Monitoring of sockeye salmon smolt abundance and inriver distribution using sonar on the Kvichak, Egegik, and Ugashik rivers in 2011

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Monitoring of sockeye salmon smolt abundance and inriver distribution using sonar on the Kvichak, Egegik, and Ugashik rivers in 2011

by

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ABSTRACT

We operated up-looking sonar systems on the Kvichak, Egegik, and Ugashik rivers in 2011 to estimate the hourly, daily, and seasonal abundance of sockeye salmon (*Oncorhynchus nerka*) smolts migrating from the watersheds. Smolt numbers can provide data needed to evaluate freshwater production, set biological escapement goals, and forecast adult returns. Two independent sonar systems were operated on each river and used to generate separate abundance estimates. Each sonar array consisted of a single row of pods placed along the river bottom, perpendicular to the bank. Smolt densities were estimated using echo integration stratified by pod and water depth. Kvichak River sonar systems were operated 3.5 rkm (Site 1, operated from 21 May to 12 June) and 7.0 rkm (Site 2, operated from 21 May to 13 June) downstream of Lake Iliamna. Total sockeye salmon smolt abundance was estimated to be 48.8 million (95% confidence interval of 45.5 – 52.0 million) at Site 1 and 41.7 (39.3 – 44.2 million) at Site 2. Run timing data indicates both sites operated for the entirety of the smolt out migration. Egegik River sonar systems were both 4.5 rkm downstream from the outlet of Lake Becharof, and each operated from 17 May through 11 June; sockeye salmon smolt abundance was estimated to be 9.9 million (8.8 – 11.1 million) at Site 1 and 8.9 (7.7 – 10.0 million) at Site 2. Ugashik River sonar systems were deployed approximately 80 m downstream of the outlet of Lower Ugashik Lake on 12 May (Site 1) and 15 May (Site 2). High water velocity (> 3.0 m/s) washed both Ugashik River arrays downstream on 24 May, preventing abundance estimates in 2011.

When water conditions allowed, the sonar systems described here effectively estimated smolt abundance and behavior. Ice and water conditions affect fish behavior and sonar operation, and must be accounted for when using this technology to estimate smolt abundance. Unusual ice conditions in 2011 may have accounted for some differences in seasonal and diel timing of smolt migration between the Kvichak and Egegik rivers, and among years on the Kvichak River. Smolts were distributed through more of the water column on the Egegik River than on the Kvichak River. The effectiveness of this approach in future years will depend on the ability to maintain operation at times of abnormally high or variable water and ice conditions, and to describe associations between water velocity and smolt swimming speed.

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INTRODUCTION

Background and history of the project

In 2008, the Bristol Bay Science and Research Institute began a multiyear study to evaluate the feasibility of using sonar to resume counting sockeye salmon smolts in Bristol Bay rivers. Sonar had first been used to estimate smolt abundance in Bristol Bay in the 1970s, when there was considerable financial support for such a program on multiple rivers in the region. Support for the program waned by the 1990s, however, for reasons that included data collection errors, the high cost of upgrading antiquated sonar equipment, and statistical uncertainty in the smolt abundance estimates even when all equipment operated correctly. The main purpose of the smolt abundance data was to forecast adult salmon returns; by the late 1990s, the prevailing belief was that these forecasts would be better accomplished using adult stock assessment (and not smolt abundance) data, and the last smolt project was ended after the 2002 season. A detailed history of the smolt program and its benefits and drawbacks is provided in reports by Crawford and Fair (2003), Maxwell et al. (2009), and Wade et al. (2010a).

Interest in smolt abundance estimates in Bristol Bay increased in the mid-2000s due to renewed interest in the information and the potential for using new approaches to address some of the shortcomings of the previous sonar methods. Renewed interest in smolt counts was especially due to increased discussion of escapement goal changes that came after the Alaska Board of Fisheries (BOF) adopted the Policy for the Statewide Escapement Goals (5 AAC 39.223); this caused Bristol Bay goals to be evaluated more frequently and more extensively in the next few years, during which time there was much discussion about raising the goals (Baker et al. 2009). Estimates of smolt abundance could provide the earliest evidence of whether changes in adult escapement affect subsequent fish production. In an era when scientists were considering raising the escapement goals for most sockeye salmon stocks (e.g., Baker et al. 2006), this provided a second important reason to monitor smolt abundance (in addition to adult run forecasting), and an incentive to develop improvements to past approaches.

By 2008, BBSRI had completed the research and design of a new sonar system that drew on extensive evaluations of the prior approaches by several researchers (e.g., Crawford and Fair 2003; Ruggerone and Link 2006; Maxwell et al. 2009; Wade et al 20101a). Two important considerations of the new design were that it provide an estimate of measurement error, and that it collect additional information to help detect potential anomalies in the smolt counts. This additional information would include smolt distribution and behavior, essentially allowing researchers to monitor the smolt run to help detect factors that could influence the abundance estimate. The resulting design was an array consisting of multiple up-looking sonar pods joined in series, combined with a single side-looking sonar unit to verify cross-river distribution of fish, and net sampling to verify species composition. Sonar signals were echo integrated and, combined with target strength estimates, provided estimates of numbers of fish stratified by time and depth strata; these were expanded to estimate the number of fish by hour over the entire river cross section. Two separate (independent) arrays were operated to test repeatability of the counts on the same fish population, and site conditions and fish distribution were monitored for diagnostic information (Wade et al. 2010a). The system was operated on the Kvichak (2008 – 2010) and Ugashik (2010) rivers, with results reported by Wade et al. (2010a; 2010b; 2012).

Current project operation

In 2011, BBSRI continued sonar operations on the Kvichak (fourth consecutive year) and Ugashik (second consecutive year), while adding a new system on the Egegik River. The sonar systems were the same bottom-founded, up-looking design described by Wade et al. (2010a). Smolts were again sampled to estimate age and body size and to verify species composition. Physical site data and smolt behavior and distribution information were again collected to help interpret the sonar estimates and identify problems or anomalies that could influence the results.

This report provides hourly, daily, and seasonal abundance of sockeye salmon smolts in 2011 and characterizes horizontal, vertical, and diel distribution of smolt schools as they migrate. As noted above, the impetus for generating smolt abundance estimates in the Bristol Bay region is to help salmon management by improving preseason forecasts of returning adult salmon abundance, and by developing associations with adult salmon abundance that can be used when developing escapement goals. Distribution behavior of smolts is important to this study because it influences smolt detection and the analyses used to estimate fish abundance. Descriptions of smolt behavior in these systems also benefits other studies by helping guide various sampling efforts, identify differences among the river systems, and understand how environmental factors such as ice and water discharge may affect smolt migrations.

Smolt abundance, body size, and age are important elements of the freshwater production of salmon, and were collected as part of the field portion of this study. The age analysis was conducted separately by the Alaska Department of Fish and Game. Age, weight, and length (AWL) data collected on the Kvichak River in 2011 are included in this report (Appendix-A). These AWL data complement the abundance estimates, helping to understand the overall health of the population leaving freshwater and to make inferences about smolt survival at sea. Over time, these datasets can be used to make preseason forecasts of adult returns and to refine system-specific escapement goals for Bristol Bay sockeye salmon (Crawford and West 2001).

OBJECTIVES

The objectives of the 2011 study were to:

1. Use sonar to estimate the hourly, daily, and seasonal abundance of sockeye salmon smolts migrating from the Kvichak, Egegik, and Ugashik rivers.
2. Characterize the vertical, horizontal and diel distribution of outmigrating smolts.
3. Collect information needed to describe smolt age, weight, and length.
4. Continue to assess the efficacy of sonar to estimate salmon smolt abundance in Bristol Bay.

STUDY AREA

Kvichak River

The Iliamna watershed is located in southwest Alaska and 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 flows into Iliamna Lake via the Newhalen River. Lake Clark is glacially fed, causing turbidity at the head of the lake; this turbidity diminishes as it reaches the Newhalen River. The Kvichak River connects Iliamna Lake to the ocean and flows southwest for approximately 106 km where it enters Kvichak Bay, in the northeastern corner of Bristol Bay. The Kvichak River is a clear-water stream exiting the western end of Iliamna Lake, near the village of Igiugig, and 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; the lowest discharge typically occurs during March, April, and May. From 1970 through 2001, total duration of ice coverage for Lake Iliamna varied from 39 d to 161 d and had an average breakup date of 13 May (Table 1; Crawford and Fair 2003).

In the initial 1.2 km below Iliamna Lake, the Kvichak River is contained within a single channel; downstream, the river is braided except in a few places (Figure 1). The river forms a single channel 3.5 and 7.0 km downstream from the lake; these two sites have been the locations of smolt studies from 1976 to present (Photos 1 and 2, Maxwell et al. 2009). This study used the upper site as Site 1 (N 59.2924, W 155.9550) and the lower site as Site 2 (N 59.3042, W 155.9715).

Egegik River

The Egegik River watershed is located on the Alaska Peninsula approximately 67 km south of King Salmon, AK (Figure 2). The head of the watershed is Becharof Lake, the second largest lake in Alaska. The lake is drained by the Egegik River, which flows westerly for ~45 km and empties into the Egegik Bay, in the southeastern portion of Bristol Bay. The King Salmon River is another major river in the drainage that empties into Egegik River near Egegik Bay. The watershed drains an area of 8,442 km^2; Becharof Lake has a surface area of 1,132 km^2.

The Egegik River has a single channel for the first 5 km, then widens out into a lagoon before splitting into braided channels. The stretch of river from the lake outlet to the lagoon is generally clear water; downstream of this point, the water is more turbid due to tidal influences. Water levels and velocities are tidally influenced for the entirety of the river. The USGS has not collected stream flow data for this area. Ice cover data for Lake Becharof were collected during the 1980s and 1990s, during which time total duration of ice coverage varied from 39 d to 128 d (Table 2; Crawford and West 2001).

In 2011, the sonar systems were located 4.5 rkm downstream of the outlet (N 58.0605, W 156.8893) in the same approximate location as the ADF&G smolt studies conducted in the 1980s and 1990s (Photo 3; Crawford and Fair 2003).

Ugashik River

The Ugashik River drainage is located on the northern portion of the Alaska Peninsula and flows westerly into Ugashik Bay, in the southernmost region of Bristol Bay (Figure 3). The Ugashik River watershed consists of the Upper and Lower Ugashik lakes, the Ugashik River connecting the lower lake to Ugashik Bay, and the King Salmon River (which enters directly into Ugashik Bay). The Ugashik lakes are relatively large, with surface areas of 177 km^2 for the upper lake and 208 km^2 for the lower lake; the entire watershed drains 4,205 km^2.

The Ugashik River is approximately 60 km long and is an alluvial river with a meandering channel pattern that is highly braided in some sections. Just below Lower Ugashik Lake, the river begins as a single channel for a short distance (~150 m) and then spreads out into a highly braided region for the next 2 km before reaching a shallow lagoon. The river is tidally influenced downstream of the braids near the lake outlet. The USGS has not collected stream flow data for this area. Ice cover data for the lakes were collected during the 1980s and 1990s, during which time total duration of ice coverage varied from 51 d to 135 d (Table 2; Crawford and West 2001).

The sonar systems were located approximately 80 m from the Lower Ugashik Lake outlet (N 58.0600, W 156.8860), near the same location as prior smolt studies operated by ADF&G (Photo 4; Crawford and West 2001).

METHODS

Sonar System Design

Each sonar system consisted of multiple up-looking sonar pods joined in line in a "daisy chain" (Figure 4; Photos 5 & 6). The number of pods in a system varied from 5 to 10. Each pod was mounted on a sled (76 cm long, 30 cm wide and 10 cm in height; Photo 5) and all sleds were tethered together by wire rope. The sleds were 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. Individual data files were collected continuously and then stored in 1 hour blocks on 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.

Data collected at each site were stored in 1 terabyte NAS configured hard drives. Power to the sonar system was supplied by 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 riverbank in weatherproof housings (Photo 7).

Sonar Pod

Each sonar pod was 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 (Photo 5). The transducer transmitted pulses at 120 kHz. Carrier removal was provided to reduce the bandwidth needed for digitization. Conversion from analog to digital 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 datastream 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. In 2011, a single split-beam pod was integrated into one sonar array on each river to estimate the target strength of individual smolts (Photo 8). This pod used a Simrad® ES120-7C, 120 kHz with a 7 x 7 degree beam angle operated at a 0.06 s ping interval and 0.064 msec pulse duration. Data control of the split-beam was designed the same as the single beam sonar.

In addition to the up-looking sonar system, a single stand alone side-looking sonar system was intended to be operated on each river for the entirety of the season. The purpose of the side-looking sonar was to verify smolt cross-river distribution. This sonar used a Simrad® 200kHz 200-35 single beam transducer with a 3-degree beam angle.

Control Box

The control box provided an interface for powering and communicating with the sonar array, handled the data storage, and monitored the input voltage. Power from the battery bank was converted from 12 V to 24 V within the control box before going to the pods. The same connection communicated with the pods, allowing the operator to start and stop the individual sonar pods and apply data collection parameters using a laptop computer. Technicians also used the computer to review files during the season for quality control. Raw data received from the pods were transferred to a NAS via a Gigabit network switch. A voltmeter located on the control box allowed the technicians to monitor voltage from the battery bank.

Power Requirements

An 8-pod sonar system required approximately 86 W to operate, of which about 30 W were used to power the NAS and 7 – 8 W for each pod. On the Kvichak River, 10 batteries were used at Site 1 and five at Site 2. All batteries were 12 V, 100 Ah. Solar panels were used on the Kvichak River and were found to maintain the batteries during periods of clear sunny weather, but for the majority of the time solar radiation levels were not high enough to use solar as a reliable source of power. On cloudy days the Kvichak system required additional charging; for Site 1 a thermoelectric generator was used and Site 2 used a 1 kW gas generator (Wade et al. 2012). On the Ugashik and Egegik rivers, each system was powered with five batteries recharged daily with a 1 kW gas generator (no solar panels were used).

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. During post-season calibrations in 2009, the 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 at the surface was 0.39 m.

Sonar Calibration

The difference between the known target strength and the measured value was used as the calibration offset for echo integrating. A pool calibration of each sonar pod was performed prior to field deployment. Tests were performed in a calibration tank where the sonar was fixed and the calibration sphere was moved systematically across the sonar beam. The calibration tank was an indoor, closed system pool measuring 5.2 m (length) x 2.1 m (width) x 1.2 m (depth). The calibration sphere was moved with an Arrick Robotics (Tyler, TX) dual axis-positioning table XY – 30 with MD-2 motion control, mounted on the calibration tank with a MiniTek (Victor, NY) aluminum profile. The positioning table moved the calibration sphere in 38 cm x 38 cm grid in 2.5 cm increments, 3.0m from the face of each transducer (Figure 5). The positioning table was synchronized with the sonar such that the sonar would collect ten pings of data from the sphere at each stop.

During calibration the sphere passes through the maximum response axis; when this occurred, the target returned a maximum target strength value. The target strength of the 33.2 mm sphere for 120 kHz frequency is –40.7 dB (using the sound speed of 1470 meters/sec).

Sonar Deployment and Operation

All sonar arrays were deployed in the same manner. The pods were attached to each other by a 7.9 mm diameter wire rope so as not to put any stress on the power and data cable. 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 setup was completed, the array was staged on the river's bank (Photo 6). Prior to deployment, a 7.9 mm diameter cable was laid on the river bottom at a right angle to the bank to be used as a towline. This towline 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.

Once operational, the sonar systems collected data 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 system was operating correctly and useful data were being collected.

Kvichak Sonar Deployment and Operation

A key feature of a suitable site to place the sonar array was a location where the river was confined to a single channel. We sought areas where the bottom gradient was gradual and suitable for towing the array 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.

In the past, to prevent damage to the hardware, the sonar systems were usually not deployed until ice broke up on Iliamna Lake and was absent from the Kvichak River. Prior to breakup, ice was extensive in the system and it was assumed that few or no smolts moved. In 2010, we operated a sonar system in the Kvichak River in relatively heavy ice, the system functioned well, and we found substantial numbers of fish moving with the ice. In 2011, the southwestern portion of Iliamna Lake held a considerable amount of ice when the crew arrived in Igiugig on 16 May. Although ice was also in the river, the flows were light enough to allow the crews to set up the sites in the same place as in 2010 (Wade et al. 2012). For each site, the terminal box and power supplies were housed on the right bank (relative to the observer looking downstream). Each array had 8 pods spaced 10 m apart.

At Site 1, the sonar array was set on 20 May in a section of river 101 m wide during light ice flow. The first pod from the control box (T1) was located 13 m off the right bank in 1.8 m of water and the last pod (T8) was 18 m off the left bank in 3.2 m of water (Table 3). A river bottom profile for each site was developed from the known distance of each pod from shore and the depth at that location. The bottom profile of Site 1 began with a gently sloping right bank to a maximum depth of 3.9 m, 74 m off shore (Figure 6). Site 2 was set on 21 May in a section of river 128 m in width during light ice flow. The first pod was set 35 m off the right bank in 2.8 m of water and the last (8th) pod was 23 m off the left bank in 2.7 m of water (Table 3). The bottom profile of Site 2 was relatively uniform across the entire river bottom, with a maximum depth of 2.8 m, 35 m offshore (Figure 7).

The side-looking sonar system could not be deployed until the river was completely clear of ice. Ice continued to flow until 2 June, at which time the side-looking transducer was deployed approximately 10 m upstream of Site 1.

Egegik Sonar Deployment and Operation

Field crews arrived on the Egegik River on 11 May, when Becharof Lake still had approximately 20% of ice remaining. The crews were housed in the ADF&G cabin that is used by the adult sockeye salmon counting crew later in the year; this is located approximately 1.5 rkm upstream from the sonar sites.

The deployment was delayed until 16 May due to heavy ice flow in the river. Both sonar arrays were deployed at 4.5 rkm downstream of the Lake Becharof outlet in a section of river 90 m in width (Figure 2; Photo 3). The sonar systems were set just after a bend in the river to help reduce the environmental noise caused by the wind. Due to the rocky bottom composition of the river, the only suitable place for deployment was restricted to a 20 m stretch of river that was free of rocks; therefore the sonar arrays were separated by only 15 m. For both sonar systems the power supply and data control terminals were housed in weather proof construction boxes on the left bank.

Site 1 was initially deployed on 16 May, and then retrieved the next afternoon after encountering technical problems on startup. An Ethernet cable was not seated firmly in the leading sonar pod, preventing communication among the pods. Once fixed, the sonar array was re-deployed on 17 May at 1800 hours, with seven pods spaced 10 m apart. The first pod was placed 11 m off the left bank in 1.1 m of water and the last pod was located 19 m off the right bank in 3.2 m or water (Table 3; Figure 8).

The Site 2 sonar array was deployed on 16 May at 1500 hours but did not begin data collection until the evening of 17 May once the power source was in place. The first pod was located 15 m off the left bank in 0.84 m of water and the last pod was 17 m off the right bank in 2.3 m of water (Table 3; Figure 9).

The side-looking sonar system was not deployed until 3 June due to ice in the river. The side-looking transducer was placed approximately 10 m upstream of the Site 1 system.

Ugashik Sonar Deployment and Operation
Crews and equipment arrived by air at the Ugashik field camp, located 2 km below the Lower Ugashik Lake outlet, on 10 May. During the flight, the crew could view both lakes and observed no ice remaining. Site 1 sonar array was deployed on 12 May at 0900 hours approximately 80 m from the outlet of the Lower Ugashik Lake on a section of river 60 m in width (Figure 3; Photo 4). Upon start-up it was determined that there was a malfunction with one of the pods and the sonar array was immediately pulled, then redeployed on 15 May at 0900 hours in the same location. The bottom profile for this site was characterized by a gradual slope off the right bank for the first 45 m to a depth of 2.5 m and then a fairly consistent bottom to an abrupt rise at the left bank (Table 3). A total of 5 pods were placed at 5 m intervals starting with T1, 35 m off the right bank in 1.6 m of water and T5, 3 m off the left bank in 2.2 m of water (Table 3).

Site 2 sonar array was deployed on 12 May at 1900 hours approximately 15 m downstream of Site 1. The river at Site 2 was 66 m in width but the bottom profile was similar to Site 1. A total of 5 pods spaced 5 m apart were deployed. T1 was 46 m off the right bank in 1.3 m of water and T5 was 2 m off the left bank in 2.0 m of water (Table 3). At both sites the first pod was placed more than 35 m off the right bank, based on data collected in 2010 that showed very few smolts moving in relatively shallow and slow moving water on the right bank. For both sonar systems, the power supply and data control terminals were housed in weather proof Knaack Boxes® on the right bank.

The side-looking sonar system was deployed on 15 May, approximately 10 m upstream of Site 1 sonar. The side-looking transducer was in 1 m of water, which allowed the sonar to cover a 50 m cross-section of the river.

Sampling Smolt for Age, Weight, and Length

Smolts were sampled each evening on each river to collect age, weight, and length (AWL) data. For all river systems, the sampling sites were in the approximate location as the sites ADF&G had used 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. On the Kvichak River, an incline plane trap (IPT) was used to capture smolts. This trap was modeled after a similar trap that operated on the Kasilof River (Todd 1994). Smolts sampled on the Ugashik and Egegik rivers were captured using a standard fyke net with a rigid 4’ x 4’ opening.

Once the smolts were captured they were measured from tip-of-snout to fork-of-tail in millimeters and weighed in grams. Smolts were aged post season from visual observations of scales mounted on glass slides. European ages 1., 2., or 3. depending on the number of freshwater annuli were used.

Sample size goals were set at a minimum of 400 smolts per day. Based on binomial proportions for the two major age groups, a sample size of 400 smolts would simultaneously estimate the percentage of each age class within 5% of the true percentage 95% of the time (Goodman 1965; Cochran 1977).

The mean length of smolt differs among samples from a single day (Minard and Brandt 1986). Thus, to ensure that daily age composition estimates were representative of the population, attempts were made daily to obtain 100 smolt from each of six different catches. Because weight and age of smolt are strongly correlated to length, the time and cost of data collection was reduced by measuring up to a maximum of 600 smolt each day for length and up to 100 of those smolt for age and weight (Bue and Eggers 1989).

Age was estimated for smolt measured only for length using an age-length key (Bue and Eggers 1989). The key used length to categorize age-1. or -2. sockeye salmon smolt by determining a discriminate length that minimized classification error. This discriminate length was chosen such that the number of age-1. smolt classified as age-2. smolt was equal to the number of age-2. smolt classified as age-1. smolt. Age-3. smolt were not included in this analysis because too few samples were collected.

Weight was estimated for smolt measured only for length using a least squares linear regression. Based on paired weight-length data obtained from smolt sampled for age, weight, and length, we estimated weights (Wj) of age j smolt measured only for length as explained by (Ricker 1975):

$$W_j = \alpha L_j^{\beta} , \tag{1}$$

where

L_j = fork length of an age *j* smolt, and

α and β = parameters which determine the y-axis intercept and the slope of the line.

Due to the variability of age and size composition estimates among subsamples (e.g., incline plane trap catches) taken the same day, daily mean weight $(\hat{W})$ and age proportions $(\hat{P}_j)$ were estimated as the mean of subsampled values:

$$\hat{W} = \frac{\sum_{k=1}^{m} \left(\frac{\sum w_k}{n_k} \right)}{m} , \tag{2}$$

where

m = number of subsamples collected during a sampling period,

w_k = observed weights from subsample *k*, and

n_k = number of observations in subsample *k*; and

$$\hat{P}_j = \frac{\sum_{k=1}^{m}\left(\frac{n_{j,k}}{n_k}\right)}{m}, \qquad (3)$$

where $n_{j,k}$ = number of observations of age *j* in subsample *k*.

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. Smolt AWL data for the Kvichak River are provided (Appendix - A), smolt data for the Egegik and Ugashik rivers are not available at the time of this writing.

Environmental Data

Water velocity measurements were taken at a depth of 1 m at each pod, from a boat anchored 2 to 3 m downstream. Measurements were taken for one minute, three times at each transducer to give an arithmetic mean. At the Kvichak River, a model 622 Gurley Price meter made by Gurley Precision Instruments (GPI; Troy, NY) was used to take measurements. Velocities were then calculated based on the GPI conversion table. For the Ugashik and Egegik rivers, we used a FP111 digital flow meter made by Global Water Instrumentation, Inc. (Sacramento, CA). In addition to the digital flow meter an acoustic Doppler based flow meter (Argonaut-ADV by SonTek®; San Diego, CA) was on the Egegik River to measure fluctuations in water velocity caused by the tidal influence. Unfortunately technical difficulties with the instrument prevented deployment.

Water velocity on the Kvichak River was measured three times at each site, roughly at the beginning, middle, and end of the sonar system operating dates (Table 4). River stage height was not measured. Water velocities on the Egegik River were measured at each transducer at the beginning and end of the season (Table 5). Water velocities on the Egegik River fluctuated daily due to tidal influence, to characterize these differences measurements were taken in 4 hour intervals over a 24 hour period once at the end of the season. Water velocity on the Ugashik River was measured 3-5 m downstream of each sonar pod on 18 May (Table 6). Measurements were taken 10 m upstream of Site 1.

Weather and other hydrologic data were recorded at the Kvichak and Ugashik rivers using a Watch Dog 2000® weather station (Spectrum Technologies, Plainfield, IL). The weather station was configured to collect the following data hourly: temperature (°C), relative humidity (%), rainfall (mm), wind direction (degrees), wind gusts (km/h), and wind speed (km/h). One weather station was operated near the primary sonar site on the Kvichak and Ugashik rivers for the duration of each project (Tables 7 and 8). Weather data were recorded on the Egegik River manually by the field crew (Table 9). Hourly water temperature data were collected on the Kvichak River using a Tidbit® v2 TempLogger, and twice daily with a hand-held thermometer and on the Ugashik and Egegik rivers (Tables 7 - 9).

Sonar Data Analysis

Data Pre-processing
Data files were pre-processed (using EchoView® 5.0 software) by removing noise events generated by ice, boat passage through the sample area, wind/rain events, and any cross-talk among transducers. The distinction between noise events and smolts was obvious the majority of the time (Figure 10). In the event that the technician could not make a distinction between smolts and noise, that region of data was excluded from the analysis. Data were processed in hourly intervals; if noise occupied greater than 10% of an hourly bin, then the entire hour of data was removed. For the regions where data were removed, the estimates were linearly interpolated based on the values prior to and following these events.

Requirements for a Reliable Abundance Estimate

Several assumptions concerning smolt behavior must be met to produce a reliable abundance estimate across years. Smolt behavior can affect the accuracy of annual abundance estimates, along with comparisons among years. Below, we describe our four main assumptions about smolt behavior, how these assumptions could affect the estimates, and how these were factored into our study design. Violations of these assumptions could bias the final estimate.

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

To estimate 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, smolt velocity was assumed to be equivalent to water velocity, which was measured three times at each transducer during 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 similar to the water velocity. If smolts swam faster than the water velocity, 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 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 data cannot be quantified to estimate abundance. 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. There is a diel fluctuation in the vertical distribution of smolts, but it has been found that the majority of fish use the upper 1 m of water, and the bulk of those fish are in the upper 30 cm (Mueller et al. 2006; 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 years of high abundance the smolts distribute deeper in the water column instead of across the river and across days within the season. If the fish are distributed deeper in the water in high abundance years compared to small abundance 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. We have begun to develop and compare metrics characterizing the vertical distribution across nights and for each season to determine whether any changes were correlated with annual abundance.

(4) Mean target strength may be used for echo integration.

Target strength of an individual fish generally increases with body size within the same species (Simmonds and MacLennan 2005). When estimating abundance, differences in individual target strength thus could affect the overall estimate. Our assumption is that there is no appreciable difference in target strength between the two age classes of smolts present in this study, and what difference may exist is compensated for by using the mean target strength for a given year. From 1955 to 2001, age 2 smolts were 24mm longer and 4g heavier than age-1 smolts (Crawford and Fair 2003); Quinn (2005) also found that age-2 smolts from Lake Iliamna were 3.6 g heavier than age-1 smolts. In this study, we did not quantify differences in target strength between the age classes.

Smolt Abundance Estimates

Echo integration was employed to obtain the abundance estimates. The majority of the time sockeye salmon smolts outmigrate, they aggregate in schools too dense for the sonar to detect single targets accurately. Abundance estimates therefore cannot be calculated by counting individual fish. Instead, echo integration must be used to estimate abundance (Simmonds and MacLennan 2005). Echo integration sums all backscatter cross-sections from multiple targets in a given sample volume, producing a backscatter coefficient. If the average target strength of a single fish is known, the total number of fish can be estimated from the backscatter coefficient.

Using EchoView® software the backscatter coefficient was calculated over a given range from the transducer to produce the area backscatter coefficient/m^2 (ABC). After noise events were removed, the ABC was calculated in 1-h x 0.2 m depth intervals, then divided by the mean sigma (target strength in linear domain) to obtain the smolt density for each cell. The smolt density for each cell is a measure of mean smolt count/cross sectional area sampled, which then is normalized to smolt density/m^2 for each strata. The fish density/m^2 is then multiplied by the water velocity to obtain the smolt flux giving the number of smolts/hour/meter of river cross section sampled at each pod.

Several models were considered for expanding the pod-specific 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 because counts were continuous from beginning to end of the enumeration project. When portions of the total season were missed due to shutdowns and environmental noise the missing hours for each transducer were filled using 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 minimal. The season total abundance and variance of the mean for each site were estimated by the following:

$$SA = \sum_{j=1}^{K} HA_j \tag{4}$$

$$HA_j = \frac{\sum_{i=1}^{n} T_{ij}}{n} \times ES_j \tag{5}$$

$$ES_j = \sum_{i=1}^{n}\sum_{m=0}^{d} T_{ij} + \left(T_{i+1,j} - T_{ij}\right)\frac{m}{d} \tag{6}$$

$$Var(SA) = \sum_{j=1}^{K}\left[Var\left(HA_j\right)\right] \tag{7}$$

$$Var\left(HA_j\right) = \frac{\sum_{i=1}^{n}\left(T_{ij} - \overline{T}_{.j}\right)^2}{n-1} \cdot \frac{fpc}{n} \times ES_j^{\ 2} \tag{8}$$

$$fpc = \frac{A-a}{A-1} \tag{9}$$

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 estimating uncertainty from all inputs.

Smolt abundance was estimated hourly, and expanded to calculate daily and total season abundance. Abundance was compared between sites within each river, and among hours within each site. Diel timing of downstream movement was described by comparing hourly abundances during nighttime and daylight hours. For the purpose of this study, daylight was defined as the hours from 0500 to 2259 hours and darkness from 2300 to 0459 hours.

RESULTS

Kvichak River

Data Pre-processing
Data were collected at Site 1 from 21 May (1600 hours) through 12 June (1400 hours), for a total of 526 h of processed data. Site 2 data were collected from the period 21 May (2100 hours) to 13 June (1400 hours), for a total of 546 h of processed data. Each site operated with eight pods for the duration of the season.

Environmental noise accounted for 11% of the unusable data collected at Site 1 and 13% at Site 2. Three big wind events occurred on 24 May, 31 May, and 6 June. Unlike ice, wind events are continuous across the river width; therefore the noise affects all sonar pods. Wind is usually a longer event and can account for hours of data being removed. Wind affects each site differently, potentially contributing to differences in the amount of unusable data among sites.

Side-looking sonar data were collected from 2 June through 12 June. Each day the sonar was checked it was found to be at an angle where the sonar beam no longer reached across the river. With the 3° beam, the angle of the transducer must be positioned precisely or the coverage is drastically reduced. The sonar would tilt off axis when the water current around the mounts scoured away the river bottom; this would happen in a relatively short time. More weight was added to the bottom of the mount, but this did not completely remedy the problem.

Abundance Estimate
The estimated abundance of sockeye salmon smolts in the Kvichak River from 21 May to 11 June at Site 1 was 48,806,237 (95% confidence interval = 45,543,071 - 52,069,403); Table 10; Figure 11). For Site 2, the estimated abundance from 21 May to 12 June was 41,730,658 (39,257,894 - 44,203,422); Table 10; Figure 11). Hourly smolt passage peaked at each site during darkness (Figure 12). Many smolts also migrated during daylight, however, and total passage during daylight hours was 49% of the run at Site 1 and 60% of the run at Site 2 (Table 11).

Smolt Distribution
Vertical distribution was split into 0.2 m depth strata down to a depth of 3.2 m at Site 1 and 2.2 m at Site 2. Smolts were detected at all depth strata sampled with the distribution highly skewed toward the surface. For both sites, there was a diel difference in vertical distribution between daylight and dark hours. During periods of darkness, smolts were concentrated in the upper 1.0 m of the water column. For both sites more than 90% of smolts detected at night were in the upper 1.0 m with the majority of these in the upper 0.6 m (81% - Site 1, 90% - Site 2; Figure 13). By contrast, smolts traveling during daylight hours tended to have a deeper vertical distribution. For both sites, 67% of smolts were detected in the upper 0.6 m of the water column and ~83 % were in the upper 1.0 m.

Smolts were detected by all sonar pods at each site (i.e., across entire river), but were disproportionately distributed. At Site 1, smolts were concentrated in the areas of deeper water and higher velocity, where approximately 75% were detected at the five pods in the main channel along the left side of the river (Figure 6). At Site 2 the distribution varied across the river, with two peaks detected approximately 45 m and 80 m from the right bank (Figure 7).

Run Timing
A relatively large number of smolts were detected during the first 24 hours of deployment in 2011 (Table 10). Although these fish account for <4% of the total run, it may be an indication that some early fish were missed. The overall run timing in 2011 was similar to previous years with a first peak in late May and a second peak in early June (Figure 14). Unlike previous years, a third peak occurred on 8 – 9 June (Figure 11). Less than 2% of the total smolt run was detected in the last two days of operation at each site, indicating that the run was nearly complete before the sonar systems were removed.

Sampling Smolt for Age, Weight, and Length
Smolt sampling on the Kvichak River began on smolt day 25 May and ended 12 June. Although the crews were mobilized by 18 May ice flow prohibited fishing until 25 May. The first night of fishing the crew caught their sampling goal of 600 smolts in 72 minutes (Appendix A-1). Based on this relatively high catch rate (CPUE=13.56) it appears the smolts were already present in fairly high numbers, which would indicate sampling began after the start of the run. Ice resumed flowing after the first sampling session preventing further fishing from 26 May to 29 May and then again on 31 May to 1 June. Although CPUE is not an exact measure of total smolt passage due to the inherent difficulties in capturing smolts it can identify relatively large changes in smolt abundance. Sonar data for the days fished appear to follow the same general trends as the catches (Figure 11).

Scales from a sub-sample of 100 smolts were taken each night and the remaining smolts (~500) were aged based on this age-length ratio (Appendices A-2 and A-3 respectively). In 2011, the nightly percentage of age-1 smolts ranged from 11.3 % on 2 June to 100% on 7 and 12 June. Overall the majority of the catch was age-1, which constituted 69.0 % of the total catch (Appendix A-5). Previous smolt studies on the Kvichak by ADF&G have seen the majority of age-2 smolts outmigrate earlier than age-1 smolts (Crawford and West 2001). Smolt sampling in 2011 did not begin until 25 May by which time 23% and 18% of smolts at sites 1 and 2 (respectively) had been counted, the majority of this early portion may have been age-2.

Egegik River

Data Pre-processing
Both sonar systems on the Egegik River were deployed on 17 May and operated continuously until 11 June, yielding 592 hours of data to analyze from each site. Due to both sites being in the same section of the river both experienced similar environmental noise events. Environmentally induced acoustic noise accounted for 19% of the data collected from each site to be unusable. High easterly winds coming off of Lake Becharof accounted for the majority of this environmental noise.

Seven pods, each spaced approximately 10 m apart, were deployed at both sites 1 and 2 (Figures 8 and 9). During analysis it was determined that the pod at T1 of Site 1 was not in deep enough water and was not used in the abundance estimate. On 1 June, T3 of Site 1 stopped recording data and was not active for the remainder of the season. On 7 June, T2 of Site 1 became inactive and was not operable for the remainder of the season. For both T3 and T2, data were interpolated between the adjacent pod and the shore to produce the abundance estimate.

The side-looking sonar was deployed on 3 June and retrieved on 11 June. Problems with the sonar moving out of alignment (similar to the Kvichak River) were experienced. Crews would re-align the sonar daily but it did not remain in position long enough to collect useful data.

Abundance Estimate

The estimated abundance of sockeye salmon smolts from 17 May to 11 June at Site 1 was 9,907,344 (95% confidence limits = 8,788,962 – 11,025,727; Table 12; Figure 15). For Site 2, the estimated abundance from 17 May to 11 June was 8,860,449 (7,692,235 – 10,028,662; Table 12; Figure 15). Unlike the Kvichak River high smolt passage was not restricted to night time. Although abundances were low from 0700 – 1300 hours, the remaining hours of daylight saw high passage (Table 11; Figure 16). For both sites 1 and 2, greater than 65 % of total smolt outmigrated during daylight (0500 – 2259) hours.

Smolt Distribution

The majority of the outmigrating smolts on the Egegik River were in the regions of the river with the greatest depth and highest velocity. For both sites 1 Site and 2, greater than 61.0% of total smolts were detected by the three transducers located approximately 37 m to 60 m off the left bank (Figures 8 and 9). Both sites were relatively close to one another and had similar bottom profiles; water depth in the area of highest smolt abundance ranged from 2.49 m to 3.33 m.

Vertical smolt distribution on the Egegik River was relatively uniform throughout the water column, and consistent between night and day. During the night at Site 1, 26% of total smolts were in the upper 0.6 m and 53% were in the upper 1.0 m; at Site 2, 35% of smolts were found in the upper 0.6 m and 56% in the upper 1.0 m (Figure 17). During the day at Site 1, 33% of the smolts were in the upper 0.6 m and 46% were in the upper 1.0 m; at Site 2, these numbers were 41 % (upper 0.6 m) and 53% (upper 1.0 m; Figure 17).

Run Timing

Based on the relatively low numbers of smolts from 17 May to 21 May, it appears the early portion of the smolt run was not missed (Table 12). Smolt abundance peaked twice during the season, on 27 May and 31 May (Figure15). From 4 June to 10 June, smolt numbers leveled off to an average of 275,000/day; this portion of the run accounted for 22% of the estimated total abundance. These relatively high, consistent numbers during the end of the project indicate that smolt outmigration may have continued after the close of the project.

Ugashik River

Abundance Estimate

Both sonar systems on the Ugashik River were deployed prior to 15 May, when river velocities were similar to those encountered in 2010 (Wade et al. 2012). On 24 May, the sonar systems were washed downstream by unusually high river discharge and water velocity. The sonar array was subsequently retrieved but not immediately re-deployed due to continued high water velocities (> 3 m/s). On 1 June at 1500 hours, Site 2 sonar was re-deployed with only 4 pods because one of the power/communication cables was broken when swept downstream earlier. The sonar array was placed near the original location but the placement of the transducers differed considerably. Because the water velocity remained high (more than 3.0 m/s), the only location to deploy the sonar was in the slower, shallow water near the right bank with the sonar array almost parallel with the shoreline. On 4 June, Site 1 sonar was re-deployed in a similar orientation in the river channel. Water velocities remained higher than 3 m/s throughout the entire field season and the sonar array could not be moved into a more suitable cross-river orientation without being washed downstream. This prevented sampling the higher-velocity portion of the river, where most smolts likely travelled.

The short deployment time and restricted cross-sections of sampled water left too many data gaps to produce a reliable abundance estimate for Ugashik River smolts in 2011. Smolt abundance estimation requires sampling the duration of the entire smolt run and the entire smolt cross river distribution. Ugashik River sockeye salmon smolts typically migrate over a window lasting from 22 May 24 through 12 June (Crawford 2001). In 2010, 75% of Ugashik River smolts were concentrated from 36 to 40 m off the right bank (Wade et al. 2012).

On 18 May, Site 1 water velocities ranged from 1.0 m/s at T1 to 1.9 m/s at T3; Site 2 velocities ranged from 0.9 m/s at T1 to 1.9 m/s at T2. Shortly after, water velocities increased to a point where the crew could not anchor in the river channel to take measurements. A total of 5 velocity measurements were recorded over the remaining deployment in a location near the right bank where the crew could anchor in the slower water. Measurements during this period were all higher than 3.0 m/s with the highest being 3.2 m/s.

DISCUSSION

The year 2011 marked the fourth season of using the new sonar system to generate smolt abundance estimates, while evaluating system performance by collecting and interpreting information on site characteristics and fish behavior. Historical problems from using sonar to estimate smolt abundance in Bristol Bay (described in Wade et al. 2010a) may have been detected and rectified had greater information about fish behavior and distribution been obtained from the sonar system used then. In this section, we thus discuss the abundance estimates, the various factors that may have affected them, and the inferences we can draw about the ability of the sonar to effectively estimate smolt abundance under various site and behavioral conditions.

Abundance Estimates

Kvichak River

The abundance of sockeye salmon smolts was the highest estimated since the project began in 2008, with estimates at both sites surpassing the previous high of 38.7 million smolts estimated at Site 2 in 2009 (Table 14). Estimates in 2011 were also consistent between the two sites, with the difference of 14.5% (48.8 million vs. 41.7 million) only slightly more than in prior years (Table 14). These two sites are not true replicates, nor can they validate the accuracy of the estimates (because the true number of smolts migrating cannot be known). The similarity of the estimates over the years, however, improves our confidence in the technology by showing the two systems provide consistent results when counting the same number of fish at two different sites. There may still be process error from the systems themselves, but such error is more easily corrected for if it is consistent across all sonar systems.

Among the two Kvichak River sites, our *a priori* belief was that Site 1 was more likely to provide an accurate estimate because it had a more pronounced thalweg that likely concentrated more of the smolts in an area easy to ensonify, thereby minimizing the uncertainty from interpolating between the outside pods and the shoreline. In reality, both sites produced similar estimates and the higher annual count has varied between the two sites since 2008, suggesting that the sonar system was robust to the (perceived) inferior conditions at Site 2.

In 2011, the sockeye salmon smolt abundance did not have the pronounced peaks in run timing observed from 2008 through 2010. In each of those three years, smolt abundance peaked both early and late in the season, when a large proportion of the run migrated in a single smolt day. These peaks were consistent among years, with a large peak on 27 or 28 May and an equal or smaller second peak on 2 or 3 June (Figure 19). There was also a lull in the run at the end of May that was consistent with prior years. In 2011, however, the run was spread over a longer time, with more of a “sawtooth” pattern of increases and decreases in abundance through time. (Figure 19). In 2011, the smolt run was also more protracted than in previous years with 14 % of all smolts outmigrating after 5 June. The difference in smolt run timing in 2011 may have been due to unusual, continued ice flow in 2011 (Figure 20). In 2011, ice from Lake Iliamna was still flowing in the river through 2 June.

The unusual ice characteristics in 2011 may have also caused unusually high daylight smolt passage events compared to previous years. Smolts may move during periods of darkness as an attempt to avoid predation from piscivorous birds (i.e., Arctic terns, Quinn 2005). With much of the river covered in ice the smolts may have taken advantage of this cover and moved during daylight more than we have seen in the past. In addition to the ice providing cover, it also altered river flow. For example, water depth at Site 1 began to drop noticeably on May 29, likely from ice damming somewhere upstream. Water depth at the T1 dropped approximately 0.5 m from 0813 to 0855 hours, then began rose again quickly. A large pulse of fish was then detected from 1100 hours to 1400 hours, with an estimated 250,000 smolts at Site 1 and 760,000 smolts at Site 2. Such high passage rates are not usually seen during this time of day. The pulse of water from an ice dam could have explained this aberration, while differences in holding locations and/or measurement error over just 3 hours may explain the difference in estimates from the two sites.

Egegik River

To estimate smolt abundance, swimming speed must be estimated and then used to calculate smolt flux. In the past studies on the Kvichak and Ugashik rivers, we have assumed smolt swimming speeds were similar to water current velocities measured at the sonar site (Wade et al. 2010a). The Egegik River presented a unique challenge in that the sonar sites are influenced by both river discharge and tide, and water current velocities thus change on an hourly basis. For example, water velocities measured every 4 hours over a 24-hour period ranged from 1.57 m/s to 2.02 m/s. We would expect the tidal effect to change over the course of the season if the river discharge changes. In an attempt to measure continuous river velocity throughout the season, the Argonaut-ADV was to be used to collect these data at a single point in the river. Due to heavy ice flow, the device could not be deployed until June 2. Upon deployment, the device was damaged and the problem could not be remedied in the field. Abundance estimates were then calculated using methods similar to those used on the Kvichak River where discrete velocity measurements were made twice (18 May and 9 June) at each pod.

Not having accurate water velocity measurements (i.e., smolt swimming speed) violates assumption number one and could bias the abundance estimates high or low. For accurate abundance estimates on the Egegik River, continuous measurements of water velocity across the river are required instead of velocity measurements at a single point (as was done with the Argonaut-ADV). One method that should be explored is a horizontally oriented acoustic Doppler current profiler that could provide continuous velocity data over each sonar pod.

Abundance estimates on the Egegik River may have also been influenced by how smolt distribute themselves in the water column. One of the assumptions made when estimating smolt abundance is that the majority of smolts travel in the upper portion of the water column. Unlike the Kvichak and Ugashik, rivers where smolts distribution is highly skewed toward to surface, smolts on the Egegik River were distributed at all depths sampled. The sonar does not sample the first 0.75 m of the water column due to the near-field effect (Wade et al. 2010a), but the uniform distribution of fish within the effective beam in the Egegik River suggests they may travel in this area. If smolts do travel in the near-field they would not be included in the estimate, biasing it low. Tests for vertical smolt distribution could be accomplished by operating a downward-looking sonar from the surface.

Ugashik River

The water velocities that prevented sonar operation on the Ugashik River in 2011 were abnormally high, and the sonar system described here may thus still be a feasible way to estimate sockeye salmon smolt abundance. In 2010, when the sonar was operated without problems, velocities across the river averaged 1.7 m/s and ranged from 0.2 m/s near the right bank to 2.9 m/s in the thalweg (Wade et al. 2012). Over a 19-year period earlier, velocities averaged 1.9 m/s, ranging from 1.0 to 2.7 m/s (Crawford 2001). In 2011, we had no trouble with the equipment until velocities exceeded these historic highs in flow. Although the 2011 water velocities may have been highly unusual, safeguards should be developed to continue operation in case high flows recur for even short periods.

Smolt Distribution

As described earlier, distribution and movement timing helps assess the accuracy of yearly abundance estimates by identifying anomalies that could influence the final abundance estimate. On the Kvichak River, behavior of migrating smolts was similar to prior years. Passage rates of outmigrating smolts, for example, were again higher during periods of darkness (2300 – 0459 hours) than daylight (0500 – 2259 hours; Table 13). Approximately 50% of the abundance estimate in 2011 was during the night; because night accounts for only 25% of each 24-hour period, smolt passage per hour was approximately three times higher at night.

Smolt vertical distribution at Site 1 on the Kvichak River has also been consistent across years for both periods of daylight and darkness (Figure 18). During darkness, over 90% of the smolts were detected in the upper 1.0 m in 2011, and on average more than 80% were found in the upper 0.6 m. Smolts in 2011 tended to be a little deeper during daylight hours, varying from 88% in 2008 to 54% in 2009 in the upper 1.0 m. In all cases, more than 80% were found in the upper 1.6 m. These distributions were consistent with those described by Maxwell et al. (2009) on the Kvichak River, where smolts used the deeper, faster water in the mid channel and the majority travelled in the top 0.3 m.

Smolt distribution and diel timing on the Egegik River were somewhat different than on the Kvichak River. In 2011, Egegik River smolts were distributed more evenly through the water column (instead of predominantly near the surface), and had more movement during daylight hours. Sites 1 on the Kvichak and Egegik rivers were similar in depth and bottom profile, yet the smolt distribution patterns differed greatly.

CONCLUSION AND RECOMMENDATIONS

Upward-looking sonar arrays appear to be an effective way to estimate smolt abundance on select rivers systems in Bristol Bay. The arrays are able to detect smolts moving downstream in both lateral and vertical segments of the river; these detections can be integrated across vertical, lateral, and time strata and used to generate abundance estimates at hourly, daily, and seasonal time intervals. The accuracy of the estimates cannot be validated without known abundances; however, the relatively low measurement error of two independent, sonar-based estimates from different sites in the same river supports the belief that the estimates are accurate. Where sonar can be operated consistently, it also yields timing and distribution data that can be used to help refine the abundance estimate and understand the smolt run. At such sites, sampling should be continued in future years to build a long-term data set that can be used for management purposes such as monitoring population changes and forecasting adult returns.

In future years, sonar arrays should be configured to better withstand peak water velocities, and be deployed at sites where the effects of water velocity and ice on smolt detections can be accounted for. Relationships between smolt swimming speed and water velocity need to be researched, especially at sites that are tidally influenced. Estimates on the Kvichak River should be prioritized because it has the longer time series (four consecutive years), and the applied benefit of smolt estimates increases greatly with time. Finally, more work is needed to develop metrics related to fish distribution to compare and contrast among sonar sites, days, and seasons on a given river system. These metrics add to the level of confidence to place in a given year's smolt abundance estimate and will ultimately lead to a useful dataset for forecasting adult returns and assessing escapement goals.

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TABLES

Table 1. Historical ice cover dates on Lake Iliamna, in the Kvichak River drainage.

Winter of	Freeze-up Date	Break-up Date	Total Days of Ice Coverage
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	
2009 - 2010		22-May	
2010 = 2011		13-May	

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

Table 2. Historical ice cover dates on Lower Ugashik Lake (Ugashik River drainage) and Becharof Lake (Egegik River drainage).

	Lower Ugashik Lake			Becharof Lake		
Winter of	Freeze-up date[a]	Break-up date	Ice cover days	Freeze-up date[a]	Break-up date	Ice cover days
1981 - 1982		12-May				
1982 - 1983	18-Jan					
1983 - 1984	16-Jan			16-Jan	16-May	121
1984 - 1985	11-Feb	14-May	92	11-Feb	3-May	82
1985 - 1986	26-Feb	9-May	74	26-Feb	27-Apr	61
1986 - 1987	12-Mar			12-Mar		
1987 - 1988	9-Dec	24-Mar	106	24-Mar		
1988 - 1989	17-Jan	10-May	113	17-Jan	27-Apr	101
1989 - 1990	21-Feb	25-Apr	63	21-Feb	25-Apr	64
1990 - 1991	8-Jan			4-Feb	1-Apr	57
1991 - 1992	27-Jan	4-May	97	27-Jan	10-May	104
1992 - 1993	20-Jan	31-Mar	70	23-Jan	31-Mar	68
1993 - 1994	16-Feb	8-Apr	51	25-Feb	4-Apr	39
1994 - 1995	24-Jan	28-Apr	94	24-Jan	28-Apr	95
1995 - 1996	8-Jan	15-Apr	97	8-Jan	28-Mar	80
1996 - 1997	13-Dec	26-Apr	135	13-Dec	19-Apr	128
1997 - 1998	5-Jan	4-Apr	89	6-Jan	4-Apr	89
1998 - 1999	22-Jan	19-May	117	5-Feb	28-May	113
1999 - 2000	25-Dec	7-Apr	104	2-Jan	12-Apr	101
2000 - 2009[b]	-	-				
2009 - 2010		10-May				
2010 - 2011	10-Dec	8-Feb	Lake ice broke 4 times		10-May	

[a]Data provided by ADF&G; most information is from local air charter companies and considered anecdotal.

[b]ADF&G smolt program discontinued in 2001.

[c]Smolt crews arrived on 10 May and noted 20 - 30 % of lake ice remaining.

Table 3. Range and depth of sonar pods placements on the Kvichak, Ugashik, and Egegik rivers in 2011.

	Kvichak River		Ugashik River		Egegik River	
Transducer	Depth (m)	Range[a] (m)	Depth (m)	Range[a] (m)	Depth (m)	Range[b] (m)
Site 1 - T1	1.75	13	1.61	35	0.84	11
Site 1 - T2	2.07	22	2.32	40	1.88	15
Site 1 - T3	2.64	35	2.44	45	2.81	28
Site 1 - T4	3.11	45	2.45	50	3.01	39
Site 1 - T5	3.48	53	2.19	55	3.32	50
Site 1 - T6	3.69	65	NA	NA	3.21	60
Site 1 - T7	3.89	74	NA	NA	NA	NA
Site 1 - T8	3.19	83	NA	NA	3.22	71
Site 2 - T1	2.84	35	1.30	46	1.1	15
Site 2 - T2	2.63	45	1.60	51	2.01	26
Site 2 - T3	2.54	56	2.24	56	2.49	37
Site 2 - T4	2.48	66	2.49	60	2.78	47
Site 2 - T5	2.44	75	2.00	64	3.33	57
Site 2 - T6	2.42	85	NA	NA	2.9	68
Site 2 - T7	2.31	95	NA	NA	2.3	79
Site 2 - T8	2.73	105	NA	NA	NA	NA

[a]Range based on distance from the right bank.

[b]Range based on distance from the left bank.

Table 4. Water velocities (m/s) at the Kvichak River sonar site, 2011.

Site 1			
Transducer	2-Jun	9-Jun	13-Jun
T1	0.92	0.82	0.92
T2	1.13	1.26	1.18
T3	1.35	1.29	1.39
T4	1.44	1.48	1.50
T5	1.50	1.59	1.57
T6	1.52	1.65	1.55
T7	1.57	1.52	1.61
T8	1.21	1.31	1.44
Site 2			
Transducer	2-Jun	9-Jun	13-Jun
T1	1.13	1.22	0.88
T2	1.16	1.24	1.13
T3	1.22	1.31	1.24
T4	1.21	1.16	1.22
T5	1.17	1.16	1.14
T6	1.13	1.22	1.26
T7	1.04	1.24	1.13
T8	1.02	1.09	1.13

Table 5. Water velocities (m/s) at the Egegik River sonar site, 2011.

Transducer	18-May	9-Jun	18:30*	22:30*	2:30*	06:30*	10:30*	14:30*	18:30*	22:30*	2:30*
T1	0.41	0.49									
T2	1.39	1.44									
T3	1.90	1.93									
T4	2.25	2.31									
T5	1.91	2.02	1.62	1.58	1.46	1.67	1.73	1.98	1.80	1.57	1.76
T6	1.40	1.62									
T7	1.38	1.60									

*Measurements taken on 9 June.

Table 6. Water velocities (m/s) at the Ugashik River sonar site, 2011.

Site 1[a]					
Transducer	18-May	27-May	3-Jun	6-Jun	10-Jun
T1	1.0	3.0	3.0	3.0	3.1
T2	1.7	-	-	-	-
T3	1.9	-	-	-	-
T4	1.3	-	-	-	-
T5	1.2	-	-	-	-
Site 2[a]					
Transducer	18-May	27-May	3-Jun	6-Jun	10-Jun
T1	0.9	-	-	-	-
T2	1.9	-	-	-	-
T3	1.3	-	-	-	-
T4	1.4	-	-	-	-
T5	1.5	-	-	-	-

[a]Measurements during flood event (24 May - 10 June) were taken only at the approximate location of T1.

Table 7. Daily climate and hydrological observations made at 0800 and 2000 hours near the Kvichak River sonar site, 2011.

	Cloud cover [a]		Precipitation (mm)	Wind direction & velocity (km/h)		Air temperature (°C)		Water temperature (°C)		Water clarity[b]
Date	0800	2000	Daily	0800	2000	800	2000	0800	2000	0800
5/23	4	4	0	N 0	N 17	6.4	7.3	1.02	0.55	1
5/24	3	4	0	N 11	N 17	6.1	6.5	1.56	1.15	1
5/25	3	3	0	NE 16	N 16	6.9	6.2	0.93	1.24	1
5/26	3	3	0	N 4	N 11	6.0	13.8	1.51	1.34	1
5/27	2	3	0	N 1	N 6	4.8	11.1	1.62	2.40	1
5/28	3	3	0	E 0	N 11	4.4	9.1	2.13	0.30	1
5/29	3	3	0	NE 0	SW 0	4.9	13.3	1.10	1.62	2
5/30	3	3	0	S 6	W 6	6.7	17.5	1.94	2.72	1
5/31	3	4	0.14	N 6	N 4	6.2	8.0	2.53	0.72	1
6/01	4	4	0.1	S 0	SW 0	5.3	11.4	0.83	1.86	1
6/02	1	3	0	N 1	E 8	5.1	16.3	1.86	2.53	1
6/03	3	4	0.06	N 19	S 3	7.5	9.4	5.77	6.33	5
6/04	3	3	0.7	NE 1	NE 3	5.1	7.6	5.90	5.82	5
6/05	4	2	0.11	SE 0	N 4	5.8	12.5	5.82	5.95	5
6/06	5	4	0.15	N 1	N 14	5.8	6.3	5.49	5.72	1
6/07	3	4	0.17	N 11	N 12	8.1	7.9	7.37	6.31	5
6/08	3	2	0.02	N 3	NE 6	7.2	11.3	5.36	7.32	5
6/09	4	4	0.07	W 0	N 4	6.1	11.6	8.02	8.27	1
6/10	2	4	0	NE 8	NE 12	7.6	10.2	8.22	8.74	1
6/11	4	4	0.14	N 8	NE 16	6.9	8.3	8.27	7.75	5
6/12	3	3	0.06	N 6	NE 3	8.3	13.7	7.37	8.15	5
6/13	4	4	0.07	S 0	n	8.6	n	8.37	n	2

[a] 1 = Cloud cover not more than 1/10

[b] Water Color Codes

n = no observation

[a]Cloud cover codes

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

1 = Clear

2 = Light Brown

3 = Brown

4 = Dark Brown

5 = Murky or Glacial

Table 8. Daily climate and hydrological observations made at 0800 and 2000 hours near the Ugashik River sonar site, 2011. Empty cells indicate no observation.

	Precipitation (mm)	Wind direction & velocity (km/h)		Air temperature (°C)		Water temperature (°C)
Date	Daily	0800	2000	0800	2000	Daily
5/14	0	E 33	E 22	4.8	5.6	3.2
5/15	0	E 14	E 12	4.4	4.6	3.3
5/16	0	NE 4	E 6	4.5	8.2	n
5/17	0	NE 1	E 9	5.2	7.7	n
5/18	0	E 4	E 0	5.3	6.1	n
5/19	0	NE 3	E 8	5.2	6.3	n
5/20	0	E 11	E 17	5.1	6.5	4.1
5/21	0	E 4	E 8	5.2	6.3	n
5/22	0	NE 3	E 9	5.2	6.1	n
5/23	0.5	E 4	E 6	5.5	6.9	n
5/24	1.0	E 24	E 20	6.4	5.4	n
5/25	0.2	NE 9	E 11	5.6	7.9	4.5
5/26	0	N 3	NE 8	8.3	12.4	n
5/27	0	E 9	E 8	6.3	9.0	n
5/28	0	E 4	SE 8	7.2	9.0	n
5/29	0	SW 3	W 11	6.2	11.0	n
5/30	0	E 1	E 3	5.8	10.2	4.5
5/31	0	E 38	E 9	6.9	7.4	n
6/01	0	SW 3	E 3	5.4	13.4	n
6/02	0	E 3	E 19	7.4	6.6	n
6/03	0	E 8	NW 3	7.7	7.9	4.7
6/04	0	E 6	E 1	6.0	8.9	n
6/05	0	E 0	SE 1	6.0	10.5	n
6/06	0	E 8	E 19	6.6	6.8	n
6/07	0	E 16	E 8	7.0	7.3	5.0
6/08	0	S 4	W 4	6.1	7.3	n
6/09	0	E 1	E 9	5.3	7.7	n
6/10	0	E 22	E 12	7.1	7.7	n
6/11	0	E 8	E 12	7.4	7.8	5.0

n = no observation

Table 9. Daily climate and hydrological observations made at 0800 and 2000 hours near the Egegik River sonar site, 2011. Empty cells indicate no observation.

	Cloud cover [a]		Precipitation [b]		Wind direction & velocity (km/h)		Air temp. (°C)		Water temp. (°C)		Water clarity [c]	
Date	0800	2000	800	2000	0800	2000	0800	2000	0800	2000	0800	2000
5/17	3	3	A	A	E 8-24	E 16-32	3	6	n	n	1	1
5/18	3	4	A	A	E 16-32	E 16-32	4	7	n	n	1	5
5/19	2	3	A	A	E 32-48	E 16-48	3	8	0.5	0.5	5	1
5/20	2	4	A	A	E 24-40	E 8-32	3	7	0.5	0.5	1	1
5/21	4	3	0	Tr	E 16-32	E Vari	4	8	1.0	1.0	1	1
5/22	4	4	0	0	E Vari	E Vari	5	7	1.0	1.0	1	1
5/23	3	3	B	Tr	E Vari	E Vari	5	7	1.0	1.5	5	1
5/24	3	3	Tr	0	E 16-32	E 32-48	5	7	1.0	1.0	1	1
5/25	2	2	0	0	E 16-32	E 16-32	6	9	1.0	1.0	1	1
5/26	3	3	Tr	Tr	E 24-40	NW 0-16	7	9	1.0	1.0	1	1
5/27	2	2	0	0	NW 0-8	Vari	9	13	1.0	1.0	1	1
5/28	2	3	0	0	NW 0-16	NW 0-16	12	13	2.0	2.0	1	1
5/29	3	2	0	0	SW 0-24	S 8-16	11	12	2.0	2.0	1	1
5/30	4	4	0	0	NW 0-8	NE 8-24	9	7	3.0	3.0	1	1
5/31	4	4	0	0	NE 16-48	NE 8-16	7	7	3.5	3.5	1	5
6/01	4	1	Tr	Tr	NE 8-16	E 0-8	5	7	3.5	3.5	1	1
6/02	2	4	B	0	E 16-40	16-40	6	7	4.0	4.5	1	1
6/03	4	4	0	A	E 16-32	E 8-16	6	7	4.5	5.0	1	1
6/04	4	3	0	Tr	E 0-16	Vari	6	7	5.6	5.6	1	1
6/05	2	1	0	A	Vari	E 8-16	10	8	5.8	6.0	1	1
6/06	4	4	0	0	E 16-32	E 20-81	6	9	6.0	6.0	1	1
6/07	4	4	A	B	E 16-48	E 16-48	7	10	6.0	6.0	1	1
6/08	2	2	0	Tr	Vari	Vari	9	12	6.0	6.0	1	1
6/09	3	3	0	0	E 16-40	E 16-48	7	8	6.2	6.3	1	1
6/10	3		0		E 16-40	n	8	n	n	n	n	n

[a] Cloud cover codes
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

n = no observation

[b] Precipitation codes
0 - No precipitation
Tr - Trace
A - Intermittent
B - Continuous rain
C - Snow
D - Snow and rain
E - Hail
F - Thunderstrom

[c] Water color codes
1 = Clear
2 = Light Brown
3 = Brown
4 = Dark Brown
5 = Murky or Glacial

Table 10. Daily abundance and proportion of the seasonal abundance of sockeye salmon smolts on the Kvichak River, 2011.

	Site 1					Site 2				
	Abundance			Proportion of total		Abundance			Proportion of total	
Smolt Day	Daily	95% CI	Cumulative	Daily	Cumulative	Daily	95% CI	Cumulative	Daily	Cumulative
21-May	1,616,705	622,298	1,616,705	0.03	0.03	1,611,722	324,234	1,611,722	0.04	0.04
22-May	3,682,265	1,005,543	5,298,970	0.08	0.11	2,374,930	548,662	3,986,651	0.06	0.10
23-May	2,465,542	360,592	7,764,512	0.05	0.16	736,589	100,297	4,723,240	0.02	0.11
24-May	2,188,986	630,430	9,953,498	0.04	0.20	1,652,580	220,533	6,375,820	0.04	0.15
25-May	1,319,530	407,795	11,273,028	0.03	0.23	1,027,240	260,659	7,403,060	0.02	0.18
26-May	4,434,906	1,049,247	15,707,934	0.09	0.32	1,921,947	518,304	9,325,007	0.05	0.22
27-May	2,229,550	808,584	17,937,483	0.05	0.37	942,918	194,322	10,267,925	0.02	0.25
28-May	4,310,472	1,218,453	22,247,955	0.09	0.46	6,142,463	1,187,083	16,410,388	0.15	0.39
29-May	2,860,778	1,060,158	25,108,733	0.06	0.51	6,948,776	1,813,826	23,359,164	0.17	0.56
30-May	1,065,828	500,591	26,174,561	0.02	0.54	624,865	185,643	23,984,030	0.01	0.57
31-May	840,757	108,451	27,015,318	0.02	0.55	156,297	13,075	24,140,326	0.00	0.58
1-Jun	172,952	31,816	27,188,270	0.00	0.56	115,857	17,920	24,256,184	0.00	0.58
2-Jun	530,031	134,762	27,718,301	0.01	0.57	864,512	127,531	25,120,695	0.02	0.60
3-Jun	5,289,992	1,307,783	33,008,294	0.11	0.68	3,307,897	393,702	28,428,593	0.08	0.68
4-Jun	2,023,763	383,620	35,032,057	0.04	0.72	1,592,131	150,992	30,020,723	0.04	0.72
5-Jun	1,726,075	304,672	36,758,132	0.04	0.75	1,949,074	219,245	31,969,797	0.05	0.77
6-Jun	3,692,110	599,043	40,450,242	0.08	0.83	4,595,554	288,273	36,565,351	0.11	0.88
7-Jun	822,273	113,175	41,272,515	0.02	0.85	618,734	85,114	37,184,085	0.01	0.89
8-Jun	4,288,950	1,158,335	45,561,465	0.09	0.93	2,201,498	404,190	39,385,583	0.05	0.94
9-Jun	2,309,213	486,548	47,870,678	0.05	0.98	1,421,310	205,136	40,806,894	0.03	0.98
10-Jun	637,367	90,296	48,508,044	0.01	0.99	313,970	36,547	41,120,864	0.01	0.99
11-Jun	298,192	52,278	48,806,237	0.01	1.00	292,730	34,486	41,413,594	0.01	0.99
12-Jun	-	-	48,806,237	-	1.00	317,064	28,783	41,730,658	0.01	1.00
Total	48,806,237	3,263,166	48,806,237	1.00	1.00	41,730,658	2,472,764	41,730,658	1.00	1.00

Table 11. Percentage of annual smolt estimates represented in hourly bins on the Kvichak and Egegik rivers.

	Kvichak River		Egegik River	
Hour	Site 1	Site 2	Site 1	Site 2
5	0.04	0.06	0.07	0.05
6	0.03	0.02	0.03	0.03
7	0.03	0.02	0.02	0.02
8	0.03	0.02	0.02	0.01
9	0.02	0.02	0.03	0.01
10	0.02	0.04	0.04	0.03
11	0.02	0.06	0.02	0.02
12	0.04	0.07	0.02	0.03
13	0.04	0.07	0.02	0.03
14	0.02	0.06	0.03	0.07
15	0.02	0.02	0.04	0.07
16	0.03	0.02	0.04	0.06
17	0.04	0.02	0.03	0.04
18	0.04	0.03	0.04	0.04
19	0.03	0.02	0.03	0.05
20	0.03	0.02	0.07	0.06
21	0.02	0.02	0.06	0.10
22	0.03	0.02	0.04	0.04
Daylight total	0.49	0.60	0.65	0.76
23	0.04	0.02	0.04	0.02
0	0.09	0.04	0.04	0.02
1	0.11	0.08	0.06	0.04
2	0.11	0.09	0.06	0.04
3	0.09	0.09	0.06	0.05
4	0.07	0.09	0.09	0.07
Darkness total	0.51	0.40	0.35	0.24

Table 12. Daily abundance and proportion of the seasonal abundance of sockeye salmon smolts on the Egegik River, 2011.

	Site 1					Site 2				
	Abundance			Proportion of total		Abundance			Proportion of total	
Smolt Day	Daily	95% CI	Cumulative	Daily	Cumulative	Daily	95% CI	Cumulative	Daily	Cumulative
5/17	82,265	26,605	82,265	0.01	0.01	63,269	12,175	63,269	0.01	0.01
5/18	163,954	39,585	246,219	0.02	0.02	62,702	11,711	125,971	0.01	0.01
5/19	79,436	16,803	325,654	0.01	0.03	67,250	13,949	193,221	0.01	0.02
5/20	130,889	20,095	456,544	0.01	0.05	119,861	21,184	313,081	0.01	0.04
5/21	42,042	9,421	498,585	0.00	0.05	58,387	13,425	371,468	0.01	0.04
5/22	67,036	11,715	565,621	0.01	0.06	145,524	22,094	516,992	0.02	0.06
5/23	74,692	11,914	640,313	0.01	0.06	232,699	28,813	749,691	0.03	0.08
5/24	96,413	18,250	736,726	0.01	0.07	319,355	52,133	1,069,046	0.04	0.12
5/25	98,358	24,555	835,084	0.01	0.08	366,533	175,902	1,435,579	0.04	0.16
5/26	26,891	3,942	861,974	0.00	0.09	52,091	10,075	1,487,670	0.01	0.17
5/27	1,036,845	696,520	1,898,819	0.10	0.19	662,399	494,276	2,150,069	0.07	0.24
5/28	255,011	144,982	2,153,831	0.03	0.22	227,309	84,635	2,377,378	0.03	0.27
5/29	275,752	87,355	2,429,583	0.03	0.25	1,129,074	638,579	3,506,452	0.13	0.40
5/30	1,451,275	355,627	3,880,858	0.15	0.39	167,574	26,619	3,674,026	0.02	0.41
5/31	1,705,191	685,573	5,586,049	0.17	0.56	1,093,518	407,462	4,767,544	0.12	0.54
6/1	1,067,158	257,135	6,653,206	0.11	0.67	1,104,936	601,052	5,872,480	0.12	0.66
6/2	641,966	67,627	7,295,172	0.06	0.74	728,196	304,355	6,600,676	0.08	0.74
6/3	577,075	164,027	7,872,247	0.06	0.79	341,592	82,780	6,942,267	0.04	0.78
6/4	317,704	74,520	8,189,952	0.03	0.83	222,493	63,217	7,164,761	0.03	0.81
6/5	327,773	84,445	8,517,725	0.03	0.86	198,905	40,399	7,363,665	0.02	0.83
6/6	508,568	112,766	9,026,293	0.05	0.91	355,009	66,707	7,718,674	0.04	0.87
6/7	302,752	86,109	9,329,045	0.03	0.94	309,689	93,378	8,028,364	0.03	0.91
6/8	101,848	35,373	9,430,893	0.01	0.95	83,385	22,199	8,111,748	0.01	0.92
6/9	259,279	56,887	9,690,172	0.03	0.98	332,051	70,195	8,443,799	0.04	0.95
6/10	217,173	36,450	9,907,344	0.02	1.00	416,649	132,583	8,860,449	0.05	1.00
Total	9,907,344	1,118,383	9,907,344	1.00	1.00	8,860,449	1,168,213	8,860,449	1.00	1.00

Table 13. Proportion of annual smolt abundance by hour on the Kvichak River, 2008 – 2011.

	Kvichak River							
	2008		2009		2010		2011	
Hour	Site 1	Site 2	Site 1	Site 2	Site 1	Site 2	Site 1	Site 2
5	0.05	0.07	0.05	0.03	0.05	0.04	0.04	0.06
6	0.04	0.05	0.04	0.03	0.03	0.02	0.03	0.02
7	0.02	0.04	0.04	0.02	0.01	0.02	0.03	0.02
8	0.02	0.04	0.02	0.01	0.02	0.02	0.03	0.02
9	0.03	0.03	0.02	0.02	0.03	0.03	0.02	0.02
10	0.03	0.05	0.02	0.02	0.03	0.02	0.02	0.04
11	0.03	0.05	0.02	0.02	0.03	0.02	0.02	0.06
12	0.03	0.05	0.02	0.02	0.03	0.02	0.04	0.07
13	0.03	0.04	0.02	0.02	0.02	0.02	0.04	0.07
14	0.02	0.04	0.03	0.03	0.04	0.02	0.02	0.06
15	0.02	0.04	0.02	0.03	0.02	0.02	0.02	0.02
16	0.02	0.03	0.03	0.04	0.02	0.03	0.03	0.02
17	0.02	0.02	0.03	0.04	0.02	0.03	0.04	0.02
18	0.02	0.01	0.03	0.04	0.02	0.03	0.04	0.03
19	0.03	0.02	0.04	0.05	0.02	0.03	0.03	0.02
20	0.03	0.02	0.04	0.04	0.02	0.04	0.03	0.02
21	0.03	0.03	0.04	0.05	0.02	0.03	0.02	0.02
22	0.04	0.03	0.05	0.05	0.04	0.03	0.03	0.02
Daylight total	0.50	0.66	0.55	0.57	0.46	0.48	0.49	0.60
23	0.05	0.03	0.07	0.07	0.04	0.04	0.04	0.02
0	0.07	0.04	0.08	0.08	0.07	0.08	0.09	0.04
1	0.11	0.06	0.08	0.07	0.12	0.09	0.11	0.08
2	0.11	0.06	0.08	0.07	0.10	0.09	0.11	0.09
3	0.08	0.07	0.07	0.07	0.12	0.11	0.09	0.09
4	0.08	0.09	0.07	0.06	0.09	0.11	0.07	0.09
Darkness total	0.50	0.34	0.45	0.43	0.54	0.52	0.51	0.40

Table 14. Comparison of annual smolt abundance estimates from each sonar systems on the Kvichak River, 2008 - 2011.

Abundance Estimates			
Year	Site 1	Site 2	Difference
2008	30,786,980	26,965,627	12.4%
2009	35,247,209	38,755,938	9.1%
2010[a]	15,805,698	15,891,807	0.5%
2011	48,806,237	41,730,658	14.5%

[a]Site 2 sonar only operated from 31 May to 13 June, 2010. Numbers shown are for only dates when both sonars operated.

FIGURES

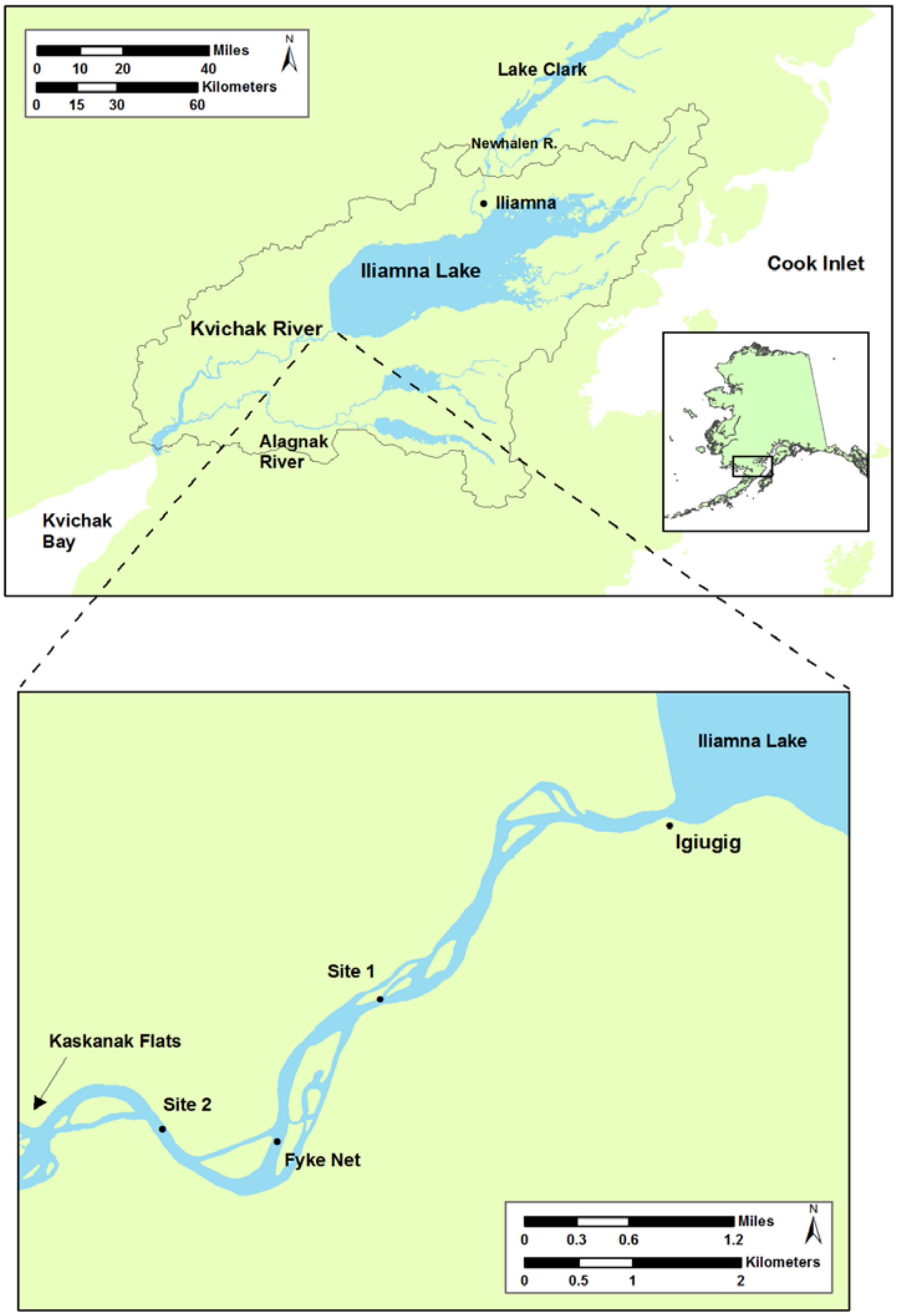


Figure 1. Map of Kvichak River watershed in Southwestern Alaska, showing locations of sonar systems (sites 1 and 2) operated near the village of Igiugig, 2011.

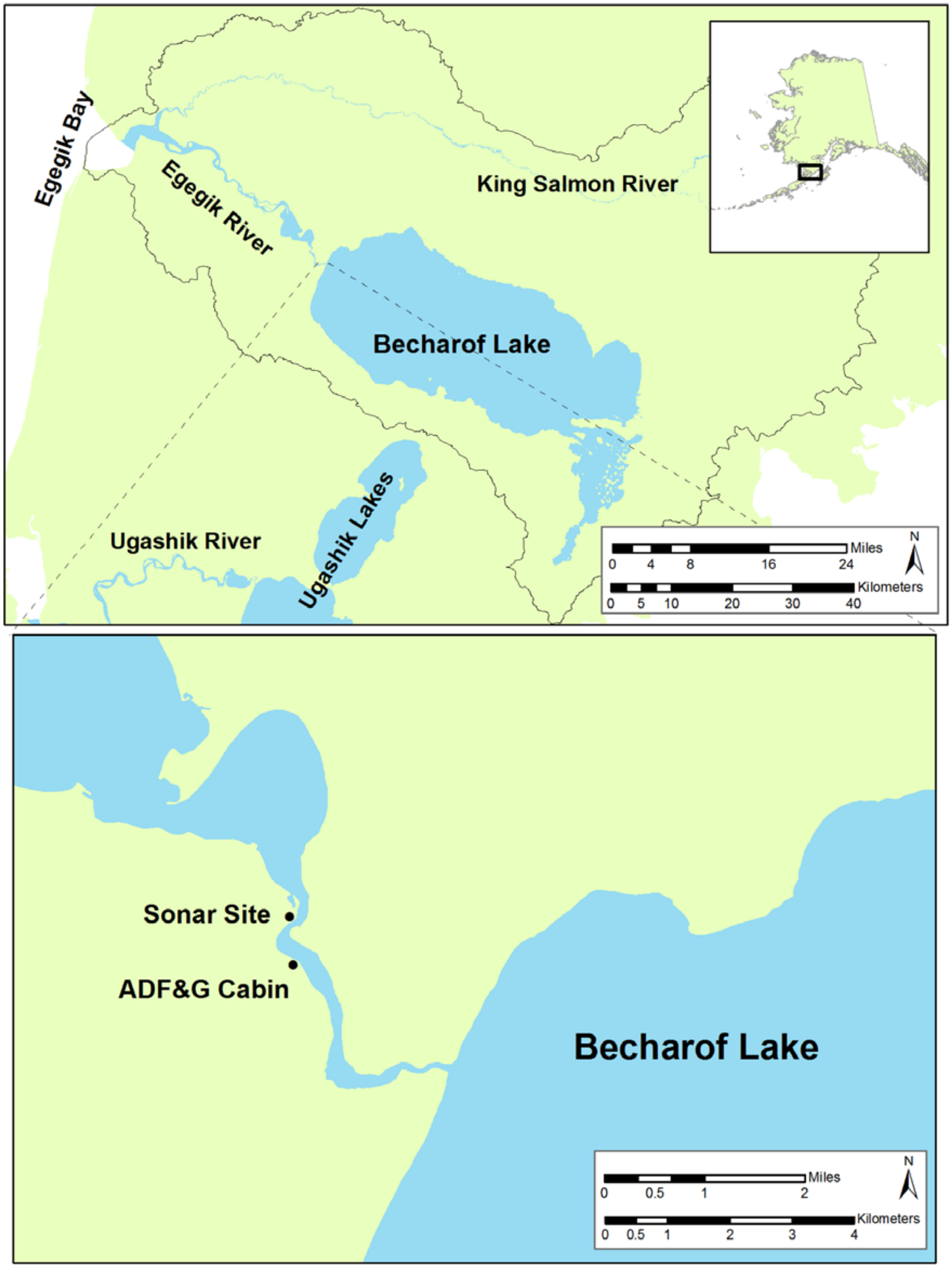


Figure 2. Map of Egegik River watershed, showing location of sonar systems operated 4.5 rkm downstream of Becharof Lake, 2011.

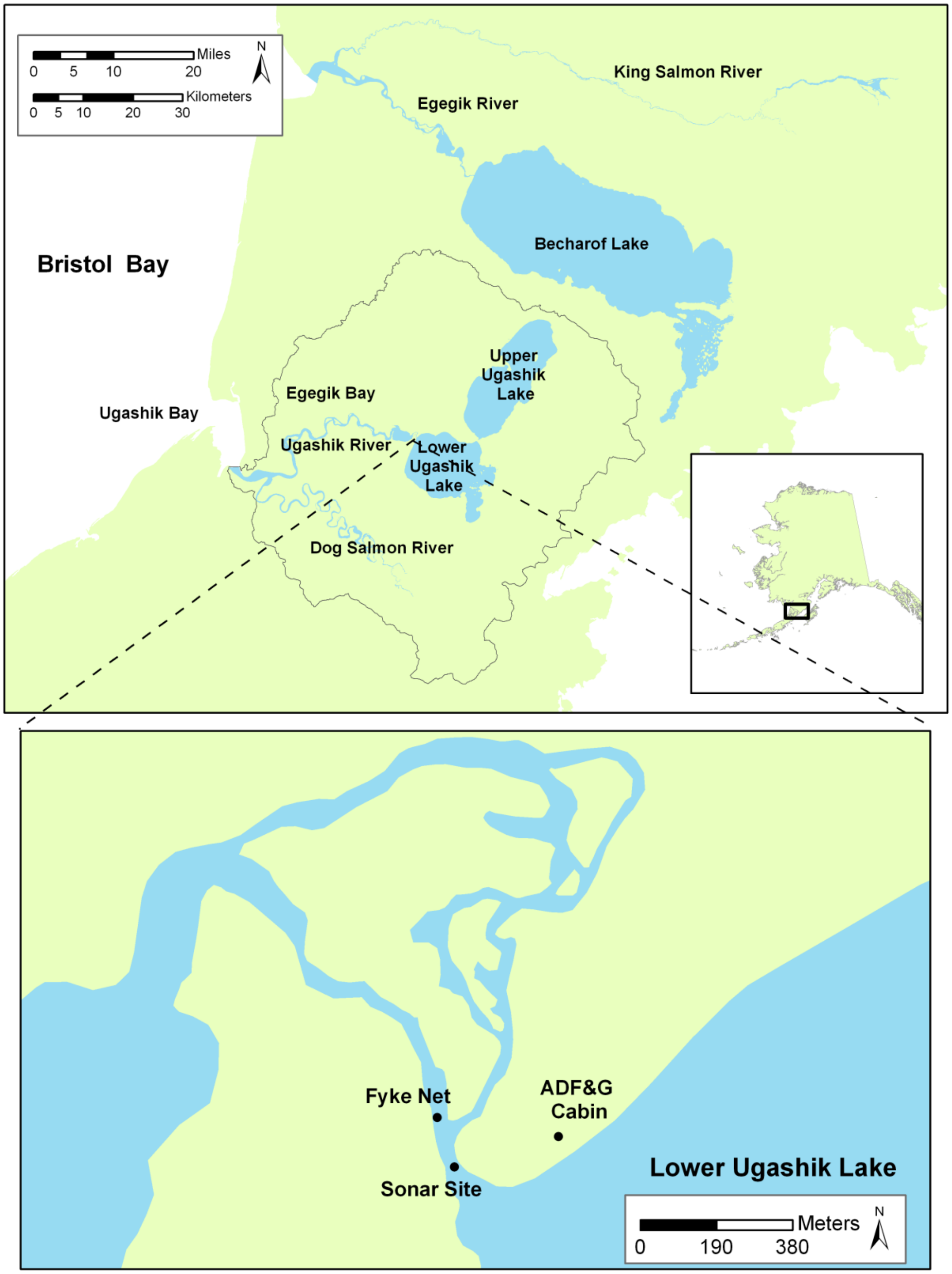


Figure 3. Map of Ugashik River watershed, showing locations of sonar systems and fyke net operated near the outlet of Lower Ugashik Lake, 2011.

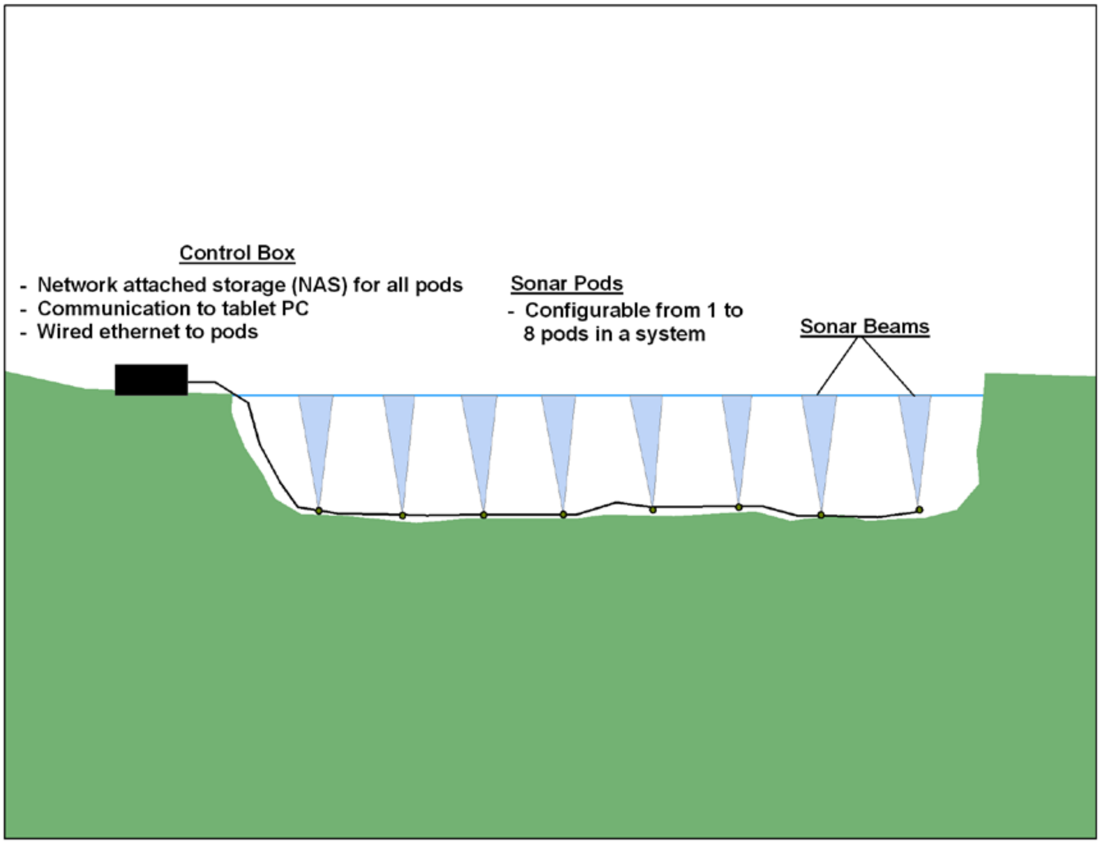


Figure 4. Conceptual drawing of the smolt sonar system used in three rivers in the Bristol Bay region, 2011.

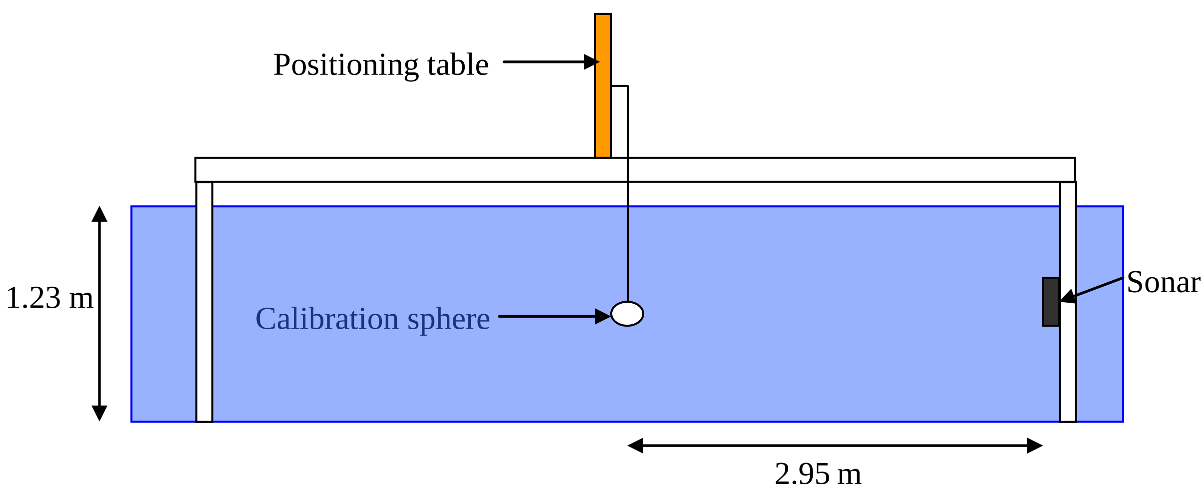


Figure 5. Calibration tank showing positioning table, calibration sphere, and transducer placement used in 2011.

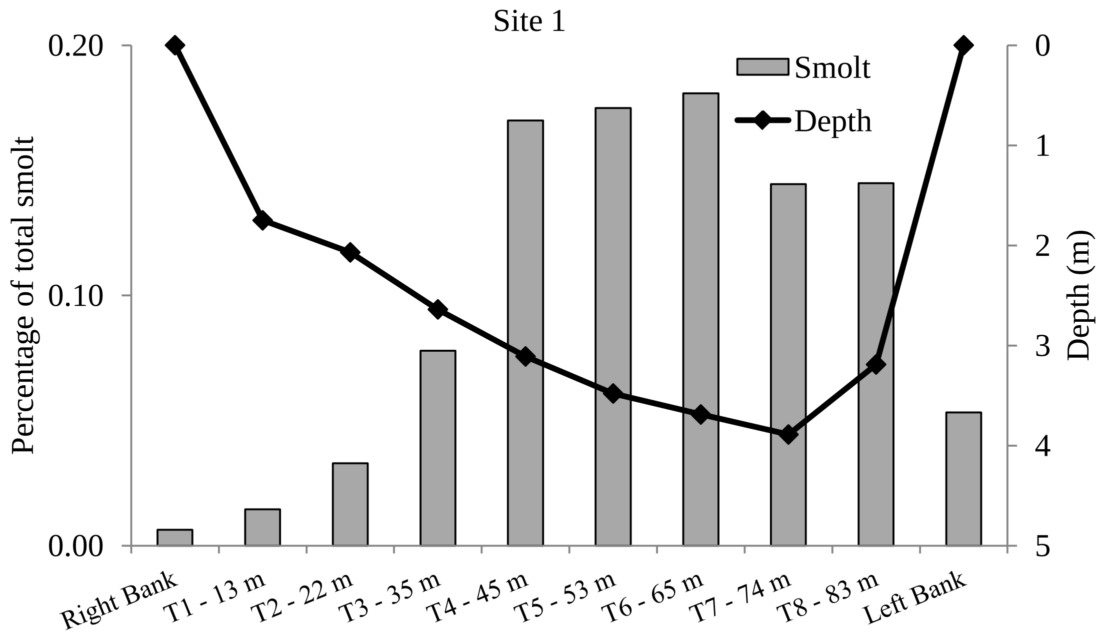


Figure 6. Water depth and percent distribution of sockeye salmon smolts at Site 1 sonar pods on the Kvichak River in 2011, showing pod distances (m) from right bank.

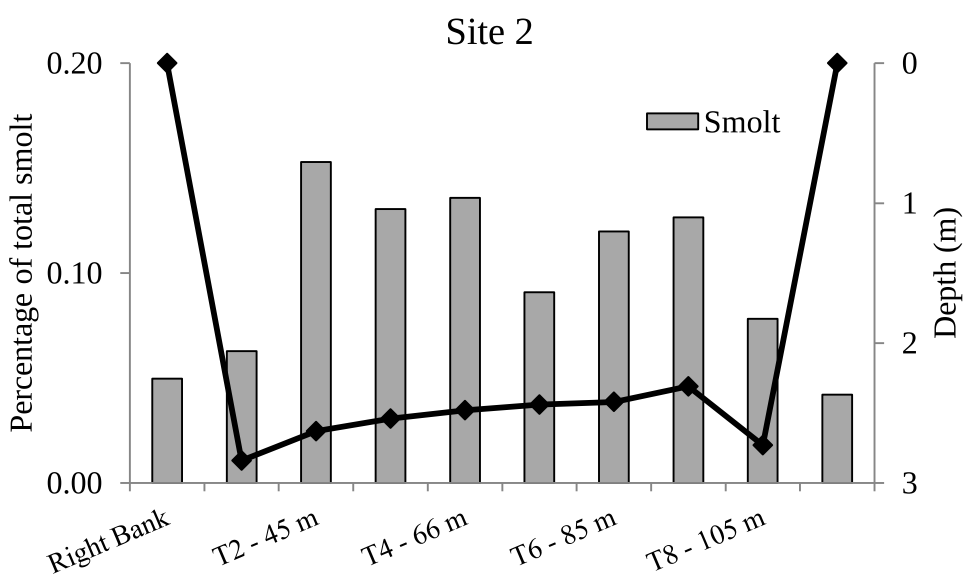


Figure 7. Water depth and percent distribution of sockeye salmon smolts at Site 2 sonar pods on the Kvichak River in 2011, showing pod distances (m) from right bank.

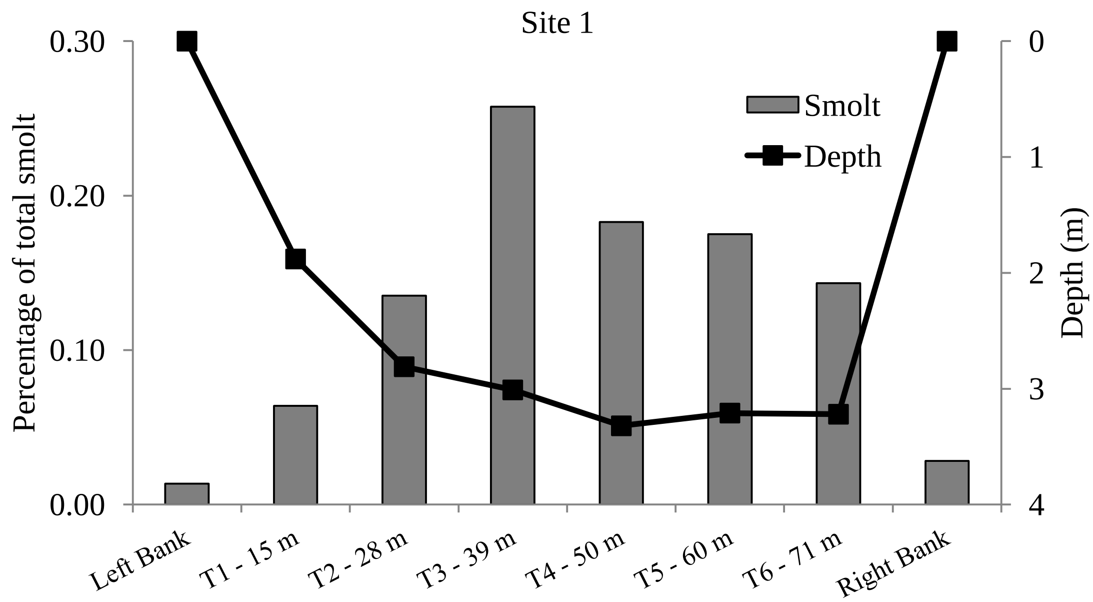


Figure 8. Water depth and percent distribution of sockeye salmon smolts at Site 1 sonar pods on the Egegik River in 2011, showing pod distances (m) from left bank.

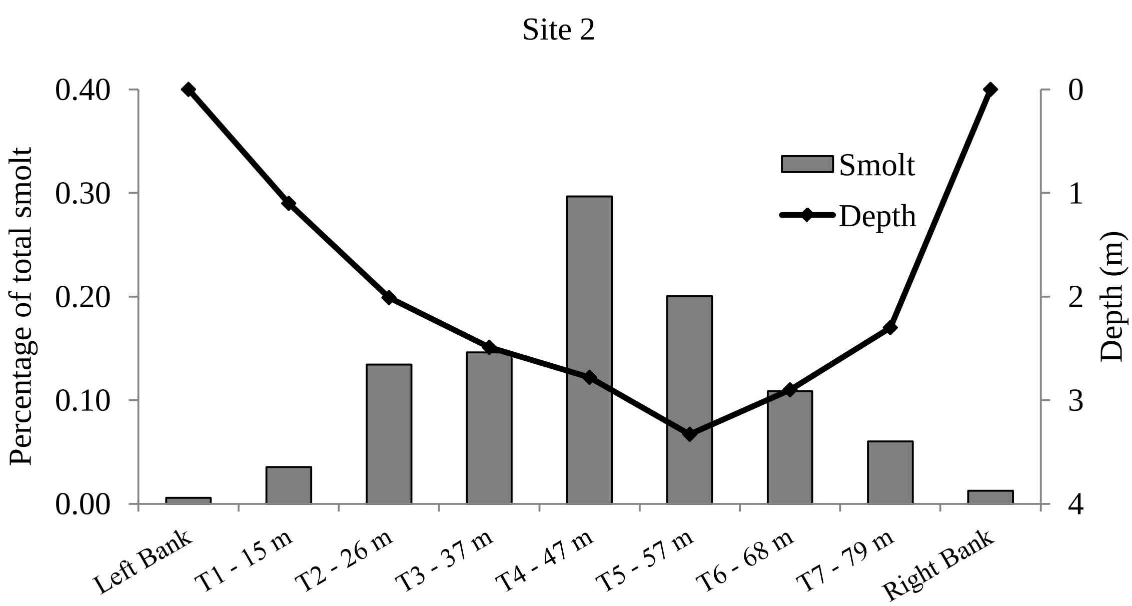


Figure 9. Water depth and percent distribution of sockeye salmon smolts at Site 2 sonar pods on the Egegik River in 2011, showing pod distances (m) from left bank.

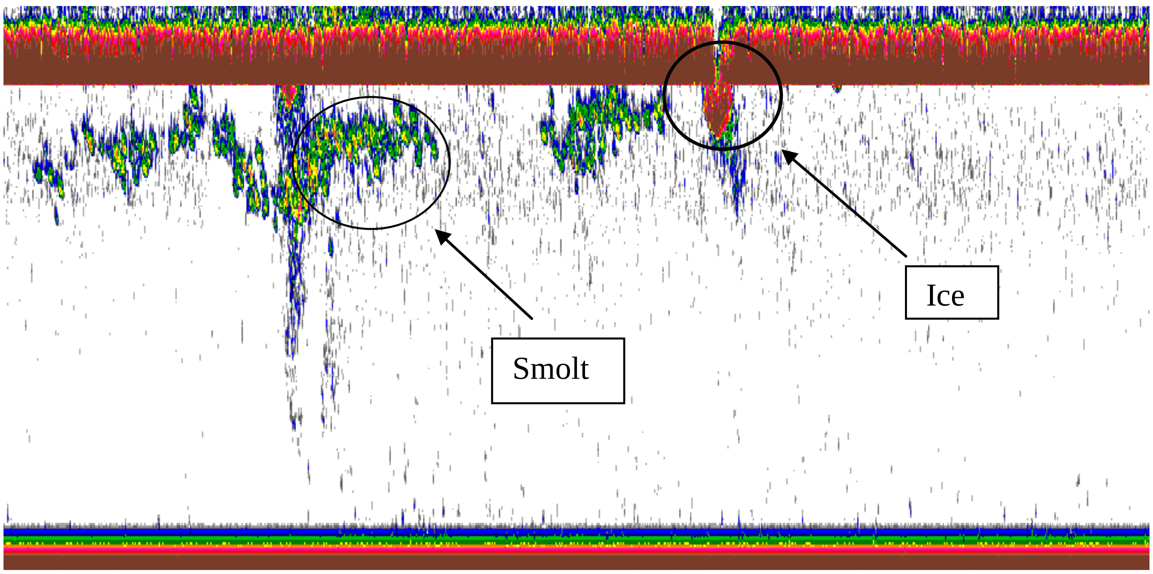


Figure 10. Approximately 1.5 minutes of an echogram showing smolt and ice from an up-looking sonar pod on the Kvichak River during moderate ice flows, 2011.

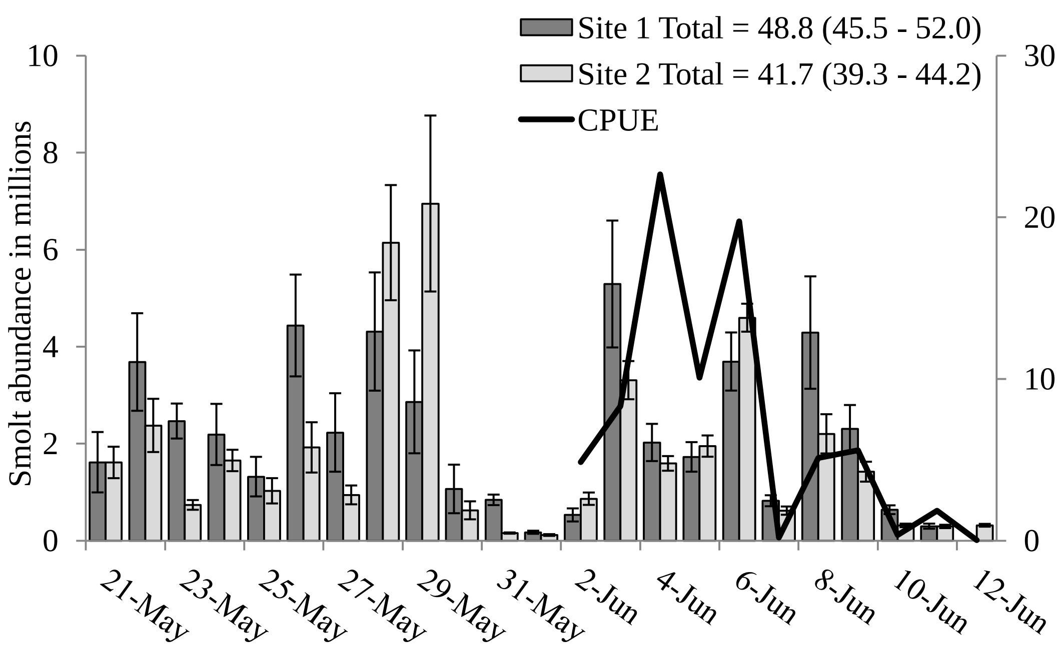


Figure 11. Estimated daily and annual abundance of smolts at sites 1 and 2 on the Kvichak River, 2011. Bars are mean daily estimates; whiskers are 95% confidence intervals. Line represents smolt catch per unit effort from the incline plane trap.

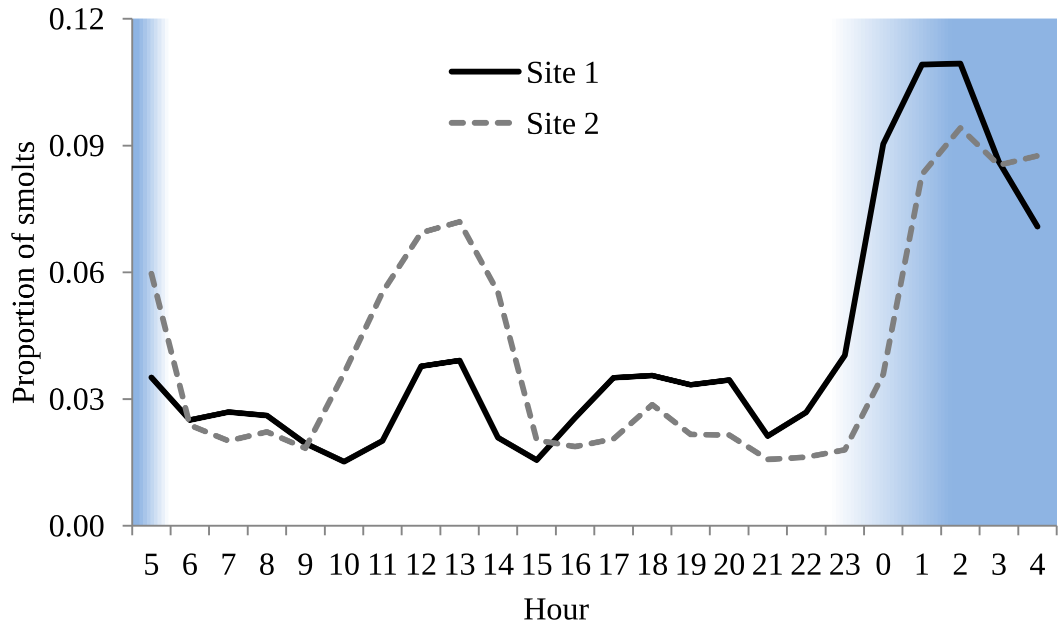
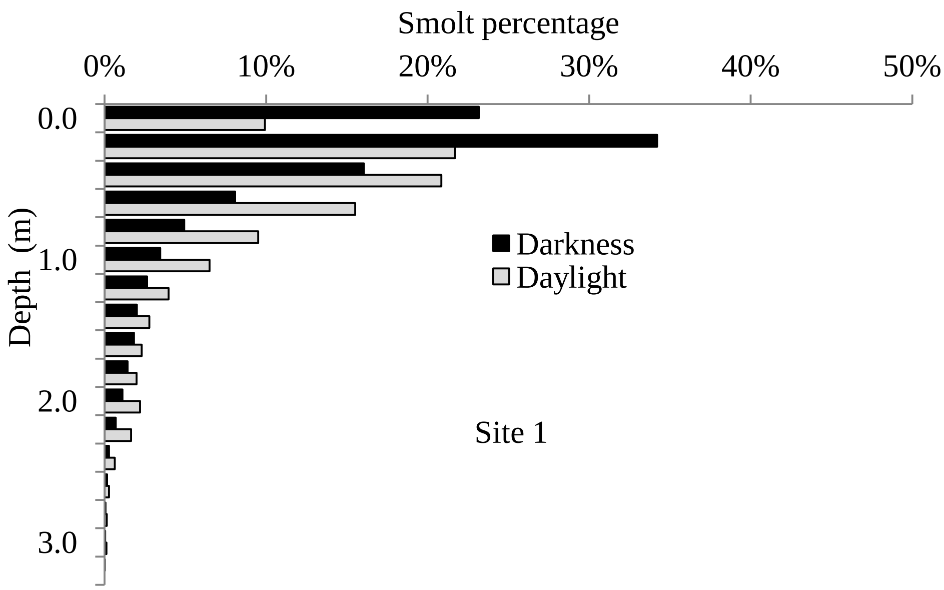


Figure 12. Proportion of total smolts by hour of the day at sonar sites 1 and 2 on the Kvichak River, 2011. Shading shows hours considered nighttime (2300-0500) during the study period (21 May to 11 June).



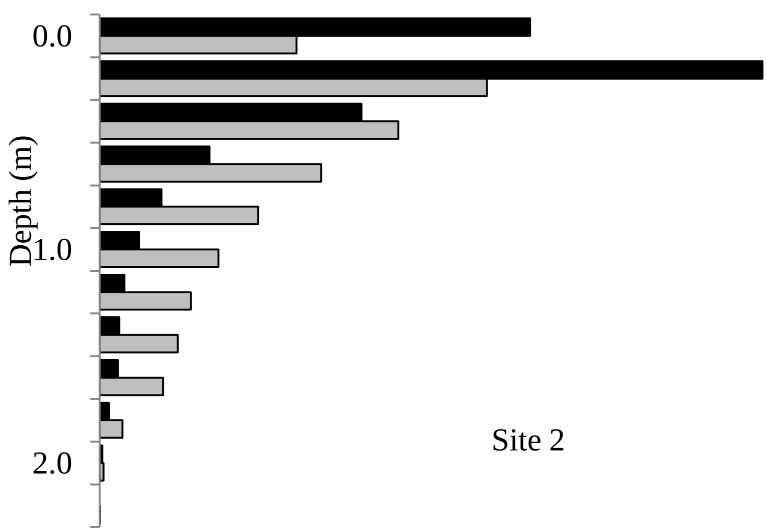


Figure 13. Vertical distribution of sockeye salmon smolts migrating in darkness (2300-0500 hrs) and light at sites 1 and 2 on the Kvichak River in 2011. Difference in vertical axes between sites reflects shallower depths at Site 2.

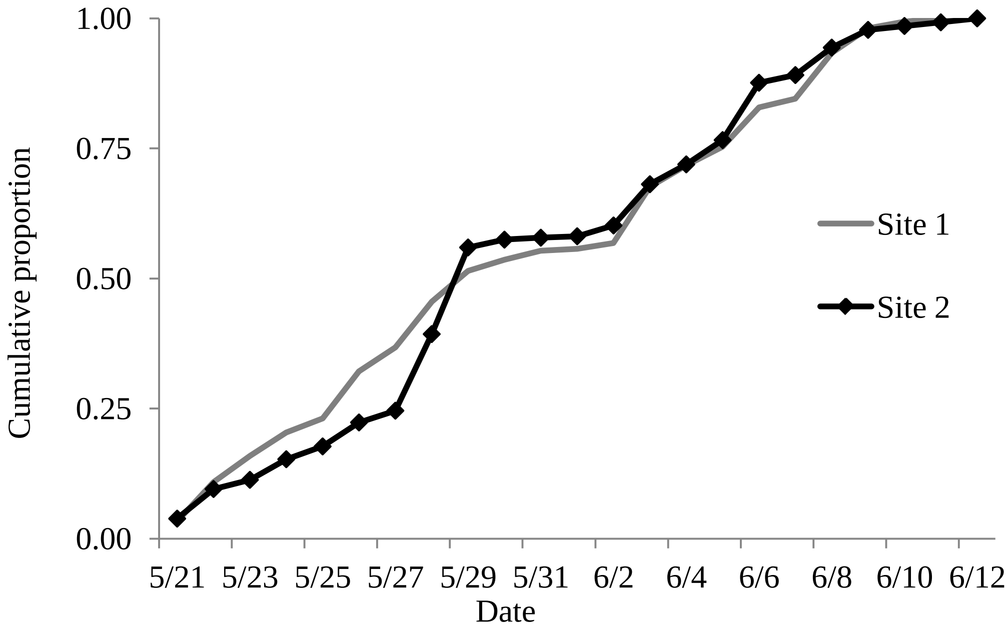


Figure 14. Run timing of sockeye salmon smolts at sites 1 and 2 on the Kvichak River, 2011.

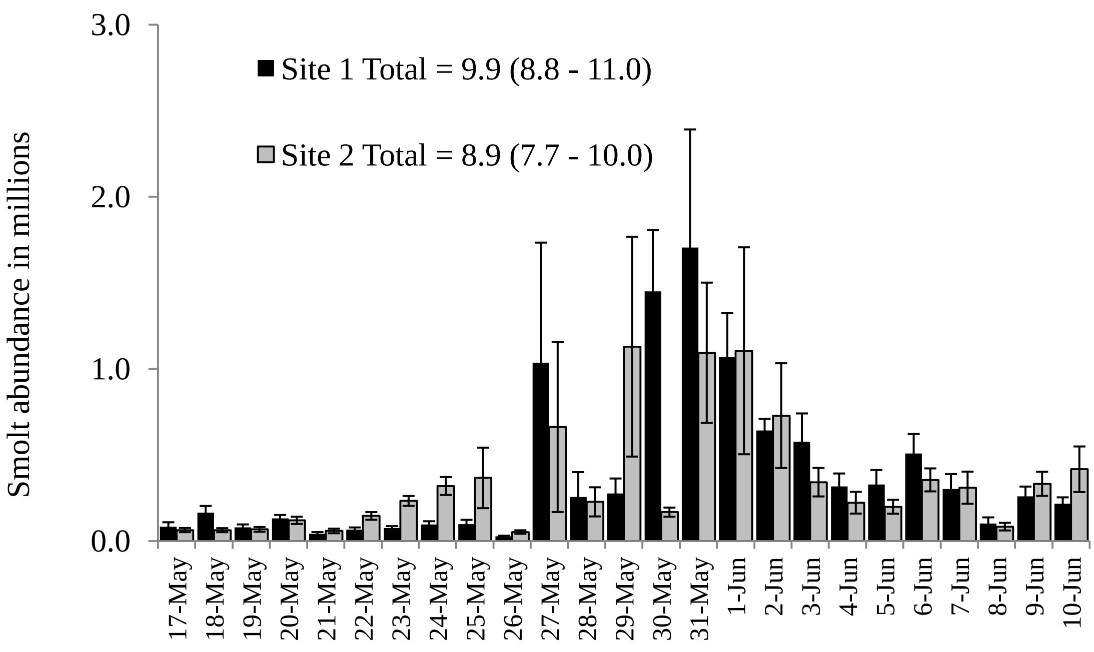


Figure 15. Estimated daily and annual abundance of smolts, in millions, at sites 1 and 2 on the Egegik River 2011. Bars are mean daily estimates; whiskers are 95% confidence intervals.

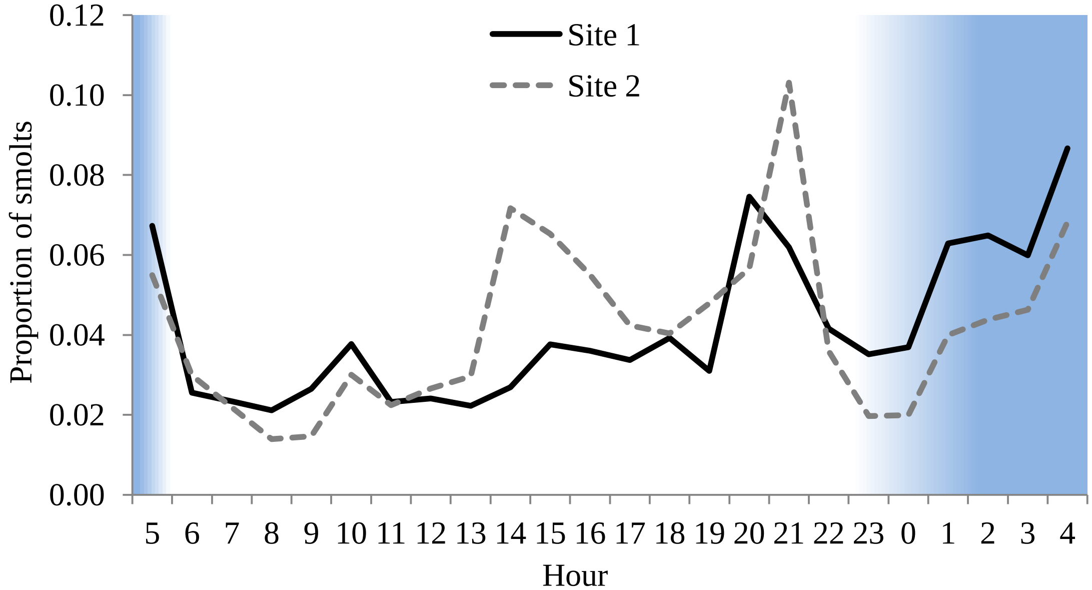


Figure 16. Proportion of total smolts by hour of the day at sonar sites 1 and 2 on the Egegik River, 2011. Shading shows hours considered nighttime (2300-0500) during the study period (17 May to 10 June).

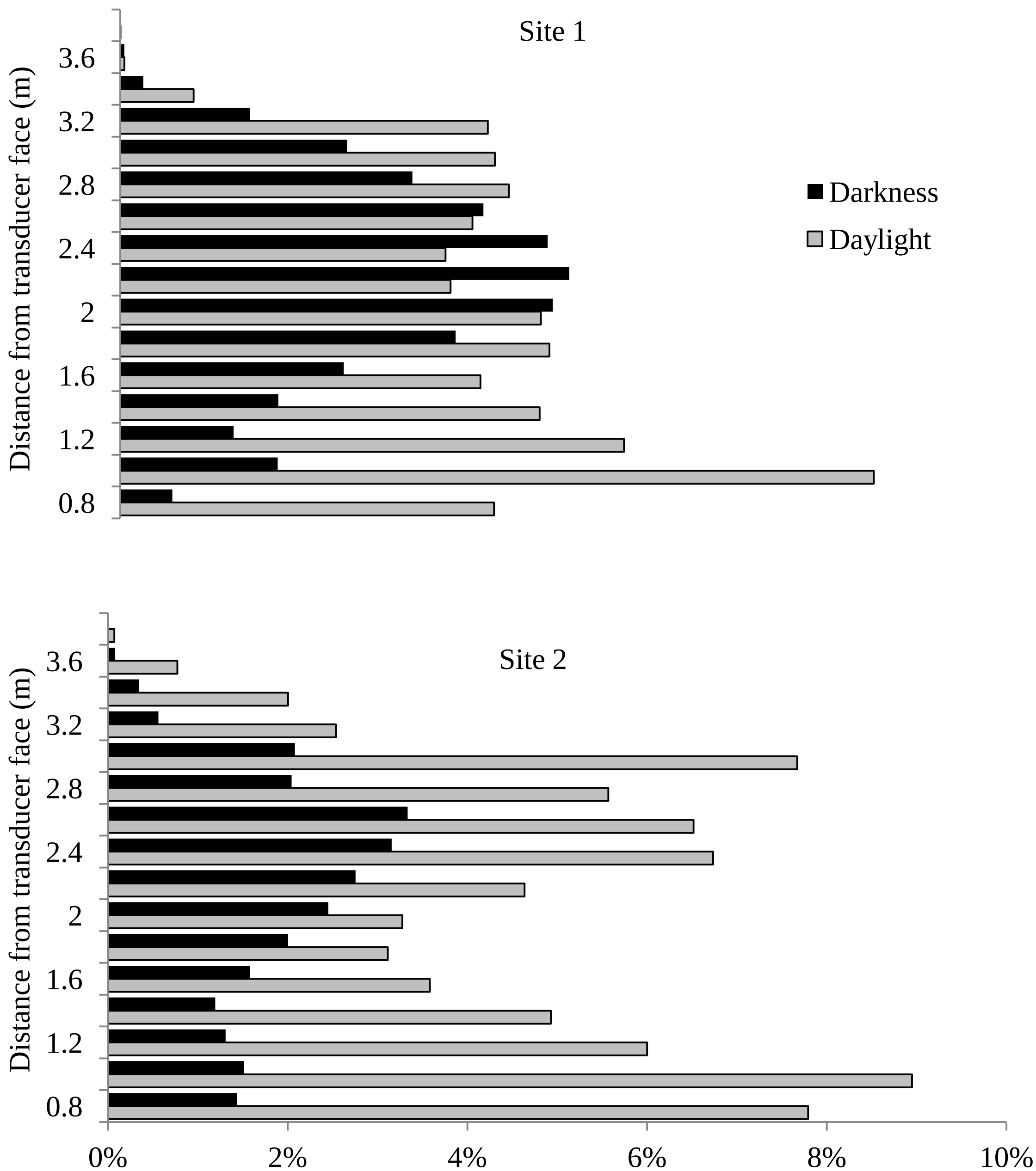


Figure 17. Vertical distribution of sockeye salmon smolts migrating in darkness (2300-0500 hrs) and light at sites 1 and 2 on the Egegik River in 2011. Distribution is in meters from the face of bottom-founded, upward-looking transducers.

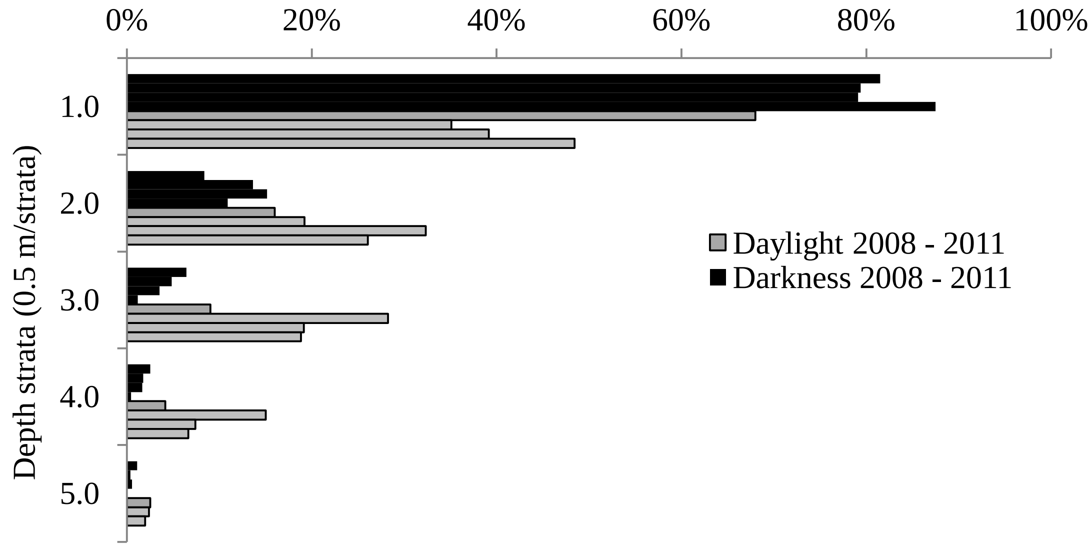


Figure 18. Site 1 vertical smolt distribution during daylight and darkness on the Kvichak River from 2008 through 2011.

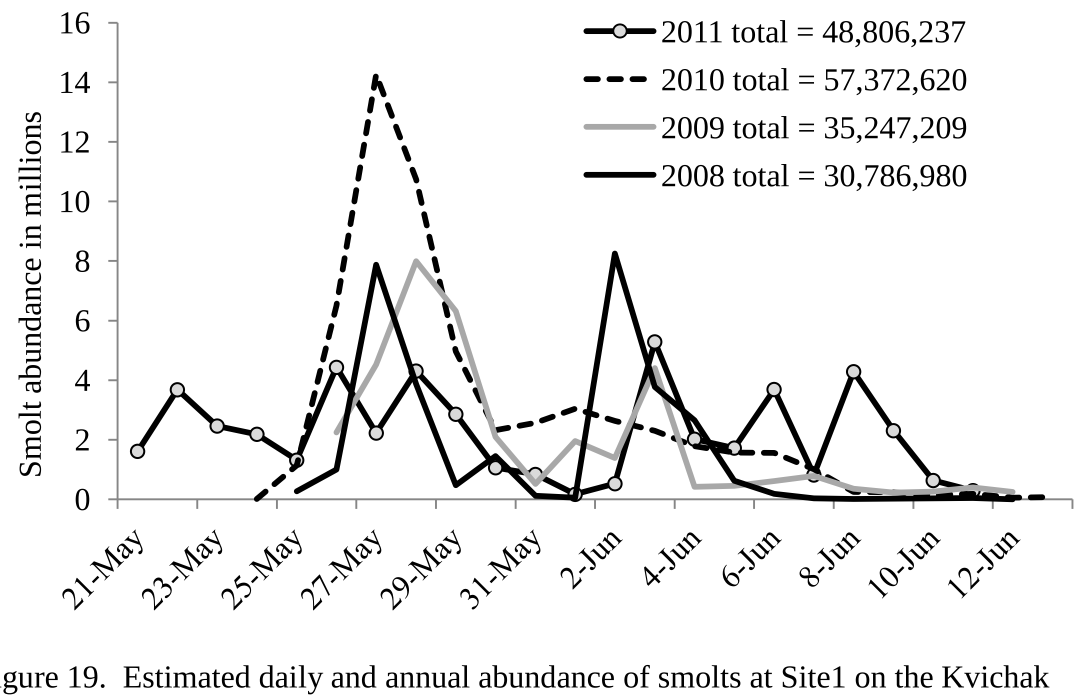


Figure 19. Estimated daily and annual abundance of smolts at Site1 on the Kvichak River, 2008 - 2011.

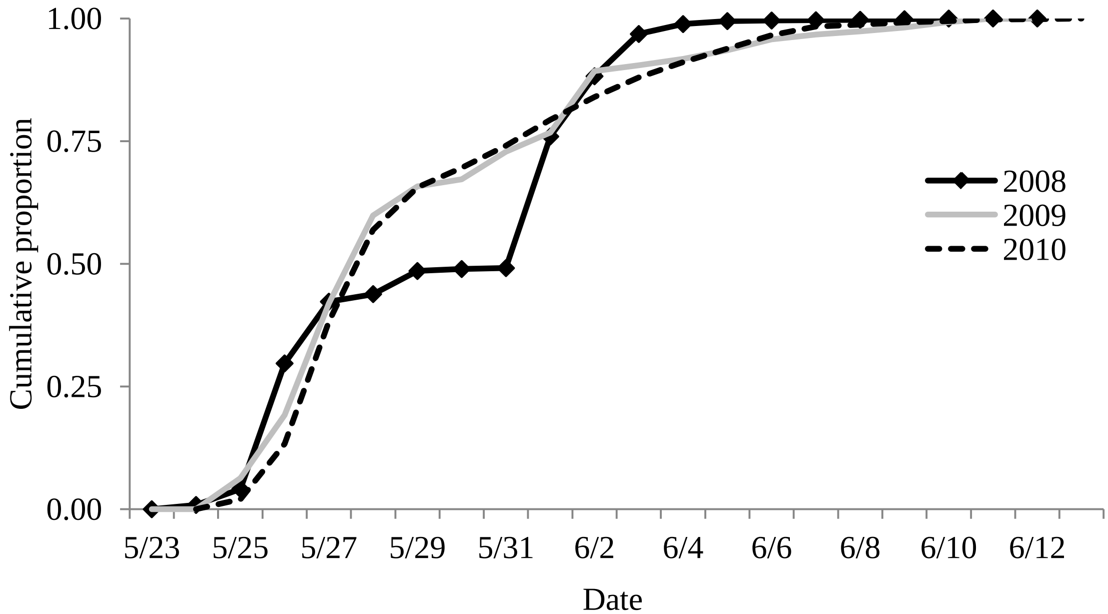


Figure 20. Run timing of sockeye salmon smolts at Site 1 on the Kvichak River, 2008 – 2010.

PHOTOS

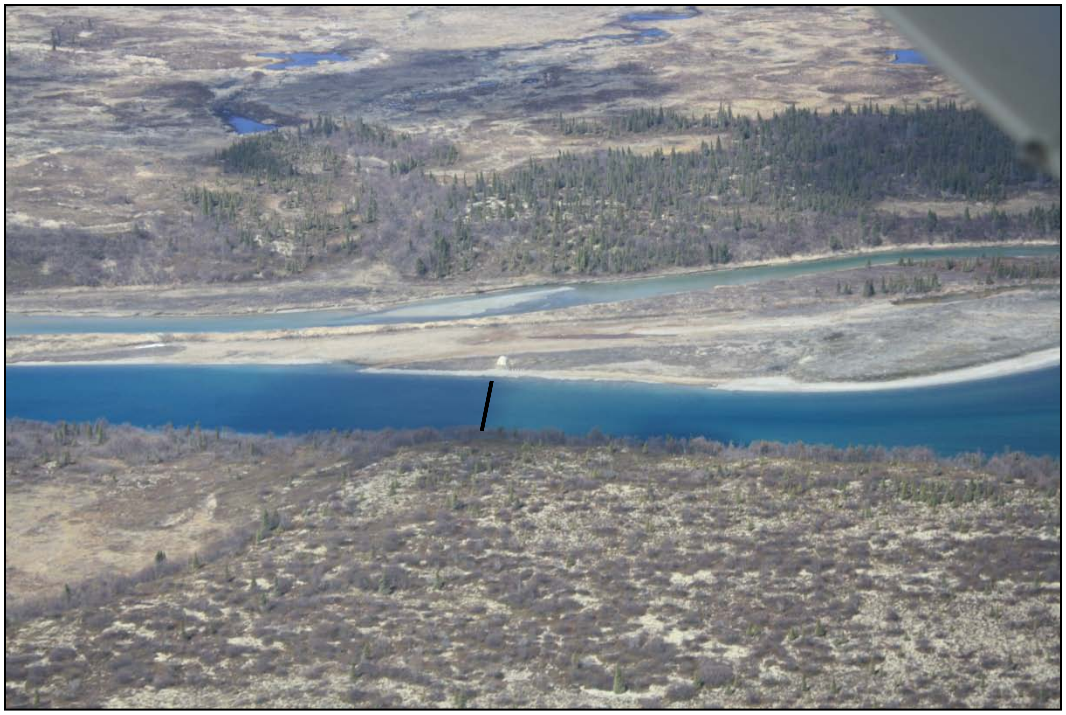


Photo 1. Black line represents the approximate location of Site 1 sonar array used in 2008 - 2011 on the Kvichak River (note WeatherPort on bank).

Photo 2. Black line represent approximate location of Site 2 sonar array used in 2008 and 2010 - 2011 on the Kvichak River.

Photo 3. Black lines represents the approximate location of the two sonar arrays used on the Egegik River in 2011.

Photo 4. Black lines represents the approximate location of the two sonar arrays used on the Ugashik River in 2010 and 2011.

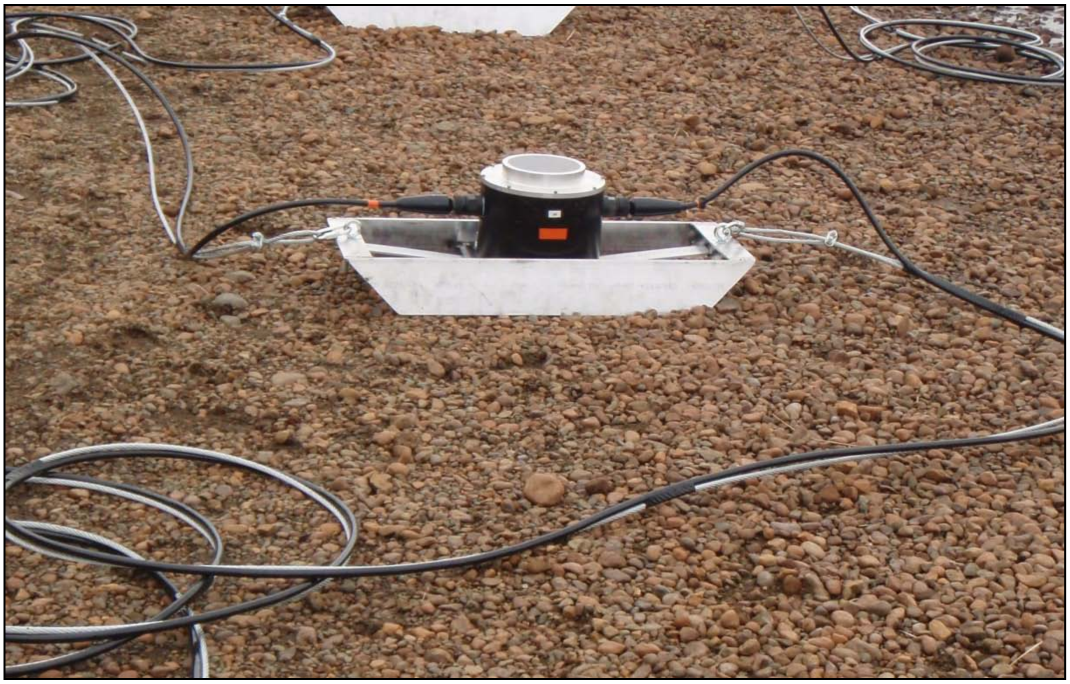


Photo 5. Sonar pod mounted on a welded aluminum sled with attached power, network cable, and tow cable used on the Ugashik River, 2011.

Photo 6. Sonar array staged for deployment on the Ugashik River, 2011.

Photo 7. Control box, NAS, and power source housed in the WeatherPort tent, 2011.

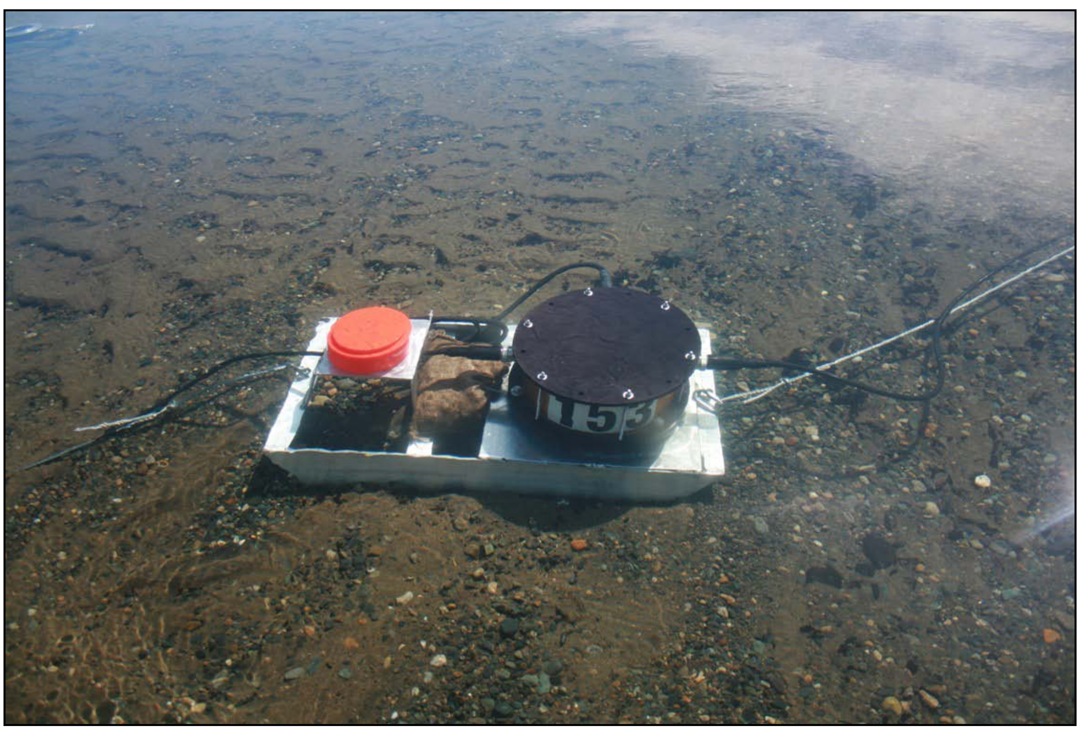


Photo 8. Split beam sonar pod mounted on aluminum sled used to estimate smolt target strength and abundance in 2011.

APPENDIX - A

Appendix A - 1. Total catch of sockeye salmon smolt on the Kvichak River, 2011.

	Incline Plane Trap[a]					
Smolt Date	Elasped time (min)	Total catch	n	CPUE [b]	% age 1	8am H_20 temp ©
05/25	72	976	600	13.56	65.3%	2.0
05/26 [c]	-		-	-		2.0
05/27 [c]	-		-	-		3.3
05/28 [c]	-		-	-		1.1
05/29 [c]	-		-	-		2.2
05/30	12	1,076	600	89.67	93.0%	3.3
05/31 [c]	-		-	-		0.5
06/01 [c]	-		-	-		2.2
06/02	134	651	576	4.86	11.3%	5.6
06/03	93	774	507	8.32	58.5%	5.6
06/04	50	1,133	600	22.66	63.4%	5.0
06/05	88	887	594	10.08	81.4%	6.1
06/06	51	1,007	601	19.75	91.4%	6.1
06/07	125	25	25	0.20	100.0%	6.1
06/08	128	656	545	5.13	77.6%	7.2
06/09	107	599	416	5.60	91.1%	7.7
06/10	120	43	43	0.36	60.5%	7.7
06/11	129	239	200	1.85	43.5%	7.7
06/12	120	5	5	0.04	100.0%	7.2
Total	1,229	8,071	5,312			
Min	12	5	5	0.04	11.3%	0.5
Ave	95	621	409	14.00	69.0%	4.7
Max	134	1,133	601	89.67	100.0%	7.7

[a] Arrived 5/16 with approximately 1/4 of Illiamna Lake still covered in ice. Sonar deployed between ice flows on 5/22. Able to set trap anchor 5/25 and fish morning of 5/26.

[b] CPUE=Catch per unit effort. Total Catch / Elapsed Fishing Time.

[c] No Fishing. Ice flows in river entire day

Appendix A - 2. Mean fork length and weight of sockeye salmon smolt captured by incline plane trap on the Kvichak River, 2011.

	Age 1.					Age 2.				
Smolt Day	Mean Length (mm)	Std. Dev.	Mean Weight (g)	Std. Dev.	Sample Size	Mean Length (mm)	Std. Dev.	Mean Weight (g)	Std. Dev.	Sample Size
05/25 [a]	88	3.7	5.7	0.8	51	111	7.0	11.2	2.1	47
05/26 [a]										
05/27 [a]										
05/28 [a]										
05/29 [a]										
05/30	86	3.5	5.7	0.6	86	102	5.5	9.4	1.1	14
05/31 [a]										
06/01 [a]										
06/02	87	5.5	5.9	1.0	6	114	6.2	12.7	1.8	94
06/03	87	5.3	6.0	0.8	49	110	9.0	11.8	2.4	51
06/04	89	3.6	6.2	0.8	48	110	7.5	11.3	2.2	52
06/05	87	4.0	6.1	0.8	74	106	6.8	10.5	1.8	26
06/06	85	3.2	5.4	0.6	82	108	7.2	10.4	2.0	18
06/07	83	2.7	4.7	0.5	25					
06/08	86	4.5	5.7	0.8	67	107	6.5	10.5	1.6	33
06/09	86	4.0	5.7	0.7	79	106	8.1	10.9	2.0	21
06/10	90	4.0	6.1	0.8	26	109	5.3	10.5	1.4	17
06/11	89	3.9	6.1	1.0	34	109	6.1	11.3	1.6	66
06/12	85	4.8	4.8	0.7	5					
Total					632					439
Mean	87		5.8			110		7.4		

[a] No Fishing due to ice flows in river

Appendix A - 3. Mean fork length and estimated mean weight for age-1. and age-2. sockeye salmon smolt on the Kvichak River, 2011.

	Age 1 [a]				Age 2 [a]			
Smolt Date	Mean Length (mm)	Std. Dev.	Estimated Weight (g)	Sample Size	Mean Length (mm)	Std. Dev.	Estimated Weight (g)	Sample Size
5/25 [b]	87.3	3.7	5.8	340	109.0	6.5	11.2	161
5/26 [b]								
5/27 [b]								
5/28 [b]								
5/29 [b]								
5/30	86.7	3.2	5.7	472	105.5	4.7	10.3	28
5/31 [b]								
6/01 [b]								
6/02	88.6	3.8	6.1	59	114.7	6.7	12.7	417
6/03	87.0	3.6	5.8	248	110.1	6.5	11.5	160
6/04	87.1	3.7	5.8	333	108.3	6.5	11.0	168
6/05	86.7	4.0	5.7	407	108.8	7.1	11.2	84
6/06	85.1	3.3	5.5	460	105.8	7.6	10.4	33
6/07 [c]	-	-	-	-	-	-	-	-
6/08	85.5	4.1	5.6	356	107.4	7.5	10.8	89
6/09	84.2	3.7	5.3	300	104.7	4.2	10.1	16
6/10 [c]	-	-	-	-	-	-	-	-
6/11	87.3	4.0	5.8	53	108.0	6.5	10.9	47
6/12	82.0	3.3	4.6	81				
Total				3,028				1,203
Mean	86.3		5.7		110.6		11.6	

[a] Length-weight parameters by age group and discriminating length used to separate ages from May 23 to June 12 were:

Age 1. a = 9.77E-05 b = 2.45978 r^2 = 0.733 n = 632

Age 2. a = 7.81E-05 b = 2.52949 r^2 = 0.860 n = 439

Discriminating Length = 97.0 mm

[b] No Fishing due to ice flows in river

[c] Sample size too small to develop length frequencies

Appendix A - 4. Age composition of total migration and mean fork length and weight by age class for sockeye salmon smolt on the Kvichak River, 2011.

	Age 1.				Age 2.				Age 3.				
Year of Migration	Brood Year	Percent of Total Estimate	Mean Length (mm)	Mean Weight (g)	Brood Year	Percent of Total Estimate	Mean Length (mm)	Mean Weight (g)	Brood Year	Percent of Total Estimate	Mean Length (mm)	Mean Weight (g)	Total Estimate
1955	1953	7	89	_	1952	93	_	_	1951	0	_	_	260,068
1956	1954	39	92	_	1953	61	116	_	1952	0	_	_	77,660
1957	1955	72	96	7.3	1954	28	120	14.4	1953	0	_	_	30,907
1958	1956	98	84	4.6	1955	2	114	_	1954	0	_	_	3,333,953
1959	1957	3	80	_	1956	97	99	7.6	1955	0	_	_	2,863,876
1960	1958	10	91	6.3	1957	90	108	10.3	1956	0	_	_	614,003
1961	1959	72	92	6.8	1958	28	117	13.1	1957	0	_	_	36,164
1962	1960	94	82	4.3	1959	6	110	9.9	1958	0	_	_	1,203,000
1963	1961	3	83	4.8	1960	97	98	7.5	1959	0	_	_	4,229,431
1964	1962	22	87	5.2	1961	78	108	9.8	1960	0	_	_	2,061,586
1965	1963	4	90	6.8	1962	96	109	11.3	1961	0	_	_	1,812,555
1966	1964	92	94	7.4	1963	8	114	12.6	1962	0	_	_	275,761
1967	1965	93	86	5.9	1964	7	118	14.2	1963	0	_	_	3,088,742
1968	1966	11	88	5.5	1965	89	104	9.2	1964	0	_	_	6,123,683
1969	1967	52	92	5.7	1966	48	109	10.6	1965	0	_	_	1,135,344
1970	1968	38	91	6.0	1967	62	110	11.0	1966	0	_	_	483,638
1971	1969	93	90	5.8	1968	7	111	11.1	1967	0	_	_	91,682,813
1972	1970	1	80	4.2	1969	99	106	10.0	1968	0	_	_	54,623,559
1973	1971	3	86	5.1	1970	97	97	8.3	1969	0	_	_	196,966,331
1974	1972	9	96	8.3	1971	79	111	13.1	1970	12	124	17.5	27,082,626
1975	1973	63	98	8.4	1972	37	122	16.4	1971	0	_	_	15,632,531
1976	1974	97	88	5.8	1973	3	121	14.2	1972	0	_	_	111,388,180
1977	1975	38	86	5.5	1974	62	106	10.1	1973	0	_	_	192,578,099

Appendix A - 4 (continued). Age composition of total migration and mean fork length and weight by age class for sockeye salmon smolt on the Kvichak River, 2011.

	Age 1.				Age 2.				Age 3.				
Year of Migration	Brood Year	Percent of Total Estimate	Mean Length (mm)	Mean Weight (g)	Brood Year	Percent of Total Estimate	Mean Length (mm)	Mean Weight (g)	Brood Year	Percent of Total Estimate	Mean Length (mm)	Mean Weight (g)	Total Estimate
1978	1976	12	88	6.0	1975	88	97	7.8	1974	0	_	_	245,591,014
1979	1977	51	90	6.0	1976	49	109	10.3	1975	0	_	_	55,181,540
1980	1978	94	88	5.9	1977	6	110	10.7	1976	0	_	_	192,853,007
1981	1979	89	85	5.4	1978	11	108	10.2	1977	0	_	_	252,222,769
1982	1980	58	84	5.1	1979	39	103	9.1	1978	0	_	_	239,721,729
1983	1981	8	80	4.9	1980	92	98	8.5	1979	0	_	_	82,793,899
1984	1982	58	90	6.8	1981	42	104	10.0	1980	0	_	_	89,489,975
1985	1983	92	85	5.3	1982	8	102	9.2	1981	0	_	_	25,527,851
1986	1984	61	84	5.5	1983	39	107	10.4	1982	<1	102	9.1	136,733,218
1987	1985	3	82	4.5	1984	97	96	7.0	1983	<1	97	8.5	342,686,918
1988	1986	13	86	5.6	1985	87	99	8.3	1984	<1	107	9.8	100,173,692
1989	1987	95	85	5.5	1986	5	108	10.8	1985	<1	105	9.5	153,464,216
1990	1988	53	87	6.1	1987	47	105	10.5	1986	0	_	_	88,004,103
1991	1989	72	85	5.5	1988	28	105	9.9	1987	0	_	_	121,454,182
1992	1990	23	84	5.6	1989	77	100	9.3	1988	0	_	_	79,490,008
1993	1991	10	86	6.0	1990	90	97	8.2	1989	0	_	_	226,407,888
1994	1992	64	84	5.7	1991	36	102	9.5	1990	0	_	_	83,845,472
1995	1993	95	87	6.2	1992	5	103	9.8	1991	0	_	_	220,892,127
1996	1994	74	89	6.5	1993	26	110	11.3	1992	0	_	_	373,166,532
1997	1995	74	88	6.8	1994	26	105	10.6	1993	0	_	_	363,397,663
1998	1996	65	90	6.7	1995	35	112	11.9	1994	0	_	_	295,470,850
1999	1997	92	86	5.8	1996	8	108	10.3	1995	0	_	_	143,543,215
2000	1998	82	86	5.8	1997	18	103	9.5	1996	0	_	_	130,038,649

Appendix A - 4 (continued). Age composition of total migration and mean fork length and weight by age class for sockeye salmon smolt on the Kvichak River, 2011.

	Age 1.				Age 2.				Age 3.				
Year of Migration	Brood Year	Percent of Total Estimate	Mean Length (mm)	Mean Weight (g)	Brood Year	Percent of Total Estimate	Mean Length (mm)	Mean Weight (g)	Brood Year	Percent of Total Estimate	Mean Length (mm)	Mean Weight (g)	Total Estimate
2001	1999	71	78	4.2	1998	29	102	8.5	1997	0	_	_	325,914,951
2002	2000	65	80	4.5	1999	35	94	7.2	1998	0	_	_	N/A
2003	2001	64	83	5.2	2000	36	109	9.0	1999	0	_	_	N/A
2004	2002	69	90	6.2	2001	31	106	10.1	2000	0	_	_	N/A
2005	2003	100	88	5.9	2002	<1	112	11	2001	0	_	_	N/A
2006	2004	100	81	4.3	2003	<1	110	8.8	2002	0	_	_	N/A
2007	2005	75	81	4.5	2004	25	99	7.9	2003	0	_	_	N/A
2008	2006	74	82	4.7	2005	26	99	7.7	2004	0	_	_	30,786,980
2009	2007	79	84	5.5	2006	21	107	10.4	2005	0	_	_	35,247,209
2010	2008	61	84	4.9	2007	39	104	9.3	2006	0	_	_	57,372,620
2011	2009	69	86	5.6	2008	31	108	11.0	2007	0	_	_	41,730,658
Mean 1955-2010		70	84	5.4		34	104	9.4			106	10.1	
Mean 2001-2010		76	83	5.0		30	104	9.0					

[a] Estimates of smolt numbers from 1955-1970 and 2005-2007 based on fyke net catches; estimates of smolt numbers from 1971 to 2004 and 2008 to 2011 based on hydroacoustic techniques.

[b] Ice flows in 2002 prevented us from deploying the sonar until June 5, about 2 weeks later than normal. It is unknown what component of the run we counted/sampled from June 5 - 14.