Monitoring sockeye salmon smolt abundance and inriver distribution using sonar on the Kvichak and Ugashik rivers in 2012

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Monitoring sockeye salmon smolt abundance and inriver distribution using sonar on the Kvichak and Ugashik rivers in 2012

by

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ABSTRACT

The Bristol Bay Science and Research Institute (BBSRI) estimated the hourly, daily, and seasonal abundance of sockeye salmon (*Oncorhynchus nerka*) smolts on the Kvichak and Ugashik rivers in 2012 using up-looking sonar arrays. Smolt abundance estimates can provide data to help characterize freshwater and marine productivity, set biological escapement goals, and forecast adult returns. Two independent up-looking sonar arrays were operated at separate sites in each river to provide independent abundance estimates. Each sonar array consisted of a row of pods placed along the river bottom, perpendicular to the bank. Pod and depth-specific smolt density estimates were obtained by echo integration. In addition to abundance, smolt distribution, run timing, and diel behavior were characterized. Kvichak River sonar systems were operated 3.5 river km (rkm) (Site 1, operated from 24 May to 18 June) and 7.0 rkm (Site 2, operated from 22 May to 18 June) downstream of Lake Iliamna. Total sockeye salmon smolt abundance was estimated to be 49.2 million (95% CIs = 44.3 – 54.1 million) at Site 1 and 47.0 million (95% CIs = 43.7 – 50.3 million) at Site 2. Ugashik River sonar systems were deployed approximately 80 m downstream of the outlet of Lower Ugashik Lake on 22 May and ran through 12 June. Total sockeye salmon smolt abundance was estimated to be 11.2 million (CIs = 9.9 – 12.5 million) for Site 1 and 11.1 million (CI = 10.1 – 12.0 million) at Site 2.

Age, weight, and length of sockeye salmon smolts were collected on the Kvichak and Ugashik rivers. On the Kvichak River, tissue samples were also collected for genetic-based derivation of spawning-stock contributions to the 2012 smolt run. For the Kvichak River, age-1 smolts made up an estimated 76% of the outmigration and averaged 84 mm in length and 5.2 g in weight. Age-2 smolts averaged 108 mm in length and 11.0 g in weight and had the earlier run timing of the two age classes. Results from the Ugashik River smolt sampling and the Kvichak River stock composition project were not available at the time of this writing.

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INTRODUCTION

The impetus for monitoring salmon smolt size, age, and abundance in the Bristol Bay region is to help salmon management by improving preseason forecasts of returning adult salmon abundance, and to understand the relationship between parent escapement and smolt production and how this changes over time. Understanding productivity as a function of escapement is useful for refining escapement goals used to manage the fishery. The utility of salmon smolt abundance estimates from Bristol Bay rivers has been long recognized. The University of Washington began estimating the age, length, and abundance of smolts on the Wood and Kvichak rivers in the early 1950s (Burgner 1968). In the early 1960s the Alaska Department of Fish and Game expanded smolt research in Bristol Bay and began experimenting with hydroacoustics for estimating abundance in the early 1970s (ADF&G; Wade et al. 2010). Smolt programs continued through the 1990s but interest had waned due to the high cost of operation and statistical uncertainty in abundance estimates. By 2002, all ADF&G sockeye salmon smolt projects in Bristol Bay were discontinued (Crawford and Fair 2003; Wade et al. 2012b).

Interest in smolt data renewed in the mid-2000s 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). The renewed interest prompted BBSRI to begin designing 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. 2010). The new design consisted of a series of up-looking sonar pods that could be deployed in such a manner as to sample the entire river width. This digitally-based sonar system was first tested on the Kvichak River in 2008 (Wade et al. 2010).

In 2012, BBSRI continued the project to enumerate sockeye salmon smolts on the Kvichak (fifth consecutive year) and Ugashik (third consecutive year) rivers. Sockeye salmon smolt abundance was estimated using sonar systems that were the same bottom-founded, up-looking design as described in Wade et al. (2010). Smolts were also sampled with an incline plane trap and fyke nets to estimate age, body size, stock composition 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 2012 and characterizes horizontal, vertical, and diel distribution of smolt schools as they migrate. The report will also highlight some of the possible sources of uncertainty in the abundance estimates (e.g., swimming speed, distribution) and how these may or may not bias the final results. 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 (ADF&G). Age, weight, and length (AWL) data collected on the Kvichak River in 2012 are included in this report; AWL data collected on the Ugashik River were not available at the time of this writing. 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; Baker et al. 2006, 2009).

In 2012, ADF&G began collecting genetic samples to provide stock composition estimates from the Lake Clark and Lake Iliamna drainages. The samples were collected during the 2012 field season. Analyses of those samples are currently being conducted and results will be made available in a separate report by ADF&G in 2013.

OBJECTIVES

The objectives of the 2012 study were to:

1. Use sonar to estimate the hourly, daily, and seasonal abundance of sockeye salmon smolts migrating from the Kvichak and Ugashik rivers.
2. Evaluate abundance estimates by characterizing the vertical, horizontal and diel distribution of smolts from the Kvichak and Ugashik rivers.
3. Estimate the age, weight, and length of sockeye salmon smolt migrating to sea from the Kvichak and Ugashik rivers.
4. Provide estimates of stock composition of sockeye salmon smolt migrating to sea from the Kvichak River.

STUDY AREA

Bristol Bay

The Kvichak and Ugashik rivers are two of the nine main rivers that produce sockeye salmon targeted in the Bristol Bay commercial, subsistence and sport fisheries (Figure 1). The commercial sockeye salmon fishery in Bristol Bay is the largest in the world; over a 20 year period (1991 – 2010) total sockeye salmon returns have averaged 37.3 million fish (Salomone et al. 2011). During the same time period the number of sockeye returning to the Kvichak and the Ugashik rivers averaged 7.3 million and 3.9 million, respectively. The Alaska Department of Fish and Game manages these stocks inseason based on pre-season forecasts and escapement goals set for each river.

Subsistence fishing for sockeye salmon in Bristol Bay has occurred since inhabitance and continues to be an important source of protein for local residents (Morstad et al. 2010). In 2009, the subsistence harvest of sockeye salmon for the Kvichak River/ Iliamna Lake sub-district totaled 46,772 from 187 permits, and in the Igiugig region totaled 1,071 from 5 permits (Salomone et al. 2011). For the Ugashik district the harvest totaled 1,061 sockeye from a total of 15 harvest permits. In addition to the subsistence fishery, sockeye salmon have been an essential segment of the sport fishing industry for both the Kvichak and Ugashik drainages. From 2003 – 2007 the annual sport fish harvest of sockeye salmon in the Kvichak and Ugashik rivers averaged 1,461 and 2,789 fish, respectively (Dye and Schwanke 2009).

Kvichak River

The Iliamna watershed is located in southwest Alaska and drains an area of 16,830 km^2 (Figure 2). This watershed includes Lake Clark and Iliamna Lake. Iliamna 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, which is approximately 14 m above sea level.

Mean annual discharge for the Kvichak River collected near Igiugig from 1968 to 1986 ranged from 361 m^3/s to 729 m^3/s and averaged 503 m^3/s (USGS 2008). Peak discharge occurs during August, September, and October; 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).

The initial 1.2 km of the Kvichak River below Iliamna Lake is contained within a single channel; downstream, the river is mostly braided with a few exceptions (Figure 2). 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).

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 and Dog Salmon rivers. 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 is confined to 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. There is no USGS stream flow data available 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 3; 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 4 and 5). The number of pods in a system varied from 5 to 12. Each pod was mounted on an aluminum sled (76 cm long, 30 cm wide and 10 cm in height; Photo 4) and all sleds were tethered together by wire rope. The sleds were designed to remain upright while perpendicular to the current (Wade et al. 2010). The pods were connected to a shoreside control box by a cable for power and data transmission. The control box provided an interface for powering and communicating with the sonar array, handled the data storage, and monitored the input voltage. 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. Power to the sonar was supplied by a bank of 12 V batteries and supplemented with gas or thermoelectric generators (Wade et al. 2012a). An eight-pod sonar system required approximately 86 W to operate, of which about 30 W were used to power the data storage device and 7 – 8 W were for each pod.

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 4; Wade et al. 2010). Each pod was outfitted with a 7.5^{o} (at -3 dB) single beam transducer, model # 1111, manufactured by BioSonics (Wade et al. 2012b). In addition to the single beam pods, one split-beam pod was integrated into one sonar array on each river to estimate the target strength of individual smolts (Photo 5). 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. A pool calibration of each sonar pod was performed prior to field deployment (Wade et al. 2012a).

As well as 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.

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 differences in the results between sonar systems, we sought two sites sufficiently far apart to allow mixing and redistribution of smolts between sites.

All sonar arrays were deployed in the same manner (Wade et al. 2010). A 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. In 2011, the Ugashik River water velocities reached such levels that the sonar arrays were washed downstream preventing abundance estimates for that year (Wade et al. 2012a). To prevent this from happening again, each sled from Site 1 was equipped with two eyebolts on the upstream side of the pod (Photo 4). Prior to deployment a 7.9 mm (5/16”) diameter wire rope was anchored on the river bottom upstream of the site; as the pods were deployed they were “threaded” onto the cable which prevented tipping events.

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® 5.1 by Myriax Software Pty. Ltd., Tasmania, Australia).

Kvichak Sonar Deployment and Operation

In the past, to prevent damage to the hardware, the sonar systems were 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 had begun migration. In 2010 and 2011, we operated a sonar system in the Kvichak River in relatively heavy ice conditions, the system functioned well, and we found substantial numbers of fish moving with the ice.

In 2012, Lake Iliamna was 95% covered with ice when the crews arrived on 17 May. As the crew began to stage the sonar equipment at the sites and prepare for deployment, the ice would flow intermittently or not at all due to a prevailing southwesterly wind that held the ice in the upper portion of the lake. By 21 May both sites were staged and ready for deployment while the lake still had 70% of its ice remaining. Based on past run timing on the Kvichak River, a decision was made to deploy one system immediately in order to avoid missing an early movement of smolts. Site 2 was determined to be the safer of the two sites; it was 3.5 km further downstream than Site 1 and therefore this location had lighter ice flow.

Site 2 had one eight-pod array of single beam transducers that was set on 22 May and a separately operated four-pod array of single beam transducers that was set on 23 May in a section of river 147 m in width (Figure 2). Combined, these two arrays essentially provided data from a 12-pod array (Figure 5), with each of the 12 pods sampling a different area. The terminal box and power supplies were housed on the right bank, relative to the observer looking downstream. In previous years only one eight-pod sonar array was set at Site 2. All pods at Site 2 were spaced 10 m apart; therefore the twelve-pod array would cover a 120 m cross section of the river.

The first pod from the control box (T1) was located 15 m off the right bank in 2.24 m of water and the last pod (T12) was 16 m from the left bank in 3.35 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 2 began with a rather abrupt drop off on the right bank to a maximum depth of 3.01 m (T3) followed by a shallow area near the middle of the river (2.45 m) then a drop back down to a deeper section near the left bank (Figure 6).

On 24 May, Site 1 was set in a section of river 114 m in width; this array had a total of eight pods one of which was a split-beam transducer. The first pod was set 19 m from the right bank in 1.73 m of water and the last (8th) pod was 15 m from the left bank in 3.38 m of water (Table 3). The bottom profile of Site 1 began with a gently sloping right bank to a maximum depth of 3.77 m, 79 m from shore (Figure 7).

Although the ice flow was relatively light for much of the season, the deployment of the side-looking sonar was delayed until 7 May and then it was retrieved on 13 May.

Ugashik Sonar Deployment and Operation

On 15 May, crews and equipment arrived by air at the Ugashik field camp, located 2 km below the Lower Ugashik Lake outlet; during the flight, the crew could view both the upper and lower lakes and observed 90% ice remaining on each. Ice began to flow out of the lakes on 16 May and remained constant through 21 May.

On 22 May, the Site 1 sonar array was deployed approximately 70 m from the outlet of the Lower Ugashik Lake on a section of river 44 m in width (Figure 3). This sonar system was originally made up of four single beam pods and one split-beam. Upon start-up the split beam pod malfunctioned and was replaced with a single beam pod from Site 2 and redeployed the same day. Pods were spaced in 5 m intervals with the first pod (T1) 22 m from the right bank and the last pod (T5) 2 m from the left bank. The bottom profile of Site 1 was characterized by a gradual slope from the right bank for the first 34 m to a depth of 3.16 m and then a fairly consistent bottom to an abrupt rise near the left bank (Table 3, Figure 8).

On 22 May the Site 2 array was deployed approximately 20 m downstream of Site 1. The river at Site 2 was 56 m in width with a bottom profile similar to Site 1. A total of four single beam pods spaced 5 m apart were deployed. T1 was 41 m off the right bank in 1.81 m of water and T4 was 2 m off the left bank in 2.01 m of water (Table 3, Figure 9).

For both sonar systems, the power supply and data control terminals were housed in weather proof steel boxes on the right bank (Photo 5).

On 23 May, the side-looking sonar system was deployed, approximately 10 m upstream of Site 1. The side-looking transducer was in 1 m of water, which allowed the sonar to cover a 30 m cross-section of the river.

Estimating Abundance

Data Pre-processing

Data files were pre-processed (using EchoView® 5.1 software) by removing noise events generated by ice, boat passage through the sample area, wind/rain events, and any interference 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 distinguish 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.

Echo Integration and Calculation of Abundance

Echo integration was used 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; therefore abundance estimates 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 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 was a measure of mean smolt count/cross sectional area sampled, then normalized to smolt density/m^2 for each strata. The fish density/m^2 was then multiplied by the water velocity to obtain the smolt flux, which gives 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. The season total abundance and variance of the mean for each site were estimated by the following:

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

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

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

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

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

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

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

Evaluation of Factors Effecting Abundance Estimates

Smolt Distribution

Systematic changes in smolt behavior across time or among seasons could influence the accuracy and usefulness of the abundance estimates; therefore it is necessary to describe this behavior to determine potential sources of biases. The characterization of smolt distribution was based on the abundance of smolt detected in time, depth, or width strata. For cross-river distribution, the width of the river was divided into relatively large strata with bounds on either side of the pods and toward the shore. The hourly abundance estimate in each stratum was summed for all depths to give the total amount of smolts in that section of river. Depth distribution was calculated in 0.2 m depth strata from the surface down to the transducer near field (Wade et al. 2010). The estimated abundance was then summed for all hours of daylight and darkness.

Sample Duration and Run Timing

Deployment of the sonar prior to the run and operation for its entirety was essential for accurate abundance estimates. Large numbers of smolts can outmigrate in a single night; if these fish were missed due to inadequate temporal sampling coverage the final abundance estimates would be biased low.

Environmental Conditions

River ice flow may alter smolt behavior at certain times during the outmigration. On the Kvichak River in 2011, there was some indication that smolts behave differently during periods of high ice in the river (Wade et al. 2012b). Ice information was collected in the hydroacoustic data, and can be used to describe ice conditions throughout the season.

Water velocity plays a large role in estimating smolt abundance. In order to calculate smolt flux (smolt/hour/meter), swimming speed must be known. Smolts are thought to travel near the same speed as the water velocity, therefore accurate velocity measurements are crucial. Velocity was generally the highest near the thalweg and decreases toward the shore. Because of this, measurements are recorded at set locations throughout the width of the river.

Water velocity measurements in 2012 were taken at a depth of 1 m at each pod. Measurements were taken from a boat anchored 2 to 3 m downstream of each pod. 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 calculated based on the GPI conversion table. For the Ugashik River, we used a FP111 digital flow meter made by Global Water Instrumentation, Inc. (Sacramento, CA).

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). Water velocities on the Ugashik River were measured four separate times throughout the season (Table 4). River stage height was not measured for either river.

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 speed (km/h), and wind gusts (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 5 and 6). Hourly water temperature data were collected on the Kvichak and Ugashik rivers using a Tidbit® v2 TempLogger.

Modeling Assumptions

Several assumptions 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. The four main assumptions about smolt behavior are:

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

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

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

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

Violations of these assumptions could bias the final estimate (Wade et al. 2012a).

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 River were captured using a standard fyke net with a rigid 4' x 4' opening.

Once the smolts were captured they were anaesthetized and measured from tip-of-snout to fork-of-tail in millimeters and weighed in grams. Smolts were aged later from visual observations of scales mounted on glass slides; age-1 and age-2 represent smolts that spent one or two years, respectively, in freshwater.

Sampling goals to determine the age composition 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 (Cochran 1977).

The mean length of smolt differs among samples from a single day (Minard and Brandt 1986), presumably because of size segregation among schools. 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 age-2 sockeye salmon smolt by determining a discriminant length that minimized classification error. This discriminant 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 (W_j) of age j smolt measured only for length as explained by (Ricker 1975):

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

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:

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

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

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

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.

RESULTS

Kvichak River

Data Pre-processing

Data were collected at Site 1 from 24 May (1900 hours) through 18 June (1100 hours); the eight-pod system collected 593 h of data. Site 2 data collection began on 22 May (0000 hours) with one eight-pod sonar array. On 23 May (1500 hours) a smaller four-pod sonar array was deployed. The two sonar arrays operated as one twelve-pod sonar system to produce the Site 2 abundance estimate. The Site 2 sonar collected 638 h of data; 39 h of this as an eight-pod system.

Environmental noise accounted 14% (73 h) and 4% (24 h) of the data collected at sites 1 and 2, respectively, to be unusable (Figures 11 and 12). Wind events accounted for a portion of the unusable data but the majority was from ice in the river. In 2012, the ice flowed for the majority of the sonar deployment and at times was thick enough to preclude data analysis, at these times abundance estimates were linearly interpolated. The difference in the amount of unusable data was due to the location of each site and proximity to the lake. Site 2 was 3.5 km further from the outlet of Lake Iliamna than Site 1; within this distance much of the ice breaks apart and melts. Due to problems with configuring the side-looking sonar, no useable data were collected.

Abundance Estimate

The estimated abundance of sockeye salmon smolts in the Kvichak River from 24 May to 18 June at Site 1 was 49,198,830 (95% CIs = 44,322,128 – 54,075,533; Table 7; Figure 13). For Site 2, the estimated abundance from 22 May to 17 June was 47,011,636 (95% CIs = 43,693,294 – 50,329,979; Table 8; Figure 13). Hourly smolt passage peaked at each site during darkness (Figure 14). Many smolts also migrated during daylight, however, and total passage during daylight hours was 47% of the run at Site 1 and 45% of the run at Site 2.

Smolt Distribution

Vertical distribution was split into 0.2 m depth strata down to a maximum depth of 3.0 m at Site 1 and a maximum depth of 2.6 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 97% of smolts detected at night were in the upper 1.0 m with the majority of these in the upper 0.6 m (90% - Site 1, 92% - Site 2; Figure 15). By contrast, smolts traveling during daylight hours tended to have a deeper vertical distribution. For both sites, 75% of smolts were detected in the upper 1.0 m of the water column; of those 46 % were in the upper 0.6 m of the water column.

Smolts were detected by all sonar pods at each site (i.e., across the entire river), but were disproportionately distributed. At Site 1, smolts were concentrated in the areas of deeper water and higher velocity, where approximately 72% of the smolts were detected at the four pods (T4 – T7) in the main channel along the left side of the river (Figure 7). At Site 2 smolts were more concentrated in the middle portion of the river where T5 – T10 accounted for 76% of total smolt (Figure 6).

Sample Duration and Run Timing

Run timing patterns for both sites followed the same general trend as previous years (Figure 13) with a large peak around 27 May and another smaller peak on 31 May. The smolt run appeared to begin prior to the deployment of both sonars. Site 2 sonar was deployed on 22 May; this was two days before Site 1 deployment. During those two days an estimated 2.8 million smolt passed the sonar. In 2012, the sonars remained in the river until 18 June longer than in previous years, this was to determine if the smolt run continued after 14 May. For both sites greater than 95% of all smolts were estimated to have passed the sonars by 12 June. On 15 June a small spike in smolt abundance was detected but it appeared that the majority of the run had passed by 18 June (Figure 13).

Environmental Conditions

Water temperatures on the Kvichak River were measured from 25 May to 15 June. On 25 May, the water temperature at 0800 hours was 2.7° C and at 2000 hours the temperature was 3.0° C (Table 5). The water temperature rose steadily until it reached a high of 6.8° C at 0800 and 2000 on 6 June. The spike in temperature was followed by a cooling trend where temperatures dipped down to 4.8° C on 8 June then rose steadily to 6.5° C. Ice flow was light but persisted for the entirety of the project.

Sampling Smolt for Age, Weight, and Length

Smolt sampling on the Kvichak River began on smolt day 19 May and ended 14 June. During the second night of fishing the crew caught their sampling goal of 600 smolts in 34 minutes (Table 9). Based on this relatively high catch rate (CPUE=27.65 smolts/minute) it appears the smolts were already present in moderate numbers, which would indicate sampling began after the start of the run. Ice resumed flowing after the first two sampling sessions preventing further fishing from 21 May to 22 May and then again on 25 May.

Scales from a sub-sample of 100 smolts were taken each night and the remaining smolts (~500) were aged based on an age-length ratio (Table 10). In 2012, the nightly percentage of age-1 smolts ranged from 0.7 % on 20 May to 97% on 1 June. Age-1 sockeye smolts constituted 76.7 % of the total catch. Previous smolt studies on the Kvichak by ADF&G have seen the majority of age-2 smolts outmigrate earlier than age-1 smolts (Table 11; Crawford and West 2001).

Ugashik River

Data Pre-processing

Sonar systems on the Ugashik River were deployed on 22 May and operated continuously until 12 June, yielding 506 and 505 hours of data to analyze from sites 1 and 2, respectively. Although only 20 m separated the two sites, wind induced unusable data at Site 1 (28%; Figure 16) was much higher than at Site 2 (13%; Figure 17).

During a pre-deployment test run on the Site 1 sonar array, it was found that the split-beam pod would not function correctly therefore a single beam pod was used as a replacement. During post season analysis it was discovered that those data collected from the Site 1, T5 pod could not be included in the abundance estimate because of a malfunction with the pod that resulted in an extremely high level of noise. For the entirety of the season smolt abundance was estimated by linear interpolation from T4 to the left bank.

Based on river width and smolt distribution (Wade et al. 2012b), the pre-season project operational plan called for two sonar arrays with five pods each. Due to the problems with the split beam at Site 1, Site 2 operated with four pods in the array. All pods in the array functioned well until 5 June (1100 hours), when T1 lost power and could not be restarted. For the remainder of the season, smolt abundance was estimated by linear interpolation from T2 to the right bank.

The side-looking sonar was deployed on 23 May and operated continuously until retrieval on 12 June. As in the past, problems with the sonar falling out of alignment rendered much of these data unusable. During the season the crew would re-align the sonar so there were times when the side-looking sonar operated as planned; these data were then analyzed to verify smolt cross-river distribution (Figure 18). Based on a qualitative review of these data, the side-looking sonar corroborated the data from the sonar array in that the majority of the smolts traveled 30 – 35 m from the right bank at Site 1.

Abundance Estimate

The estimated abundance of sockeye salmon smolts from 22 May to 12 June at Site 1 was 11,193,920 (95% CIs = 9,933,129 – 12,454,710; Table 12; Figure 19). For Site 2, the estimated abundance from 22 May to 12 June was 11,064,475 (95% CIs = 10,086,664 – 12,042,286; Table 12; Figure 19). Like the Kvichak River, the rate of hourly smolt passage peaked during hours of darkness but the total estimated number occurred during the hours of daylight (Figure 20). Diel smolt distribution was consistent between sites with both estimating 59.0% smolts migrating during the hours of daylight and 41.0% of smolts migrating during the hours of darkness.

Smolt Distribution

Vertical smolt distribution on the Ugashik River was predominately in the upper 1.0 m of the water column, with Site 1 distribution being more skewed toward the surface than Site 2 (Figure 21). For Site 1, 91% of all smolt detected during hours of darkness were located in the upper 1.0 m, with 75% of total smolts in the upper 0.6 m. For Site 2, only 82% were detected in the upper 1.0 m, but distribution within the 1.0 m strata was a little more evenly distributed with 62% in the upper 0.6 m. Diel distribution differed from the Kvichak in that more smolts were detected during the day in the upper 0.2 m than at night in the same stratum.

Smolt cross-river distribution varied between sites 1 and 2, possibly from differences in river width and bottom profile of the two sites (Figures 7 and 6). At Site 1, 66% of the total smolt abundance were accounted for by the two pods (T3 and T4) located in the deepest portion of the river. At Site 2, smolts were more evenly distributed across the river with each pod accounting for approximately 20% of the total smolt estimated.

Sample Duration and Run Timing

Both sonars began operation on 22 May, which was the first day after ice out. Based on the relatively low numbers of smolts estimated during the first two full days of operation (23 – 24 May), it appears the sonar was in place near the beginning of the smolt outmigration (Figure 19). By contrast, at both sites, the smolt numbers near the end of deployment averaged greater than 400,000 smolts per day. These large numbers of smolts near the end of the season would indicate the run had not ceased for the year.

Environmental Conditions

Water temperature was recorded from 23 May to 13 June. At the beginning of the season it was 3.4° C at 0800 hours and 4.4° C at 2000 hours (Table 6). Similar to the Kvichak, a peak temperature of 6.5° C occurred on 6 June at 2000 hours; after this date the temperature dropped for the remainder of the season averaging 4.8° C and 5.4° C at 0800 and 2000 hours, respectively).

Sampling Smolt for Age, Weight, and Length

A total of 2,395 smolts were sampled on the Ugashik River from 27 May to 11 June. At the time of this writing those data are still being analyzed for AWL by ADF&G.

DISCUSSION

The 2012 sampling season marked the fifth season on the Kvichak River and a third season on the Ugashik River for using the BBSRI sonar system to generate smolt abundance estimates. Smolt behavior data have also been collected and analyzed for all years on both rivers and are useful in several ways. The most immediate benefit of the behavioral data is that it can be used to discuss abundance estimates and how various factors may affect them. Smolt distribution data can also be used to lay the groundwork for designing new smolt projects in Bristol Bay or elsewhere in Alaska.

Kvichak River

Abundance Estimate

Over the last five years sockeye salmon smolt abundance estimates have ranged from 27.0 million (2008) to 57.3 million (2010; Table 13). In 2012, an estimated 49.1 million smolts passed the sonar sites making it the second highest since BBSRI began the program. Smolt abundance estimates between the two sites were also very consistent with a difference of 4.6% (49.2 million vs. 47.0 million). Changes to the configuration of the Site 2 sonar array may have played a role in tightening up the estimates between the two sites. In previous years, the Site 2 array was made up of eight sonar pods spaced 10 m apart in a section of river that was 130 m in width, which left considerable space between either end of the array and the shoreline. With this configuration yearly estimates from Site 2 were consistent with Site 1, but the daily and hourly estimates were not as uniform as we saw in 2012. In 2012, a separate four-pod array was positioned 10 m downstream of the eight-pod array; but sampled areas not sampled by the eight pods immediately upstream; together these two systems were treated as a single array that was 110 m in width (Figure 5). This new twelve-pod configuration provided more complete cross-river coverage than in past years.

In the past we have assumed the Site 1 estimate to be the more accurate of the two sites because it is located on a narrower portion of the river with a higher proportion of smolts migrate through the ensonified area. Based on the results from 2012, it appears the twelve-pod array adequately covers the cross sectional portion of the river; this bolsters our confidence in using Site 2 as a reliable alternative for estimating abundance.

Distribution

Smolt cross-river distribution in 2012 was similar to previous years for Site 1; changes in sonar configuration at Site 2 prohibit direct comparison (Figure 22). Smolt cross-river distribution was thought to be constant for the duration of the outmigration. In 2012 we looked at individual days to see if this held true during periods of high abundance. The largest days of smolt abundance for Site 1 occurred on 26, 27 and 30 May when 5.9, 12.3, and 6.2 million smolts, respectively, were estimated passing the sonar. Smolt distributions for these periods were plotted next to the yearly distribution (minus 26, 27, and 30 May) in order to examine distribution when abundance was high (Figure 23). Changes in distribution appear to occur on 27 May when the abundance was the highest but little change was noted on 26 and 30 May. On 27 May smolts were more evenly distributed across the river as opposed to the majority being near the thalweg.

For Site 2, the highest days of abundance were 26, 27 and 29 May when 6.0, 12.1, and 5.7 million smolts, respectively, were estimated passing the sonar. Site 2 data were plotted in the same manner as Site 1; there did not appear to be any changes in distribution that could be attributed to high smolt passage (Figure 24). Site 1 was 35 m narrower than Site 2; this may cause overcrowding in the area of the river smolts generally occupy (i.e., deeper, faster water).

Changes in smolt distribution on days of high abundance, similar to Site 1 on 27 May, could have an effect on the abundance estimate by causing it to be biased low. If smolts are distributed more evenly across the river it increases the likelihood of missing near shore fish. Smolt abundance was linearly interpolated from the outside pods to the shoreline, which was given a value of zero. Given that approximately 25% of the total smolt estimate at Site 1 came from 27 May, the amount of error could be large. At Site 2, this change in behavior did not appear to occur. The total and hourly estimates for both sites were consistent, indicating few smolts were missed at Site 1 (Figure 13).

Vertical distribution in 2012 was also consistent with previous years, and continued to show a diel migration pattern (Figure 25). For all years, during hours of darkness greater than 90% of all smolts were located in the upper 1.0 m and 80% of those smolts were in the upper 0.5 m. During daylight hours, smolts traveled deeper, with only 40% in the upper 0.5 m.

In years previous there has been no test for changes in smolt vertical distribution during periods of high abundance, and whether this could bias the abundance estimate. Due to the high smolt abundance on 27 May we looked at that day to see if smolts use the deeper water during periods of high abundance (Figure 26). Smolt distribution during high passage follows the same trend with the majority of smolts in the upper portion of the water column but there were a higher proportion on 27 May below the 0.0 – 0.4 depth strata. Vertical distribution should not have too much influence on the abundance estimates as long as smolts remain in the upper 2.0 m strata.

Sample Duration and Run Timing

The run timing pattern in 2012 was typical for most years with a peak in late May and another near the first of June, yet the actual timing was earlier than most years (Figure 27). In 2012, the majority of the smolts outmigrated somewhat earlier than in the previous 4 years of this study. Eighty five percent of the total smolt estimate was accounted for by 1 June. In the past studies we did not reach 85% until after 5 June. The median migration date (50% of total estimate) in 2012 was 27 May; within the last 5 years of this study it was tied for the earliest with 2010 (Table 14).

Based on data collected by ADF&G, Quinn (2005) suggested there is a relationship between spring water temperatures and smolt run timing on the Kvichak River with lower temperatures causing smolts to outmigrate later. The average water temperature for 2012 was 5.1° C; this was the third coldest of the five years of this program (Table 14). Although the smolts in 2012 were earlier than most years of the study overall there been only five days that separate the median outmigration date. The sockeye salmon smolt runs in Bristol Bay are typically compressed so large changes in run timing may not occur unless water temperature varies drastically.

Environmental Conditions

River ice on the Kvichak River was light compared to past years, yet it persisted all season. With the prevailing wind pushing most of the ice to the head Lake Iliamna the river ice continued to trickle all season. Several times in 2011 the river would fill up with ice for hours at a time; this appeared to influence the horizontal, vertical, and diel distribution of smolts during those flows (Wade et al. 2012b). River ice in 2012 never accumulated enough to alter smolt behavior. Environmental conditions during 2012 were favorable for accomplishing the project objectives.

Sampling Smolt for Age, Weight, and Length

Smolt sampling in 2012 was not as impacted by river ice as in the previous years of this project. A total of three nightly sampling sessions were missed during the early portion of the season (21, 22, and 25 May), which may have resulted in missing a large component of age-2 smolts. Typically the larger age-2 smolts have an earlier outmigration than the age-1 smolts. On 19 and 20 May age-2 fish made up greater than 90% of all smolt captured. When fishing resumed on 23 May the catches were closer to 50/50 and quickly began to be dominated by age-1 smolts (Figure 28). It would be useful have those missing data points to help determine when the shift in age class occurred.

Uncertainty in Abundance Estimate

Swimming speed is used to calculate smolt flux (smolt/hour), which in turn lets us calculate the hourly, daily and yearly abundance estimates (Mueller et al. 2006). To date, smolt swimming speed has been assumed to be at or near water velocity, based on work by Maxwell et al. (2009). In 2000 and 2001, Maxwell et al. (2009) used 3-D video techniques to estimate smolt velocity relative to the shore at 0.1 s intervals and then subtracted the known water velocity to get swimming speed. Velocity measurements were recorded over a 24 h period and then divided into four sampling groups (0000 – 0100 hours, 0215 – 0245 hours, 0400 – 0430 hours, and 2034 – 2045 hours) to account for diel differences. In all cases smolt velocity centered on zero but differed by as much as 0.8 m/s on either side of zero (Maxwell et al. 2009).

Error in swimming speed could bias the abundance estimates either high or low (Wade et al. 2010), and will have the greatest impact on indexing the smolt run if it varies as a function of the overall abundance of the smolt run. Also, if swimming speed varies as a function of smolt size, we will underestimate the contribution of the larger age-2 fish to the overall run. In the current study no attempt has been made to verify that smolts are traveling at or near river velocity or if this changes throughout the season. The swimming speed data collected by Maxwell et al. (2009) were recorded over a three day span in the early portion of the smolt outmigration; this relatively short period may not detect seasonal difference (pers. comm. Don Degan). Seasonal changes in swimming speed may occur as the different age classes migrate, with the larger age-2 smolts traveling faster than the age-1 smolts. In 2012, from 19 May to 26 May greater than 50% of all smolts were age-2 after 26 May the outmigration had a daily average of 88% age-1 smolts (Figure 28). This pattern of larger age-2 smolts migrating earlier than the smaller age-1 smolts is typical for the Kvichak River (Quinn 2005). In addition to the age-2 smolts making up a larger component of the early migration, according to Quinn (2005), age-1 smolts that migrate early are larger than later fish of the same age class.

In summary, if we have misidentified the swimming speed of smolts then our estimates of absolute abundance will be in error, but as an index among years, the smolt estimates are only influenced if the swimming speed varies as a function of overall seasonal abundance. If the larger smolts travel faster than smaller smolts this would bias our estimates of age-2 contribution low. Smolt swimming speed across the season, and in particular between periods of large age-2 contribution and age-1 contribution should be measured in the future.

Ugashik River

Abundance Estimate

2012 was the third year for this project (2010 – 2012) but only the second year to obtain abundance estimates (Figure 29). Due to unusually high water in 2011, river velocities were such that the sonar equipment would not remain in the faster portions of the river for the majority of the smolt outmigration. Smolt abundance in 2012 was 11.2 million for Site 1 and 11.1 million for Site 2, which was approximately 50% less than the 20.4 million estimated in 2010. In 2010, the two sonar arrays were configured with 10 m spacing between each pod; due to the relatively narrow river width (45 m) the 10 m spacing did not provide adequate coverage (Wade et al. 2012b). In order to provide sufficient coverage, sites 1 and 2 were treated as a single array during analysis and only one estimate was produced. By generating a single estimate from both arrays in 2010 there was no way to develop an independent estimate. In 2012, the sonar arrays were deployed with 5 m spacing between pods; this provided good spatial coverage and produced two independent abundance estimates.

Site 1 and 2 yearly abundance estimates in 2012 differed by 1%, a good indication that both sonar systems were operating correctly (Figure 19). Although the yearly estimate differed little between the two sites the daily estimates varied more (Table 12). For example on 5 June the Site 1 sonar system estimated 336,106 smolts outmigrated whereas the Site 2 system estimated 1,162,355 smolts. Differences in daily estimates throughout the season could be a result of how the sonar arrays were configured. Both sites 1 and 2 were supposed to operate with a total of five sonar pods on each array. Site 1 began with five but Site 2 was deployed with only four. Inseason problems with pod T5 at Site 1 prohibited those data from being included in the final abundance; instead data were interpolated from T4 to the shore. As a result of the problems with each sonar system, the coverage at each site differed, which may account for the daily difference between the two sites.

Distribution

Smolt cross-river distribution at Site 1 in 2012 was similar to 2010 with greater than 70% of all smolts within 15 m of the left bank (Figure 30). Although the river width at Site 1 was 45 m, the water velocity off the first 20 m off the right bank was extremely slow due to a slight eddy in that portion of the river. Based on what is known about smolt behavior, the distribution at Site 1 was what we would have expected. Smolts at Site 2 were detected in nearly equal proportions at all transducers; this more homogenous distribution may have more to do with the sonar array configuration than actual smolt behavior. Ideally, the sonar array will cover the majority of the river bottom where smolts are likely to be found. The four-pod array at Site 2 only covered a 15 m section of the river closer to the left bank leaving a 41 m section of river on the right bank unsampled. Based on the similarity in the yearly abundance estimates between the two sites, it is likely that the interpolation methods used were adequate.

Depth distribution on the Ugashik River was skewed toward the surface but unlike the Kvichak River, the majority of the smolts migrating during the day were in the upper 0.5 m. This was consistent for both 2010 and 2012 (Figure 31). Due to the “dead zone” in sonars those fish traveling within the upper 2.0 – 3.0 cm of the water column stand a higher likelihood of not being included in the abundance estimate (Wade et al. 2010). With all smolts on the Ugashik River detected in these upper strata, it is likely the estimate could be biased low.

Sample Duration and Run Timing

Smolt run timing on the Ugashik River indicates that the 2012 estimate may be low due to pulling the sonar before the entire outmigration was over (Figures 13 and 32). Both Sites 1 and 2 averaged greater than 400,000 smolts per day for the last three days of operations (10 – 12 June). Judging from historic run timing data collect by ADF&G for 1991 – 2000 it appears the smolt run is typically over by 12 June. In the future the operation of the sonar should be extended by 5 – 7 days to ensure adequate temporal coverage.

Environmental Conditions

Ice flow on the Ugashik River ceased after 21 May. Although there was some ice still in the lower lake the prevailing winds prevented it from getting into the river. Water velocity in 2012 never exceeded 3.0 m/s, as happened in 2011. With the velocity closer to the historic average the sonar pods remained upright for the duration of the project. Environmental conditions during 2012 were favorable for accomplishing the project objectives.

Uncertainty in Abundance Estimate

The assumption that smolts migrate at the same speed as the water velocity has not been tested. Personal communication with the technicians on the project provides anecdotal evidence that smolts appear to be moving at or near the water velocity. In order to obtain absolute abundance estimates, accurate swimming speed is essential and is recommended for future studies. It is not known if swimming speeds vary hourly, daily, or seasonally, so it may be necessary to sub-sample swimming speed during the outmigration over several years.

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 clearly able to detect large changes in smolt abundance 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 as absolute numbers of fish cannot be validated without known abundances. However, the relatively low measurement error of two independent, sonar-based estimates from significantly different sites in the same river supports the belief that the estimates are a relatively precise index of daily abundance within each year; how well we can index the smolt abundance among years will be more difficult to determine. A portion of the ultimate usefulness of the program to forecast adult returns will emerge as more smolt and adult returns are gathered. Large and unpredictable variability in marine survival may limit usefulness in this regard but would not necessarily limit the usefulness to understand variation in freshwater productivity and refine escapement goals.

Sonar array configuration and duration of sampling can effect abundance estimates at each site, so it is necessary to have adequate spatial and temporal coverage. On the Kvichak River, the Site 2 sonar array was expanded from 8 to 12 pods in 2012, which increased the cross-river sampled from 70 m to 110 m and is recommended for future studies. Due to sonar pod malfunctions in 2012 on the Ugashik River, both sites 1 and 2 operated with only four pods which was one less than the minimum recommended. Spare pods and cables should be available for each site in order to ensure there will be enough equipment to sufficiently sample the desired area.

Adequate temporal coverage for all rivers and sites needs to be a goal for future studies because smolt numbers can change dramatically in a manner of one or two days, which is why it is essential to sample the entire duration of the smolt run. On the Kvichak River the first day a sonar array was fully operational (22 May) an estimated 2.7 million smolts passed the site (5.7% of the seasonal abundance). Similarly, on the Ugashik River the last three days of sampling (10 – 12 June) averaged greater than 400,000 smolt per day (3.6% of the seasonal abundance). When planning for the 2013 field season it is recommended that deployment on the Kvichak River begin near 1 May to test for early smolt outmigration. On the Ugashik River the program should be extended by 5 – 7 days to ensure the tail end of the run is accounted for.

Swimming speed is an important metric for calculating absolute smolt abundance. The speed is used to calculate abundance and is currently based on data collected by ADF&G over a relatively short period of time (3 days). If there are diel or seasonal changes in smolt swimming speed, or if it varies by body size of smolt these are not currently taken into account when calculating abundance. It is recommended that future work should include a study to estimate daily swimming speed for the entire season on both rivers.

Refinements to the BBSRI smolt sonar over the years have brought improvements to the operation of the program and increased our confidence in the abundance estimates and in the sources of uncertainty. Sonar hardware and software modifications have made operation of the sonar easier to understand and operate, reducing mistakes in the field. Physical changes to the sonar sleds and configuration of arrays have improved spatial coverage and ultimately the utility of smolt abundance estimates. Moving forward, BBSRI will continue to look for ways to improve the efficiency and accuracy of the project with the goal of a sustainable program that will be useful for future generations of stakeholders in Bristol Bay.

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TABLES

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

Winter of	Freeze-up Date[a]	Break-up Date	Ice Cover Days
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	
2011 - 2012		22-May	

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

Table 2. Historical ice cover dates on Lower Ugashik Lake in the Ugashik River drainage.

Winter of	Freeze-up Date[a]	Break-up Date	Ice Cover Days
1981 - 1982		12-May	
1982 - 1983	18-Jan		
1983 - 1984	16-Jan		
1984 - 1985	11-Feb	14-May	92
1985 - 1986	26-Feb	9-May	74
1986 - 1987	12-Mar		
1987 - 1988	9-Dec	24-Mar	106
1988 - 1989	17-Jan	10-May	113
1989 - 1990	21-Feb	25-Apr	63
1990 - 1991	8-Jan		
1991 - 1992	27-Jan	4-May	97
1992 - 1993	20-Jan	31-Mar	70
1993 - 1994	16-Feb	8-Apr	51
1994 - 1995	24-Jan	28-Apr	94
1995 - 1996	8-Jan	15-Apr	97
1996 - 1997	13-Dec	26-Apr	135
1997 - 1998	5-Jan	4-Apr	89
1998 - 1999	22-Jan	19-May	117
1999 - 2000	25-Dec	7-Apr	104
2000 - 2009[b]	-	-	
2009 - 2010		10-May	
2010 - 2011	10-Dec	8-Feb	Lake ice broke 4 times
2011 - 2012	15-Nov	16-May	Ice flowed until 22 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.

Table 3. Range and depth of sonar pod placements on the Kvichak and Ugashik rivers in 2012.

	Kvichak River		Ugashik River	
Transducer	Depth (m)	Range[a] (m)	Depth (m)	Range[a] (m)
Site 1 - T1	1.73	19	1.70	22
Site 1 - T2	2.29	29	2.62	27
Site 1 - T3	2.72	39	3.16	34
Site 1 - T4	3.14	49	2.98	38
Site 1 - T5	3.58	59	2.01	42
Site 1 - T6	3.66	69	NA	NA
Site 1 - T7	3.77	79	NA	NA
Site 1 - T8	3.38	89	NA	NA
Site 2 - T1	2.24	15	1.81	41
Site 2 - T2	2.93	26	2.19	46
Site 2 - T3	3.01	36	2.39	50
Site 2 - T4	2.82	46	2.01	54
Site 2 - T5	2.69	57	NA	NA
Site 2 - T6	2.65	68	NA	NA
Site 2 - T7	2.58	78	NA	NA
Site 2 - T8	2.54	88	NA	NA
Site 2 - T9	2.45	99	NA	NA
Site 2 - T10	2.57	110	NA	NA
Site 2 - T11	3.26	120	NA	NA
Site 2 - T12	3.35	131	NA	NA

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

Table 4. Water velocities (m/s) at the Kvichak and Ugashik rivers sonar sites, 2012.

Kvichak River Site 1

Transducer	25-May	6-Jun	13-Jun
T1	1.05	0.98	1.13
T2	1.27	1.35	1.39
T3	1.46	1.54	1.48
T4	1.59	1.65	1.74
T5	1.57	1.67	1.74
T6	1.57	1.67	1.74
T7	1.63	1.74	1.74
T8	1.55	1.67	1.74

Ugashik River Site 1

Transducer	22-May	30-May	5-Jun	11-Jun
T1	1.10	1.20	1.20	1.33
T2	1.80	1.70	1.73	1.77
T3	2.00	2.10	2.13	2.40
T4	2.20	2.40	2.47	2.40
T5	1.30	2.00	1.97	1.47

Kvichak River Site 2

Transducer	25-May	6-Jun	13-Jun
T1	0.77	0.79	0.86
T2	0.90	1.01	1.09
T3	1.03	1.13	1.14
T4	1.22	1.26	1.33
T5	1.31	1.37	1.46
T6	1.37	1.37	1.42
T7	1.26	1.39	1.48
T8	1.26	1.41	1.46
T9	1.22	1.31	1.46
T10	1.11	1.27	1.41
T11	1.01	1.13	1.29
T12	0.94	1.07	1.14

Ugashik River Site 2

Transducer	22-May	30-May	5-Jun	11-Jun
T1	1.60	1.80	1.73	1.23
T2	1.60	2.10	2.07	2.13
T3	1.90	2.33	2.40	2.3
T4	1.40	1.80	1.73	1.37

Table 5. Daily climate and hydrological observations made at 0800 and 2000 hours near the Kvichak River sonar site, 2012.

	Cloud cover[a]		Precipitation[b]		Wind Dir./Vel. (km/h)		Air temp. °C		Water temp. °C		Water color[c]	
Date	8:00	20:00	8:00	20:00	8:00	20:00	8:00	20:00	8:00	20:00	8:00	20:00
25-May	4	2	A	0	n	n	n	6.0	2.7	3.0	1	1
26-May	4	2	Tr	0	WSW-3	WSW-7	3.0	8.0	3.1	3.4	1	1
27-May	4	2	0	0	WSW-14	WSW-11	1.0	8.0	3.4	3.8	1	1
28-May	2	2	0	0	E-9	E-26	4.0	10.0	3.7	5.3	1	1
29-May	3	3	0	0	E-13	E-10	5.0	9.0	4.6	4.6	1	1
30-May	3	3	0	0	E-3	E-12	6.0	10.0	4.2	4.7	1	1
31-May	3	3	0	0	Calm	SE-10	4.0	12.0	4.7	4.7	1	1
1-Jun	2	2	0	0	Calm	SE-10	6.0	13.0	5.0	5.6	1	1
2-Jun	4	3	0	B	SE-9	Calm	5.0	12.0	5.0	5.4	1	1
3-Jun	2	2	0	0	SW-9	NE-4	2.0	15.0	5.4	5.7	1	1
4-Jun	3	3	0	0	SW-6	NE-6	7.0	14.0	5.5	5.9	1	1
5-Jun	2	1	0	0	Calm	Calm	2.0	13.0	6.5	6.9	1	1
6-Jun	2	3	0	0	W-7	NE-6	3.0	13.0	6.8	6.8	1	1
7-Jun	4	3	B	0	Calm	W-6	7.0	12.0	6.2	6.9	1	1
8-Jun	4	4	0	0	WSW-12	SW-11	6.0	12.0	4.8	4.9	1	1
9-Jun	4	4	0	0	Calm	SW-5	4.0	13.0	4.9	5.3	1	1
10-Jun	3	3	0	0	Calm	NE-8	5.0	14.0	5.1	5.4	1	1
11-Jun	3	3	B	0	SW-9	SW-14	7.0	13.0	4.9	5.2	1	1
12-Jun	4	4	0	A	WSW-16	W-10	4.0	12.0	5.3	5.0	1	1
13-Jun	3	2	0	0	W-10	NE-5	7.0	16.0	5.7	6.0	1	1
14-Jun	5	1	0	0	Calm	E-16	7.0	20.0	6.3	6.5	1	1
15-Jun	1	2	0	0	NE-7	E-8	5.0	13.0	6.3	6.5	1	1

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

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

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

Table 6. Daily climate and hydrological observations made at 0800 and 2000 hours near the Ugashik River sonar site, 2012.

	Cloud cover[a]		Precipitation[b]		Wind Dir./Vel. (km/h)		Air temp. °C		Water temp. °C		Water color[c]	
Date	8:00	20:00	8:00	20:00	8:00	20:00	8:00	20:00	8:00	20:00	8:00	20:00
23-May	4	4	Tr	A	SE 5	SE 5-10	6.9	6.9	3.4	4.4	1	1
24-May	4	4	Tr	Tr	E 5	E 10	3.1	6.4	3.8	4.5	1	1
25-May	4	4	A	B	W 15	W 10	5.2	9.4	4.1	4.8	1	1
26-May	4	4	A	Tr	SW 25-40	SW 25-40	3.4	2.9	4.7	4.8	1	1
27-May	4	4	0	0	SW 20-40	SW 20-40	1.9	4.1	3.3	3.8	1	1
28-May	4	4	0	A	W 10-20	W 15-25	6.0	6.5	3.3	4.0	5	5
29-May	3	3	A	A	NE 10-30	NE 10-30	6.6	10.4	4.1	4.4	5	5
30-May	4	4	A	A	NE 10-30	VAR 5	5.3	8.4	4.0	5.2	5	1
31-May	4	4	A	A	SW 10-20	SW 10-20	5.4	9.0	4.5	5.8	1	1
1-Jun	4	4	B	A	SW 10-15	SW 5-10	2.6	6.2	5.3	5.9	5	5
2-Jun	4	3	D	A	SW 15-30	SW 15-35	1.1	3.3	4.5	4.2	5	1
3-Jun	2	1	n	n	VAR 5	VAR 10	2.0	13.7	3.4	4.7	1	1
4-Jun	2	1	n	0	SE 10-20	SE 10-20	6.1	9.7	4.6	5.5	1	1
5-Jun	1	1	0	0	NE 10-15	NE 10-15	6.6	11.6	5.0	6.1	1	1
6-Jun	1	1	0	Tr	NE 10-15	NE 15-20	6.2	11.9	5.3	6.5	1	2
7-Jun	4	4	A	A	SW 15-20	SW 25-30	4.9	4.1	5.8	5.1	2	2
8-Jun	4	4	D	A	SW 5-10	SW 10-15	1.5	3.3	4.3	4.8	2	2
9-Jun	4	4	Tr	A	SW 5	SW 5-20	2.7	11.4	4.4	5.7	1	1
10-Jun	2	1	0	0	NW 5-15	NE 5-15	1.7	8.4	4.5	5.1	1	1
11-Jun	1	2	0	0	SW 5-10	SW 15-20	2.9	7.9	4.9	6.0	1	1
12-Jun	3	4	A	0	SW 5-20	SW 5-20	2.5	6.7	5.0	5.8	1	2
13-Jun	3	1	Tr	0	N 5-10	N 15-15	4.3	9.6	4.9	n	1	1

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

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

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

Table 7. Daily abundance and proportion of the seasonal abundance of sockeye salmon smolts at Site 1 on the Kvichak River, 2012.

	Site 1				
	Abundance			Proportion of Total	
Smolt Day	Daily	95% CI	Cumulative	Daily	Cumulative
24-May	105,308	60,838	105,308	0.00	0.00
25-May	3,751,124	816,501	3,856,431	0.08	0.08
26-May	5,927,745	2,192,695	9,784,176	0.12	0.20
27-May	12,268,596	3,205,921	22,052,773	0.25	0.45
28-May	4,135,645	964,720	26,188,418	0.08	0.53
29-May	4,998,516	881,960	31,186,934	0.10	0.63
30-May	6,151,723	2,082,674	37,338,657	0.13	0.76
31-May	3,005,090	1,219,932	40,343,747	0.06	0.82
1-Jun	1,388,915	538,167	41,732,662	0.03	0.85
2-Jun	781,013	200,707	42,513,675	0.02	0.86
3-Jun	377,291	84,107	42,890,966	0.01	0.87
4-Jun	382,851	57,992	43,273,817	0.01	0.88
5-Jun	650,895	150,962	43,924,712	0.01	0.89
6-Jun	433,728	173,385	44,358,440	0.01	0.90
7-Jun	363,251	62,901	44,721,692	0.01	0.91
8-Jun	350,094	67,141	45,071,785	0.01	0.92
9-Jun	204,842	38,935	45,276,627	0.00	0.92
10-Jun	335,123	73,669	45,611,750	0.01	0.93
11-Jun	545,729	105,267	46,157,479	0.01	0.94
12-Jun	489,359	79,584	46,646,838	0.01	0.95
13-Jun	121,833	24,722	46,768,671	0.00	0.95
14-Jun	284,637	80,726	47,053,307	0.01	0.96
15-Jun	1,074,500	186,145	48,127,807	0.02	0.98
16-Jun	409,679	123,063	48,537,486	0.01	0.99
17-Jun	391,080	73,674	48,928,566	0.01	0.99
18-Jun	270,264	57,782	49,198,830	0.01	1.00
Total	49,198,830	4,876,702		1.00	

Table 8. Daily abundance and proportion of the seasonal abundance of sockeye salmon smolts at Site 2 on the Kvichak River, 2012.

	Site 2				
	Abundance			Proportion of Total	
Smolt Day	Daily	95% CI	Cumulative	Daily	Cumulative
22-May	2,661,967	1,152,694	2,661,967	0.06	0.06
23-May	191,437	48,846	2,853,403	0.00	0.06
24-May	141,076	36,197	2,994,480	0.00	0.06
25-May	3,686,681	575,671	6,681,160	0.08	0.14
26-May	5,951,055	1,482,534	12,632,215	0.13	0.27
27-May	12,050,563	2,309,981	24,682,778	0.26	0.53
28-May	2,908,647	558,572	27,591,425	0.06	0.59
29-May	5,797,007	806,050	33,388,432	0.12	0.71
30-May	4,110,241	638,155	37,498,673	0.09	0.80
31-May	2,364,604	527,784	39,863,277	0.05	0.85
1-Jun	1,289,810	280,605	41,153,087	0.03	0.88
2-Jun	537,752	145,101	41,690,839	0.01	0.89
3-Jun	129,009	19,889	41,819,848	0.00	0.89
4-Jun	276,054	29,375	42,095,902	0.01	0.90
5-Jun	483,167	117,547	42,579,070	0.01	0.91
6-Jun	476,712	99,727	43,055,782	0.01	0.92
7-Jun	268,187	49,521	43,323,970	0.01	0.92
8-Jun	196,419	26,063	43,520,388	0.00	0.93
9-Jun	179,017	26,647	43,699,405	0.00	0.93
10-Jun	402,874	55,281	44,102,279	0.01	0.94
11-Jun	406,742	100,393	44,509,021	0.01	0.95
12-Jun	287,547	49,140	44,796,567	0.01	0.95
13-Jun	199,164	34,169	44,995,731	0.00	0.96
14-Jun	352,320	55,629	45,348,051	0.01	0.96
15-Jun	971,592	102,825	46,319,643	0.02	0.99
16-Jun	554,209	80,892	46,873,852	0.01	1.00
17-Jun	137,784	24,018	47,011,636	0.00	1.00
18-Jun					
Total	47,011,636	3,318,343		1.00	

Table 9. Total catch of sockeye salmon smolt on the Kvichak River, 2012.

Smolt Date	Fishing Time (min)	Total Catch	*n*	CPUE [b]	% Age-1
19-May	121	197	197	1.63	1.6%
20-May	34	940	600	27.65	0.7%
21-May [c]	-		-	-	
22-May [d]	-		-	-	
23-May	121	116	116	0.96	34.9%
24-May	20	1,000	600	50.00	24.7%
25-May [d]	-		-	-	
26-May	12	2,490	600	207.50	45.9%
27-May	10	2,880	600	288.00	60.3%
28-May	81	960	600	11.85	57.8%
29-May	23	1,490	600	64.78	83.3%
30-May	6	2,490	600	415.00	90.7%
31-May	6	2,290	600	381.67	94.4%
1-Jun	7	1,575	600	225.00	97.0%
2-Jun	54	1,150	600	21.30	95.9%
3-Jun	51	855	600	16.76	94.2%
4-Jun	40	900	604	22.50	81.2%
5-Jun	10	960	600	96.00	96.4%
6-Jun	54	995	601	18.43	95.4%
7-Jun	52	1040	600	20.00	88.8%
8-Jun	47	1000	600	21.28	90.5%
9-Jun	27	1050	600	38.89	95.5%
10-Jun	26	950	600	36.54	90.8%
11-Jun	48	850	600	17.71	91.9%
12-Jun	35	725	600	20.71	94.8%
13-Jun	122	230	200	1.89	73.3%
14-Jun	84	820	600	9.76	95.7%
Total	529	27,953	8,521		
Minimum	6	116	116	0.96	0.7%
Average	35	1,165	568	87.57	76.1%
Maximum	121	2,880	604	415.00	97.0%

[a] Arrived 17-May with approximately 1/2 of Illiamna Lake still covered in ice. Able to set trap and fish morning of 19-May. Site 2 sonar deployed between ice flows on 22-May.

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

[c] No Fishing. Setting up and deploying sonar gear.

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

Table 10. Mean fork length and estimated mean weight for age-1 and age-2 sockeye salmon smolt on the Kvichak River, 2012.

	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
19-May	88	1.7	5.8	3	117	6.8	13.8	90
20-May	84	2.6	5.2	4	118	5.2	14.0	478
21-May [b]								
22-May [c]								
23-May	88	3.2	5.9	59	115	5.7	13.0	50
24-May	88	3.4	5.8	177	111	6.5	11.8	444
25-May [c]								
26-May	85	3.4	5.3	315	106	6.2	10.6	322
27-May	84	3.7	5.3	251	108	6.7	11.1	178
28-May	84	3.6	5.2	403	110	7.1	11.5	245
29-May	83	3.5	5.1	450	106	6.7	10.5	96
30-May	82	3.6	4.9	475	103	5.1	9.8	49
31-May	82	3.4	4.9	467	106	7.8	10.5	24
1-Jun	82	3.2	4.9	481	105	7.4	10.2	15
2-Jun	83	3.6	5.1	472	102	4.9	9.5	17
3-Jun	83	3.9	5.0	392	105	6.9	10.3	28
4-Jun	83	3.2	5.0	481	108	7.0	11.0	111
5-Jun	82	3.3	5.0	465	104	7.3	9.9	18
6-Jun	83	3.4	5.0	463	105	5.4	10.2	22
7-Jun	84	3.2	5.1	457	106	7.3	10.4	58
8-Jun	82	3.7	4.9	460	104	5.8	9.9	41
9-Jun	83	3.1	5.0	454	108	7.4	11.1	19
10-Jun	82	3.2	5.0	453	105	8.0	10.3	48
11-Jun	82	2.8	4.9	496	107	7.6	10.8	47
12-Jun	83	3.4	5.1	85	110	5.5	11.6	9
13-Jun	76		4.1	1	103	6.9	9.8	15
14-Jun	83	2.9	5.1	476	104	7.4	10.1	24
Total				8,240				2,448
Mean	83		5.1		110		11.7	

[a] Length-weight parameters by age group and discriminating length used to separate ages

Age-1 a = 9.2E-05 b = 2.468038 r^2 = 0.707 n = 1689

Age-2 a = 3.6E-05 b = 2.69324 r^2 = 0.895 n = 677 Discriminating length = 94.0 mm

[b] No Fishing. Setting up and deploying sonar gear.

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

Table 11. Age composition of total migration and mean fork length and weight by age class for sockeye salmon smolt on the Kvichak River, 2000 – 2012.

	Age-1				Age-2				
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)	Total[a] Estimate
2000	1998	82	86	5.8	1997	18	103	9.5	130,038,649
2001	1999	71	78	4.2	1998	29	102	8.5	325,914,951
2002 [b]	2000	65	80	4.5	1999	35	94	7.2	N/A
2003	2001	64	83	5.2	2000	36	109	9.0	N/A
2004	2002	69	90	6.2	2001	31	106	10.1	N/A
2005	2003	100	88	5.9	2002	<1	112	11	N/A
2006	2004	100	81	4.3	2003	<1	110	8.8	N/A
2007	2005	75	81	4.5	2004	25	99	7.9	N/A
2008 [b]	2006	74	82	4.7	2005	26	99	7.7	30,786,980
2009 [b]	2007	79	84	5.5	2006	21	107	10.4	35,247,209
2010 [b]	2008	61	84	4.9	2007	39	104	9.3	57,372,620
2011 [b]	2009	69	86	5.6	2008	31	108	11.0	41,730,658
2012	2010	76	84	5.2	2009	24	108	11.0	49,198,830
Mean 2000-2012		76	84	5.1		29	105	9.3	

[a] Estimates from 2000 and 2001 from ADF&G sonar, 2008 - 2012 BBSRI sonar

[b] Ice flows interupted sampling regularly in the early portion of the season

Table 12. Daily abundance and proportion of the seasonal abundance of sockeye salmon smolts at sites 1 and 2 on the Ugashik River, 2012.

	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
22-May	63,363	54,810	63,363	0.01	0.01	35,496	43,227	35,496	0.00	0.00
23-May	330,213	125,037	393,577	0.03	0.04	72,715	26,434	108,211	0.01	0.01
24-May	159,723	85,382	553,299	0.01	0.05	152,047	56,592	260,258	0.01	0.02
25-May	733,095	511,499	1,286,395	0.07	0.11	323,404	76,500	583,662	0.03	0.05
26-May	598,892	160,446	1,885,287	0.05	0.17	192,693	39,993	776,355	0.02	0.07
27-May	338,491	109,390	2,223,777	0.03	0.20	175,370	42,111	951,725	0.02	0.09
28-May	179,049	47,670	2,402,826	0.02	0.21	513,229	114,747	1,464,954	0.05	0.13
29-May	849,638	375,461	3,252,464	0.08	0.29	713,591	175,482	2,178,545	0.06	0.20
30-May	439,681	224,493	3,692,145	0.04	0.33	786,726	330,491	2,965,271	0.07	0.27
31-May	1,331,034	912,553	5,023,179	0.12	0.45	841,605	188,440	3,806,876	0.08	0.34
1-Jun	639,447	160,378	5,662,626	0.06	0.51	524,908	165,022	4,331,784	0.05	0.39
2-Jun	1,100,550	225,299	6,763,176	0.10	0.60	348,745	108,184	4,680,529	0.03	0.42
3-Jun	361,752	107,796	7,124,927	0.03	0.64	268,497	72,415	4,949,026	0.02	0.45
4-Jun	371,133	68,911	7,496,061	0.03	0.67	688,649	62,569	5,637,676	0.06	0.51
5-Jun	336,106	80,281	7,832,167	0.03	0.70	1,651,954	564,727	7,289,629	0.15	0.66
6-Jun	357,320	98,103	8,189,487	0.03	0.73	537,256	316,492	7,826,885	0.05	0.71
7-Jun	1,063,181	232,446	9,252,668	0.09	0.83	1,162,355	410,898	8,989,241	0.11	0.81
8-Jun	488,815	126,388	9,741,483	0.04	0.87	530,764	155,760	9,520,004	0.05	0.86
9-Jun	144,129	47,013	9,885,611	0.01	0.88	261,808	49,757	9,781,812	0.02	0.88
10-Jun	335,000	108,277	10,220,611	0.03	0.91	448,031	97,055	10,229,843	0.04	0.92
11-Jun	314,625	84,670	10,535,236	0.03	0.94	463,095	149,508	10,692,938	0.04	0.97
12-Jun	658,683	194,689	11,193,920	0.06	1.00	371,537	240,624	11,064,475	0.03	1.00
Total	11,193,920	1,260,791		1.00		11,064,475	977,811		1.00	

Table 13. Comparison of annual smolt abundance estimates from each sonar systems on the Kvichak River, 2008 – 2012.

Year	Site 1	Site 2	Difference
2008	30,786,980	26,965,627	13.1%
2009	35,247,209	38,755,938	9.7%
2010[a]	15,805,698	15,891,807	0.6%
2011	48,806,237	41,730,658	15.7%
2012	49,198,830	47,011,636	4.6%

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

Table 14. Smolt run timing and average temperature during outmigration at Site 1 on the Kvichak River for 2008 – 2012.

Year	Median Migration Date	Average Temp. (°C)
2008	1-Jun	6.3
2009	28-May	6.0
2010	27-May	4.7
2011	28-May	4.5
2012	27-May	5.1

FIGURES

Figure 1. The Kvichak and Ugashik rivers with the other seven main rivers that produce sockeye salmon targeted in the Bristol Bay commercial, sport and subsistence fisheries.

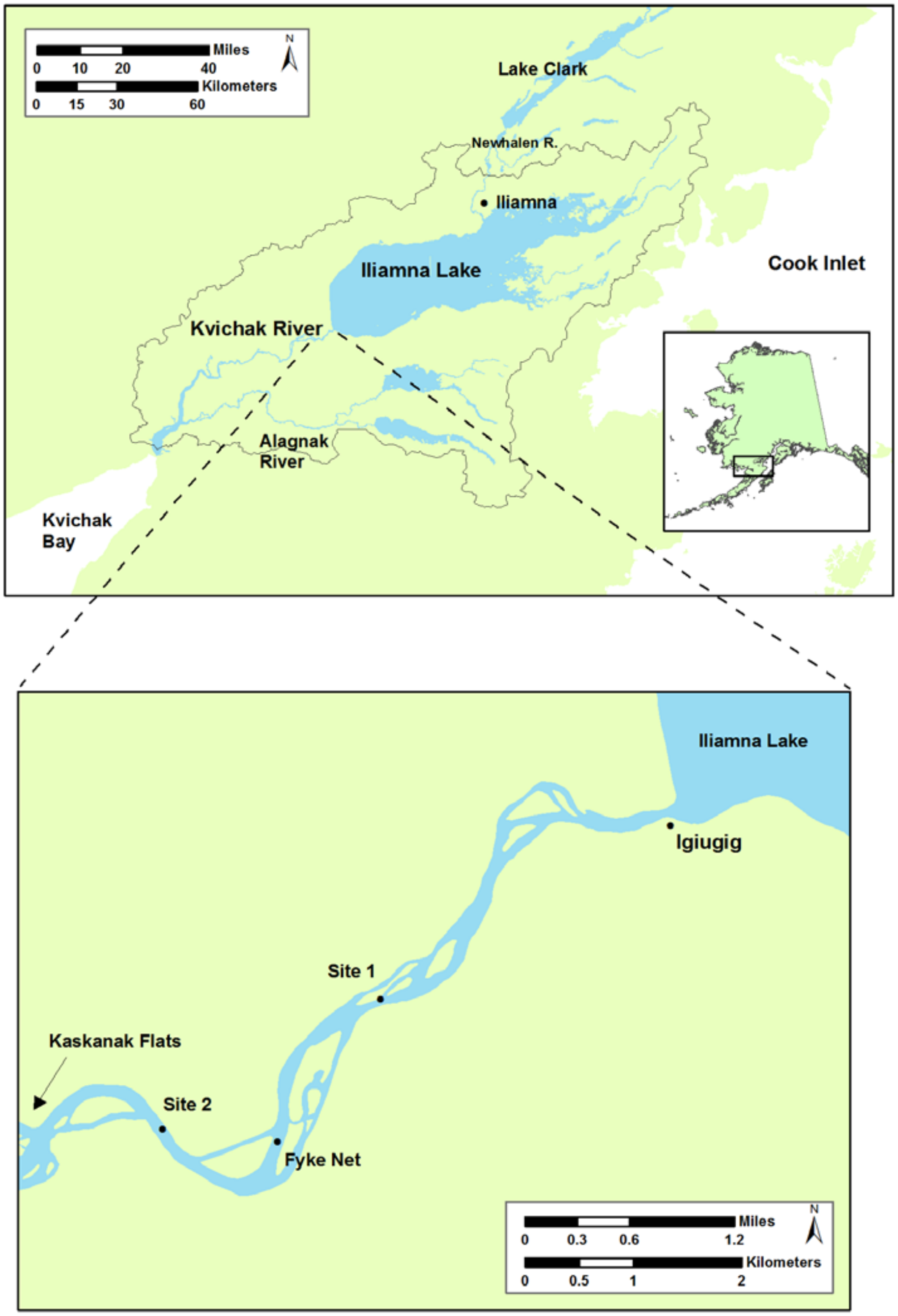

Figure 2. Map of Kvichak River and Lake Clark drainages in Southwestern Alaska, showing locations of sonar sites 1 and 2 operated near the village of Igiugig, 2012.

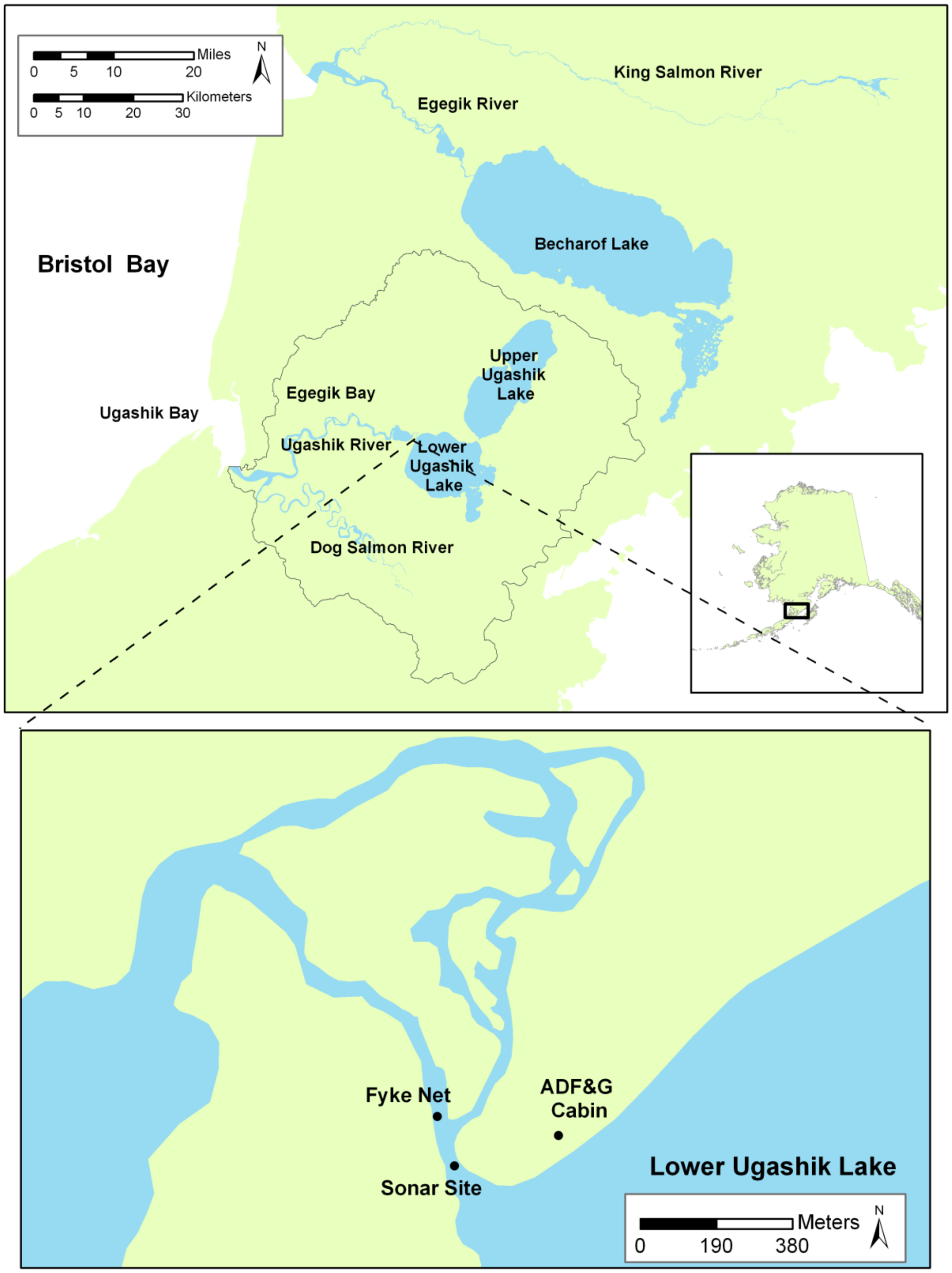

Figure 3. Map of Ugashik River watershed, showing locations of sonar systems and fyke net operated near the outlet of Lower Ugashik Lake, 2012.

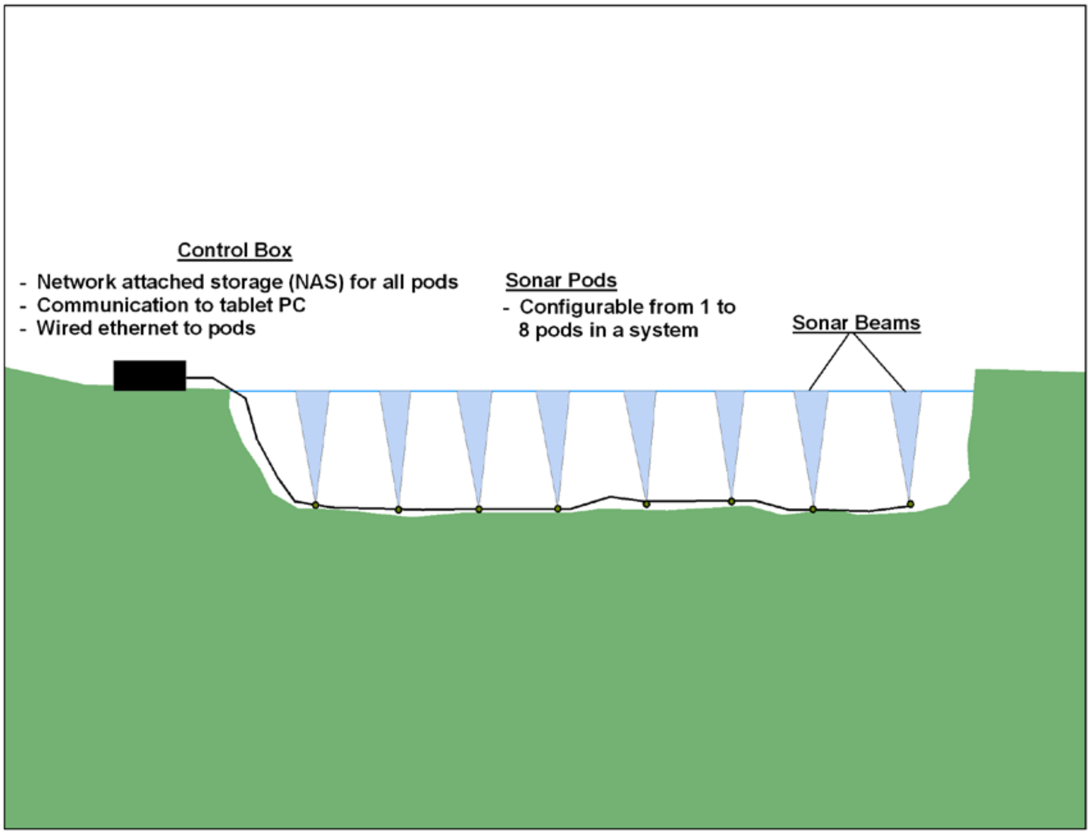

Figure 4. Conceptual drawing of the smolt sonar system used in Kvichak and Ugashik rivers in the Bristol Bay region, 2012.

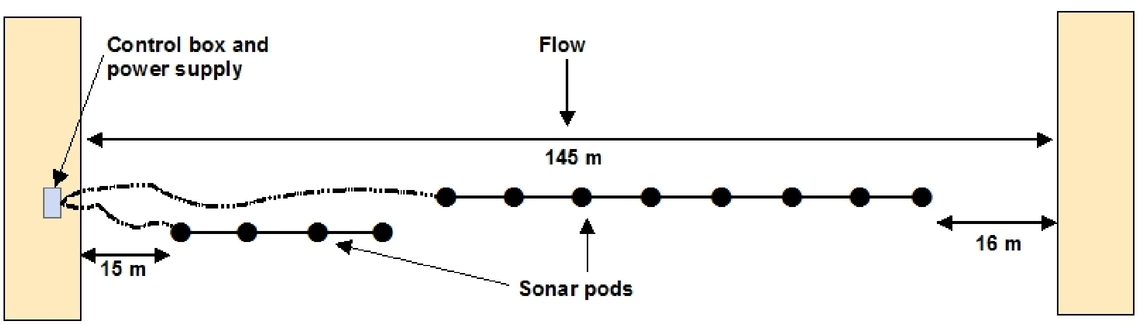

Figure 5. Schematic of Site 2 sonar array configuration on the Kvichak River, 2012.

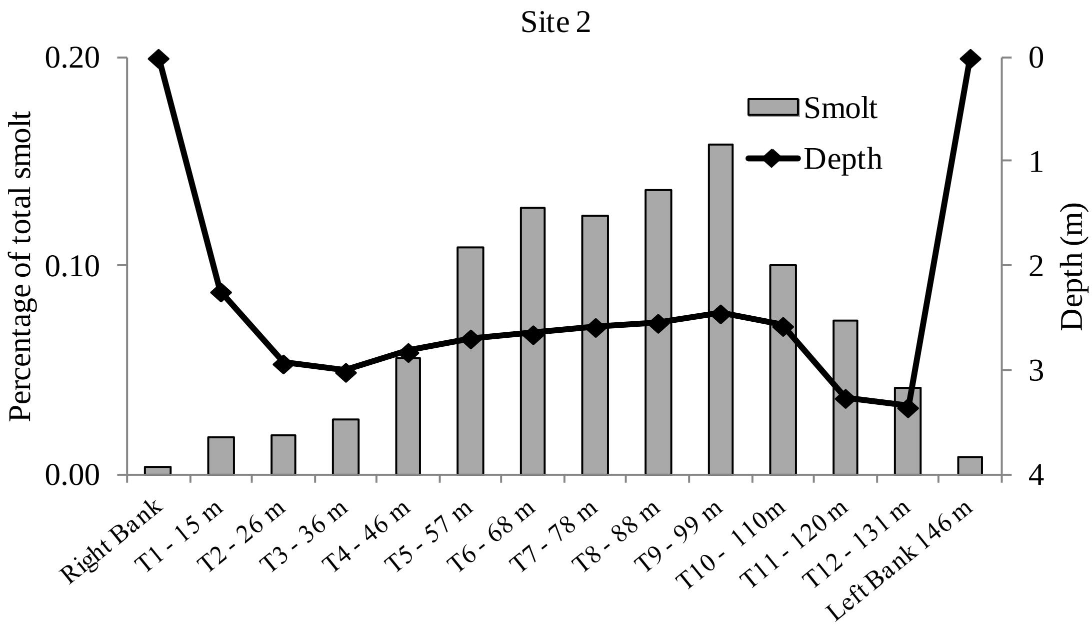

Figure 6. Water depth and percent distribution of sockeye salmon smolts at Site 2 sonar pods on the Kvichak River in 2012, showing pod distances (m) from right bank.

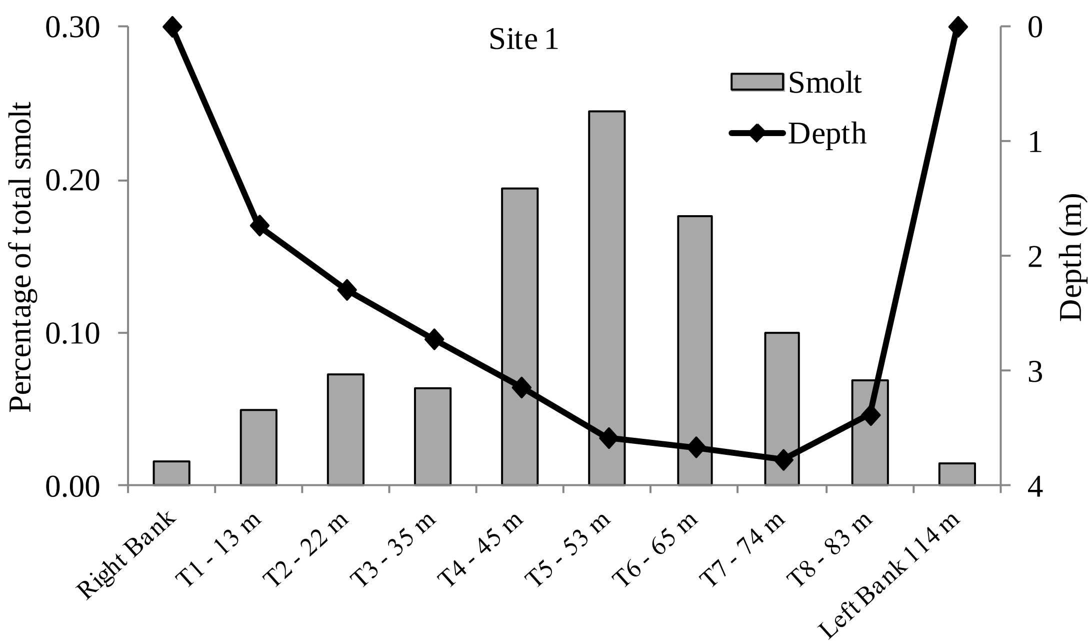

Figure 7. Water depth and percent distribution of sockeye salmon smolts at Site 1 sonar pods on the Kvichak River in 2012, showing pod distances (m) from right bank.

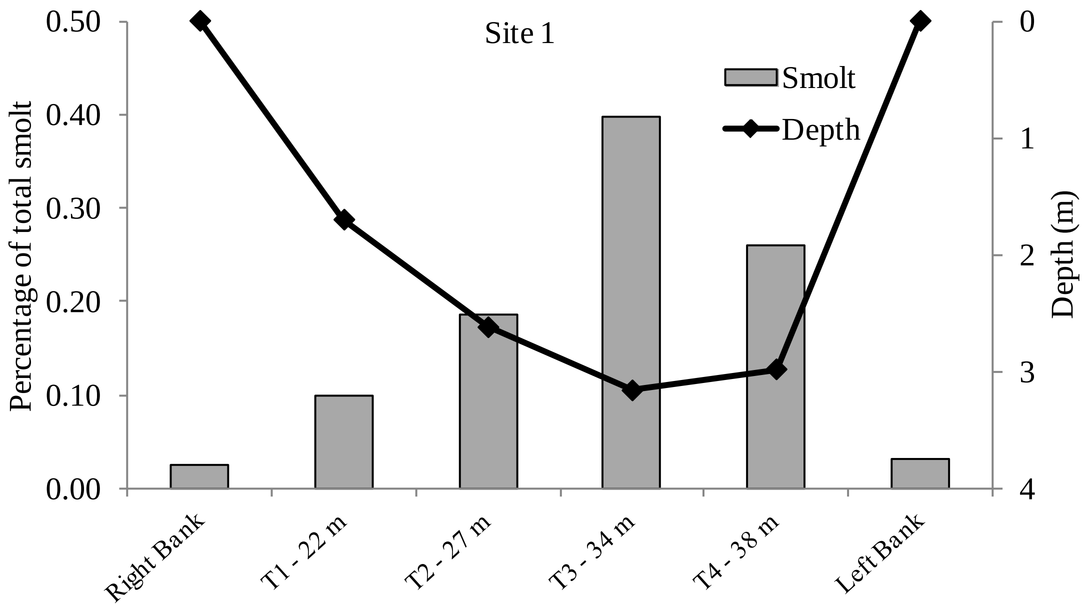

Figure 8. Water depth and percent distribution of sockeye salmon smolts at Site 1 sonar pods on the Ugashik River in 2012, showing pod distances (m) from right bank.

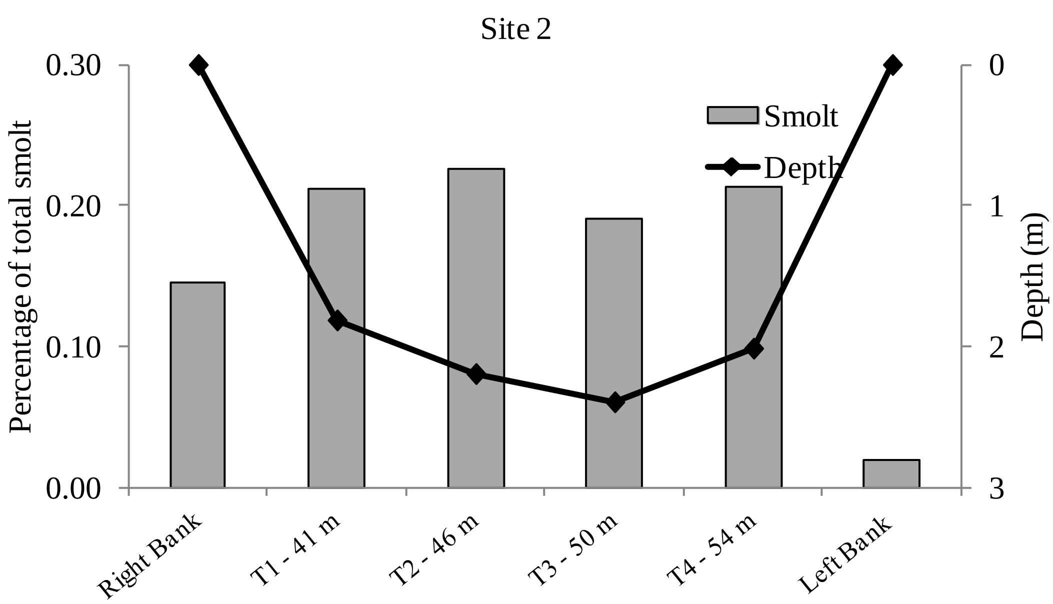

Figure 9. Water depth and percent distribution of sockeye salmon smolts at Site 2 sonar pods on the Ugashik River in 2012, showing pod distances (m) from right bank.

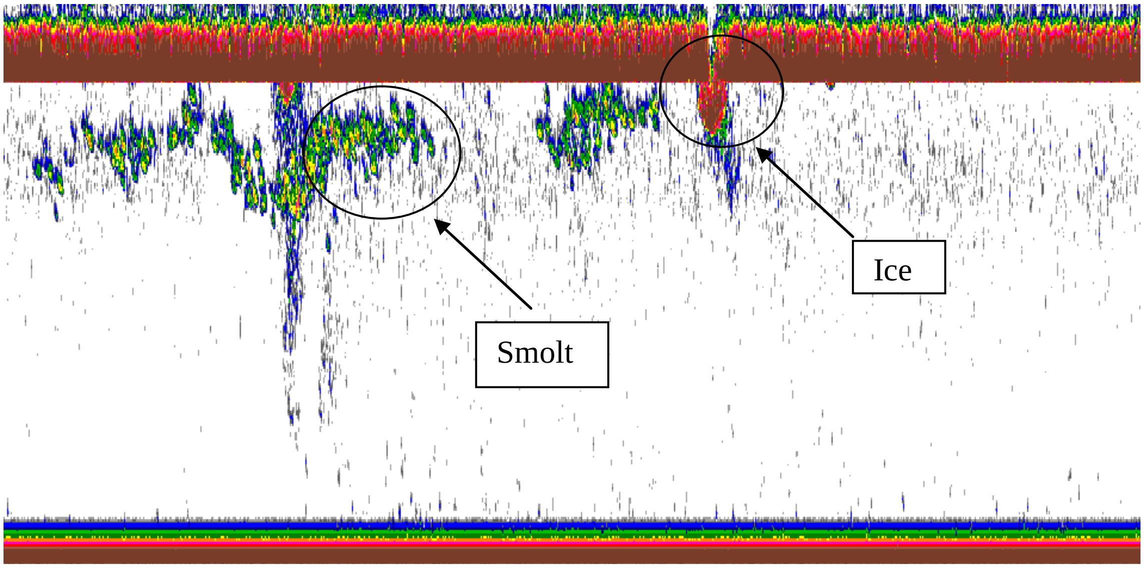

Figure 10. Approximately 1.5 minutes of an echogram showing smolt and ice from an up-looking sonar pod on the Kvichak River during moderate ice flows in 2011.

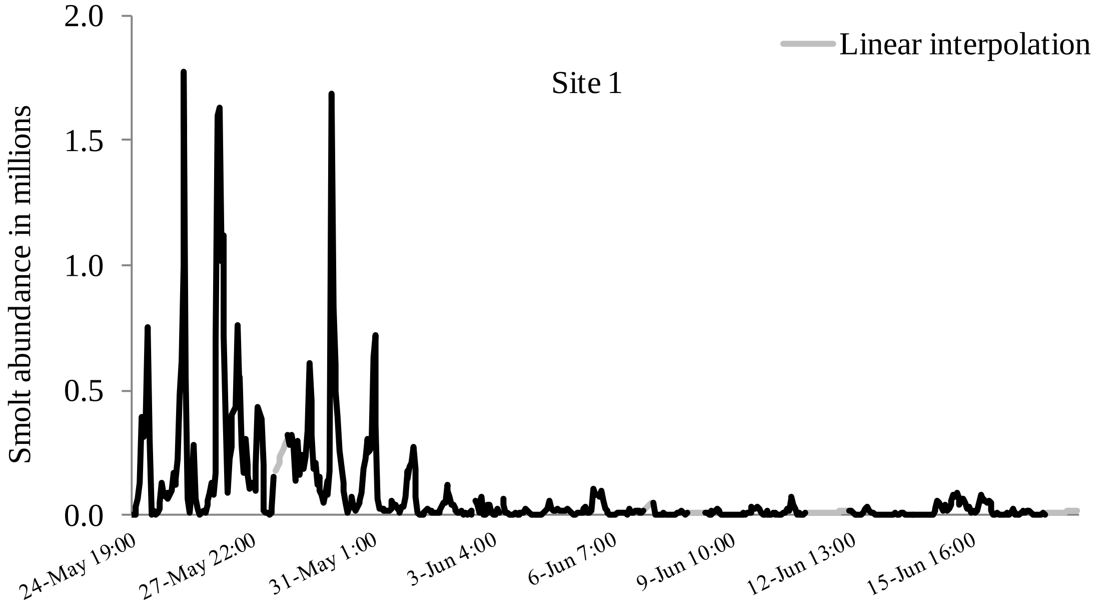

Figure 11. Smolt estimates at Site 1 on the Kvichak River showing periods when abundance was estimated via linear interpolation, 2012.

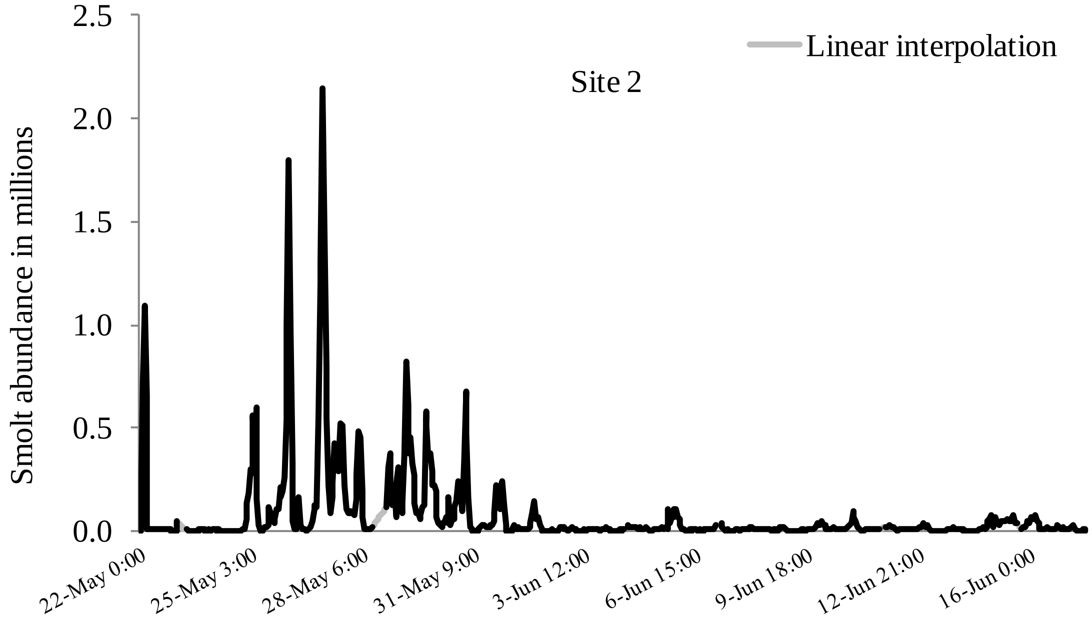

Figure 12. Smolt estimates at Site 2 on the Kvichak River showing periods when abundance was estimated via linear interpolation, 2012.

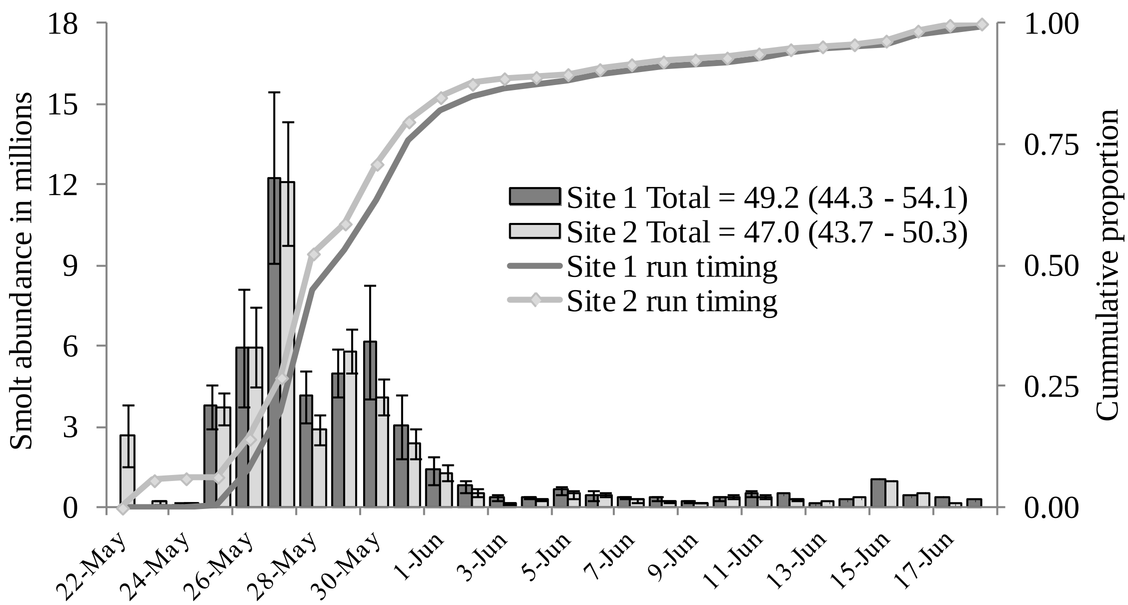

Figure 13. Estimated daily and annual abundance of smolts and run timing at sites 1 and 2 on the Kvichak River, 2012. Bars are mean daily estimates; whiskers are 95% confidence intervals.

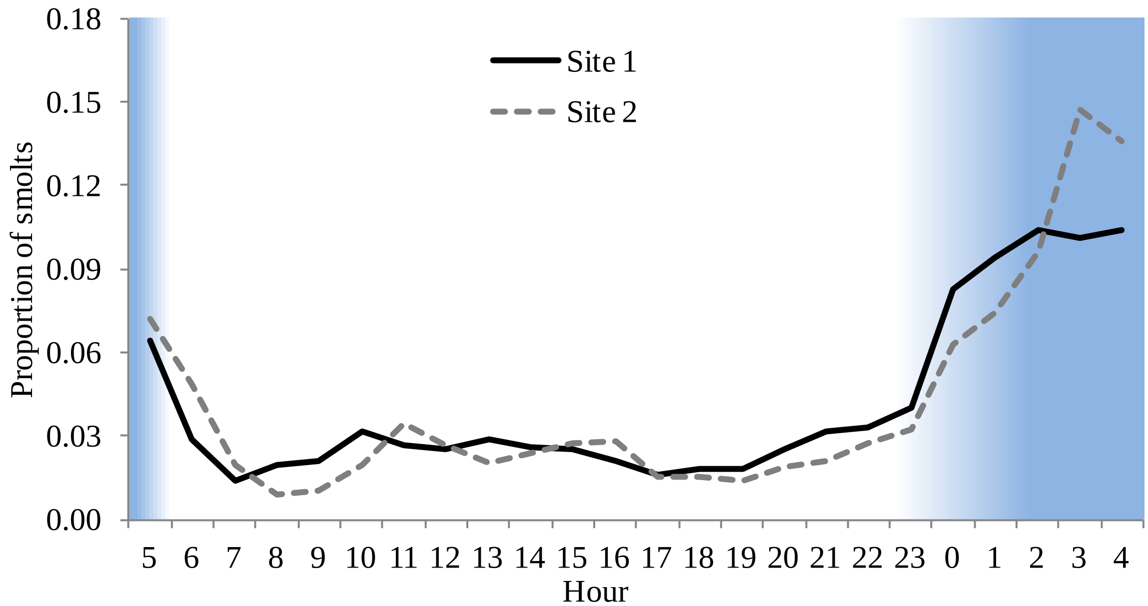

Figure 14. Proportion of total smolts by hour of the day at sonar sites 1 and 2 on the Kvichak River, 2012. Shading shows hours considered nighttime (2300 – 0500) during the study period (22 May to 18 June).

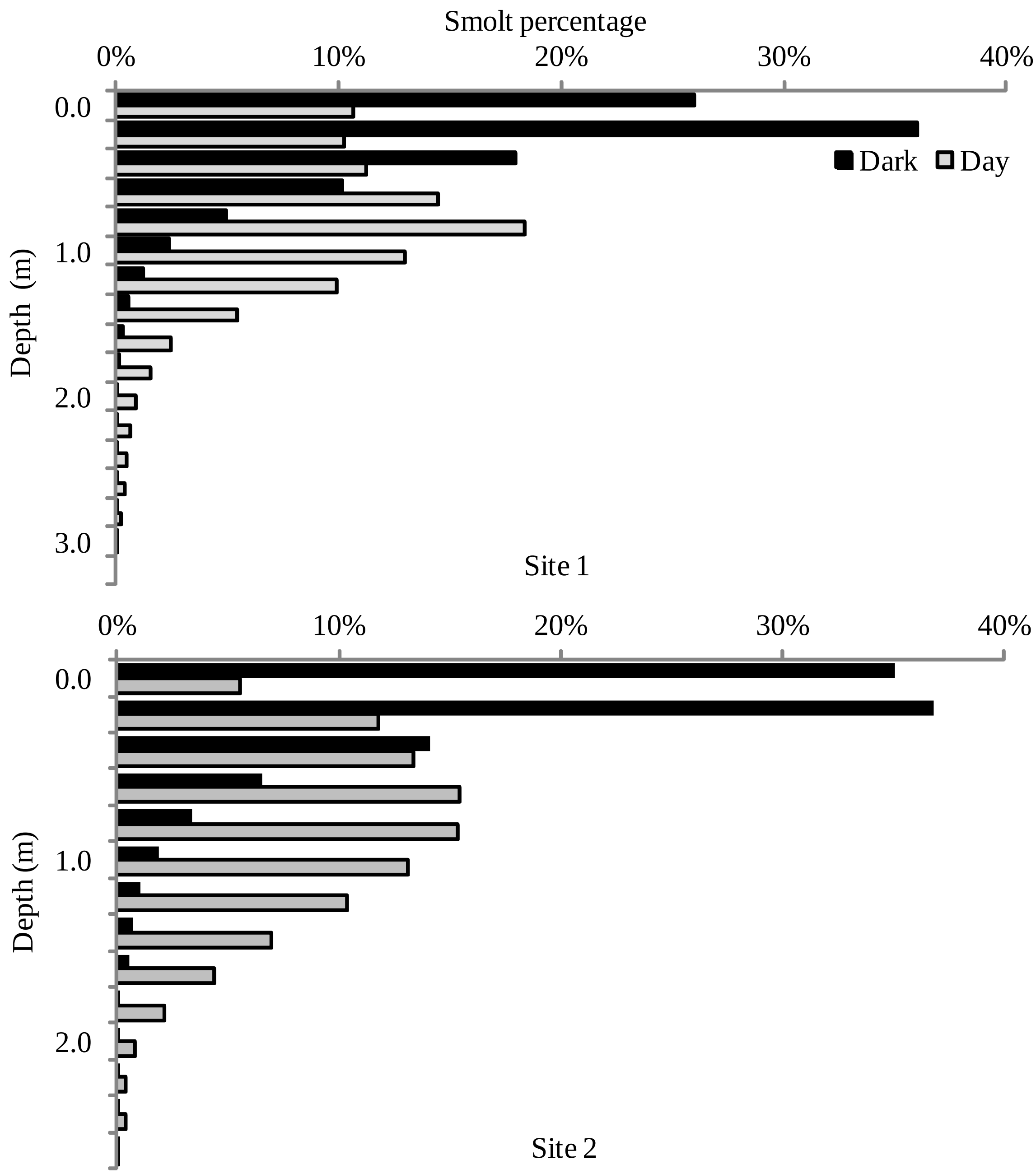

Figure 15. Vertical distribution of sockeye salmon smolts migrating in darkness (2300 – 0500 hrs) and light at sites 1 and 2 on the Kvichak River in 2012. Difference in vertical axes between sites reflects shallower depths at Site 2.

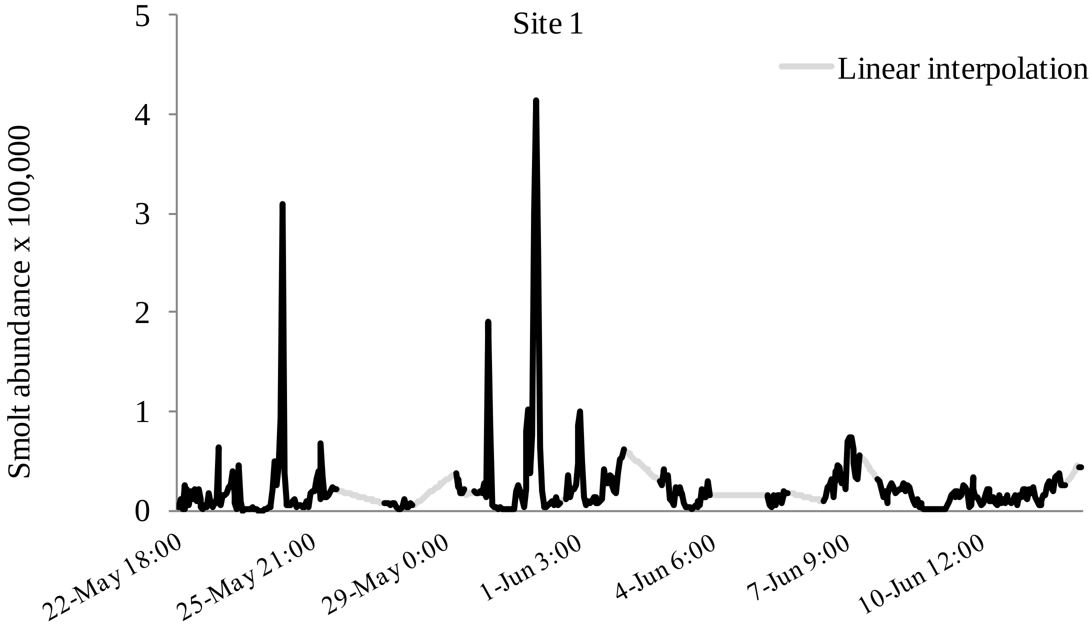

Figure 16. Smolt estimates at Site 1 on the Ugashik River showing periods when abundance was estimated via linear interpolation, 2012.

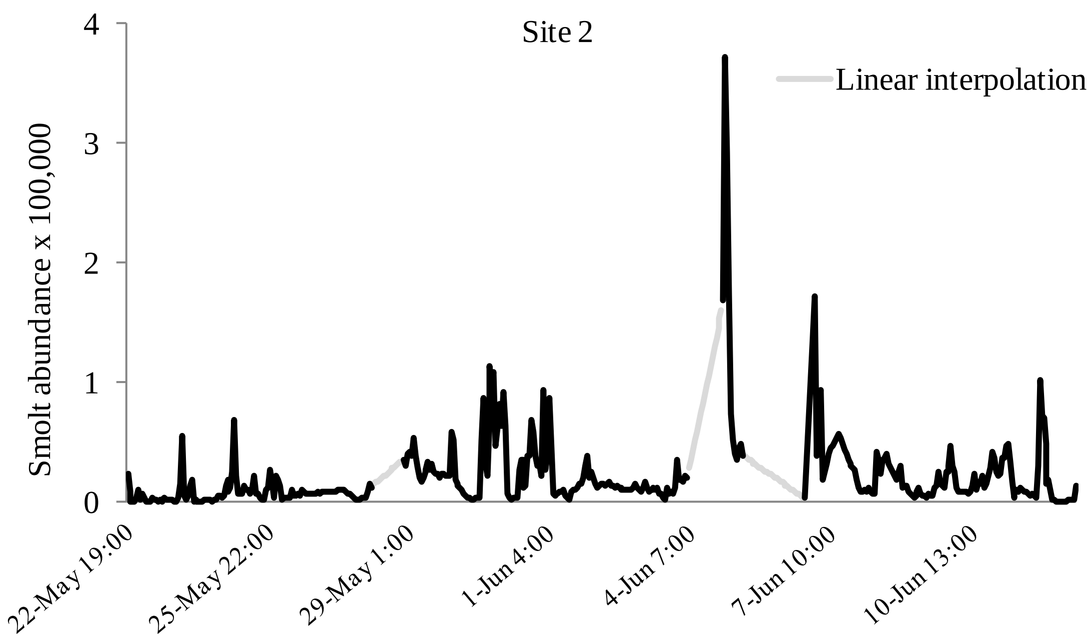

Figure 17. Smolt estimates at Site 2 on the Ugashik River showing periods when abundance was estimated via linear interpolation, 2012.

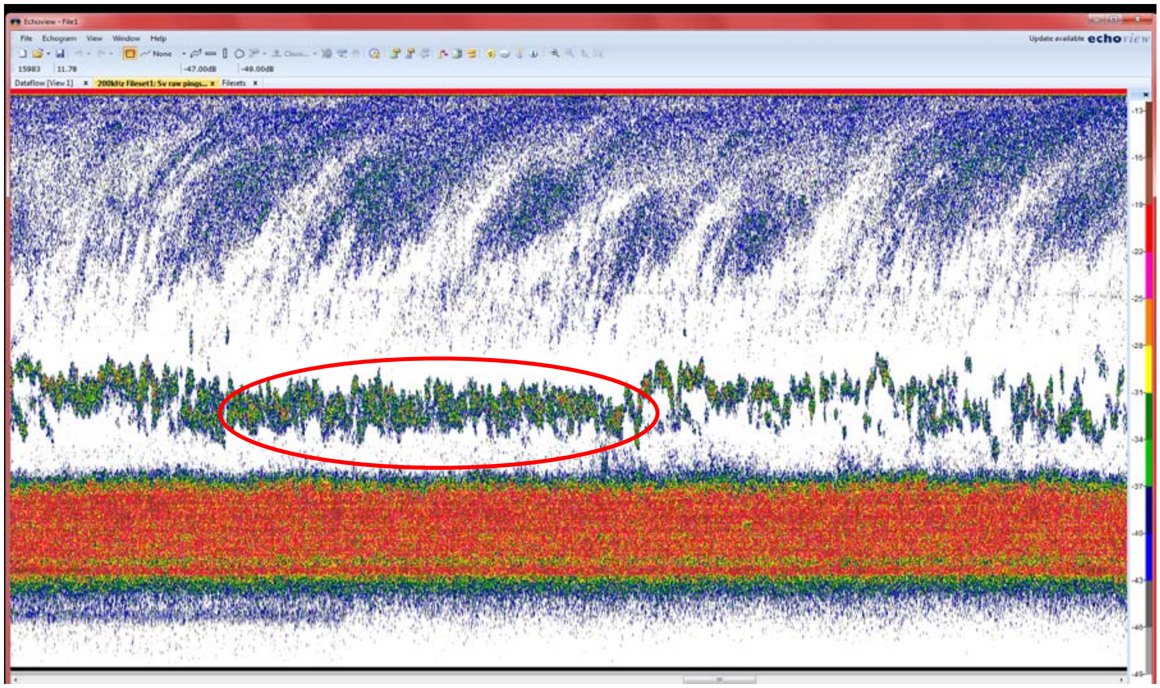

Figure 18. Screen shot of side-looking sonar echogram showing smolts (in red oval) approximately 30 – 40 m off the right bank on 5 June at 0140 hours, 2012.

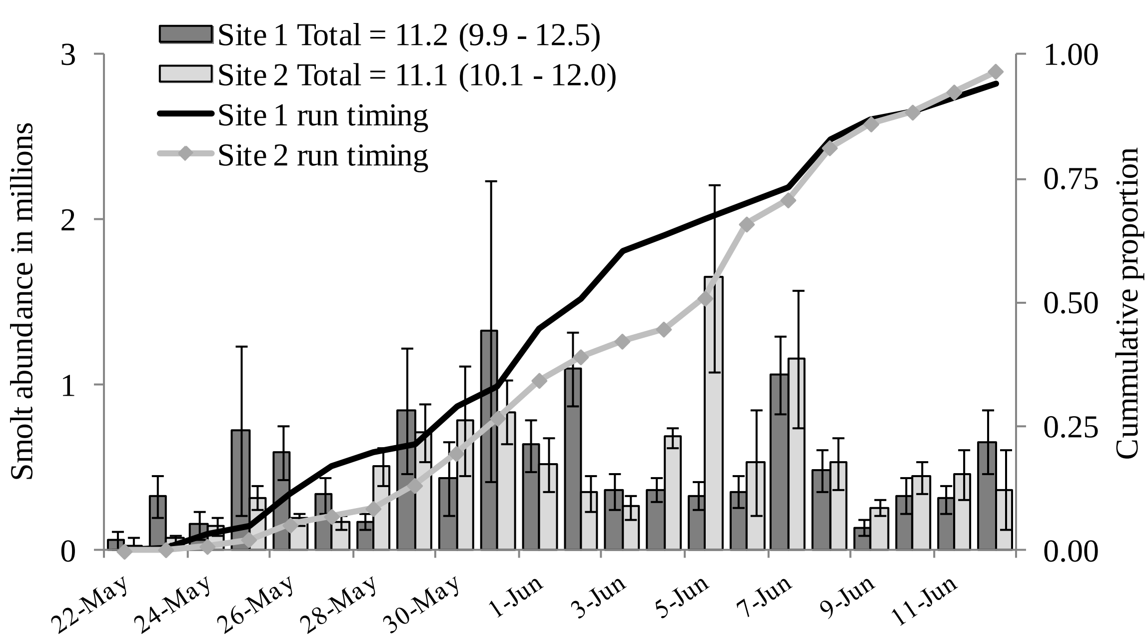

Figure 19. Estimated daily and annual abundance of smolts and run timing at sites 1 and 2 on the Ugashik River, 2012. Bars are mean daily estimates; whiskers are 95% confidence intervals.

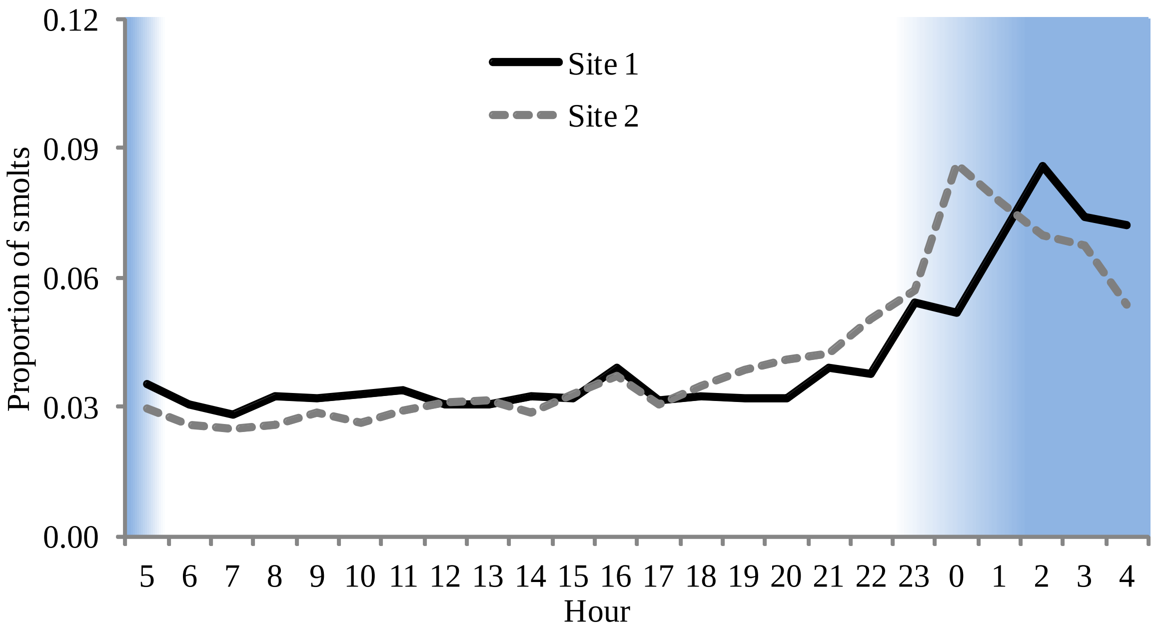

Figure 20. Proportion of total smolts by hour of the day at sonar sites 1 and 2 on the Ugashik River, 2012. Shading shows hours considered nighttime (2300 – 0500) during the study period (22 May to 13 June).

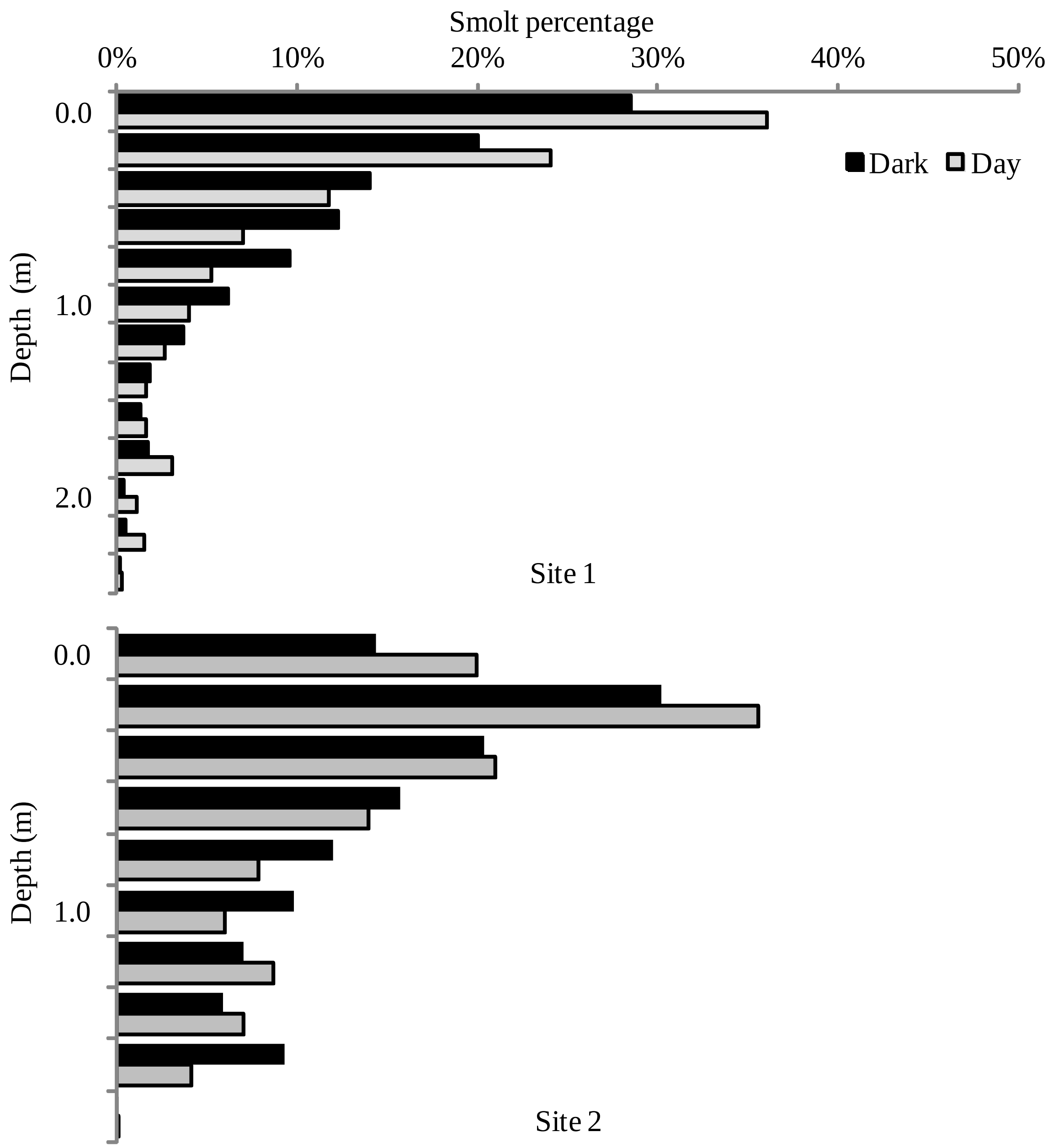

Figure 21. Vertical distribution of sockeye salmon smolts migrating in darkness (2300 – 0500 hrs) and light at sites 1 and 2 on the Ugashik River in 2012. Difference in vertical axes between sites reflects shallower depths at Site 2.

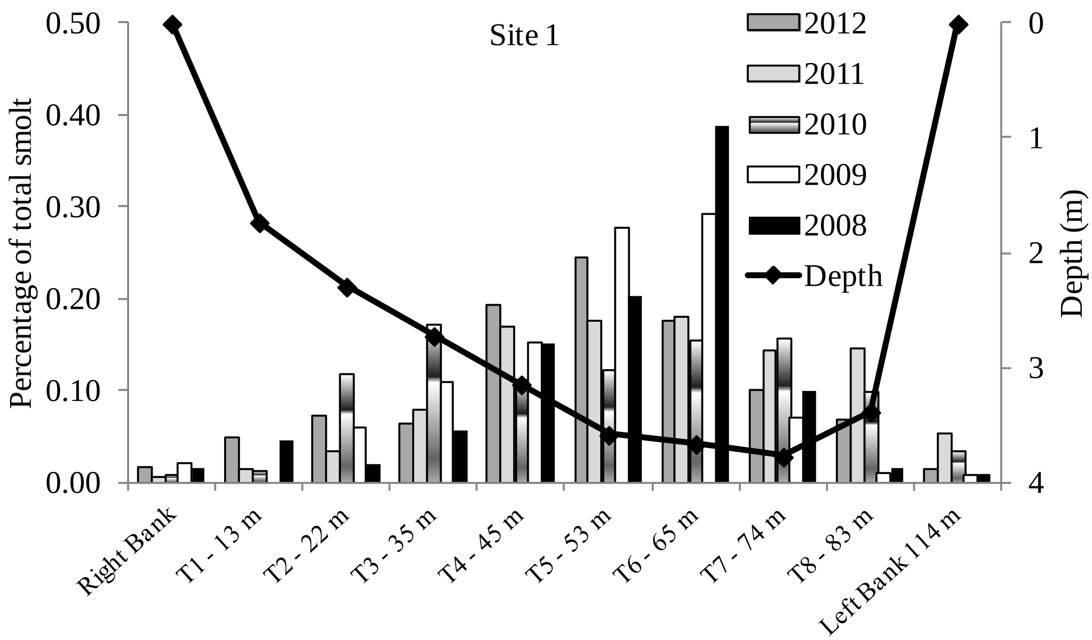

Figure 22. Cross-river distribution of smolts at Site 1 on the Kvichak River for the year 2008 – 2012.

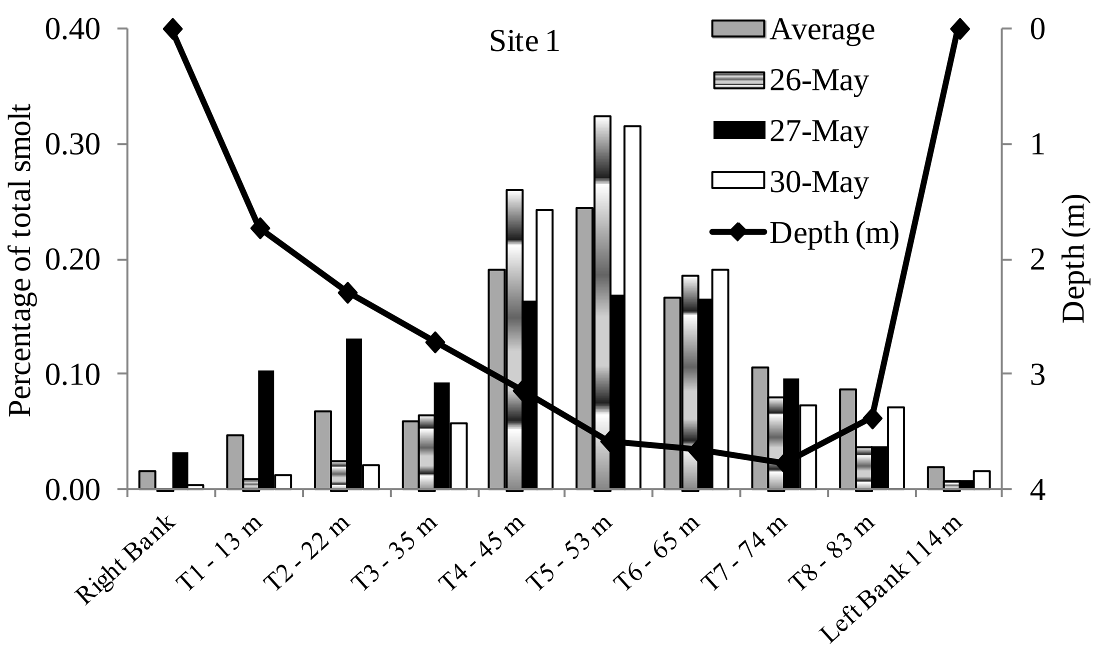

Figure 23. Cross-river distribution during periods (26, 27, and 30 May) of high abundance with the seasonal average as reference at Site 1 on the Kvichak River, 2012.

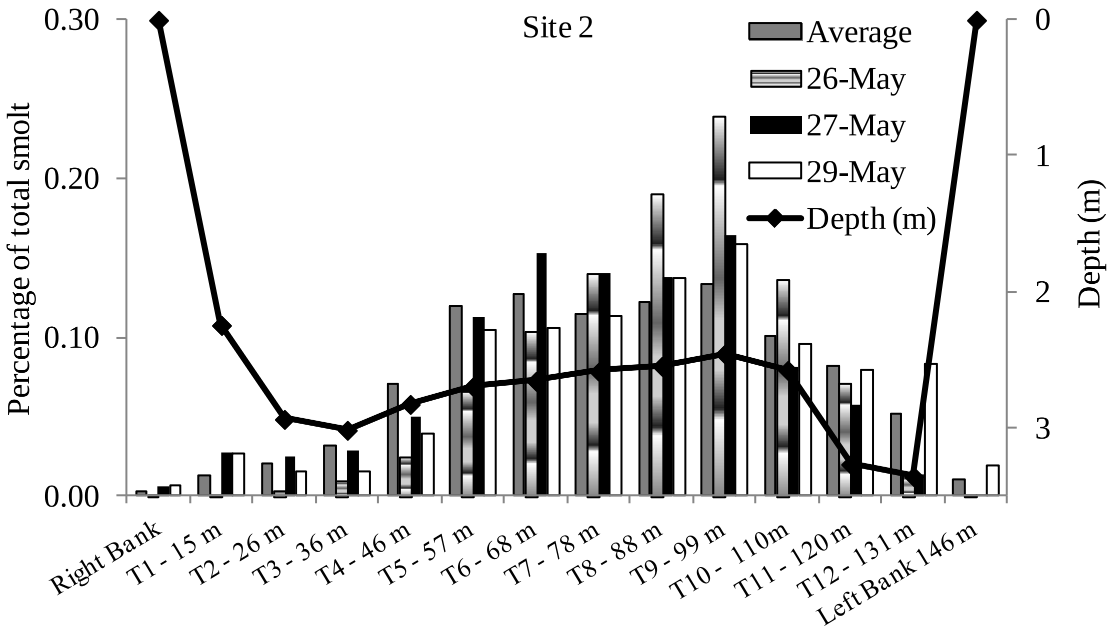

Figure 24. Cross-river distribution during periods (26, 27, and 29 May) of high abundance with the seasonal average as reference at Site 2 on the Kvichak River, 2012.

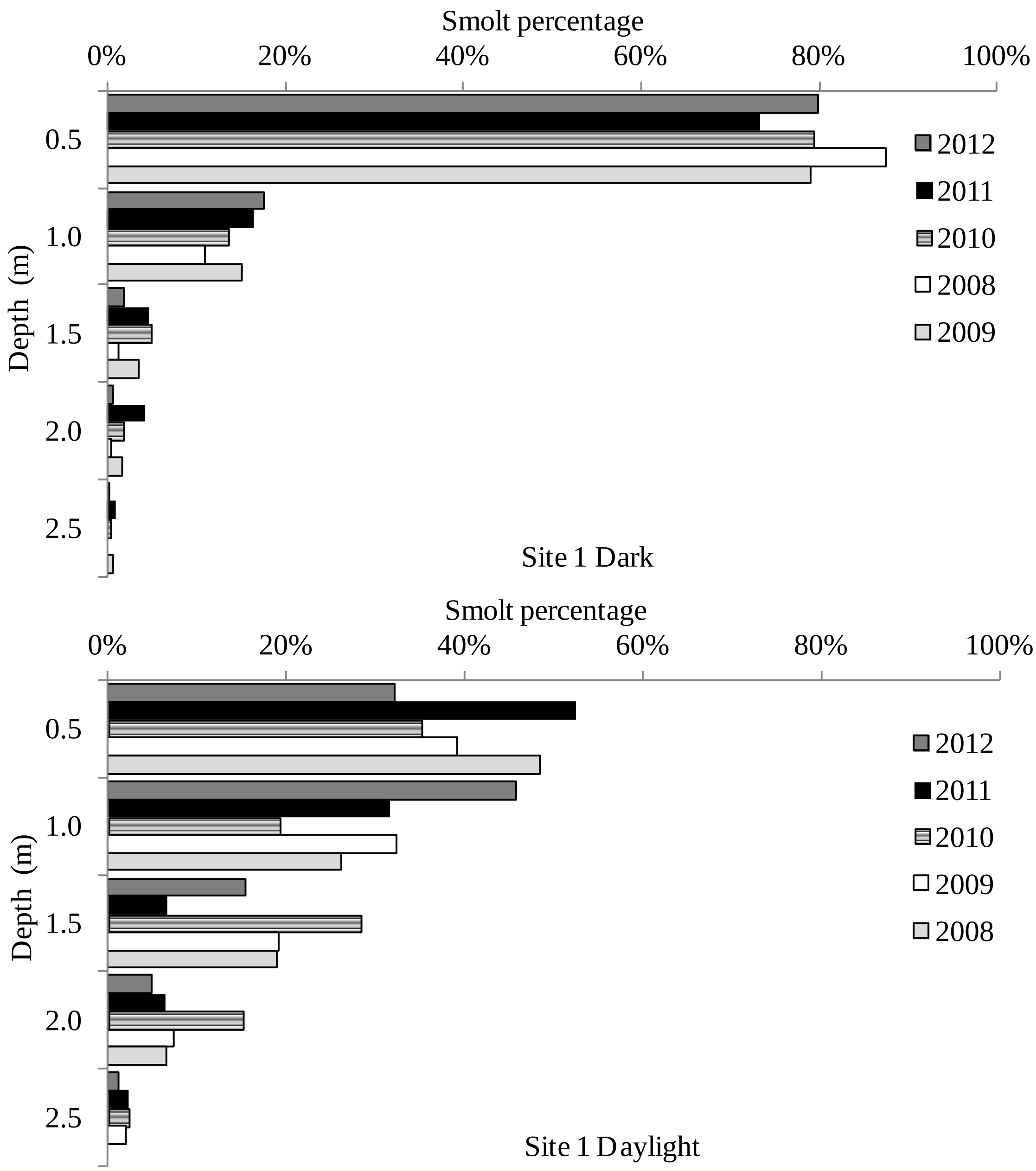

Figure 25. Vertical distribution of sockeye salmon smolts migrating in darkness (2300 – 0500 hrs) and light at Site 2 on the Kvichak River in 2008 – 2012.

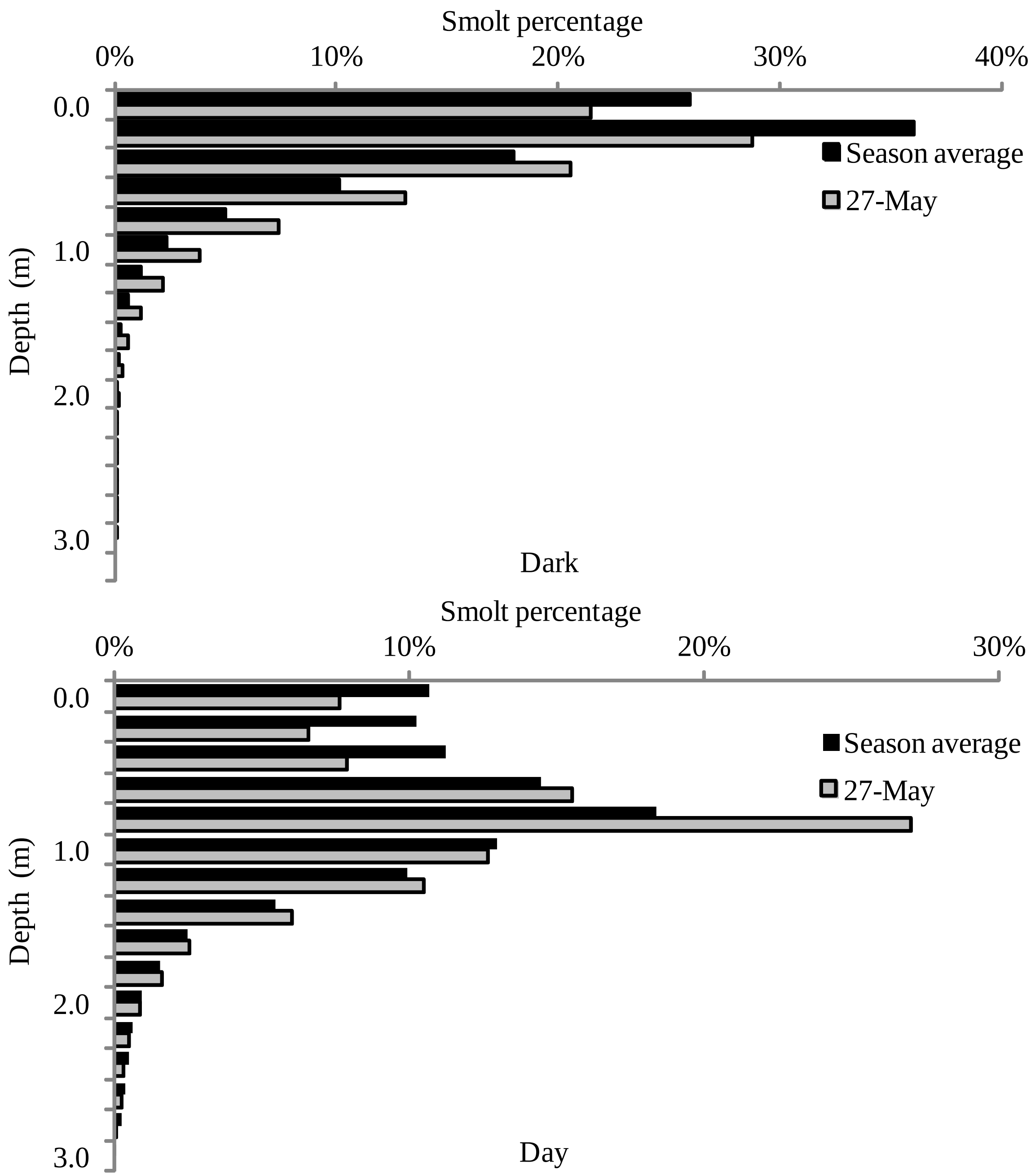

Figure 26. Seasonal average and 27 May vertical distribution of sockeye salmon smolts migrating in darkness (2300 – 0500 hrs) and light at Site 1 on the Kvichak River in 2012.

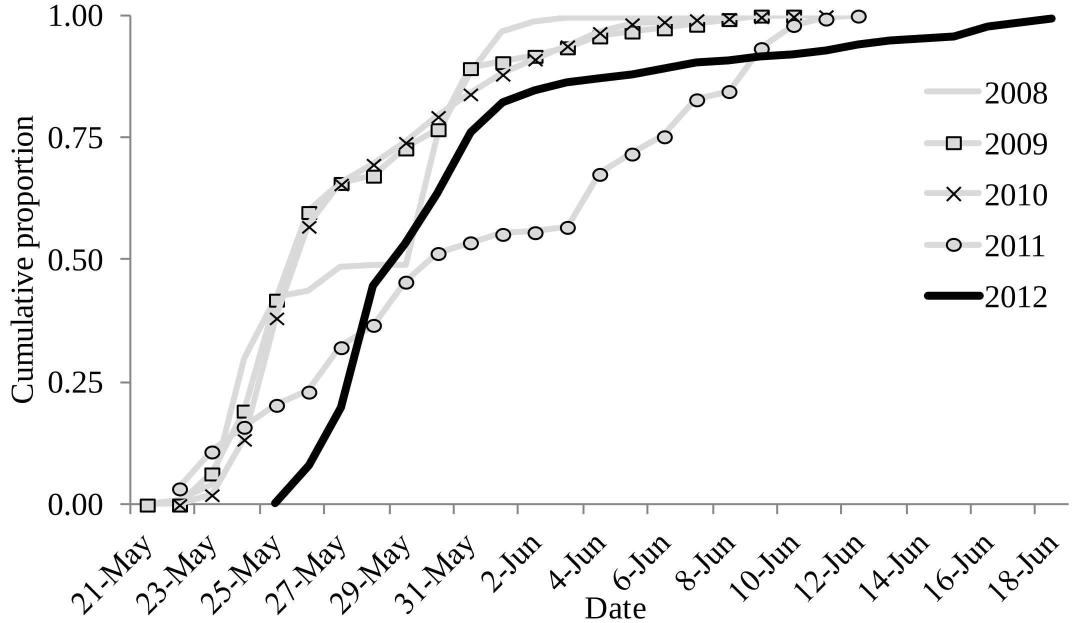

Figure 27. Run timing curves for sockeye salmon smolts at Site 1 on the Kvichak River for the years 2008 – 2012.

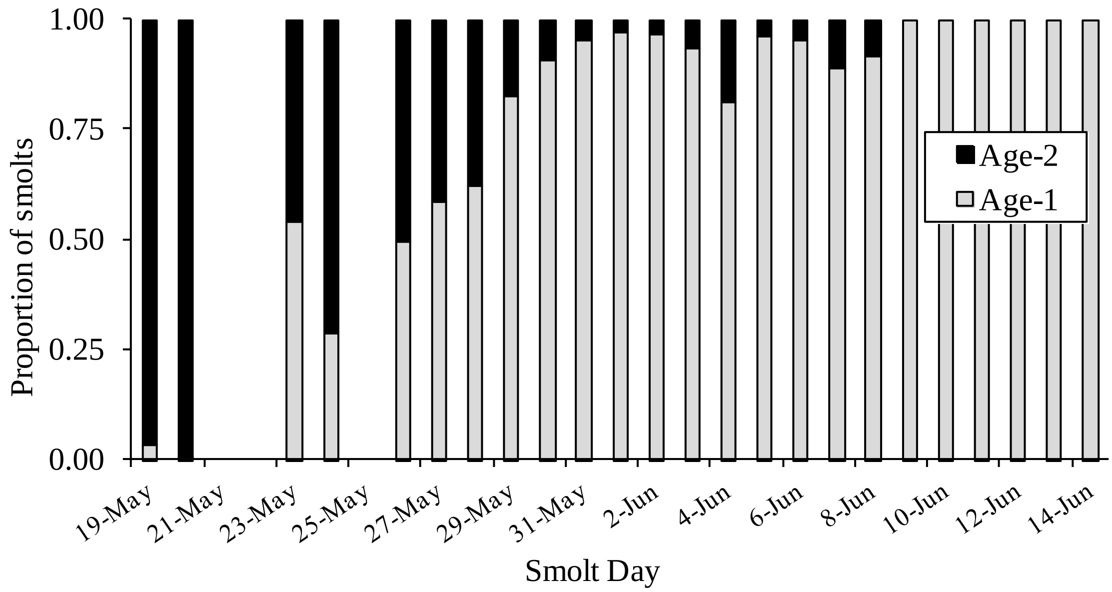

Figure 28. Proportion of age-1 and age-2 sockeye salmon smolts outmigrating on the Kvichak River in 2012.

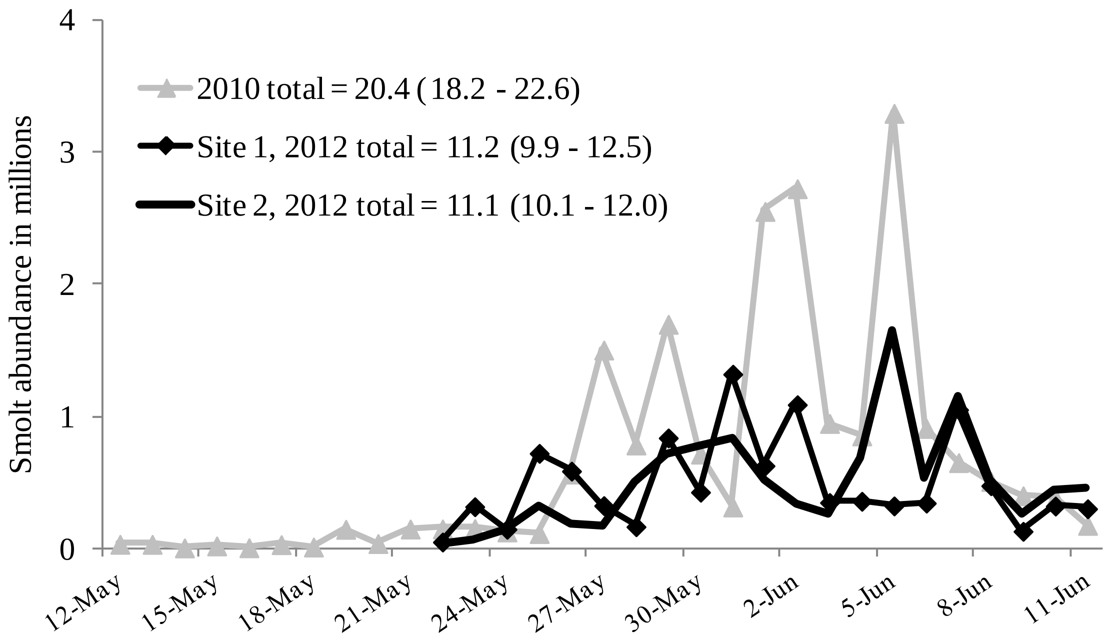

Figure 29. Estimated sockeye salmon smolt abundance on the Ugashik River for 2010 and 2012. In 2010 the two sonar arrays were configured to provide a single estimate for total smolts.

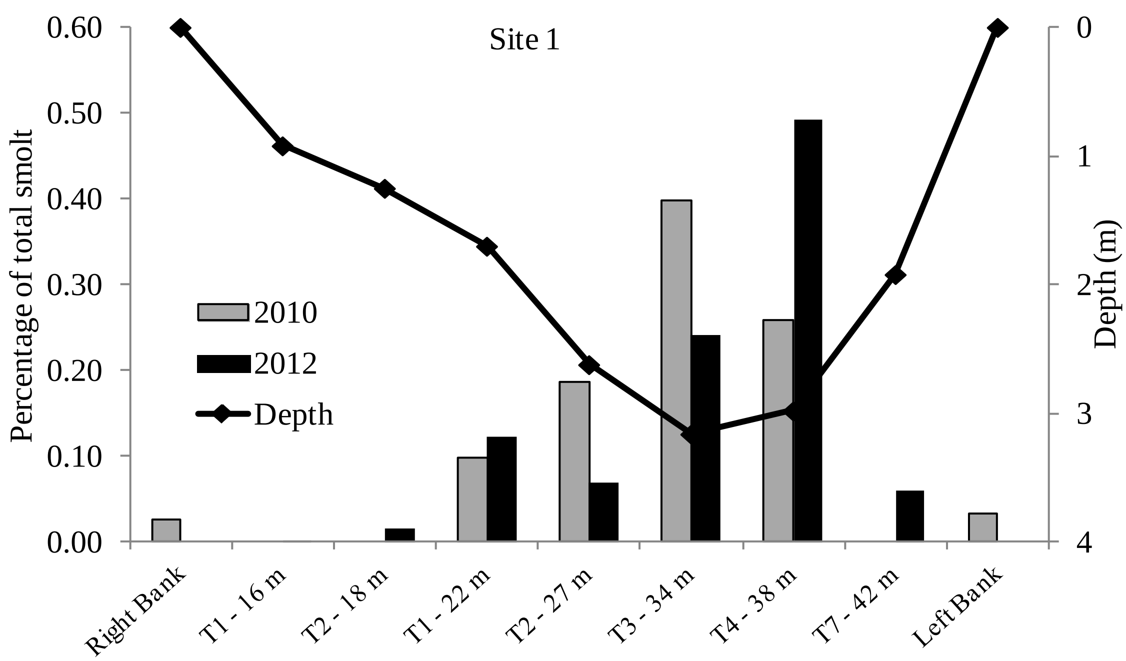

Figure 30. Cross-river distribution of sockeye salmon smolts at Site 1 on the Ugashik River for the year 2010 and 2012.

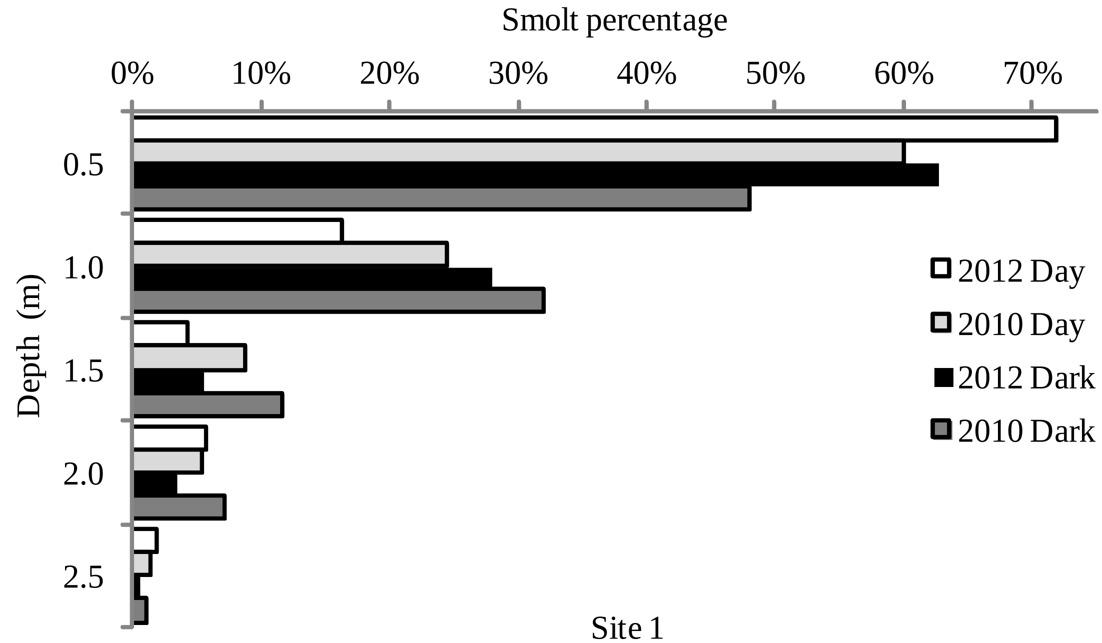

Figure 31. Vertical distribution of sockeye salmon smolts migrating in darkness (2300 – 0500 hrs) and light at Site 1 on the Ugashik River in 2010 and 2012.

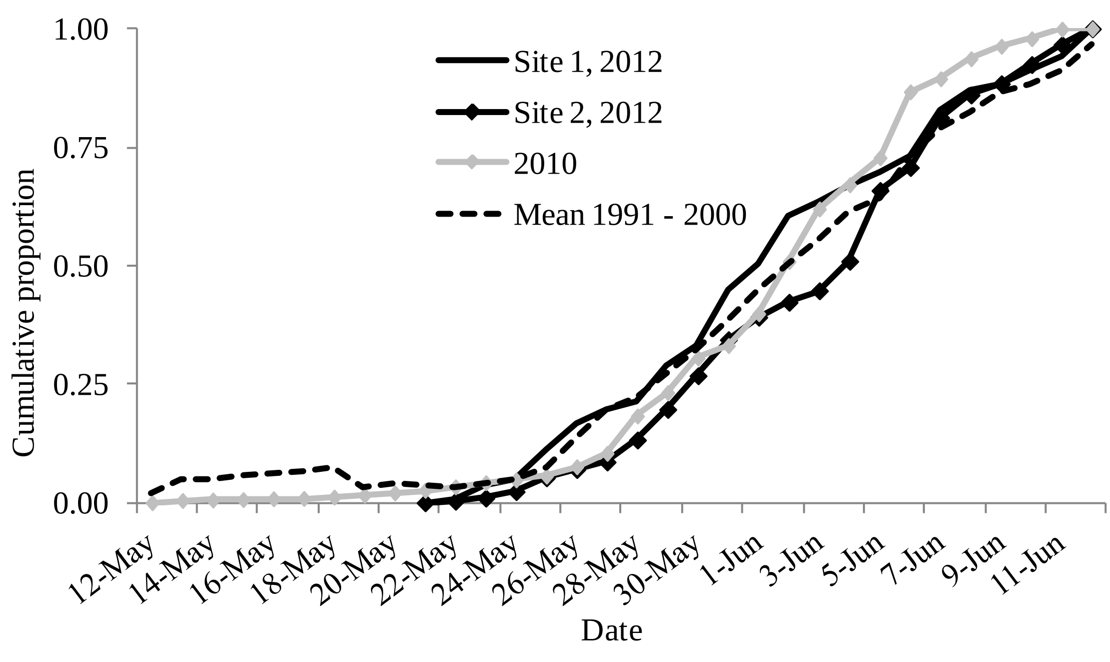

Figure 32. Sockeye salmon smolt run timing on the Ugashik River during 2010, 2012, and mean run timing for 1991 – 2000 (Crawford and Fair 2003).

PHOTOS

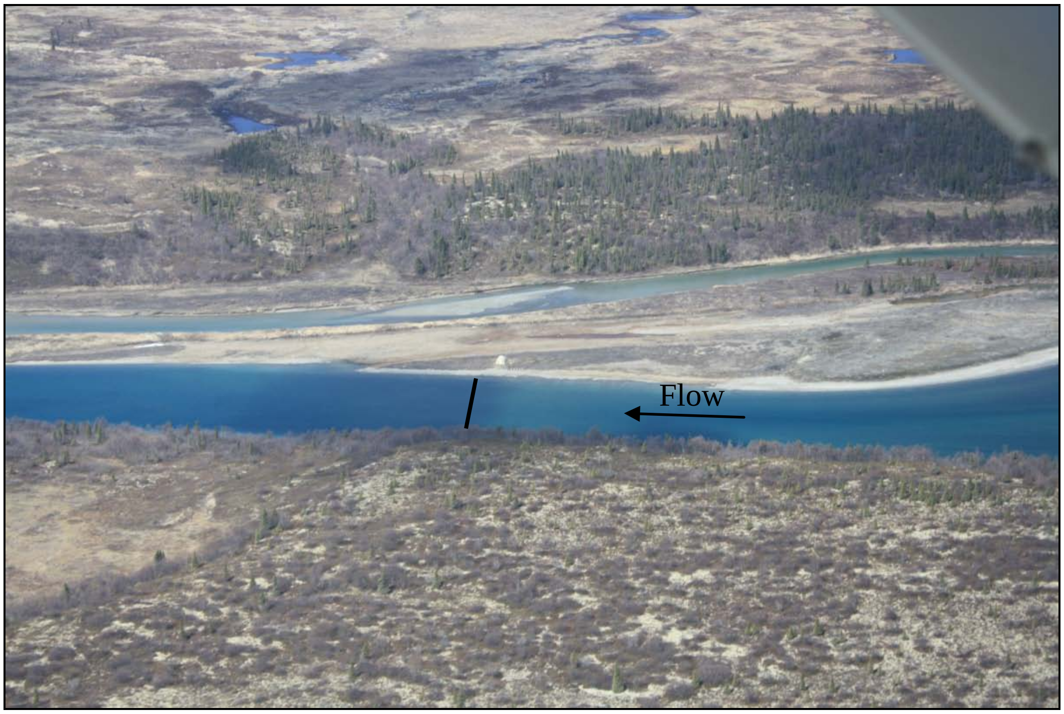

Photo 1. Black line showing the approximate location of Site 1 sonar array used in 2008 – 2012 on the Kvichak River (note WeatherPort on bank).

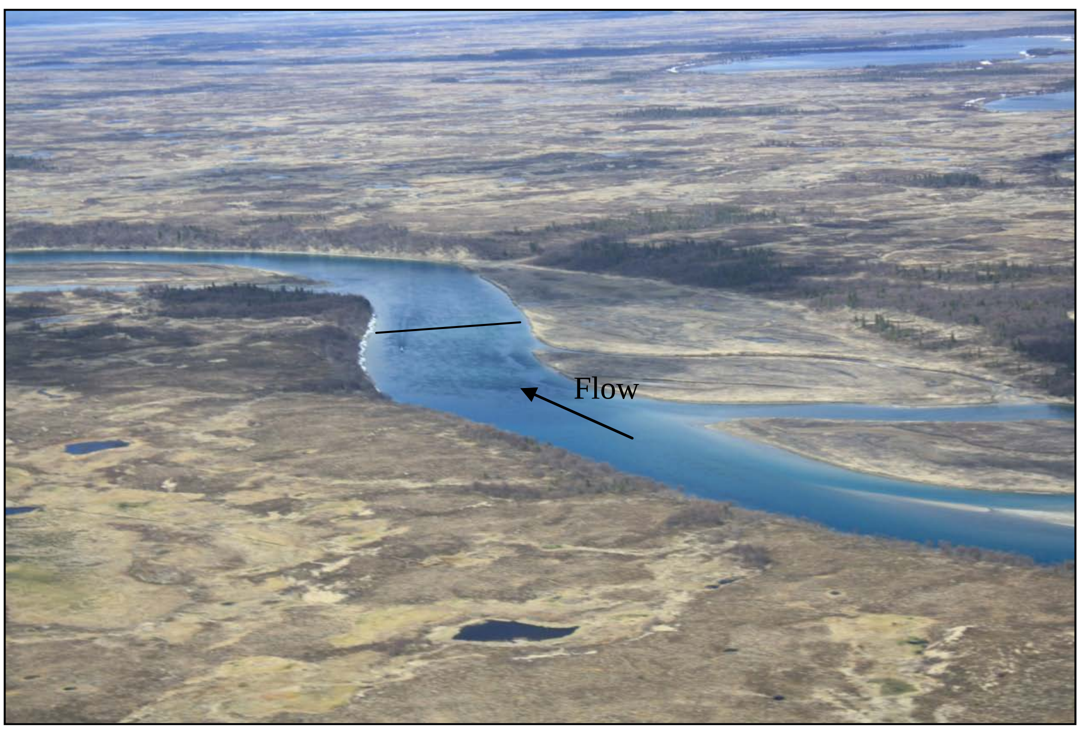

Photo 2. Black line showing the approximate location of Site 2 sonar array used in 2008 and 2010 – 2012 on the Kvichak River.

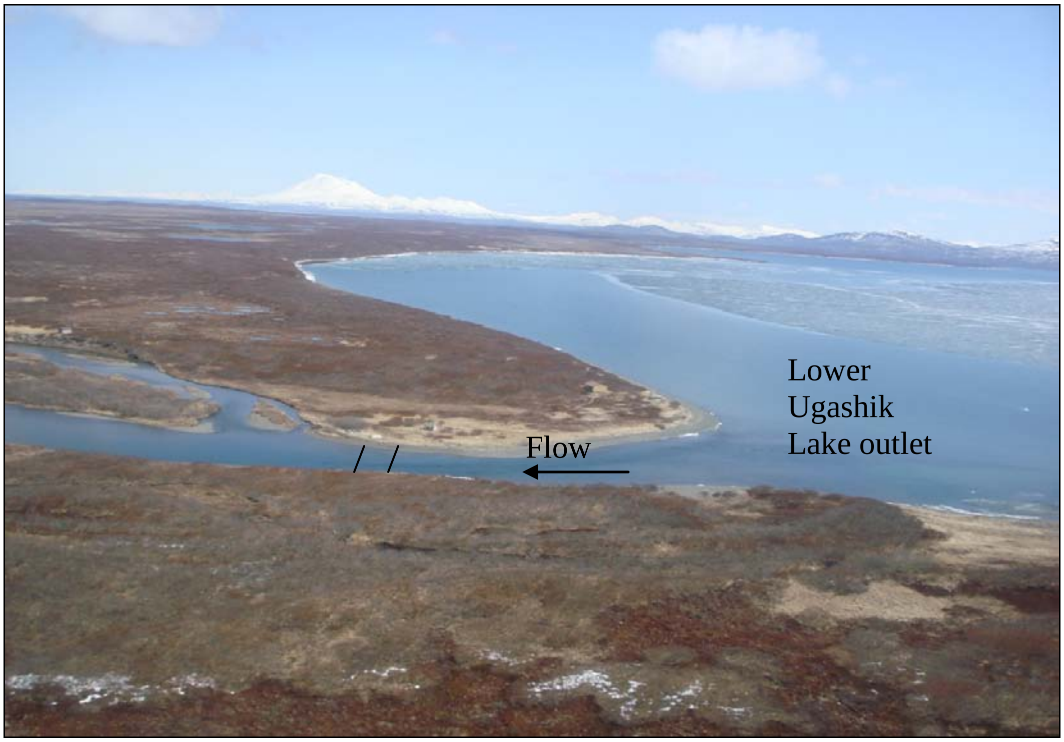

Photo 3. Black lines showing the approximate location of the two sonar arrays used on the Ugashik River in 2010 – 2012.

Photo 4. Sonar pod on shore during deployment with wire rope anchor harness running through eyebolts on the upstream side to prevent tipping, 2012.

Photo 5. Sonar pods mounted (large orange pod is the split beam) on a welded aluminum sled with attached power, network cable, and power/control housings, 2012.