noticed, with smolts being nearer the surface in the late evening through the early morning hours and deeper during the daylight hours. During periods of daylight at Site 1 in both 2008 and 2009 approximately the same proportion (70%) of smolts utilized the upper 1.0 m of water. At Site 2 in 2008 close to 80% of smolts were detected in the upper 1.0 m but at the 2009 Site 2 the fish appeared to swim a little deeper with only half of all smolts found there. The 2009 Site 2 differed considerably from the 2008 location in bottom profile and depth and this may have played a part in the different behavior observed between years. The depth of the 2009 site was consistently > 1.5 m deeper in the portion of river where the majority of smolts were detected allowing the fish to make use of these deeper areas.

Cross-river distribution of smolts at both sites in 2009 was very similar to that observed at Site 1 in 2008 (Figures 3, 16). At Site 1 for both years the majority of smolts tended to utilize the deeper, higher velocity water associated with the thalweg. At Site 1 for 2008 and 2009 the distribution was very consistent with approximately 59% of total smolts detected by the two transducers located 59 m and 69 m from the west bank. Based on recommendations from 2008 the Site 2 location changed in 2009. In 2008, Site 2 had a more uniform river bottom profile resulting in a more uniform distribution of smolts. However in 2009, the new upriver location had higher flows toward the river center where smolts were found in higher densities compared to the near shore areas (Figures 4, 17).

In 2009, a side-looking sonar was operated at Site1 to better characterize the cross-river distribution of smolts. These data indicated that smolts used the faster water associated with the deeper portions of the river. On the evening of 28 May, when overall smolt passage was highest, smolts were observed traveling together in highly concentrated “rivers” of fish that tended to move back and forth across much of the river. Huttenen and Skvorc (1991, 1992) used side-looking sonar and found that at peak passage smolt distribution was dynamic, with the highest concentrations detected at different ranges over the course of each night. This phenomenon may be what was observed in 2009 during the evening of 28 May on the Kvichak River.

Since smolts exhibit a skewed cross-river distribution, it is important to sample as much of the river as possible. In both 2008 and 2009, problems with one or more sonar pods did not allow both sites to operate with a full array that would be capable of sampling the entire river width. Improvements to the sonar systems in 2010 will include building two extra pods to have on site to be used as replacements (if needed). Technicians will also be better trained to recognize and troubleshoot equipment problems in-season (e.g., tipped pods).

In both years of the study a diel fluctuation in the cross-river distribution of smolts was observed where fish were more shore-orientated during the day. At both sites, the rate of smolt passage at the shallower near shore pods was close to or higher than that observed in the same location during the night (Figures 18and 19). Note the Site 2, T7 night time passage far exceeds the daytime passage. This was probably due to the fact the T7 transducer was located in 3.7 m of water where the velocity was higher than the shallower regions.

Abundance estimates

Similar to 2008, the 2009 daily estimates were extremely consistent between the two sites. This suggests that the sonar systems performed an adequate job of estimating or indexing actual fish passage (Figures 20 and 21). In 2009, the abundance estimate at Site 2 was 10% (3.5 million fish) greater than the estimate at Site 1. The highest daily passage of smolts for the season was recorded between 2200 hours on 28 May and 0400 hours on 29 May. The difference between the estimates during this period accounted for a large portion of the difference between the overall estimates at each site.

During the first eight days of the season, abundance estimates at Site 2 were higher than those at Site 1. However, beginning on 2 June, abundance estimates at Site 1 became higher. This change may be attributed to sampling bias due to equipment failure. From 26 May to 2 June both sonar sites were collecting data from a total of seven pods each. On 2 June, S^2-T7 tipped over leaving only six pods collecting data at Site 2. This coincided with the Site 2 estimates being consistently lower than Site 1 for the remaining portion of the season. After the pod tipped at Site 2 smolts were accounted for by interpolating the data between the last pod and the shore line, however due to uneven smolt distribution this method of interpolation may not be suited for such a wide distance.

CONCLUSION

In 2010, BBSRI will invest effort in creating a more robust smolt project that will include improvements to the sonar system and operating protocol. Although the overall abundance estimates from the two sites in 2008 and 2009 were within 12% of each other, it is believed that this difference can be reduced with further improvements to the sonar system and sampling protocol. Specialized equipment, such as the smolt sonar, cannot be replaced or fixed on short notice during the field season. In order to reduce the chances of losing data due to equipment failure, extra components will be built to be used as spares (e.g., 2 sonar pods and 1 control box). In addition to new equipment, modifications to the system will allow technicians in the field to better diagnose problems. Each sonar pod will be equipped with tilt sensors that can be accessed through the software interface each day when the technicians are performing their daily visits. We expect that, improvements to the system coupled with a more stringent operating protocol will ultimately result in better data collected.

This was the second 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 has met the project's objectives and our expectations. We were successful in developing abundance estimates from two independent and redundant sonar systems. In 2009 the estimate from Site 1 was 10% lower than the estimate from Site 2 which was a modest difference that we suspect was due to less effective sampling at Site 2. We offer the Site 1 estimate of 35.2 million (95% confidence limits = 32,164,876 – 38,329,542) as the best estimate for sockeye salmon smolt abundance in the Kvichak River in 2009.

RECOMMENDATIONS FOR 2010

Based on the results above and lessons learned from the 2008 and 2009 seasons, the following are recommended improvements for the 2010 program:

1. Continue to operate a side-looking sonar system to characterize the horizontal (cross-river) distribution of smolts.
2. Operate a split-beam sonar for a larger portion of the season to verify TS.
3. Establish more stringent operating protocol.
4. Operate the Site 1 sonar in the same location as in 2008 and 2009.
5. Operate the second sonar at the same location as Site 2 in 2008.
6. Explore the feasibility of using alternative energy sources in order to reduce the dependence on high maintenance gas generators at each site.

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TABLES

Table 1. Ice cover dates of Lake Iliamna, 2009.

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	
2008 - 2009		20-May	

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

Table 2. Daily climate and hydrological observations made at 0800 and 2000 hours near Igiugig on the Kvichak River, 2009.

	Cloud Cover [a]			Wind Direction & Velocity (km/h)		Air Temp. (C)		Water Temp. (C)		
Date	0800	2000	Precipitation (mm)	0800	2000	0800	2000	0800	2000	Water Clarity [b]
5/20	n	2	0.0	n	E 5	n	n	n	3.5	n
5/21	4	4	trace	E 5	E 15	7.0	9.0	3.5	6.0	clear
5/22	1	3	0.0	E 5	E 10	6.0	12.5	3.0	4.0	clear
5/23	1	3	0.0	NE 5	NE 5	9.5	10.0	5.0	4.0	clear
5/24	2	1	0.0	E 5	0	13.0	13.0	5.0	5.0	clear
5/25	1	1	0.0	NE 5	NE 5	9.5	21.0	2.5	4.0	clear
5/26	n	1	0.0	n	W 10	8.0	18.0	4.5	4.5	clear
5/27	4	3	0.0	W 5	Vari 5	6.0	12.0	4.5	4.5	brown
5/28	4	4	0.1	W 5	n	6.0	6.0	3.5	4.5	clear
5/29	2	1	0.0	n	Vari 5	5.0	12.0	4.5	5.0	clear
5/30	4	4	trace	Vari 5	E 10	5.0	6.0	5.5	5.5	clear
5/31	3	n	2.0	E 5	E 10	6.0	n	5.0	n	brown
6/01	4	4	5.0	E 20	E 30	n	9.0	n	6.0	murky
6/02	4	3	trace	E 25	Vari 5	n	10.0	n	6.0	murky
6/03	2	3	0.0	Vari 2	SW 10	4.0	14.0	5.5	7.5	brown
6/04	3	2	trace	SE 25	SW 15	7.0	11.0	3.0	7.5	brown
6/05	3	4	trace	E 2	E 4	9.0	10.0	7.0	7.0	brown
6/06	1	1	0.0	0	0	4.0	13.0	7.0	8.0	clear
6/07	1	1	0.0	0	0	5.5	21.0	6.0	7.0	clear
6/08	2	2	0.0	W 5	W 5	12.0	10.0	7.0	7.0	clear
6/09	4	1	0.0	E 5	0	7.5	14.5	6.5	7.5	clear
6/10	1	1	0.0	0	0	3.5	20.5	7.0	8.0	clear
6/11	1	2	0.0	0	0	7.0	7.5	7.0	7.5	clear
6/12	4	4	trace	0	0	8.0	n	8.0	n	brown
6/13	4	4	0.0	S 5	0	8.0	11.0	8.5	n	clear

[a] 1 = Cloud cover not more than 1/10
2 = Cloud cover not more than 1/2
3 = Cloud cover more than 1/2
4 = Completely overcast
5 = Fog

[b] Water clarity at 0800 hours

n = no observation

Table 3. EchoView data processing parameters used for sites 1 and 2 analysis, 2009.

Echo integration settings	
Data analysis threshold	-40 dB
Analysis range	Suface to 2.5 m below surface
Analysis cell size	0.5 m depth by 1 minute interva

Single target settings	
Data analysis threshold	-60 dB
Analysis range	Surface to 2.5 m below surface
Pulse length determination level	9 dB below peak
Minimum normalized pulse leng	50%
Maximum normalized pulse leng	150%

Table 4. Transducer pool calibrations and offset used for data processing, 2009.

Transducer	Measured	Expected	Offset	EV Gain
S^1-T1	-33.5	-41.7	8.2	39.2
S^1-T2	-32.78	-41.7	8.92	39.6
S^1-T3	-42.43	-41.7	-0.73	34.8
S^1-T4	-41.28	-41.7	0.42	35.4
S^1-T5	-37.5	-41.7	4.2	37.2
S^1-T6	-31.84	-41.7	9.86	40.1
S^1-T7	-34.59	-41.7	7.11	38.7
S^2-T1	-38.49	-41.7	3.21	36.7
S^2-T2	-37.98	-41.7	3.72	37
S^2-T3	-34.09	-41.7	7.61	38.9
S^2-T4	-32.6	-41.7	9.1	39.7
S^2-T5	-36.97	-41.7	4.73	37.5
S^2-T6	-33.14	-41.7	8.56	39.4
S^2-T7	-32.02	-41.7	9.68	40

Table 5. Range and depth for pods at sites 1 and 2, 2009.

Transducer	Depth (m)	Range[a] (m)
S^1-T1	2.4	29
S^1-T2	2.9	39
S^1-T3	3.5	49
S^1-T4	3.9	59
S^1-T5	4.4	69
S^1-T6	3.5	79
S^1-T7	2.2	89
S^2-T1	1.4	97
S^2-T2	2.6	87
S^2-T3	4.3	77
S^2-T4	4.3	67
S^2-T5	4	57
S^2-T6	3.8	47
S^2-T7	3.7	37

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

Table 6. Water velocity (m/s) measurements from sonar sites 1 and 2 on the Kvichak River, 2009.

Site 1

Transducer	30-May	7-Jun	15-Jun	Average
T1	1.50	1.28	1.57	1.45
T2	1.63	1.44	1.70	1.59
T3	1.76	1.69	1.83	1.76
T4	1.80	1.78	1.85	1.81
T5	1.87	1.95	1.95	1.92
T6	1.87	1.80	1.82	1.83
T7	1.42	1.81	1.37	1.53

Site 2

Transducer	30-May	7-Jun	15-Jun	Average
T1	0.75	0.68		0.72
T2	1.20	0.90	0.68	0.93
T3	1.50	1.20	1.01	1.24
T4	1.87	1.61	1.51	1.66
T5	1.84	1.97	2.02	1.94
T6	1.84	1.78	1.91	1.84
T7	1.39	1.81	1.41	1.54

Table 7. Daily abundance of sockeye smolts at Site 1 on the Kvichak River, 2009.

	Abundance				Proportion	
Smolt Day	Daily	Cumulative	SE	95% CI	Daily	Cumulative
26-May	2,243,292	2,243,292	441,712	865,755	0.06	0.06
27-May	4,529,460	6,772,752	448,207	878,486	0.13	0.19
28-May	7,995,644	14,768,396	1,137,197	2,228,907	0.23	0.42
29-May	6,318,930	21,087,325	621,901	1,218,926	0.18	0.60
30-May	2,096,630	23,183,956	280,829	550,425	0.06	0.66
31-May	524,016	23,707,971	61,885	121,295	0.01	0.67
1-Jun	1,962,318	25,670,289	267,897	525,078	0.06	0.73
2-Jun	1,386,502	27,056,791	235,865	462,295	0.04	0.77
3-Jun	4,405,441	31,462,232	482,511	945,722	0.12	0.89
4-Jun	426,141	31,888,372	36,988	72,496	0.01	0.90
5-Jun	458,866	32,347,238	52,646	103,186	0.01	0.92
6-Jun	613,580	32,960,819	52,401	102,706	0.02	0.94
7-Jun	785,235	33,746,054	90,139	176,672	0.02	0.96
8-Jun	353,364	34,099,418	57,771	113,231	0.01	0.97
9-Jun	231,290	34,330,708	30,710	60,191	0.01	0.97
10-Jun	259,037	34,589,745	30,075	58,947	0.01	0.98
11-Jun	404,329	34,994,074	43,760	85,770	0.01	0.99
12-Jun	253,135	35,247,209	39,733	77,876	0.01	1.00
Total	35,247,209			3,125,312	1.00	

Table 8. Daily abundance of sockeye smolts at Site 2 on the Kvichak River, 2009.

	Abundance				Proportion	
Smolt Day	Daily	Cumulative	SE	95% CI	Daily	Cumulative
26-May	3,184,689	3,184,689	432,777	848,243	0.08	0.08
27-May	5,097,817	8,282,505	801,575	1,571,086	0.13	0.21
28-May	10,350,365	18,632,870	1,889,373	3,703,172	0.27	0.48
29-May	9,123,116	27,755,986	1,333,652	2,613,958	0.24	0.72
30-May	2,536,815	30,292,801	371,300	727,747	0.07	0.78
31-May	539,001	30,831,802	54,685	107,182	0.01	0.80
1-Jun	1,851,142	32,682,944	254,919	499,641	0.05	0.84
2-Jun	965,176	33,648,120	184,724	362,059	0.02	0.87
3-Jun	2,230,794	35,878,914	518,148	1,015,571	0.06	0.93
4-Jun	542,461	36,421,375	81,222	159,195	0.01	0.94
5-Jun	364,379	36,785,754	51,593	101,121	0.01	0.95
6-Jun	512,165	37,297,919	60,070	117,738	0.01	0.96
7-Jun	643,635	37,941,554	98,109	192,295	0.02	0.98
8-Jun	179,229	38,120,783	22,532	44,164	0.00	0.98
9-Jun	111,158	38,231,941	13,317	26,101	0.00	0.99
10-Jun	274,859	38,506,800	61,503	120,547	0.01	0.99
11-Jun	174,428	38,681,228	22,861	44,807	0.00	1.00
12-Jun	74,710	38,755,938	10,978	21,516	0.00	1.00
Total	38,755,938		2,591,181		1.00	

FIGURES

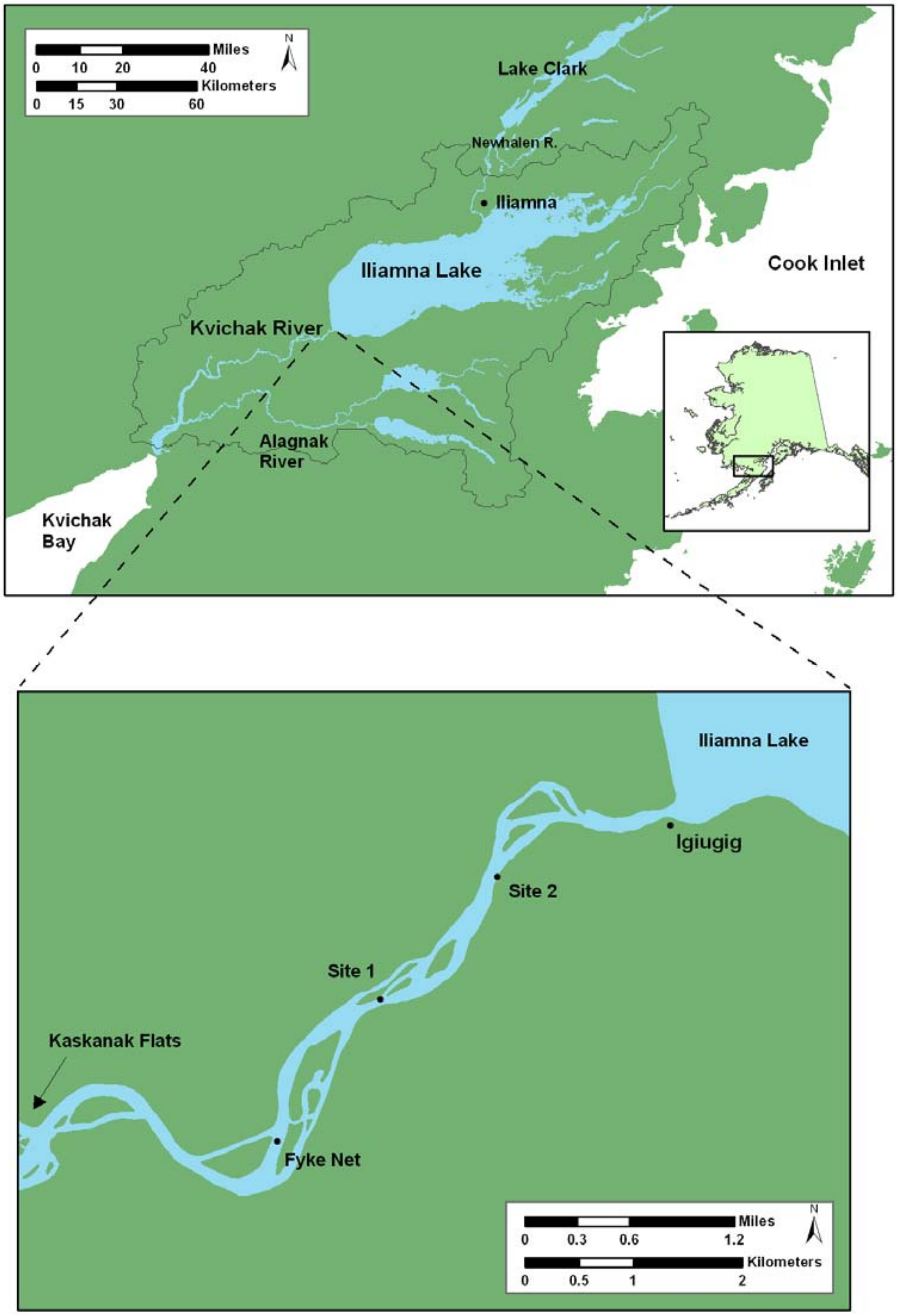


Figure 1. Map of Iliamna watershed in Southwestern Alaska showing the location where sonar systems operated near the village of Igiugig, 2009.

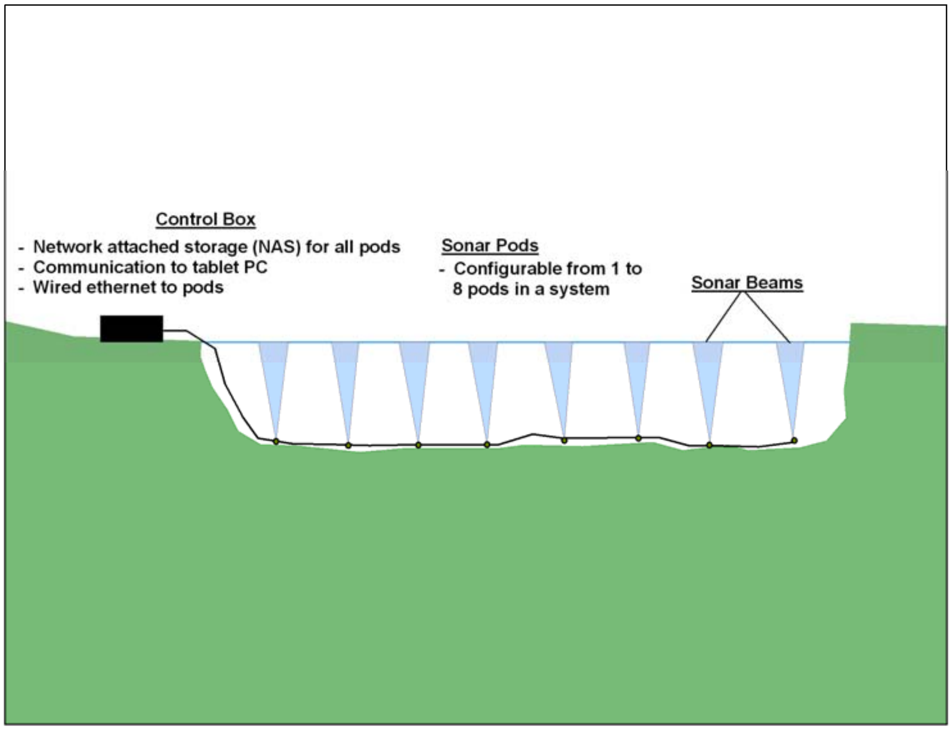


Figure 2. Conceptual drawing of the smolt sonar designed for rivers in the Bristol Bay region, 2009.

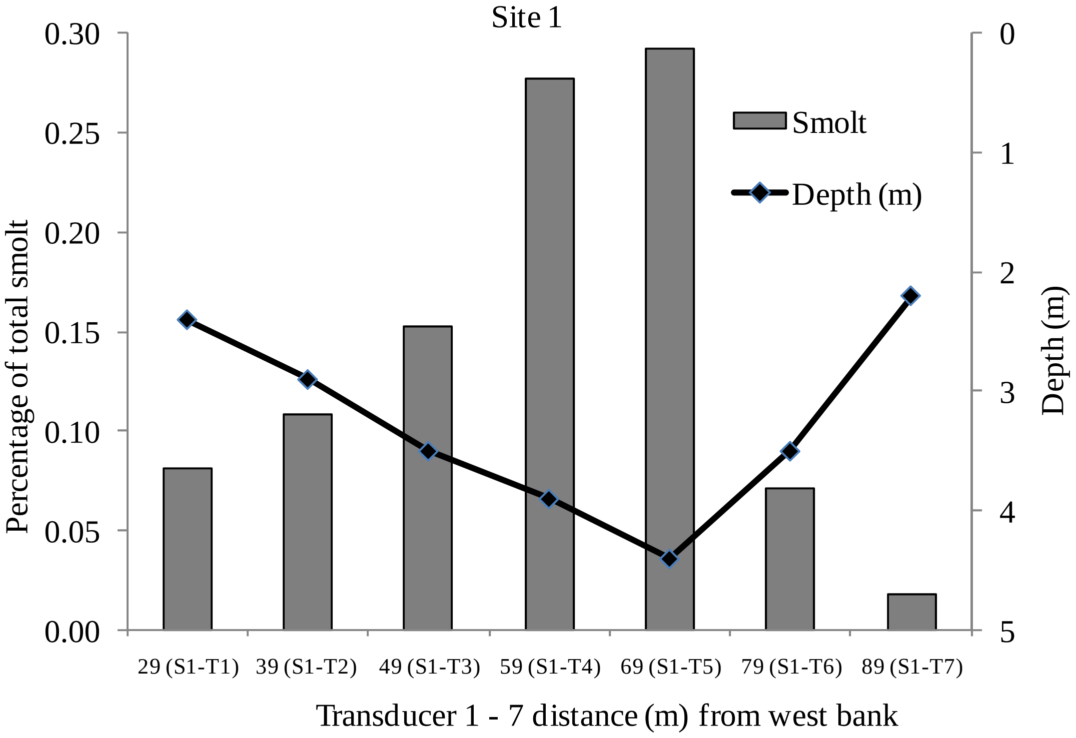


Figure 3. Site 1 bottom profile (based on transducer depth) plus cross river distribution of smolts, 2009.

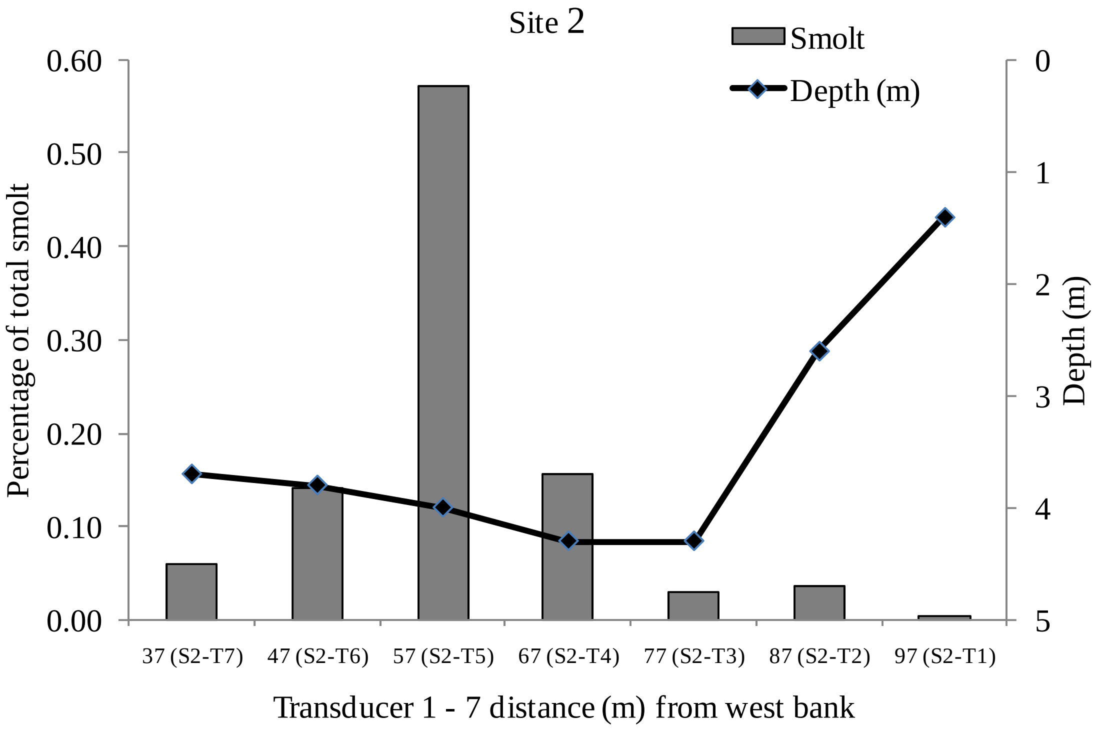


Figure 4. Site 2 bottom profile (based on transducer depth) plus cross river distribution of smolts, 2009.

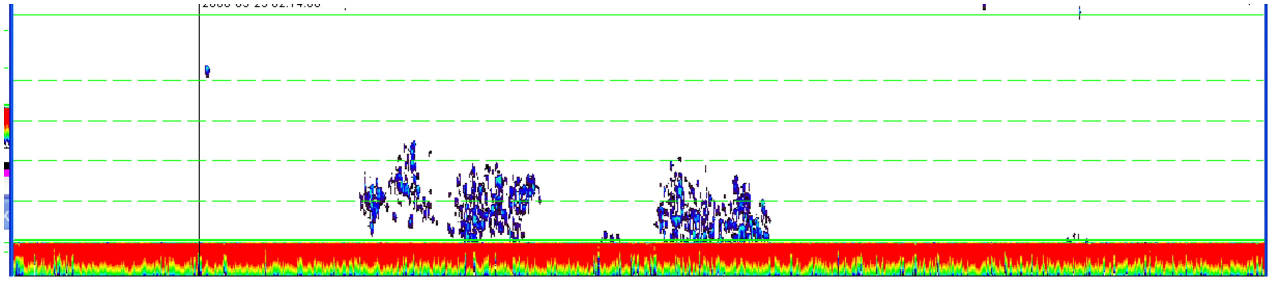


Figure 5. Echogram of smolt detected at Site 1. Dashed green lines signify 0.5 m depth strata and show majority of smolts are in the upper 1.0 m. (EchoView ® 4.5 software displays echogram of smolt data as “upside down” due to up-looking transducers.)

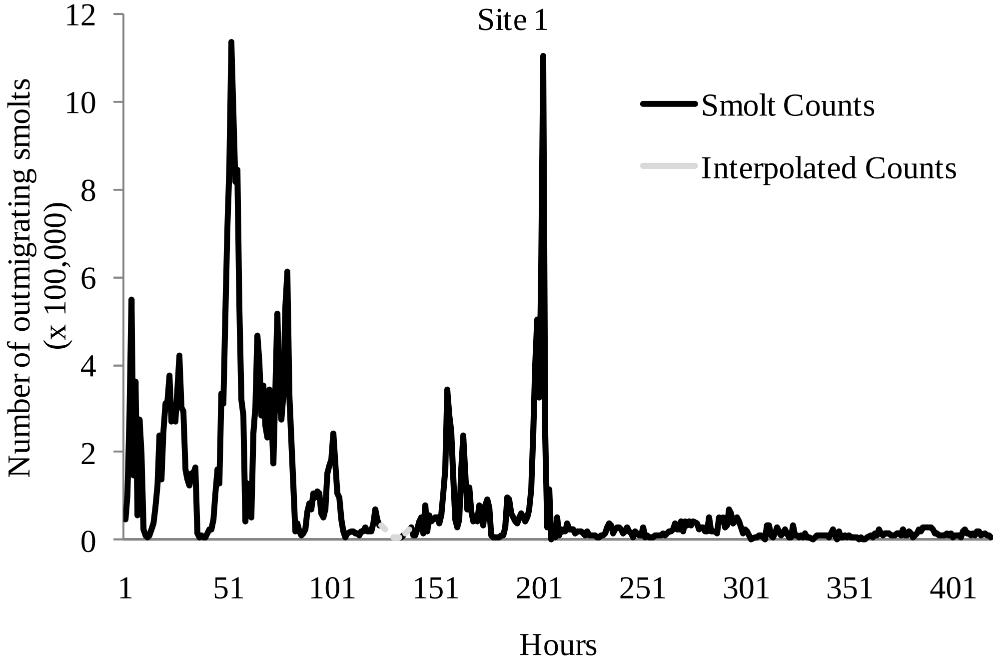


Figure 6. Hourly smolt estimates at Site1 showing periods of missing data via linear interpolation, 2009.

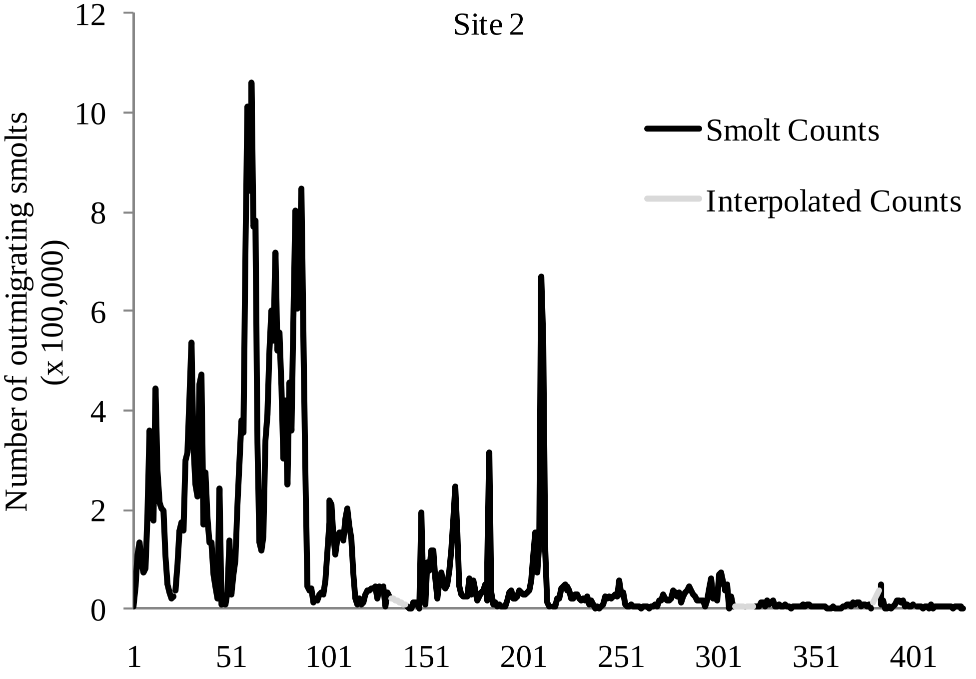


Figure 7. Hourly smolt estimates at Site2 showing periods of missing data via linear interpolation, 2009.

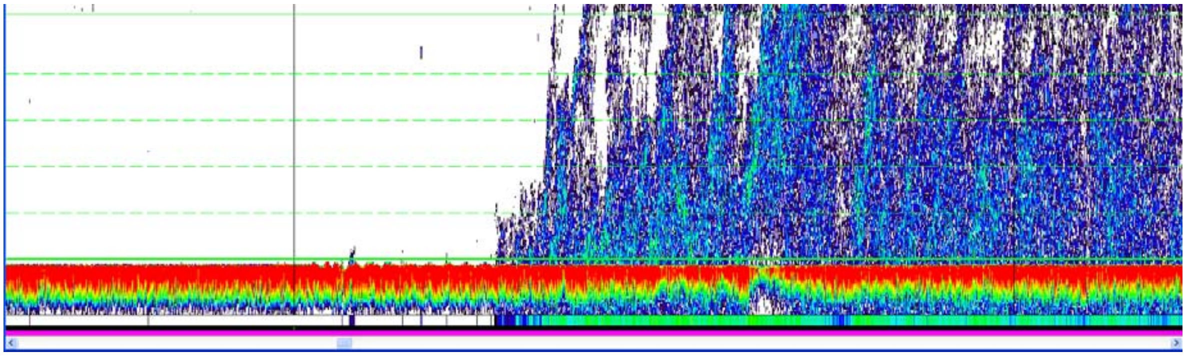


Figure 8. Echogram of noise generated by boat passage at Site 1, note the boat wake that precedes the noise created by entrained air from the propeller. (EchoView ® 4.5 software displays echogram of smolt data as “upside down” due to up-looking transducers.)

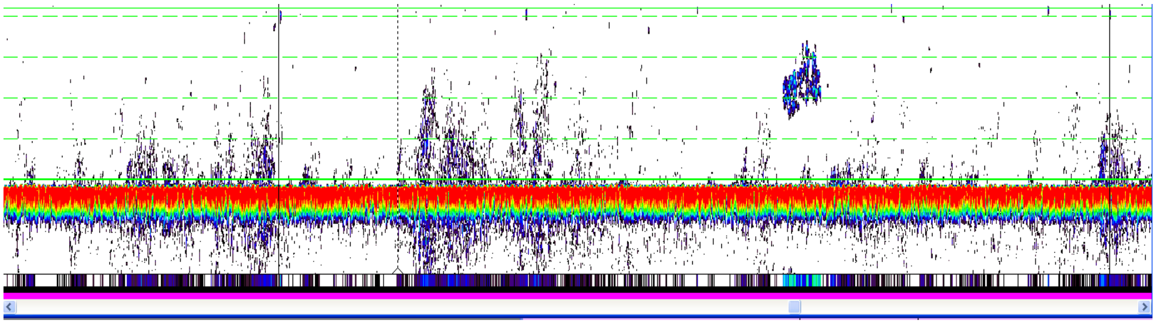


Figure 9. Echogram of a wind event at Site 1, notice smolts at 1.5 m depth. (EchoView ® 4.5 software displays echogram of smolt data as “upside down” due to up-looking transducers.)

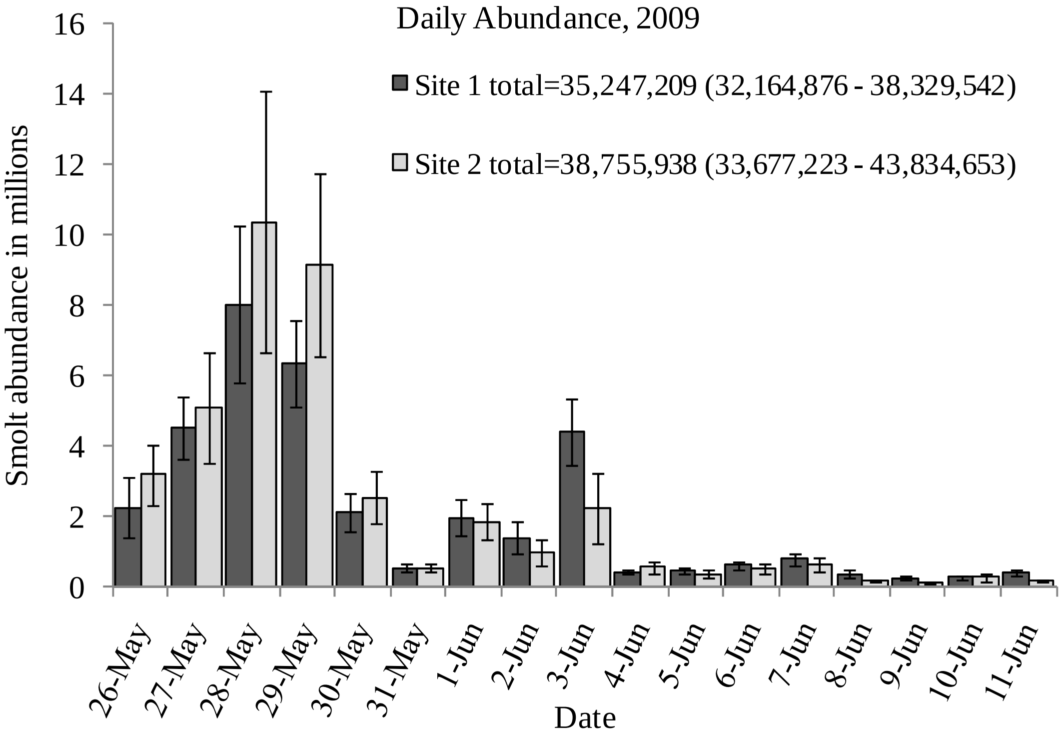


Figure 10. Estimated daily and annual abundance of smolt for Site1 and 2 on the Kvichak River, 2009.

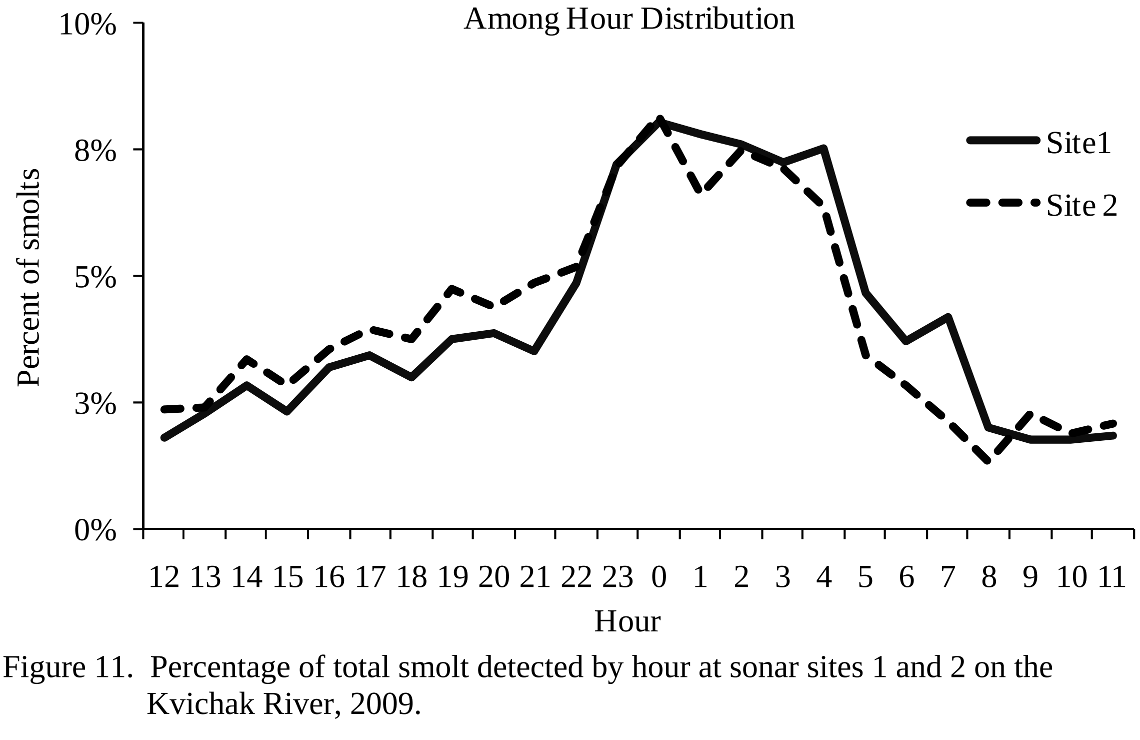


Figure 11. Percentage of total smolt detected by hour at sonar sites 1 and 2 on the Kvichak River, 2009.

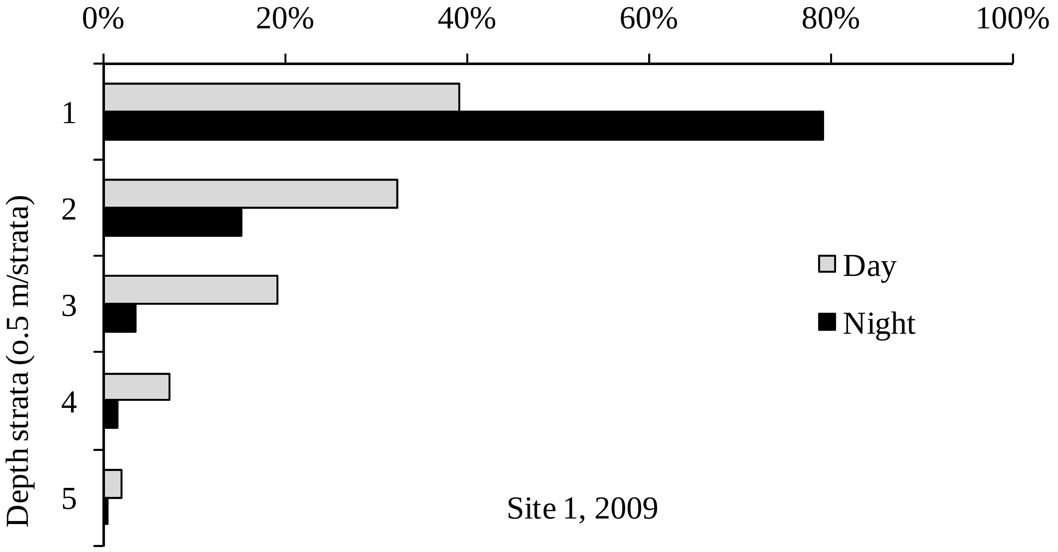


Figure 12. Site 1 vertical smolt distribution by 0.5 m strata for daylight and dark hours on the Kvichak River, 2009.

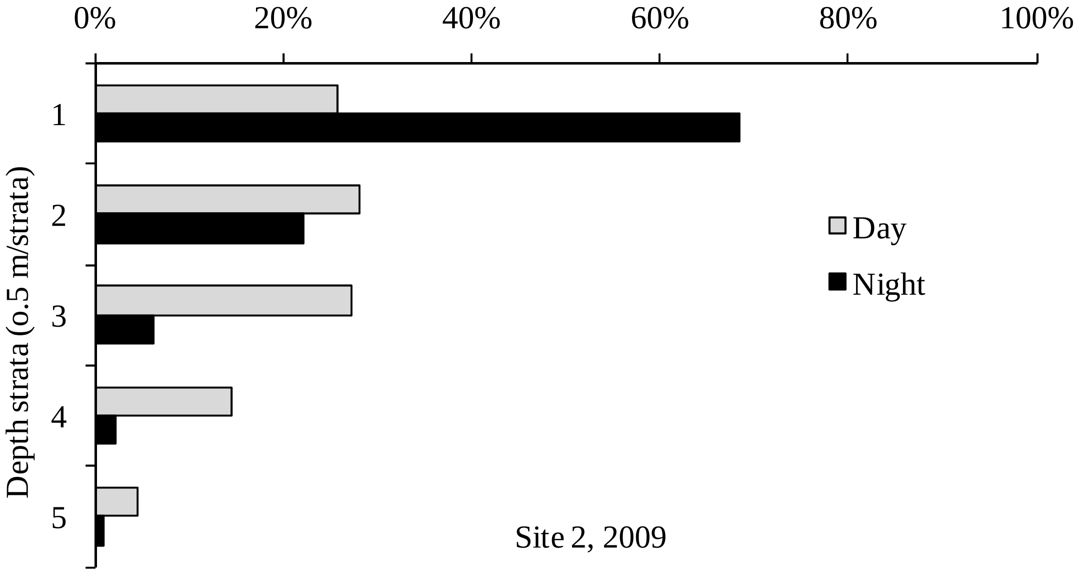


Figure 13. Site 2 vertical smolt distribution by 0.5 m strata for daylight and dark hours on the Kvichak River, 2009.

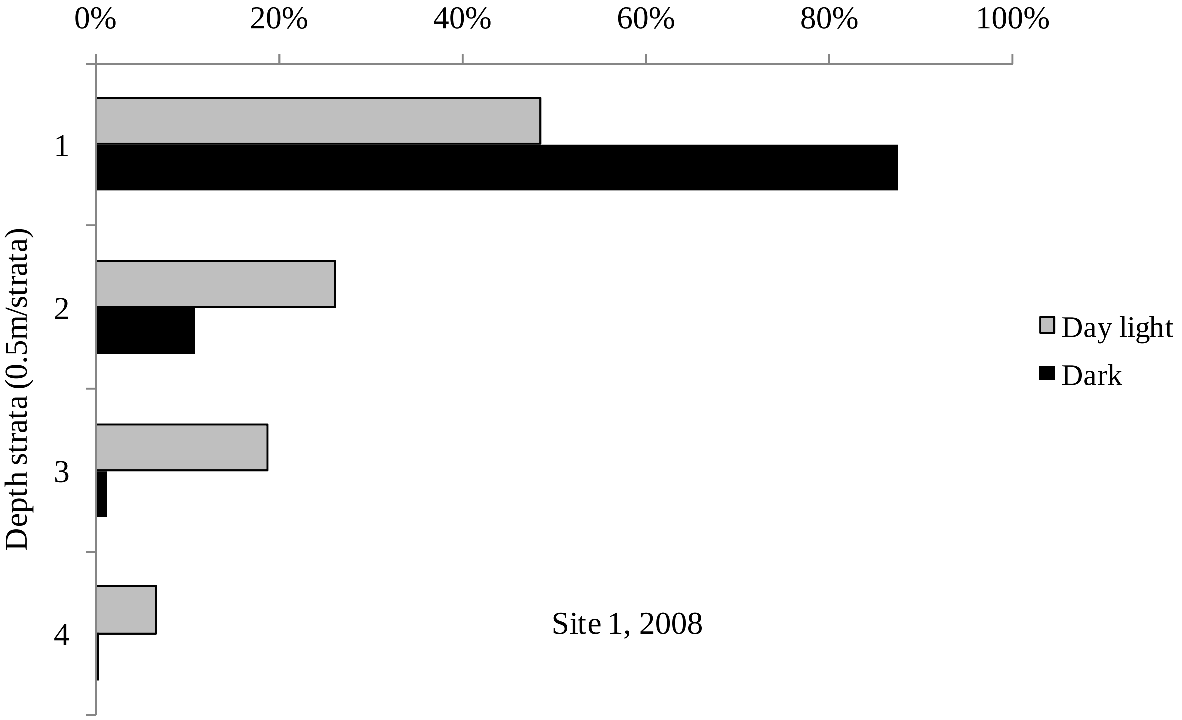


Figure 14. Site 1 vertical smolt distribution by 0.5 m strata for daylight and dark hours on the Kvichak River, 2008.

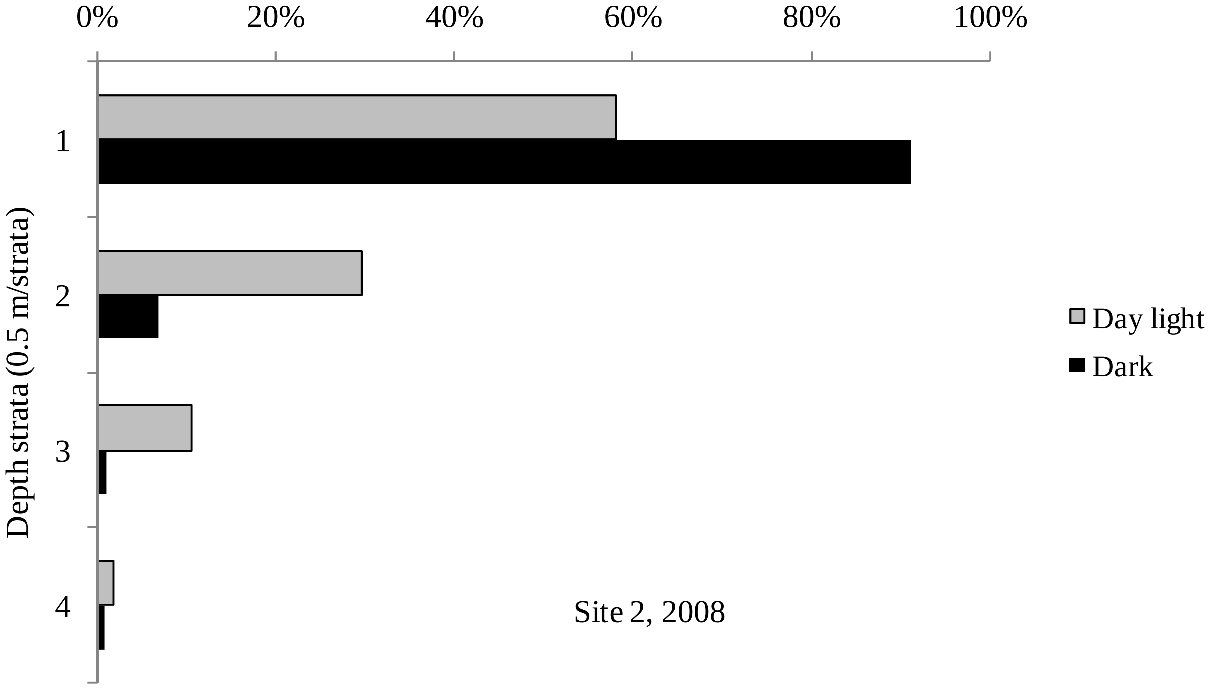


Figure 15. Site 2 vertical smolt distribution by 0.5 m strata for daylight and dark hours on the Kvichak River, 2008.

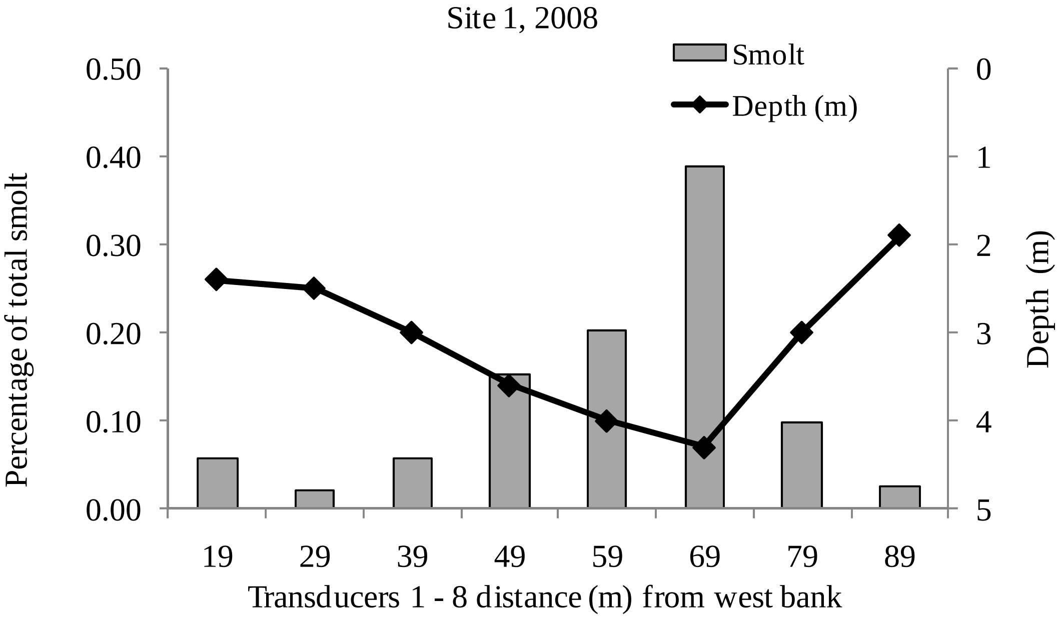


Figure 16. Site 1 bottom profile (based on transducer depth) plus cross river distribution of smolts, 2008.

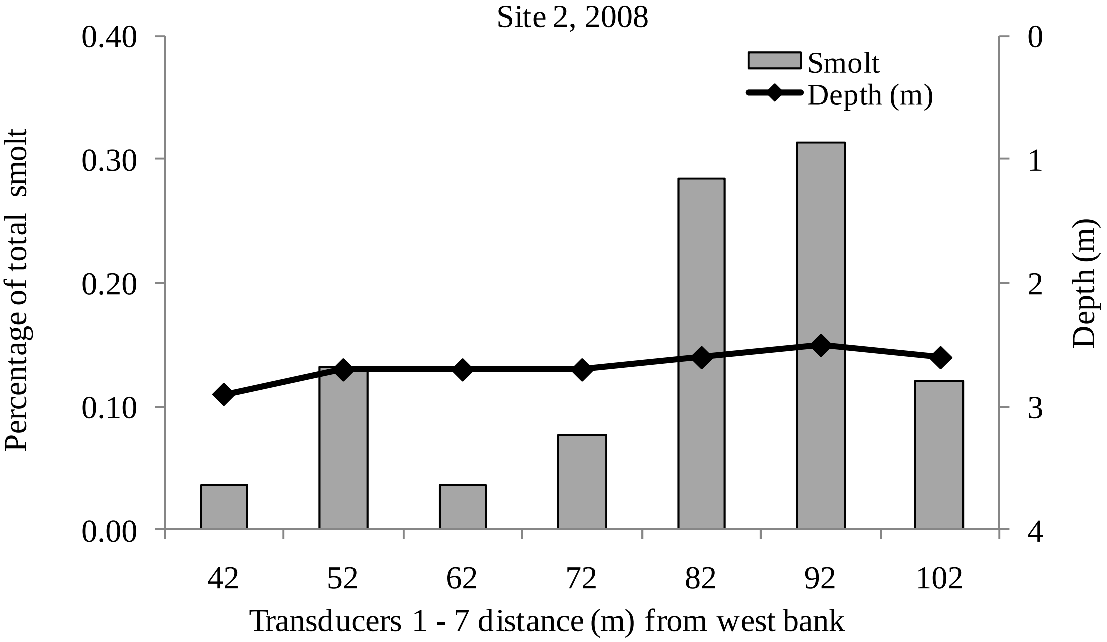


Figure 17. Site 2 bottom profile (based on transducer depth) plus cross river distribution of smolts, 2008.

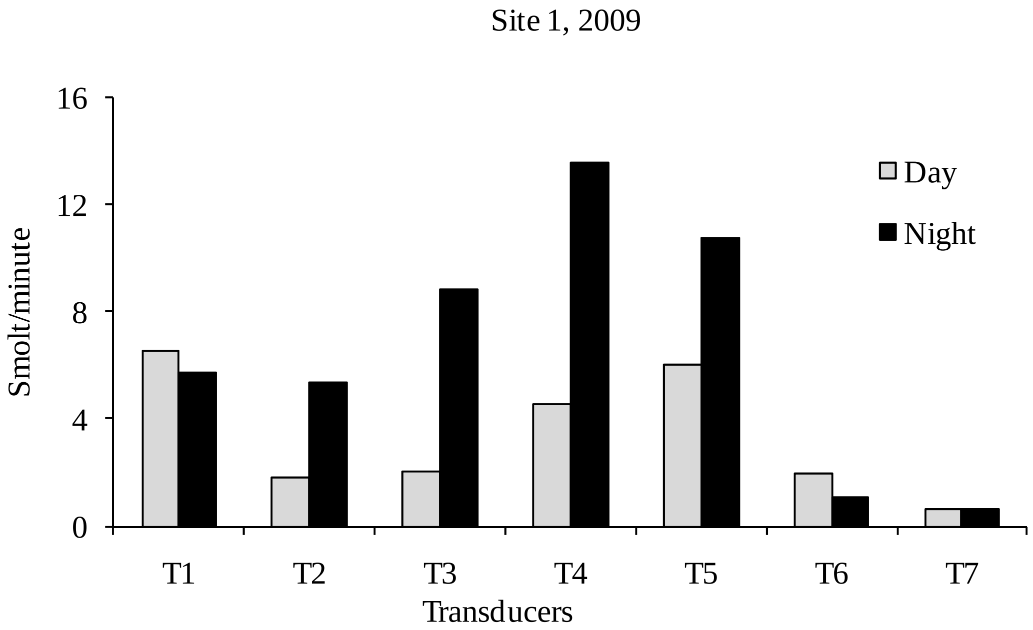


Figure 18. Smolt passage/minute at each transducer for Site 1 during daylight and dark hours on the Kvichak River, 2009.

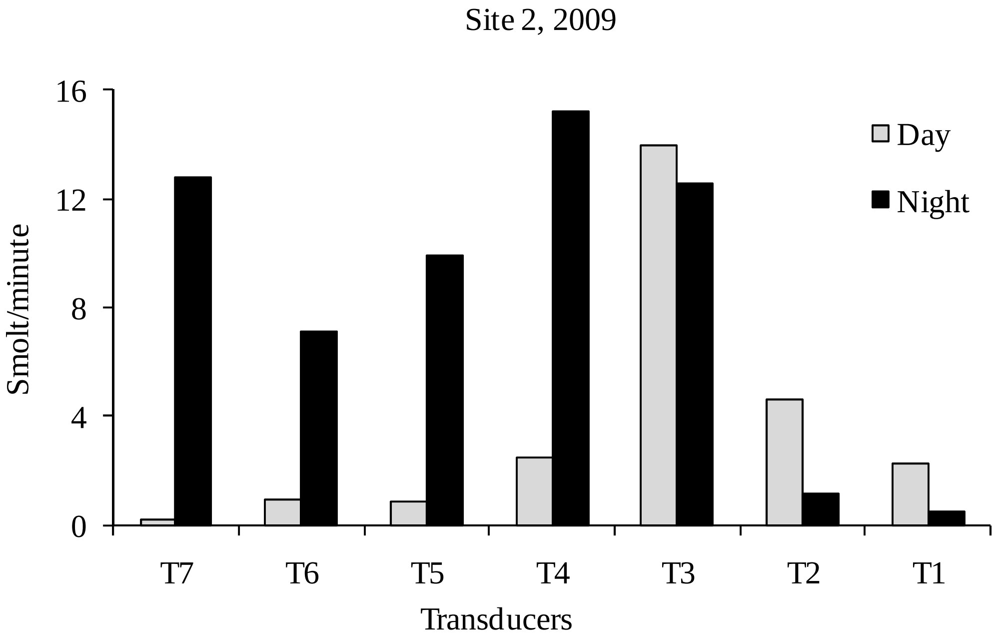


Figure 19. Smolt passage/minute at each transducer for Site 2 during daylight and dark hours on the Kvichak River, 2009.

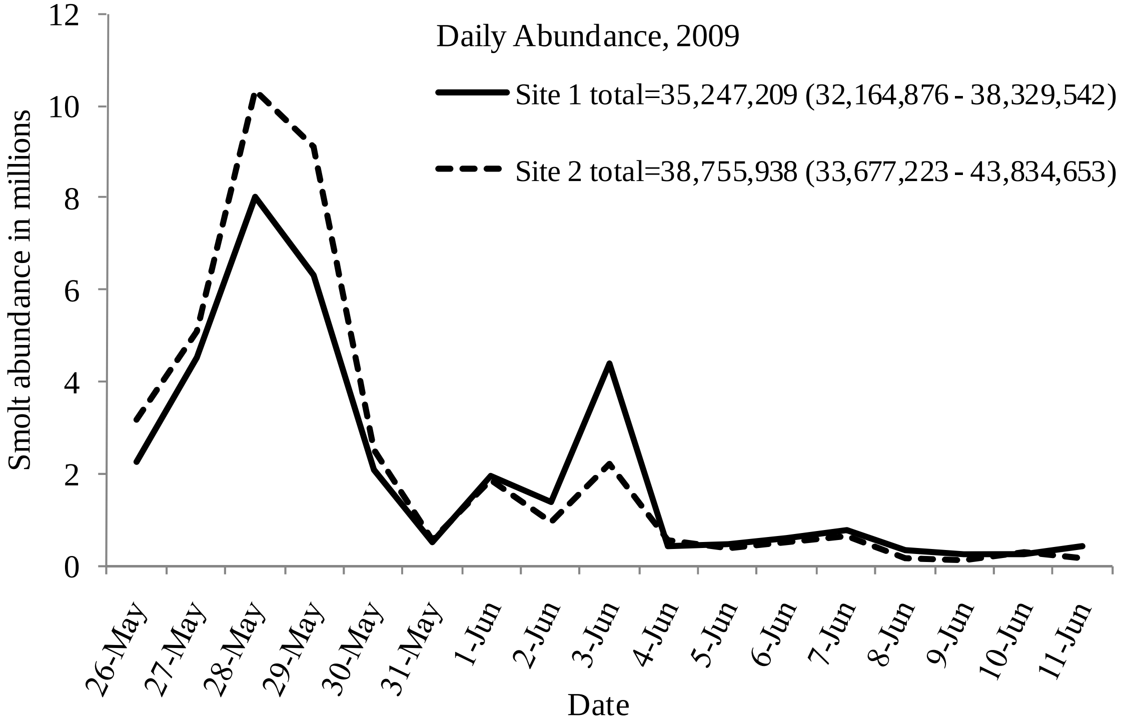


Figure 20. Estimated daily smolt abundance at sonar sites 1 and 2 on the Kvichak River, 2009.

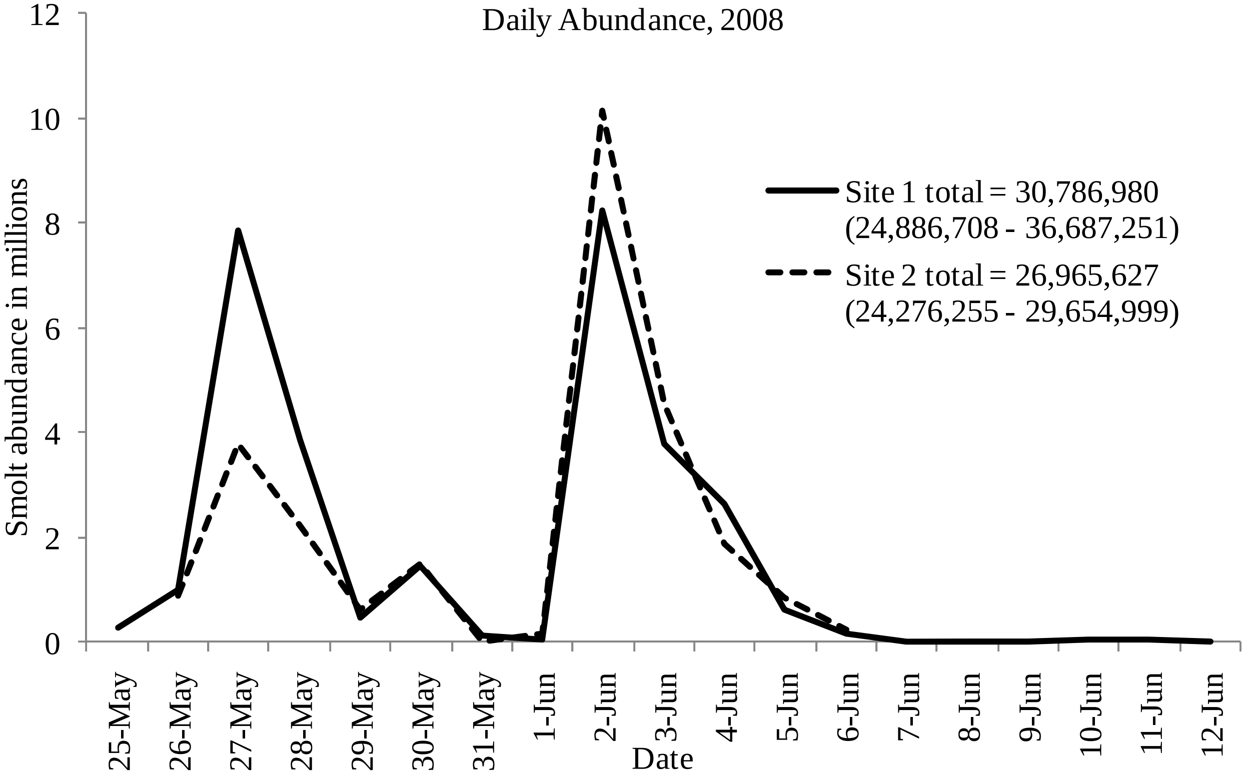


Figure 21. Estimated daily smolt abundance at sonar sites 1 and 2 on the Kvichak River, 2008.

PHOTOS

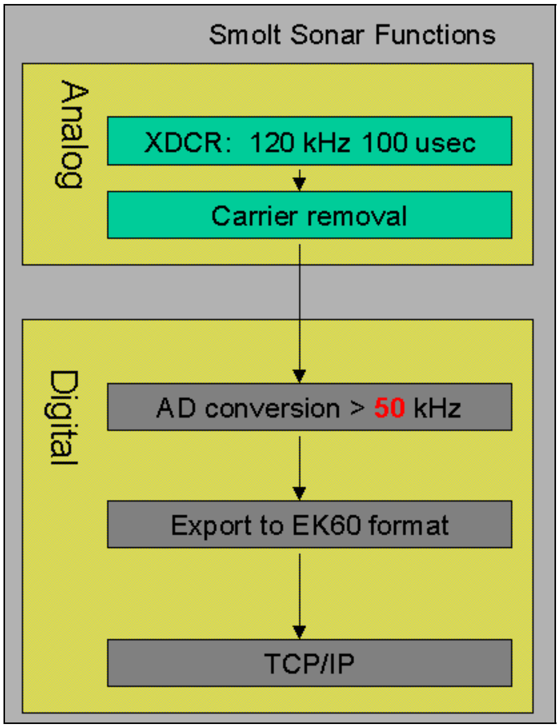
Photo 1. Up-looking transducer mounted on sled with attached power and tow cables used in the Kvichak River, 2009.

Photo 2. Sonar array of 8 pods prepared for deployment at Site 1 on the river's west bank, 2009.

Photo 3. Control box, NAS and power source for the Site 1 sonar system housed in the WeatherPort tent, 2009.

Photo 4. Side looking sonar operated at Site 1, 10 m off the west bank, 2009.

APPENDIX A



Appendix A-1. Functional overview of sonar pod used on the Kvichak River in 2009.