Sockeye salmon smolt abundance and inriver distribution: results from the Kvichak, Ugashik, and Egegik rivers in Bristol Bay, Alaska, 2014

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Bristol Bay Science and Research Institute
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by

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EXECUTIVE SUMMARY

Information on the abundance and age structure of sockeye salmon (*Oncorhynchus nerka*) smolts can help characterize freshwater and marine productivity, set biological escapement goals, and forecast adult returns. In 2014, the Bristol Bay Science and Research Institute used sonar arrays to estimate the hourly, daily, and seasonal abundance of sockeye salmon smolts migrating from three rivers in the Bristol Bay region of Alaska. This was the seventh study year on the Kvichak River (all consecutive), fifth on the Ugashik River, and third on the Egegik River. On each river, a series of upward-looking sonar transducers were placed across the river bottom, perpendicular to the water flow, in an array that ranged from 5 to 12 transducers. Each array was operated separately to generate independent estimates of smolt abundance. Smolt distribution and run timing were also described to assess factors that may affect abundance estimates. Finally, smolts were captured to characterize the age, weight, and length of the migrating population.

The full smolt run appeared to have been monitored on all three rivers in 2014. Notable overall results were that smolt abundances were higher on Kvichak and Ugashik rivers than in 2013, that estimates were consistent between the two arrays on all rivers, and that both main age classes had unusually large body size on all three rivers. Smolt populations appeared to be in good health on all three watersheds, based on these measures.

Major results by river are summarized by river, below.

Kvichak River

- Two independent sonar arrays were operated from May 18 through June 13 in 2014. Sonar arrays operated reliably, with minimal down time or sound interference. Smolt abundance was estimated to be 60.9 million (95% CI of +/- 7.3 million) at Site 1 and 64.5 million (95% CI of +/- 4.9 million) at Site 2. Smolt run timing began slightly earlier than in prior years, but a late second peak caused the overall run timing to be later than usual; overall, the main run was from May 23 to June 8, with a median date of June 4. Water temperatures were the highest recorded at the run midpoint (6.5 °C) since project inception in 2008 (previous range 4.5 to 6.3 °C).

- Smolt distribution and behavior were similar to prior years. Laterally, most smolts were spread evenly across the deepest part of the channel. Vertically, most smolts migrated within the upper 1.0 m of the water column, with a higher percentage towards the surface at night than during the day. Approximately half the smolt run migrated during daylight hours, with passage per hour therefore being highest during the relatively few hours of darkness. Water velocity ranged from about 1.3 to 1.7 m/sec in areas with highest smolt passage.

- All smolts were either age-1 or age-2, with the proportion of age-1 (46%) being somewhat lower and the proportion of age-2 (54%) somewhat higher than in most years. Notably, both age classes had unusually large body size. Tissues samples

were collected for genetic analysis, to be reported separately by the Alaska Department of Fish and Game (ADF&G).

Ugashik River

- Two sonar arrays were operated from May 9 through June 12 in 2014, at the same sites used since 2010 and near the site of past studies by ADF&G. Estimated smolt abundance was 7.6 million (95% CI = +/- 0.8 million) at Site 1 and 7.6 million (95% CI = +/- 1.1 million) at Site 2. Smolt run timing began a few days earlier than in recent years; the main run was from May 21 through June 6, with a median date of May 28. Water temperatures were higher at the run midpoint (6.8 °C) than in recent years.

- Smolt distribution and behavior were similar to prior years and to the Kvichak River in 2013. Laterally, most Ugashik River smolts migrated down the center to center-left of the channel (downstream perspective), where the water was relatively deep. Vertically, most smolts migrated within the upper 1.0 m of the water column, with a higher percentage towards the surface at night than during the day. Passage rates were higher at night than during daylight, but, as in 2013, substantial numbers also migrated during daylight. Water velocity ranged from 1.0 to 1.7 m/sec in areas with highest smolt passage.

- All smolts were either age-1 (67%) or age-2 (33%). As on the Kvichak River, both age classes had unusually large body size.

Egegik River

- Two sonar arrays were operated from May 15 through June 12 in 2014, one at the same site as in 2013 and the other at a new site. Estimated smolt abundance was 9.1 million (95% CI = +/- 2.2 million) at Site 1 and 9.4 million (95% CI = +/- 2.4 million) at Site 2. The main run extended from May 22 through June 5, with a median date of May 25. The overall run timing was more compressed than on the Kvichak and Ugashik rivers, with half the run migrating May 24–26. The new array of sonar pods (tested on the Kvichak River in 2013) worked well.

- As in 2013, most Egegik River smolts migrated down the right half of the river, and several aspects of smolt distribution and timing remained different from the Kvichak and Egegik rivers. Vertically, smolts were distributed much deeper in the water column, and did not redistribute towards the surface as much at night. Finally, many smolts migrated during daylight hours.

- The Egegik River was the only location with large numbers of age-3 smolt. Outmigrating smolts were 19% age-1, 64% age-2, and 18% age-3. As on the other rivers, all age classes had unusually large body size relative to prior years. Age-1 and age-2 fish had larger body size than cohorts on the Kvichak and Ugashik rivers.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PHOTOS

LIST OF APPENDICES

INTRODUCTION

The value of monitoring salmon smolt abundance and populations characteristics in Bristol Bay rivers has been long recognized, even as the scope of the monitoring program has changed. Historically, the impetus for monitoring sockeye salmon (*Oncorhynchus nerka*) smolts in Bristol Bay has been to help salmon management by improving preseason forecasts of returning adult salmon abundance, and to help 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. Although less of an original impetus, there is also value to monitoring smolts simply because they are an early sentinel of changes in population characteristics such as body size and weight, age structure, and abundance. These characteristics can reflect changes in the forage base or in environmental conditions that can subsequently affect the returns of adult salmon.

For all these reasons, the University of Washington began estimating age, length, and abundance of sockeye salmon smolts on the Wood and Kvichak rivers in the early 1950s (Burgner 1968). The Alaska Department of Fish and Game (ADF&G) expanded smolt research in Bristol Bay in the 1960s, then 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 budget cuts, statistical uncertainty, and apparent usefulness of abundance estimates. By 2002, ADF&G had discontinued sockeye salmon smolt projects in Bristol Bay (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 after the Alaska Board of Fisheries 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 was a series of custom-designed, up-looking sonar pods (each with a transducer and echo sounder) that could be deployed in ways to sample the entire river width. This digitally-based sonar system was first tested on the Kvichak River in 2008 (Wade et al. 2010), then expanded with pilot years on the Ugashik River in 2010 and the Egegik River in 2011.

In 2014, BBSRI continued the project to enumerate sockeye salmon smolts on the Kvichak (seventh consecutive year), Ugashik (fifth year, not all consecutive), and Egegik rivers (third year, with the first being in 2011). 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 (hereafter, assumed to be sockeye salmon unless otherwise noted) were also collected with an incline plane trap and fyke nets to estimate age, body size, stock composition and to verify species composition (Kvichak and Ugashik rivers only). 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 abundance estimates.

This report provides hourly, daily, and seasonal abundance of smolts in 2014 and characterizes horizontal, vertical, and diel distribution of smolt schools as they migrate. The report also discusses possible sources of uncertainty in the abundance estimates (e.g., smolt swimming speed, distribution) and how these could theoretically bias the final results. Descriptions of smolt behavior in these systems also benefits other studies by helping guide various sampling efforts, identifying differences among river systems, and documenting how factors such as ice and water discharge may affect smolt migrations.

Smolt age, weight, and length (AWL) data are important elements of the freshwater production of salmon, and were also collected as part of the field portion of this study. The 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). The AWL analyses reported here were conducted separately by ADF&G.

In 2012, ADF&G began collecting genetic samples from smolts as the first of three years of sampling designed to estimate the stock composition of smolts from the Lake Clark and Lake Iliamna drainages. The third and final year of samples were again collected during the 2014 field season. Analyses of those samples are currently being conducted and results will be made available in a separate report by ADF&G in 2015.

OBJECTIVES

The objectives of the 2014 study were to:

1. Estimate the hourly, daily, and seasonal abundance of sockeye salmon smolts migrating from the Kvichak, Ugashik, and Egegik rivers.
2. Characterize the vertical, horizontal, and diel distribution of smolts emigrating from all three rivers.
3. Estimate the age, weight, and length of sockeye salmon smolts from all three rivers.
4. Describe spatiotemporal variability in water velocity on the Egegik River.
5. Estimate the stock composition of sockeye salmon smolts from the Kvichak River.

STUDY AREA

Bristol Bay

The Kvichak, Ugashik, and Egegik rivers are three 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 the 20-year period from 1993 through 2012, the annual run averaged 37.1 million sockeye salmon and the total harvest averaged 24.8 million (Jones et al. 2014). The Alaska Department of Fish and Game manages Bristol Bay stocks for river-specific escapement goal ranges using pre-season forecasts and several in-season indicators of run strength.

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). For the 20-year period from 1993 through 2012, annual harvest of sockeye salmon was 73,000 fish (504 permit holders) from the Naknek/Kvichak district, 1,000 fish (from 20 permits) from the Ugashik District, and 2,000 fish (on 38 permits) from the Egegik District (Jones et al. 2014). 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 through 2007, average annual sport harvest of sockeye salmon was 1,461 from the Kvichak River (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 May 13 (Appendix C1; Crawford and Fair 2003).

The initial 1.2 km of the Kvichak River below Iliamna Lake is 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, with the exception of Site 2 having been ~3 km upstream in 2009 (Photo 1; Photo 2; Maxwell et al. 2009; Wade et al. 2012b). In 2014, this study used the upstream site as Site 1 and the downstream site as Site 2. The coordinates of the Kvichak River sampling sites in 2014 are in Appendix B1.

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 199 km^2 for the upper lake and 182 km^2 for the lower lake (Edmundson and Todd 2000). The mainstem Ugashik River drains an estimated 4,203 km^2 (USGS 2014).

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 two km before reaching a shallow lagoon. The river is tidally influenced downstream of the braids near the lake outlet. There are 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 to 135 days (Appendix C2; Crawford and West 2001).

In 2014, the sonar systems were located approximately 80 m from the Lower Ugashik Lake outlet (N 58.0600, W 156.8860), at or near the same locations used for smolts studies by BBSRI in 2010 and 2012 and by ADF&G in the 1980s and 1990s (Photo 3; Crawford and West 2001). Coordinates of Ugashik River sampling sites in 2014 are in Appendix B1.

Egegik River

The Egegik River watershed is on the Alaska Peninsula, approximately 67 km south of King Salmon, AK (Figure 4). The head of the watershed is Becharof Lake, the second largest lake in Alaska. Becharof Lake is drained by the Egegik River, which flows westerly for ~45 km and empties into the Egegik Bay, in the southeastern portion of Bristol Bay. The King Salmon River is another major river in the drainage that empties into Egegik River near Egegik Bay. The mainstem Egegik River drains an estimated 4,580 km^2 (USGS 2014), not including the King Salmon river. Becharof Lake has a surface area of 1,142 km^2 (Edmundson and Todd 2000).

The Egegik River has a single channel for the first 5 km, then widens out into a lagoon before splitting into braided channels. The stretch of river from the lake outlet to the lagoon is generally clear water; downstream of this point, the water is more turbid due to tidal influences. Water levels and velocities are tidally influenced for the entirety of the river. The USGS has not collected stream flow data for this area. Ice cover data for Lake Becharof were collected during the 1980s and 1990s, during which time total duration of ice coverage varied from 39 d to 128 d (Appendix C2; Crawford and West 2001).

In 2014, the sonar systems were approximately 4.5 rkm downstream of the outlet (N 58.0605, W 156.8893), near the site of smolt studies conducted by BBSRI in 2011 and by ADF&G in the 1980s and 1990s (Photo 4; Crawford and Fair 2003). Coordinates of Egegik River sampling sites in 2014 are in Appendix B1.

METHODS

Sonar System Design Summary

Components and General Design

Each sonar system consisted of 4 to 12 up-looking sonar pods joined in line to form an array (Figure 5), along with supporting hardware, controllers, data communication and storage, and a power supply system. Each pod was mounted on an aluminum sled designed to remain upright on the river bottom, and all sleds were tethered together by wire rope to form the array. Each sonar array was then connected to a shoreside control box by a power and data cable, allowing data communication, storage, and system monitoring. Individual data files were collected continuously and then stored in 1-hour blocks. Power to the array was supplied by a bank of 12

V batteries and supplemented with a gas generator; more detail about components and specifications are provided by Wade et al. (2012a).

Optimal sonar sites were where the river was confined to a single channel, with a gradual bottom cross section suitable for towing the array across the river. In 2014, all sonar arrays were deployed in the same manner, following the methods described by Wade et al. (2010). A towline was attached to the chain on the first sled, and the array was pulled across the river by boat or with a chainsaw winch (Photo 6). Once in a suitable location, the ends of the sonar array were anchored to each bank.

Once operational, the sonar systems collected data 24 hours per day for the entire season. Each system was checked twice daily, generally at 0800 hours and 2300 hours, to ensure adequate power supply and operation. Data stored streamside for each of the arrays were downloaded onto a portable computer each day and examined visually using specialized software (EchoView® 5.1 by Myriax Software Pty. Ltd., Tasmania, Australia).

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 (Figure 5; Wade et al. 2010). Each pod was outfitted with a 7.5 ^{o} (at -3 dB) single beam transducer, manufactured by BioSonics or Airmar. A split-beam transducer (Simrad model ES120-7C) was integrated into the sonar array at Kvichak Site 1 to estimate the acoustic target strength of individual smolts. Tests in prior years show each Biosonics transducer detected targets from within 0.5 cm of the water surface, down to 71 cm from the face of the transducer (Wade et al 2012b). Within 71 cm of the transducer face, detections were unreliable due to “near field” effect. On the Airmar transducers, this near field effect was estimated at 50 cm in 2014.

Kvichak River Deployment and Operation

Site 1 was set in a section of river 108 m wide. This array had a total of eight pods, one of which was the split-beam transducer. The first pod (T1) was set 21 m from the right bank in 2.5 m of water. Pods were then spaced 9–10 m apart, with the last pod (T8) 91 m from the right bank and 17 m from the left bank (Appendix B1). The bottom profile of Site 1 began with a gently sloping right bank to a maximum depth of 4.1 m, in the region 72–82 m from shore (Figure 6). The array was operated May 13–June 13.

Site 2 was set in a section of river 136 m wide. Site 2 had 12 single-beam transducers split into two arrays placed end-to-end across the river, one with four pods (0–41 m from the right bank) and the other with eight pods (43–112 m from the right bank). Overall, transducers ranged from 10 (T1) to 112 (T12) from the right bank, and were generally spaced 10 m apart. The bottom profile of Site 2 was relatively even across its width, with transducers 2 through 12 ranging from 2.7 to 3.3 m deep (Figure 6). Site 2 was operated from May 14–June 13.

Ugashik River Deployment and Operation

Site 1 was set in a section of river 38 m wide. This array had five single-beam transducers. The first pod (T1) was placed 17 m from the right bank in 2.4 m of water. Pods were then spaced 3–6 m apart, with the last pod (T5) 35 m from the right bank and 3 m from the left bank. The bottom profile was somewhat U-shaped, with the deepest point at T3, 27 m from the right bank in 3.3 m of water (Figure 7). The array was operated from May 9 through June 11.

Site 2 was set in a section of river 46 m wide. This array had four single-beam transducers. The first pod (T1) was placed 24 m from the right bank in 2.5 m of water. Pods were then spaced 4–6 m apart. The bottom profile was somewhat U-shaped, with the deepest point at T2 and T3, 28–33 m from the right bank in 3.2 m of water (Figure 7). The array was operated from May 10 through June 12.

Egegik River Deployment and Operation

Site 1 was set in a section of river 98 m wide. This array had six single-beam transducers. The first pod (T1) was placed 19 m from the right bank in 2.6 m of water. Pods were then spaced 9–12 m apart. The bottom profile was somewhat U-shaped but with a flat bottom 31–61 m from shore (transducers 2–5), ranging from 3.4–3.8 m deep (Figure 8). The array was operated from May 13 through June 12.

Site 2 was set in a section of river 95 m wide. This array had seven single-beam transducers. The first pod (T1) was placed 14 m from the right bank in 1.5 m of water. Pods were then spaced 9–12 m apart. The bottom profile was variable, dropping steeply from T2 to T3, rising slightly to T4, then dropping to the deepest part (3.4–3.6 m) at T5 and T6 (Figure 8). The array was operated from May 16 through June 12.

Data Collection and Analysis

Smolt abundance was estimated by using the echo integration of the sonar data to eventually estimate mean smolt density per hour (smolts per m^2) at each transducer each hour, within each 0.2 m vertical cell of the water column. Smolt densities for all 0.2 m strata were summed to provide total water column densities. Smolt density was multiplied by water current speed to estimate smolt passage per hour at each cell (i.e., flux). Linear interpolation was then used to estimate smolt passage among transducers and between transducers and the riverbank, in 1 m increments (and also in 0.2 m vertical cells). Hourly abundance was the total passage of smolts across the entire river. The resulting estimates of smolt abundance per hour, across the stream (i.e., each transducer), and at each vertical cell (0.2 m) in the water column allowed estimates of the vertical, lateral, and diel distribution of smolts each day.

Additionally, smolts were captured throughout the sampling period to collect age, weight, and length data (AWL). These data were used to summarize the size and age structure of the smolt run on each river.

Pre-processing and Echo Integration of Sonar Data

Data files were pre-processed (using EchoView® 5.4 software) by removing acoustic 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. If the technician could not distinguish between smolts and noise, that region of data was excluded from the analysis. For hours where data were removed, estimates were linearly interpolated based on the values surrounding these events. Removed data blocks that were shorter than five hours were linearly interpolated between the last hour with good data to the first hour after the missing data, using only data from that transducer. Removed data blocks that were six hours or longer were weighted based on the same hour of the day prior to the missing data and the day after the missing data, also only using data from that transducer.

Next, sonar data were echo integrated. Sockeye salmon smolts aggregate in schools too dense for the sonar to detect single targets accurately; therefore abundance estimates could not be calculated by counting individual fish. Instead, echo integration summed all backscatter cross-sections from multiple targets (i.e., smolts) in a given sample volume, producing a backscatter coefficient. Once average target strength of a single fish was known, the number of fish was estimated from the backscatter coefficient.

Estimating Smolt Abundance

Backscatter coefficient was calculated over a given range from each transducer to produce the area backscatter coefficient/m^2 (ABC). 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. Smolt density for each cell was a measure of mean smolt count/cross sectional area sampled, normalized to smolt density/m^2 for each strata. Fish density/m^2 was then multiplied by water velocity to obtain the smolt flux, which gave 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 smolt passage for areas 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:

$$SA = \sum_{j=1}^{K} HA_j \qquad (1)$$

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

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

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

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

$$fpc=\frac{A-a}{A-1} \qquad (6)$$

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. Estimates of variance include uncertainty due to subsampling the water column, but not uncertainty from estimating the scaling factor during echo integration

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.

Model Assumptions

Four main assumptions about smolt behavior were needed to produce reliable abundance estimates comparable across years:

1. Smolts travel at or near the same speed as the river water velocity.
2. Within the water column, smolts do not travel so low as to be undetected by the sonar transducers, or so high as to be indistinguishable from surface noise.
3. Among years, the proportion of any smolts traveling in the undetectable areas of the water column does not vary.
4. Mean target strength may be used to scale echo integration.

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

Smolt Distribution

Smolt abundance estimates were used to describe smolt distribution each hour in lateral and vertical dimensions, as well as during hours of relative light and dark. For lateral distribution (across the river), river width 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. For vertical distribution, abundance was calculated in 0.2 m depth strata from the surface down to the transducer’s near field (~71 cm for Biosonics, 50 cm for Airmar). Abundance was then summed for all hours of daylight and darkness to compare diel patterns.

Environmental Conditions

Water velocity was measured at a depth of 1 m at each pod, from a boat anchored 2 to 3 m downstream of each pod. Measurements were taken for one minute, twice at each transducer to give an arithmetic mean. Water velocity on the Kvichak River was measured four times at each site (Table 1), using a model 622 Gurley Price meter (Gurley Precision Instruments, Troy, NY). Velocities were calculated based on the GPI conversion table. Water velocity was measured four times at each of the Ugashik River sites with a FP111 digital flow meter made by Global Water Instrumentation, Inc. (Sacramento, CA). Water velocity was measured twice at each of the Egegik River sites, using a Marsh-McBirney flow meter (model Flow-Mate 2000).

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 for hourly measurements of air 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 (Appendix C4 and C5). Hourly water temperature was measured on the Kvichak and Ugashik rivers using a Tidbit® v2 TempLogger.

Water velocity on the Egegik River was also measured with an acoustic Doppler current profiler (ADCP; Argonaut SL 0.5 MHz, SonTek, San Diego CA).

Smolt Age, Weight, and Length

A subsampling design was used to estimate the daily age structure, mean body length, and mean body weight of smolts migrating from each river. 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). On the Kvichak River, an inclined plane trap (IPT) was used to capture smolts (Photo 7). This trap was modeled after a similar one operated on the Kasilof River (Todd 1994). On the Ugashik and Egegik rivers, smolts were captured using a standard fyke net with a rigid 4 ft by 4 ft opening (Photo 8).

Each calendar day, up to 100 smolts were sampled for age, weight, and length (AWL). Up to another 500 smolts were sampled for length only, thereby developing a regression relationship between length and age and between length and weight for each sampling day. These two groups (i.e., up to 600 smolts) were combined to generate a mean length, weight, and age structure for the daily sample. Sample sizes were based on binomial proportions for the two major age groups (ages 1 and 2); 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).

For age, the relationship between length and age of the 100 aged fish was used to identify a discriminant length that minimized classification error (or age-length key; Bue and Eggers 1989), 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. This discriminant length was calculated postseason, from all fish aged throughout the season, then applied retroactively to the rest of the fish sample (i.e., measured for length, but age not measured directly) to generate the daily and final age estimates. Age-3 smolts were only included in this analysis if enough age-3 fish were identified from the scale reading. All scale aging and discriminant age-length analyses were performed by ADF&G in the King Salmon office. The final age structure of the run was calculated as daily age structure of the run, weighted by the daily smolt abundance estimated from the sonar arrays. To increase sample sizes from the Egegik River, during analysis the samples from several days were pooled until the catch was ≥50 fish (eight periods over the season). This prevented erroneous conclusions based upon days where the catch was only a few fish.

For weight, the relationship between length and weight of the 100 aged fish was estimated 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

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

where

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

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

RESULTS

Kvichak River

Data Pre-processing

At Site 1, sonar data were collected for 736 hours, from May 13 (1900 hours) through June 13 (1000 hours). At Site 2, sonar data were collected for 715 hours, from May 14 (2200 hours) to June 13 (1600 hours). These resulted in 5,888 potential blocks of data at Site 1 (8 transducers x 736 operating hours) and 8,580 potential blocks at Site 2 (12 transducers by 715 operating hours).

Environmental noise from wind, ice, or vessels precluded analysis of 606 blocks of data from Site 1 (10% of total) and 1,497 blocks from Site 2 (17% of total; Figure 9). These blocks were removed from the dataset and replaced using interpolations from surrounding hourly blocks. Most blocks of interpolated data occurred during periods of low smolt movement and thus fewer numbers of fish were interpolated than otherwise expected (Figure 9).

Smolt Abundance and Run Timing

At Site 1, sockeye salmon smolt abundance was estimated at 60,901,033 (95% CIs = 53,592,600–68,209,466; Table 2; Table 3). At Site 2, estimated abundance was 64,536,275 (95% CIs = 59,595,313–69,477,236; Table 2; Table 4). Hourly smolt passage peaked at each site during darkness, defined as 2300 to 0500 (Figure 10). Many smolts also migrated during daylight however (e.g. Figure 10), accounting for 39% of the run at Site 1 and 43% of the run at Site 2.

Overall run timing was much later for the first 75% of the smolt run as compared to prior years (Figure 11). The run appeared to be bimodal with distinct peaks on May 28 and June 4. Both sonar arrays appear to have been deployed before any major smolt movements, based on patterns between the dates of deployment on May 13 and 14 and the first smolt peaks on May 23.

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 2.8 m at Site 2. At both sites, smolt distribution was highly skewed towards the surface, especially during dark hours (Figure 12). For both sites more than 98% of smolts detected at night were in the upper 1.0 m, with most of these in the upper 0.4 to 0.6 m. By contrast, smolts traveling during daylight hours tended to have a deeper vertical distribution, with only 58% to 67% of the smolts in the upper 1.0 m (Figure 12).

Smolts were detected by all sonar pods at each site (i.e., across the entire river), but were disproportionately distributed. At both sites, between 61% and 75% of the smolts were concentrated in the left side of the river channel; this corresponded with the deepest part of the river at Site 1, but not at Site 2 (Figure 12).

Environmental Conditions

Water temperatures were approximately 5.0 °C when sonar pods were deployed on May 13, then peaked at 10.6 °C on June 8 (Figure 13). Precipitation was recorded on 14 days (Appendix C3).

Smolt Age, Weight, and Length

On the Kvichak River, smolt sampling for age, weight, and length began on May 12 and ended June 12 (Appendix A1). Sampling was conducted daily, except for four days where weather prevented sampling. A total of 2,392 smolts were aged, weighed, and measured for length to use in developing the length-age and the length-weight relationships (Appendix A2). Age-1 smolts had an estimated mean length of 90 mm and mean weight of 6.7 g; age-2 smolts had an estimated mean length of 115 mm and mean weight of 13.5 g (Appendix A2). The discriminant body length used to separate the two age classes was 99 mm.

This discriminant length was then applied to another 9,103 smolts measured for length during the season (Appendix A3) to generate a daily age fraction that was a weighted blend of smolts for which age was measured directly (from scales) and indirectly (from body length). The blended daily age fraction was applied to the daily abundance estimate from the sonar counts to generate a final estimated age proportion of 46% age-1 and 54% age-2 for the season (Table 10).

Run Timing by Age Class

The first portion of the run, including the first peak on May 28, was predominantly age-2 smolts (Table 10). The second portion of the run, which was larger and included the second peak on June 4 and 5, was predominantly age-1 (Table 10).

Ugashik River

Data Pre-processing

At Site 1, sonar data were collected for 793 hours, from May 9 (1800 hrs) through June 11 (1800 hours). At Site 2, sonar data were collected for 798 hours, from May 10 (1200 hours) to June 12 (1700 hours). These resulted in 3,965 potential blocks of data at Site 1 (five transducers by 793 operating hours) and 3,192 potential blocks at Site 2 (four transducers by 798 operating hours).

The predominant environmental noise in the Ugashik River was from high wind events and air bubbles from waves from the lake.. These events precluded analysis of 867 data blocks from Site 1 (22% of total) and 180 data blocks from Site 2 (6% of total; Figure 14). These blocks were removed from the dataset and replaced using interpolations from surrounding hourly blocks. Individual transducers occasionally malfunctioned causing outages for that transducer alone. These missing blocks were interpolated from surrounding hourly blocks and nearby transducers. Outlier values (produced by glitches in the sonar array), were excluded if they were an order of magnitude greater than the hourly counts prior to and after the data excluded.

Smolt Abundance and Run Timing

At Site 1, sockeye salmon smolt abundance was estimated at 7,570,811, with a 95% CI of +/- 841,044 (Table 2; Table 5). At Site 2, estimated abundance was 7,646,234, with a 95% CI of +/- 1,110,604 smolts (Table 2; Table 6). Hourly smolt passage increased at each site at the onset of darkness, though less pronounced for Site 1 (the actual peak of smolt flux at Site 1 was during the 1300 hour; Figure 10). Smolt migration during daylight hours accounted for 68% of the run at Site 1 and 45% of the run at Site 2.

Overall smolt run timing in Ugashik River was much earlier than previous years (Figure 15), with two peaks on May 26/27 and June 3 (Figure 14). Both sonar arrays appeared to have been deployed before any major smolt movements, based on a lack of detectable movement before deployment on May 9 and 10; the first notable smolt detections were on May 21.

Smolt Distribution

Vertical distribution was split into 0.2 m depth strata down to a maximum depth of 2.6 m at Site 1 and a maximum depth of 2.0 m at Site 2. Smolts were surface-oriented at both sites (Figure 16). Smolts had a deeper vertical distribution during daylight hours than at night. At night, over 95% of the smolts at each site travelled in the upper 1.0 meter of the water column (Figure 16). Cross channel distribution differed between sites: at Site 1 the majority of fish were detected by transducer 2 (21 m from river right) while at Site 2 the majority of fish were detected by transducer 3 (33 m from river right).

Environmental Conditions

Water temperature was 6.2 °C at the initial measurement the morning of May 11, rising to peak at 10.6 °C on June 5. Precipitation was recorded on 13 days.

Smolt Age, Weight, and Length

On the Ugashik River, smolts were sampled for age, weight, and length on 22 days between May 15 and June 12 (Appendix A3). A total of 1,445 smolts were aged, weighed, and measured for length to use in developing the length-age and the length-weight relationships (Appendix A5).

Of the 1,445 smolts sampled in 2014, 66% were age-1 and 34% at age-2 (Appendix A7). Age-1 smolts had an estimated mean length of 103 mm and mean weight of 10.8 g; age-2 smolts had an estimated mean length of 122 mm and mean weight of 16.8 g (Appendix A7). The discriminant body length of 115 mm was used to separate the two age classes. Early in the run age-2 smolt were more common, though as the run progressed, age-1 smolts became more numerous (Appendix A7).

The estimated age structure of the run was 67% age-1 and 33% age-2, after adjusting for estimated daily abundance using the sonar data (Table 11).

Egegik River

Data Pre-processing

Sonar data were collected at (Site 1) for 660 hours, from May 16 (0000 hrs) through June 12 (1100 hours). At Site 2, sonar data were collected for 673 hours, from May 15 (1300 hrs) through

June 12 (1300 hrs). These resulted in 3,960 potential blocks of data at Site 1 (six transducers by 660 operating hours) and 4,711 potential blocks at Site 2 (seven transducers by 673 operating hours).

Equipment malfunctions or environmental noise (e.g., wind, entrained air, or vessel traffic) precluded analysis of a minimum of 715 transducer-hour blocks of data from Site 1 (18% of total), and 497 transducer-hour blocks of data from Site 2 (11% of total; Figure 17).

Smolt Abundance and Run Timing

At Site 1, sockeye salmon smolt abundance was estimated at 9,132,601 (95% CIs = 6,893,234–11,371,969; Table 2; Table 7). At Site 2, estimated abundance was 9,406,952 (95% CIs = 6,990,242–11,823,663; Table 2; Table 8).

Overall run timing was much earlier than both 2013 and 2011 (Figure 18). Most of the run emigrated between May 22 through June 1, a more compressed run timing than on the Ugashik or Kvichak rivers in 2014 (Figure 19). The sonar system appeared to have been deployed before any major smolt movements, based on patterns between the dates of deployment on May 16 and the first main smolt detections May 20.

Hourly smolt passage peaked at each site at the onset of darkness (Figure 10), with the hours between 2300 and 0500 accounting for 49% of the estimated smolt passage at Site 1 and 59% at Site 2.

Smolt Distribution

Vertical distribution was split into 0.2 m depth strata down to a maximum depth of 2.8 m at Site 1 and a maximum depth of 3.0 m at Site 2. Smolts were surface-oriented at both sites during hours of darkness, though much less so than at the Kvichak and Ugashik rivers: in the Egegik River, only 54% of the smolts were in the top 1.0 m of the water column at Site 1 and 71% at Site 2 (e.g., Figure 20). By contrast, smolts traveling during daylight hours had a deeper vertical distribution, with only 36% of smolts in the upper 1.0 m of the water column at Site 1 and 50% at Site 2 (Figure 20).

Smolts were detected by all sonar pods at each site (i.e., across the entire river), with approximately 86% of the run estimated to have been on the right half of the river (looking downstream) at Site 1 and 81% at Site 2. Relatively uniform transducer depths prevented assessing whether smolt density varied with depth (Figure 8).

Environmental Conditions

Water temperature was 7.4 °C at the initial measurement the afternoon of May 15, but did not consistently rise for another week. Water temperatures peaked at 9.4 °C the afternoon of June 5. Precipitation was recorded on 12 days.

Smolt Age, Weight, and Length

On the Egegik River, smolt sampling began on May 17 and ended on June 11 (Appendix A5), with a total of 794 smolts captured. Sampling was conducted daily, except for seven days with poor sampling conditions. A total of 710 sockeye salmon smolts were aged, weighed, and measured for length to use in developing length-age and length-weight relationships (Appendix A6).

Age-1 smolts had a mean length of 104 mm and mean weight of 9.7 g. Age-2 smolts had a mean length of 126 mm and mean weight of 18.9 g. Age-3 smolts had a mean length of 145 mm and mean weight of 29.5 g (Appendix A6).

The estimated age structure of the run was 19% age-1, 64% age-2, and 18% age-3, after adjusting for estimated periodic abundance using the sonar data (Table 12). Age-2 smolts were the most abundant age class during all times of the run (Table 12).

DISCUSSION

Project growth continued in 2014, marking the first time the main objectives of smolt abundance, spatial distribution, run timing, and AWL structure have been addressed on all three rivers in the same year. Other important results were that abundance estimates were consistent between two arrays on all rivers, the full run appeared to have been captured at all sites, and varying water velocity on the Egegik River was incorporated into estimates for the first time. The early ice-out in 2014 helped our sampling coverage by allowing us to deploy the sonar sites about a week earlier than usual, while not causing an unusually early smolt migration.

Smolt run timing began one to three days earlier on each river than in recent years; this early timing was then sustained on the Ugashik and Kvichak rivers, but not on the Kvichak River. Overall, results supported past observations that the onset of smolt migration may be more closely connected to ice out in some years than others. Our working hypothesis is that we need to be prepared to sample amid ice conditions, but that this is more necessary in years when the ice stays late than when it clears early (Nemeth et. al. 2013).

The smolt populations appeared to be in good health on all three watersheds, based on production data collected in 2014. On the Kvichak and Ugashik rivers, smolts were more abundant than in 2013, and were the most abundant on the Kvichak since project inception in 2008. Concurrently, smolts were larger (both length and weight) on each river, and this size increase was for both age-1 and age-2 fish. Egegik River smolts were even larger than their age cohorts from the other two rivers. Overall, these measurements auger well for future adult returns. On the Kvichak River, this combination of body size, age structure, and relative abundance may be historic (see below).

Kvichak River

Smolt Abundance

The 2014 Kvichak River smolt abundance estimate at both sites was at the upper end of the range reported over the past six seasons (2008–2013; Table 2), and was consistent between the two sites. 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 migrating through the ensonified area, and/or Site 1 had better operational conditions for a given season. Both arrays functioned well in 2014 with few operational outages and only a 5.6%

difference between site abundance estimates; we have no reason to think either site was more accurate than the other in 2014.

This was the third consecutive year that Site 2 used a design of two sub-arrays, intended to provide more complete cross-river coverage than in past years. The design posed no complications and should be retained in future years.

Assumptions and Uncertainty in Abundance Estimates

Swimming speed is used to calculate smolt flux (smolt/hour), which is used to estimate hourly, daily, and yearly abundance (Mueller et al. 2006). Smolt swimming speed is assumed to be at or near water velocity, based on work conducted over a three-day span in the early portion of the smolt migration by Maxwell et al. (2009). Although the best available data, the relatively short study period would not have been able to detect seasonal differences in swimming speed.

Errors in assumed swimming speed could bias smolt abundance estimates either high or low (Wade et al. 2010), and would have the greatest impact on indexing the smolt run if swimming speed varies as a function of the overall abundance of the smolt run. Also, if swimming speed increases with smolt size, we would 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 traveled at or near river velocity, or if this changes throughout the season. This assumption could be tested in the course of field work in future years.

Distribution and Run Timing

Smolt spatial distribution was similar to prior years. Across the channel, smolts were most prevalent in the center to center-left of the river, in areas at or approaching the maximum river depth. Vertically, smolts were predominantly in the upper 1 meter of the water column, with a tendency to be distributed deeper during the day than night. The diel pattern of increased density during nighttime hours was also consistent with prior years. All of this information increases our understanding of smolt migration behavior, and provides a baseline useful for evaluating changes in future annual abundance estimates.

The bimodal run timing in 2014 was caused by separate peaks for age-2 (late May) and age-1 (early June) smolts, and was also seen in 2008, 2009, and 2011 (Wade et al. 2012a). The 2014 season was unusual, however, in that the second peak was much larger; whereas the peaks were roughly equivalent in past bimodal years, the second peak in 2014 was two to three times the size of the first. The second peak included a relatively high number of age-2 fish (41% of the run on June 4th), leading to a relatively high proportion of age-2 smolts (54%) in the overall run.

Smolt Age, Weight, and Length

Both age classes of smolts in 2014 had unusually large body size, based on long-term annual averages from ADF&G (presented in Appendix A4 in Nemeth et al. 2014). The combination of size and abundance is historic for several reasons:

- Age-1 smolts had the highest combination of body length and weight since 1998, and age-2 smolts had the highest since 1976. Combined, they were the largest smolts since those emigrating from the 1972–1973 brood years, which had the highest and 12th-highest recruits per spawner in the current 43-year data set (data provided by ADF&G).

- Qualitatively, there have been only four years when age-1 and -2 fish were each so large: 1957, 1961, 1974, and 1975. In each of those four years, relative smolt abundances were unusually low (at time of press, we don't know if this was a sampling artifact). In 2014, by contrast, relative abundance was the highest of its era.
- Large age-2 fish usually comprise small proportions of the run, possibly because they results from favorable growth conditions that lead to high numbers emigrating as age-1 fish the prior year. Age-2 fish accounted for over half the run in 2014; for that sized fish, no other age-2 cohort has accounted for more than 37% of the run since recordkeeping began in 1955.

We need to review the supporting data from other years with such large fish; initially, however, the 2014 smolt run appeared to have an unusual or even unique combination of AWL and abundance measures that would likely reflect good rearing conditions and a favorable contribution to future adult runs.

Ugashik River

Smolt Abundance

Smolt abundance estimates in 2014 were higher than in 2013, though lower than in 2010 and 2012. In 2014, each array provided consistent estimates (7.57 and 7.65 million smolts), approximately double the number estimated from identically-operated arrays in 2013. Operational changes may account for the lower estimates in 2013 and 2014 compared to 2010 and 2012 (Nemeth et al. 2014).

The same caveats about swimming speed and abundance estimates discussed for the Kvichak River, above, also apply to the Ugashik River estimates.

Distribution and Run Timing

Across the river, smolts were disproportionately present at the thalweg, in the middle of the river, similar to prior years and to the pattern seen on the Kvichak River. As on the Kvichak River, Ugashik River smolts were predominantly in the upper 1.0 m of the water column, and the vertical distributions tended to be deeper in daylight hours than at night. Smolts were not as concentrated in the upper 0.5 m of the water column as they were in 2012 and 2010 (Wade et al. 2012b, 2013). Finally, the increased movement during nighttime hours was consistent with prior years, and on the other rivers.

As on the Kvichak River, Ugashik River water temperature (8.0 °C) was higher at the run midpoint than in prior years (Table 9).

Smolt Age, Weight, and Length

Ugashik River smolts were large (both length and weight) in 2014 compared to prior years. Age-1 smolts were the largest recorded since recordkeeping began in 1958; age-2 fish were among the largest during this time, and similar in size to those in 2013. In combination, these were the largest age-1 and -2 fish seen in the same year since 1996.

The fact that the last two years has yielded the largest age-2 fish on record suggests it might be an artifact of sampling; the same gear type did not yield unusual results for age-1 fish until now, however, or for age-2 fish in 2010 and 2012. As in most years, Ugashik River smolts were larger in length and weight than Kvichak River smolts (Appendices A2 and A4).

Egegik River

Smolt Abundance

Revised water velocity collection methods in 2014 showed that water velocity differed among "cells" across the width of the river, and that velocity in these individual cells also fluctuated at different times (Figure 22). These variations were confirmed by cross-referencing ADCP and hand-held measurements throughout the season, and were attributed to tidal influence.

Although the 2014 estimates accounted for spatiotemporal variance in water velocity, they did not different substantially from the estimate in 2011 generated using fixed water velocities at a single site (Table 4). Going forward, a sensitivity analysis should be performed to model the effects of fixed vs. varying velocity on estimates from 2011 and 2013; if little difference is found, these abundance estimates should be generated and formally added to the ongoing time series reported in Table 2.

Distribution and Run Timing

The entirety of the run appeared to have been captured in 2014. Run timing on the Egegik River in 2014 was both earlier and more compressed than previous years (approximately 7 days; Figure 18). Run timing was also earlier and more compressed than both the Kvichak and Ugashik Rivers, with over half the run migrating during the three days of May 24–26 (Figure 19; Table 12). Temperature at the median migration date was 6.9 °C compared to 3.8 °C in 2013 (Table 9).

Horizontally, Egegik River smolts were distributed disproportionally to the right-center of the channel, roughly corresponding to the deepest section of the river bed (approximately 66% within a ten meter section; Figure 8). Relative to the other rivers, Egegik River smolts travelled deeper within the water column (both day and night) and were more likely to travel below one meter depth during the daytime than smolts from the Kvichak and Ugashik rivers (Figure 21). Diel timing of smolt emigration peaked at both dusk and dawn, with a less pronounced mid-day peak (Figure 10). Near field effects may have affected estimates from Transducer 5 at Site 1 (Figure 16).

Smolt Age, Weight, and Length

Of the three rivers sampled in 2014, the Egegik River was the only one with noticeable numbers of age 3 smolts. Age-1 and age-2 fish (Appendix A6) were similar in size (both length and weight) to Ugashik River cohorts (Appendix A4), but notably larger than Kvichak River cohorts (Appendix A2). The run peak of May 24–25 was mostly age-2 smolts, but accounted for the majority of each age class's total run: 54% of age 1, 53% of age 2, and 64% of age 3 smolts migrated during these two days (Table 12).

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. The usefulness in forecasting adult salmon returns will emerge as more smolt and adult return data are gathered. Large and unpredictable variability in marine survival may limit usefulness in this regard, but not affect the value in helping to understand variation in freshwater productivity and to refine escapement goals.

Sonar array configuration and duration of sampling can affect abundance estimates at each site, so it is necessary to have adequate spatial and temporal coverage. Several sonar changes implemented in 2012 (Wade et al. 2012b) were retained in 2013 and 2014 and functioned well.

Swimming speed is an important metric for calculating absolute smolt abundance. 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. Future work should estimate smolt swimming speeds over time and over different water velocities.

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. Key changes recommended for 2015 are as follows:

1. Describe smolt swimming speeds *in situ* on at least one river.
2. On the Egegik River, repeat water velocity measurements with the ADCP to examine interannual variability, and perform a retrospective data analysis to incorporate new flow information into abundance estimates from 2011 and 2013.
3. Evaluate how representative the smolt AWL catches are on each river, and examine ways to increase AWL sample sizes on the Ugashik and Egegik rivers.

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LITERATURE CITED

Baker, T. T., L. W. Fair, R. A. Clark, and J. J. Hasbrouck. 2006. Review of salmon escapement goals in Bristol Bay, Alaska, 2006. Alaska Department of Fish and Game, Fishery Manuscript Series No. 06-05, Anchorage.

Baker, T. T., L. W. Fair, F. W. West, G. B. Buck, X. Zhang, S. Fleischman, and J. Erickson. 2009. Review of salmon escapement goals in Bristol Bay, Alaska 2009. Alaska Department of Fish and Game, Fishery Manuscript Series No. 09-05, Anchorage.

Bue, B. G., and D. M. Eggers. 1989. An age-length key for sockeye salmon. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 2D89-5, Anchorage.

Burgner, R. L. 1968. Further studies of Alaska sockeye salmon. University of Washington, Seattle.

Cochran, W. G. 1977. Sampling Techniques. John Wiley and Sons, New York, New York.

Crawford, D. L., and F. W. West. 2001. Bristol Bay sockeye salmon smolt studies for 2000. Alaska Department of Fish and Game, Regional Information Report 2A01-12, Anchorage.

Crawford, D. L., and L. F. Fair. 2003. Bristol Bay salmon smolt studies using upward-looking sonar, 2002. Alaska Department of Fish and Game, Commercial Fisheries Division. Regional Information Report No. 2A03-17, Anchorage.

Dye, J. E., and C. J. Schwanke. 2009. Report to the Alaska Board of Fisheries for the recreational fisheries of Bristol Bay, 2002, 2008, and 2009. Alaska Department of Fish and Game, Special Publication No. 09-14, Anchorage.

Edmundson, J. A., & Todd, G. L. (2000). Limnological perspectives on stock and recruitment for Egegik and Ugashik River sockeye salmon. Alaska Department of Fish and Game, Division of Commercial Fisheries.

Jones, M., T. Sands, C. Brazil, G. Buck, F. West, P. Salomone, S. Morstad, and T. Kreig. 2014. 2013 Bristol Bay area annual management report. Alaska Department of Fish and Game, Fishery Management Report No. 14-23, Anchorage.

Maxwell, S., A. Mueller, D. Degan, D. Crawford, L. McKinley, and N. Hughes. 2009. An evaluation of the Bendix smolt counter used to estimate outmigrating sockeye salmon smolt in the Kvichak River, Alaska, and the development of a replacement sonar, 2000-2001. Alaska Department of Fish and Game, Fishery Manuscript No. 09-02, Anchorage.

Morstad, S., M. Jones, T. Sands, P. Salomone, G. Buck, and F. West. 2010. 2009 Bristol Bay area annual management report. Alaska Department of Fish and Game, Fishery Management Report No. 10-25, Anchorage.

Mueller, A. M., D. J. Degan, R. Kieser, and T. Mulligan. 2006. Estimating sockeye salmon smolt flux and abundance with side-looking sonar. North American Journal of Fisheries Management 26: 523-534.

Nemeth, M. J., G. D. Wade, D. J. Degan, and M. R. Link. 2014. Monitoring sockeye salmon smolt abundance and inriver distribution using sonar on the Kvichak and Ugashik rivers in 2012. Report prepared by LGL Alaska Research Associates, Inc., Anchorage, AK, and Aquacoustics, Inc. Sterling, AK, for the Bristol Bay Science and Research Institute, Dillingham, AK, 65 p.

Quinn, T. P. 2005. The behavior and ecology of Pacific Salmon and Trout. University of Washington Press, Seattle, Washington.

Ricker, W. E. 1975. Computation and interpretation of biological statistics of fish populations. Bulletin of the Fisheries Research Board of Canada No. 191, Ottawa, Canada.

Ruggerone, G. T., and M. R. Link. 2006. Collapse of Kvichak sockeye salmon production brood years 1991-1999: Population characteristics, possible factors, and management implications. Unpublished report prepared by Natural Resources Consultants, Inc. and LGL Alaska Research Associates, Inc. for the North Pacific Research Board, Anchorage, AK. xiv + 103 p.

Todd, G. T. 1994. A lightweight, inclined-plane trap for sampling salmon smolts in rivers. Alaska Fishery Research Bulletin 1 (2):168-175.

USGS. 2008. National Water Information System: Web Interface, 15300500. Retrieved on 20 December 2008 from the United States Geological Survey webpage: http://waterdata.usgs.gov/ak/nwis/nwismap/?site_no=15300500&agency_cd=USGS.

USGS. 2014. U.S. Geological Survey, 2007-2014, National Hydrography Dataset, 2007–2014. Retrieved on 25 November 2014 from the United States Geological Survey webpage: http://nhd.usgs.gov.

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

Wade, G. D., D. J. Degan, M. R. Link, and S. W. Raborn. 2012a. Estimates of hourly, daily, and seasonal sockeye salmon smolt abundance on the Kvichak and Ugashik Rivers in 2010. Report prepared by LGL Alaska Research Associates, Inc., Anchorage, AK, and Aquacoustics, Inc. Sterling, AK, for the Bristol Bay Science and Research Institute, Dillingham, AK, 61 p + Appendix A.

Wade, G. D., D. J. Degan, M. R. Link, and M. J. Nemeth. 2012b. Monitoring of sockeye salmon smolt abundance and inriver distribution using sonar on the Kvichak, Egegik, and Ugashik rivers in 2011. Report prepared by LGL Alaska Research Associates, Inc., Anchorage, AK, and Aquacoustics, Inc. Sterling, AK, for the Bristol Bay Science and Research Institute, Dillingham, AK, 64 p.

Wade, G. D., D. J. Degan, M. R. Link, and M. J. Nemeth. 2013. Monitoring sockeye salmon smolt abundance and inriver distribution using sonar on the Kvichak and Ugashik rivers in 2012. Report prepared by LGL Alaska Research Associates, Inc., Anchorage, AK, and Aquacoustics, Inc. Sterling, AK, for the Bristol Bay Science and Research Institute, Dillingham, AK, 65 p.

TABLES

Table 1. Mean water velocity (m/s) by date at sonar pods on the Kvichak, Ugashik, and Egegik rivers, 2014. NA indicates no pods used.

			Average water velocity (m/s) at sonar pods											
River	Site	Date	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12
Kvichak River														
	1	May 21	0.93	1.15	1.35	1.38	1.57	1.46	1.52	1.35	NA	NA	NA	NA
		May 30	0.90	1.27	1.35	1.41	1.55	1.57	1.57	1.46	NA	NA	NA	NA
		June 04	1.07	1.32	1.49	1.52	1.55	1.63	1.60	1.52	NA	NA	NA	NA
		June 10	1.04	1.24	1.41	1.46	1.52	1.57	1.63	1.57	NA	NA	NA	NA
	2	May 21	0.62	0.85	0.87	1.04	1.13	1.18	1.24	1.24	1.15	1.18	0.96	0.93
		May 30	0.71	0.76	0.93	1.10	1.15	1.24	1.21	1.21	1.21	1.04	0.93	0.90
		June 04	0.68	0.82	0.96	1.15	1.15	1.35	1.35	1.35	1.38	1.29	1.13	0.99
		June 10	0.76	0.87	0.96	1.13	1.15	1.27	1.32	1.32	1.29	1.35	1.18	1.04
Ugashik River														
	1	May 17	0.62	1.04	1.70	1.52	0.92	NA	NA	NA	NA	NA	NA	NA
		May 24	0.56	1.04	1.58	1.32	0.81	NA	NA	NA	NA	NA	NA	NA
		May 31	0.57	0.98	1.28	1.28	0.79	NA	NA	NA	NA	NA	NA	NA
		June 07	0.37	0.93	1.29	1.25	0.90	NA	NA	NA	NA	NA	NA	NA
	2	May 17	1.02	1.45	1.62	1.28	NA	NA	NA	NA	NA	NA	NA	NA
		May 24	1.02	1.15	1.56	1.20	NA	NA	NA	NA	NA	NA	NA	NA
		May 31	0.94	1.15	1.55	1.20	NA	NA	NA	NA	NA	NA	NA	NA
		June 07	0.91	1.07	1.51	1.08	NA	NA	NA	NA	NA	NA	NA	NA
Egegik River														
	1	May 15	0.53	0.64	0.59	0.54	0.43	0.37	NA	NA	NA	NA	NA	NA
		May 31	0.44	0.62	0.58	0.59	0.65	0.42	NA	NA	NA	NA	NA	NA
	2	May 15	0.67	0.53	0.69	0.65	0.67	0.57	0.38	NA	NA	NA	NA	NA
		May 31	0.52	0.58	0.82	0.65	0.67	0.62	0.53	NA	NA	NA	NA	NA

Table 2. Annual abundance estimates of sockeye salmon smolts, by site, on the Kvichak, Ugashik, and Egegik rivers since project inception in 2008.

		Site 1		Site 2		Difference, Sites 1 & 2	
River	Year	Abundance	95% CI	Abundance	95% CI	No. smolts	Percent
Kvichak River							
	2008	30,786,980	+/- Pending	26,965,627	+/- Pending	3,821,353	13.2
	2009	35,247,209	+/- 3,125,312	38,755,938	+/- Pending	3,508,729	13.6
	2010[a]	57,320,620	+/- Pending	Not operated			
	2010[b]	15,805,698	+/- Pending	15,891,807	+/- Pending	86,109	0.5
	2011	48,806,237	+/- 3,263,166	41,730,658	+/- 2,472,764	7,075,579	22.6
	2012	49,198,830	+/- 4,876,702	47,011,636	+/- 3,318,343	2,187,194	6.5
	2013	41,861,000	+/- 5,002,876	34,001,000	+/- 2,951,901	7,860,000	29.2
	2014	60,901,033	+/- 7,308,433	64,536,275	+/- 4,940,961	3,635,242	8.2
Ugashik River							
	2010	20,400,000	+/- Pending	Not operated			
	2012	11,193,920	+/- 1,260,791	11,064,475	+/- 997,811	129,445	1.7
	2013	3,060,357	+/- 335,010	3,200,639	+/- 550,402	140,282	6.4
	2014	7,570,811	+/- 841,044	7,646,234	+/- 1,110,604	75,423	1.4
Egegik River							
	2011	9,907,344	+/- 1,118,383	8,860,449	+/- 1,168,213	1,046,895	15.8
	2012	Not operated		Not operated			
	2013	Not reported		Not operated			
	2014	9,132,601	+/- 2,239,367	9,406,952	+/- 2,416,711	274,351	4.0

[a] Estimate for entire run, Site 1 only, May 24–June 13.

[b] Estimate for partial run when both sites operated concurrently, May 31 - June 13.

Table 3. Estimated daily abundance and annual proportion of sockeye salmon smolts at Site 1 on the Kvichak River, 2014.

Site 1, Kvichak River					
	Abundance			Percentage of total	
Date	Daily	95% CI	Cumulative	Daily	Cumulative
May 13	13,655	6,784	13,655	0	0
May 14	38,317	7,034	51,972	0	0
May 15	53,535	16,345	105,507	0	0
May 16	78,234	53,368	183,741	0	0
May 17	40,491	9,034	224,232	0	0
May 18	87,660	65,686	311,893	0	1
May 19	32,092	6,294	343,985	0	1
May 20	37,950	8,734	381,935	0	1
May 21	38,462	14,409	420,397	0	1
May 22	142,325	80,205	562,722	0	1
May 23	3,972,041	1,042,848	4,534,763	7	7
May 24	2,589,506	762,962	7,124,269	4	12
May 25	3,356,093	817,622	10,480,362	6	17
May 26	3,162,158	813,390	13,642,520	5	22
May 27	2,577,077	901,250	16,219,596	4	27
May 28	6,012,509	1,861,894	22,232,106	10	37
May 29	258,947	39,777	22,491,052	0	37
May 30	35,137	8,473	22,526,190	0	37
May 31	89,920	37,917	22,616,109	0	37
June 01	273,638	69,981	22,889,748	0	38
June 02	1,089,502	232,103	23,979,250	2	39
June 03	642,670	178,476	24,621,920	1	40
June 04	18,229,319	5,463,766	42,851,239	30	70
June 05	10,568,367	3,844,659	53,419,606	17	88
June 06	1,553,546	471,909	54,973,152	3	90
June 07	1,026,204	229,694	55,999,355	2	92
June 08	3,974,969	1,044,625	59,974,325	7	98
June 09	373,228	146,468	60,347,553	1	99
June 10	44,980	13,140	60,392,533	0	99
June 11	94,622	25,049	60,487,155	0	99
June 12	130,172	27,917	60,617,327	0	100
June 13	283,706	50,880	60,901,033	0	100
Total	60,901,033	7,308,433			

Table 4. Estimated daily abundance and annual proportion of sockeye salmon smolts at Site 2 on the Kvichak River, 2014.

Site 2, Kvichak River					
	Abundance			Percentage of total	
Date	Daily	95% CI	Cumulative	Daily	Cumulative
May 13	No sampling	NA	NA	NA	NA
May 14	1,410	485	1,410	0	0
May 15	26,297	10,045	27,707	0	0
May 16	13,659	2,215	41,366	0	0
May 17	59,644	21,285	101,010	0	0
May 18	20,871	3,956	121,882	0	0
May 19	22,593	3,893	144,474	0	0
May 20	37,418	27,589	181,892	0	0
May 21	11,788	2,053	193,680	0	0
May 22	69,376	13,338	263,055	0	0
May 23	3,629,679	1,160,376	3,892,735	6	6
May 24	2,163,591	485,828	6,056,326	3	9
May 25	2,781,366	668,868	8,837,691	4	14
May 26	4,282,599	792,595	13,120,290	7	20
May 27	4,291,944	983,753	17,412,234	7	27
May 28	6,913,239	1,626,290	24,325,473	11	38
May 29	284,146	50,927	24,609,619	0	38
May 30	93,200	21,878	24,702,819	0	38
May 31	84,381	21,848	24,787,200	0	38
June 01	333,152	91,498	25,120,352	1	39
June 02	1,295,932	249,020	26,416,284	2	41
June 03	1,245,902	412,618	27,662,186	2	43
June 04	20,562,185	3,400,135	48,224,371	32	75
June 05	9,264,078	2,357,759	57,488,450	14	89
June 06	788,226	202,309	58,276,676	1	90
June 07	1,318,250	252,931	59,594,925	2	92
June 08	3,952,291	806,586	63,547,216	6	98
June 09	330,729	114,460	63,877,946	1	99
June 10	58,897	21,708	63,936,843	0	99
June 11	84,412	21,457	64,021,255	0	99
June 12	112,804	36,311	64,134,059	0	99
June 13	402,215	76,909	64,536,275	1	100
Total	64,536,275	4,940,961			

Table 5. Estimated daily abundance and annual proportion of sockeye salmon smolts at Site 1 on the Ugashik River, 2014.

Site 1, Ugashik River					
	Abundance			Percentage of total	
Date	Daily	95% CI	Cumulative	Daily	Cumulative
May 09	765	444	765	0	0
May 10	20,585	8,010	21,350	0	0
May 11	33,152	14,223	54,501	0	1
May 12	17,252	7,044	71,754	0	1
May 13	20,285	8,551	92,039	0	1
May 14	23,367	10,437	115,407	0	2
May 15	20,972	10,850	136,378	0	2
May 16	9,328	4,499	145,706	0	2
May 17	9,213	4,253	154,919	0	2
May 18	8,151	7,274	163,070	0	2
May 19	9,866	5,783	172,936	0	2
May 20	18,476	8,960	191,412	0	3
May 21	179,424	52,325	370,836	2	5
May 22	85,039	31,387	455,875	1	6
May 23	172,945	76,988	628,821	2	8
May 24	321,384	159,683	950,205	4	13
May 25	547,296	218,735	1,497,501	7	20
May 26	917,621	326,124	2,415,123	12	32
May 27	453,784	164,207	2,868,907	6	38
May 28	359,958	99,924	3,228,865	5	43
May 29	227,317	78,509	3,456,182	3	46
May 30	162,232	75,562	3,618,414	2	48
May 31	185,400	63,136	3,803,814	2	50
June 01	170,702	45,824	3,974,516	2	52
June 02	406,300	105,046	4,380,815	5	58
June 03	1,792,368	637,954	6,173,183	24	82
June 04	553,851	165,586	6,727,034	7	89
June 05	317,700	100,342	7,044,735	4	93
June 06	116,489	33,901	7,161,224	2	95
June 07	136,915	56,331	7,298,138	2	96
June 08	91,938	38,284	7,390,076	1	98
June 09	71,288	17,710	7,461,364	1	99
June 10	77,187	21,428	7,538,551	1	100
June 11	32,260	14,371	7,570,811	0	100
June 12	No sampling	NA	NA	NA	100
Total	7,570,811	841,044			

Table 6. Estimated daily abundance and annual proportion of sockeye salmon smolts at Site 2 on the Ugashik River, 2014.

Site 2, Ugashik River					
	Abundance			Percentage of total	
Date	Daily	95% CI	Cumulative	Daily	Cumulative
May 09	No sampling	NA	NA	NA	0
May 10	110	86	110	0	0
May 11	416	239	527	0	0
May 12	299	207	826	0	0
May 13	338	168	1,164	0	0
May 14	2,813	3,117	3,977	0	0
May 15	1,762	530	5,738	0	0
May 16	3,836	1,355	9,574	0	0
May 17	9,375	2,757	18,949	0	0
May 18	21,420	12,099	40,369	0	1
May 19	15,918	5,518	56,287	0	1
May 20	12,255	5,305	68,542	0	1
May 21	13,473	8,282	82,015	0	1
May 22	40,876	21,306	122,891	1	2
May 23	100,516	43,364	223,407	1	3
May 24	178,713	73,740	402,120	2	5
May 25	351,639	124,273	753,758	5	10
May 26	1,058,272	433,543	1,812,030	14	24
May 27	1,425,207	766,403	3,237,238	19	42
May 28	963,968	513,554	4,201,206	13	55
May 29	480,721	182,186	4,681,926	6	61
May 30	161,698	72,436	4,843,624	2	63
May 31	200,886	70,218	5,044,511	3	66
June 01	188,851	76,212	5,233,362	2	68
June 02	459,438	145,146	5,692,800	6	74
June 03	1,168,613	225,943	6,861,413	15	90
June 04	255,346	161,463	7,116,759	3	93
June 05	276,865	117,856	7,393,625	4	97
June 06	36,652	18,083	7,430,276	0	97
June 07	134,332	91,741	7,564,608	2	99
June 08	43,562	27,890	7,608,170	1	100
June 09	12,121	4,277	7,620,291	0	100
June 10	19,527	7,814	7,639,817	0	100
June 11	4,425	2,094	7,644,242	0	100
June 12	1,991	717	7,646,234	0	100
Total	7,646,234	1,110,604			

Table 7. Estimated daily abundance and annual proportion of sockeye salmon smolts at Site 1 on the Egegik River, 2014.

Site 1, Egegik River					
	Abundance			Percentage of total	
Date	Daily	95% CI	Cumulative	Daily	Cumulative
May 15	No sampling	NA	NA	NA	0
May 16	5,418	2,327	5,418	0	0
May 17	4,860	1,490	4,860	0	0
May 18	3,204	1,144	3,204	0	0
May 19	54,458	30,224	54,458	1	1
May 20	122,373	133,871	122,373	1	2
May 21	2,670	1,063	2,670	0	2
May 22	592,157	218,879	592,157	6	9
May 23	404,766	161,529	404,766	4	13
May 24	2,403,480	1,582,728	2,403,480	26	39
May 25	2,646,982	1,398,729	2,646,982	29	68
May 26	848,350	585,150	848,350	9	78
May 27	209,253	89,252	209,253	2	80
May 28	89,905	46,512	89,905	1	81
May 29	415,046	289,158	415,046	5	85
May 30	135,013	52,648	135,013	1	87
May 31	181,446	75,100	181,446	2	89
June 01	183,215	73,656	183,215	2	91
June 02	44,937	19,193	44,937	0	91
June 03	42,098	14,668	42,098	0	92
June 04	69,945	26,566	69,945	1	93
June 05	105,632	45,941	105,632	1	94
June 06	125,397	48,808	125,397	1	95
June 07	146,493	56,237	146,493	2	97
June 08	71,597	19,402	71,597	1	98
June 09	93,290	23,082	93,290	1	99
June 10	59,164	16,600	59,164	1	99
June 11	41,371	12,181	41,371	0	100
June 12	30,082	13,892	30,082	0	100
Total	9,132,601	2,239,367			

Table 8. Estimated daily abundance and annual proportion of sockeye salmon smolts at Site 2 on the Egegik River, 2014.

Site 2, Egegik River					
	Abundance			Percentage of total	
Date	Daily	95% CI	Cumulative	Daily	Cumulative
May 15	7,659	3,242	7,659	0	0
May 16	9,967	3,779	17,627	0	0
May 17	8,968	3,132	26,595	0	0
May 18	11,538	5,381	38,133	0	0
May 19	8,481	2,620	46,614	0	0
May 20	12,507	5,477	59,120	0	1
May 21	6,847	3,323	65,967	0	1
May 22	575,304	247,748	641,271	6	7
May 23	298,972	169,084	940,243	3	10
May 24	3,189,039	1,985,896	4,129,281	34	44
May 25	1,995,021	855,331	6,124,303	21	65
May 26	1,183,245	930,712	7,307,547	13	78
May 27	463,997	233,047	7,771,545	5	83
May 28	227,723	120,395	7,999,267	2	85
May 29	305,537	302,448	8,304,804	3	88
May 30	146,018	136,648	8,450,822	2	90
May 31	137,438	58,460	8,588,260	1	91
June 01	160,950	70,494	8,749,210	2	93
June 02	35,470	15,679	8,784,679	0	93
June 03	72,394	54,044	8,857,073	1	94
June 04	52,108	29,629	8,909,182	1	95
June 05	60,629	17,866	8,969,811	1	95
June 06	146,037	108,125	9,115,847	2	97
June 07	115,890	63,511	9,231,737	1	98
June 08	50,167	23,252	9,281,904	1	99
June 09	69,033	22,989	9,350,937	1	99
June 10	35,004	11,163	9,385,941	0	100
June 11	6,141	2,990	9,392,081	0	100
June 12	14,871	13,351	9,406,952	0	100
Total	9,406,952	2,416,711			

Table 9. Median migration date of sockeye smolts from the Kvichak, Ugashik, and Egegik rivers since project inception in 2008, along with corresponding water temperature.

River	Year	Median migration date	Water temp.[a] (°C)
Kvichak River			
	2008	June 01	6.3
	2009	May 28	6.0
	2010	May 27	4.7
	2011	May 28	4.5
	2012	May 27	5.1
	2013	May 27	6.5
	2014	June 04	7.3
Ugashik River			
	2010	June 02	Pending
	2012	June 01	5.5
	2013	June 02	6.8
	2014	May 28	8
Egegik River			
	2013	May 31	3.8
	2014	May 25	6.9

[a] Water temperature is calculated as daily average.

Table 10. Daily abundance and age composition from the Kvichak River, 2014. Age composition not reported on dates without scale sampling.

	Kvichak River age composition				
	Daily abundance	%		*n*	
Date	estimate	Age 1	Age 2	Age 1	Age 2
May 12		0%	100%		
May 13	13,655				
May 14	39,864	0%	100%	0	39,864
May 15	53,535	3%	97%	1,373	52,163
May 16	78,234				
May 17	40,491				
May 18	87,660	0%	100%	0	87,660
May 19	32,092	2%	98%	648	31,444
May 20	37,950	0%	100%	0	37,950
May 21	38,462	8%	92%	3,205	35,257
May 22	142,325	3%	97%	4,518	137,807
May 23	3,972,041	1%	99%	26,658	3,945,383
May 24	2,589,506	5%	95%	119,720	2,469,786
May 25	3,356,093	7%	93%	223,740	3,132,353
May 26	3,162,158	11%	89%	358,378	2,803,780
May 27	2,577,077	27%	73%	684,065	1,893,011
May 28	6,012,509	14%	86%	831,409	5,181,100
May 29	258,947	21%	79%	55,427	203,520
May 30	35,137	67%	33%	23,425	11,712
May 31	89,920	66%	34%	59,038	30,882
June 01	273,638	81%	19%	222,077	51,562
June 02	1,089,502	67%	33%	727,547	361,955
June 03	642,670	82%	18%	524,563	118,107
June 04	18,229,319	59%	41%	10,744,433	7,484,886
June 05	10,568,367	66%	34%	6,975,122	3,593,245
June 06	1,553,546	83%	17%	1,288,306	265,240
June 07	1,026,204	94%	6%	959,612	66,592
June 08	3,974,969	93%	7%	3,708,640	266,330
June 09	373,228	95%	5%	356,405	16,823
June 10	44,980	93%	7%	41,970	3,010
June 11	94,622	72%	28%	68,355	26,266
June 12	130,172	65%	35%	85,195	44,976
June 13	283,706				
Total	60,902,580	46.4%	53.6%	28,093,831	32,392,663

Note that percentage and age totals may not add to 100% because of unknown ages.

Table 11. Daily abundance and age composition from the Ugashik River, 2014. Age composition not reported on dates without scale sampling.

		Ugashik River age composition			
	Daily abundance	%		*n*	
Date	estimate	Age 1	Age 2	Age 1	Age 2
May 09	765				
May 10	17,311				
May 11	16,713				
May 12	8,761				
May 13	10,268				
May 14	13,058				
May 15	11,309	67%	33%	7,539	3,770
May 16	6,520				
May 17	9,066	59%	41%	5,319	3,747
May 18	14,590	35%	65%	5,149	9,440
May 19	12,316	45%	55%	5,598	6,718
May 20	14,752	32%	68%	4,708	10,044
May 21	96,218	34%	66%	32,917	63,302
May 22	62,438	10%	90%	6,042	56,396
May 23	134,973	5%	95%	6,886	128,087
May 24	248,946				
May 25	441,975	51%	49%	225,407	216,568
May 26	968,226				
May 27	930,893	63%	37%	586,867	344,026
May 28	657,739	83%	17%	543,900	113,839
May 29	344,583				
May 30	161,485	41%	59%	66,878	94,608
May 31	180,237				
June 01	175,852	49%	51%	86,813	89,039
June 02	422,136				
June 03	1,420,786	73%	27%	1,033,299	387,487
June 04	397,928				
June 05	273,432	94%	6%	256,861	16,572
June 06	72,896	96%	4%	69,981	2,916
June 07	133,985	90%	10%	120,587	13,399
June 08	67,462	90%	10%	60,716	6,746
June 09	40,675	99%	1%	40,110	565
June 10	47,888	91%	9%	43,433	4,455
June 11	18,326	98%	2%	17,936	390
June 12	1,648	100%	0%	1,648	0
Total	7,436,159	67.3%	32.7%	3,228,594	1,572,111

Table 12. Abundance and age composition from the Egegik River, 2014. Dates were combined until age samples reached a minimum sample size of 50 fish (all ages combined). Daily abundances are presented in Tables 7 and 8.

		Egegik River age composition					
	Daily abundance	%			*n*		
Date	estimate	Age 1	Age 2	Age 3	Age 1	Age 2	Age 3
May 16–23	1,068,903	9.7%	85.8%	4.5%	103,700	917,343	47,861
May 24–25	5,117,261	18.3%	61.3%	20.4%	935,413	3,136,386	1,045,462
May 26–29	1,871,528	23.2%	59.4%	17.4%	433,977	1,112,067	325,483
May 30–31	299,958	26.7%	61.1%	12.2%	79,989	183,307	36,661
June 1–4	330,558	36.8%	45.6%	17.6%	121,645	150,735	58,178
June 5–6	218,847	3.2%	60.6%	36.2%	6,984	132,705	79,158
June 7–9	273,235	13.3%	75.0%	11.7%	36,431	204,926	31,877
June 10–11	93,702	11.1%	75.6%	13.3%	10,411	70,797	12,494
Total	9,273,993	18.6%	63.7%	17.7%	1,728,552	5,908,266	1,637,175

FIGURES

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

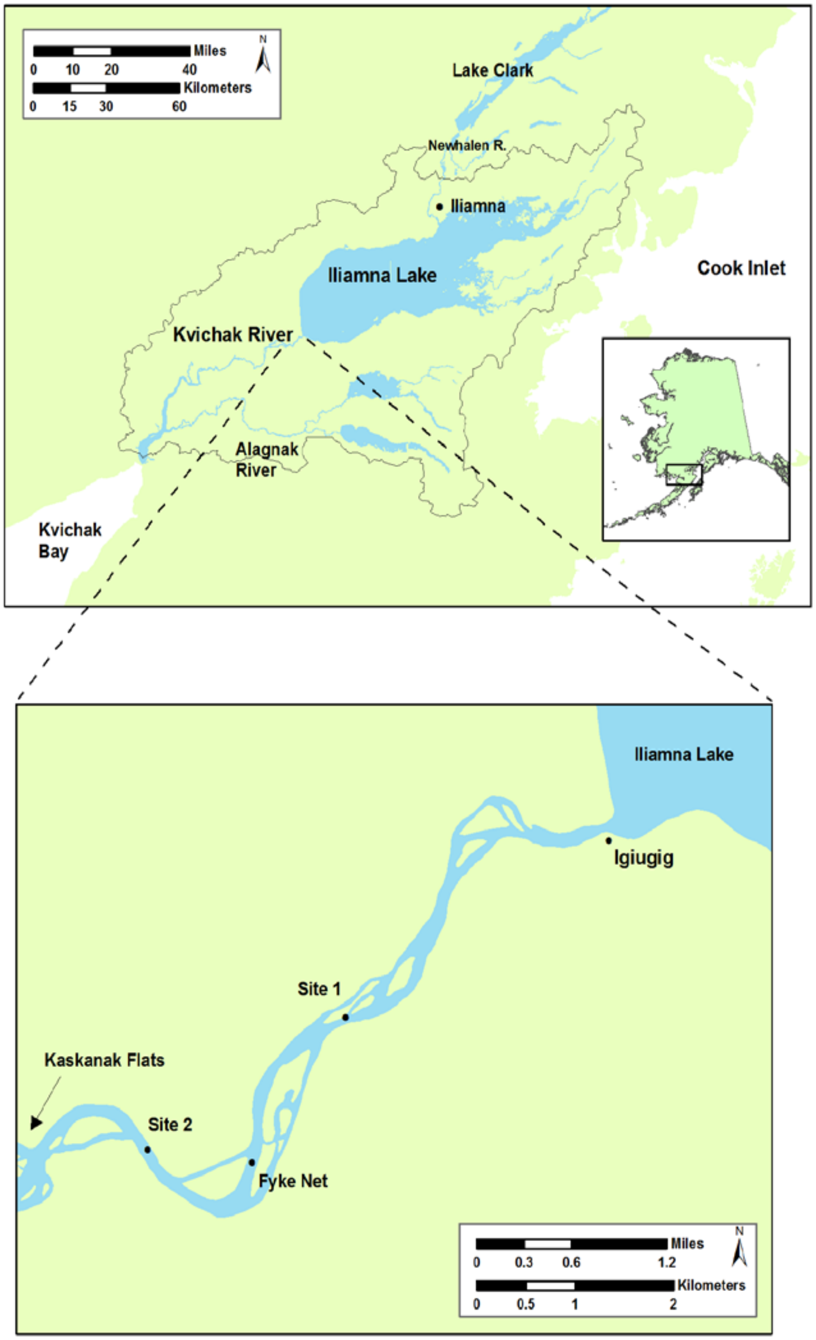


Figure 2. The Kvichak River, Iliamna Lake, and Lake Clark drainages in Southwestern Alaska, showing locations of sonar sites 1 and 2 operated near the village of Igiugig, 2014.

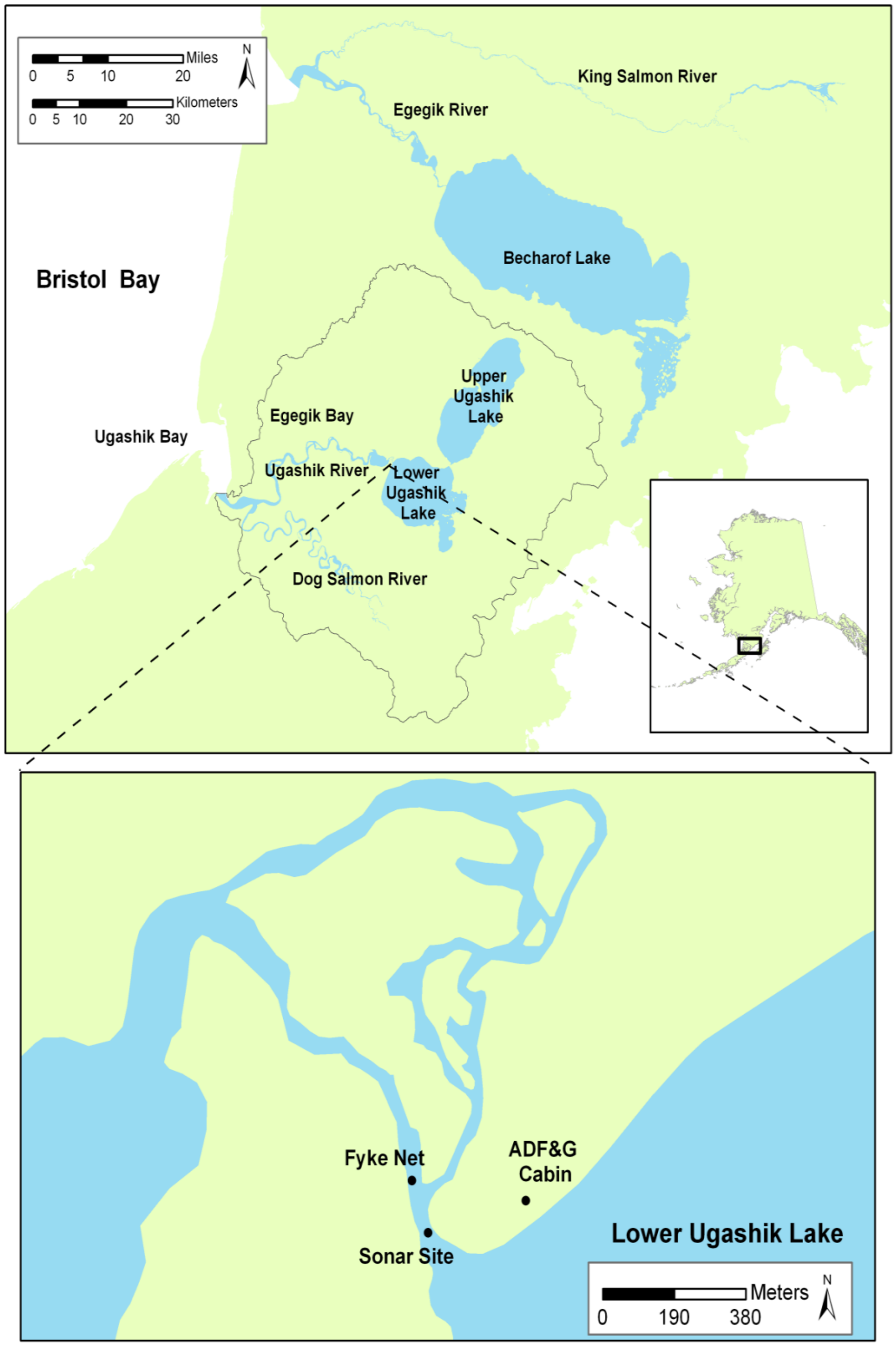


Figure 3. The Ugashik River watershed, showing locations of sonar systems and fyke net operated near the outlet of Lower Ugashik Lake, 2014.

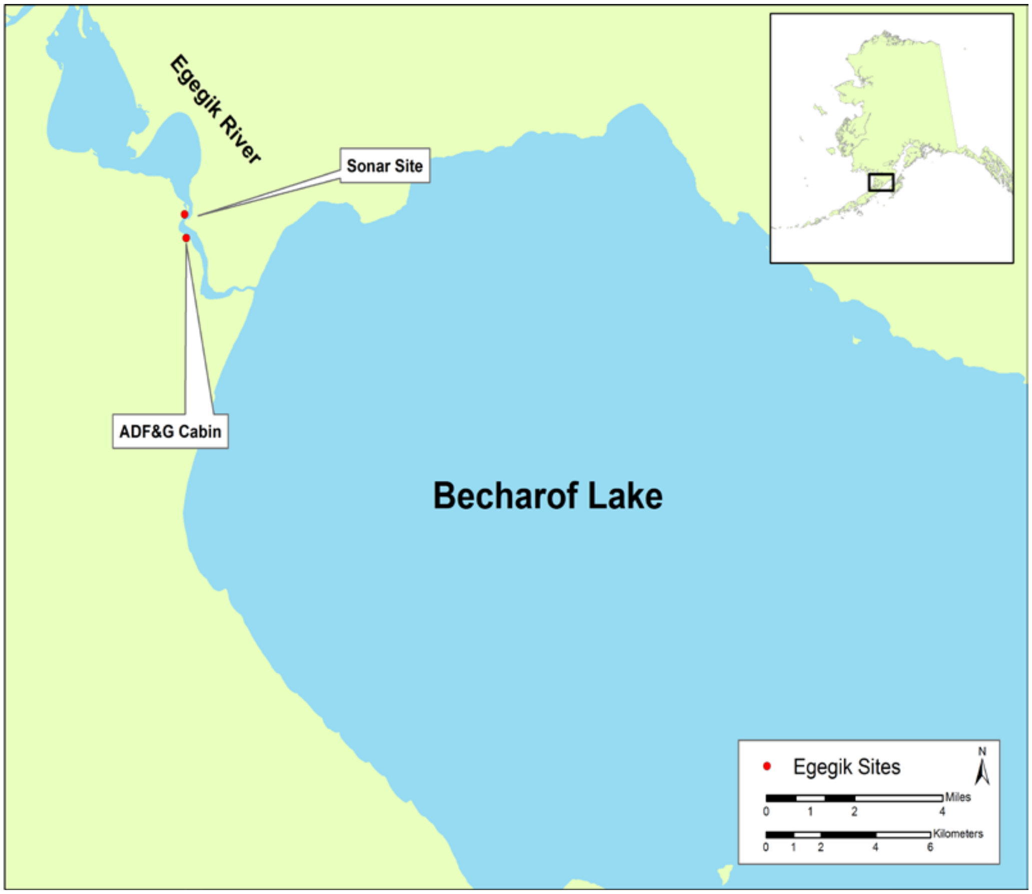


Figure 4. The Egegik River watershed, showing locations of the sonar systems and fyke nets operated near the outlet of Becharof Lake, 2014.

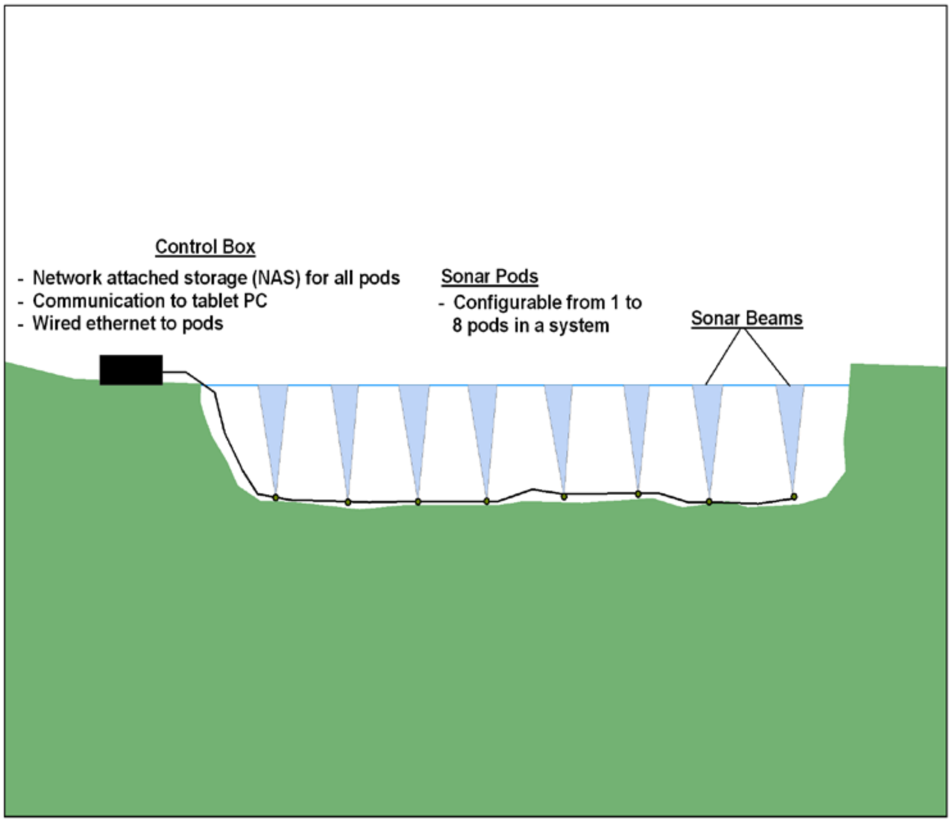


Figure 5. Conceptual drawing of the smolt sonar systems used in 2014.

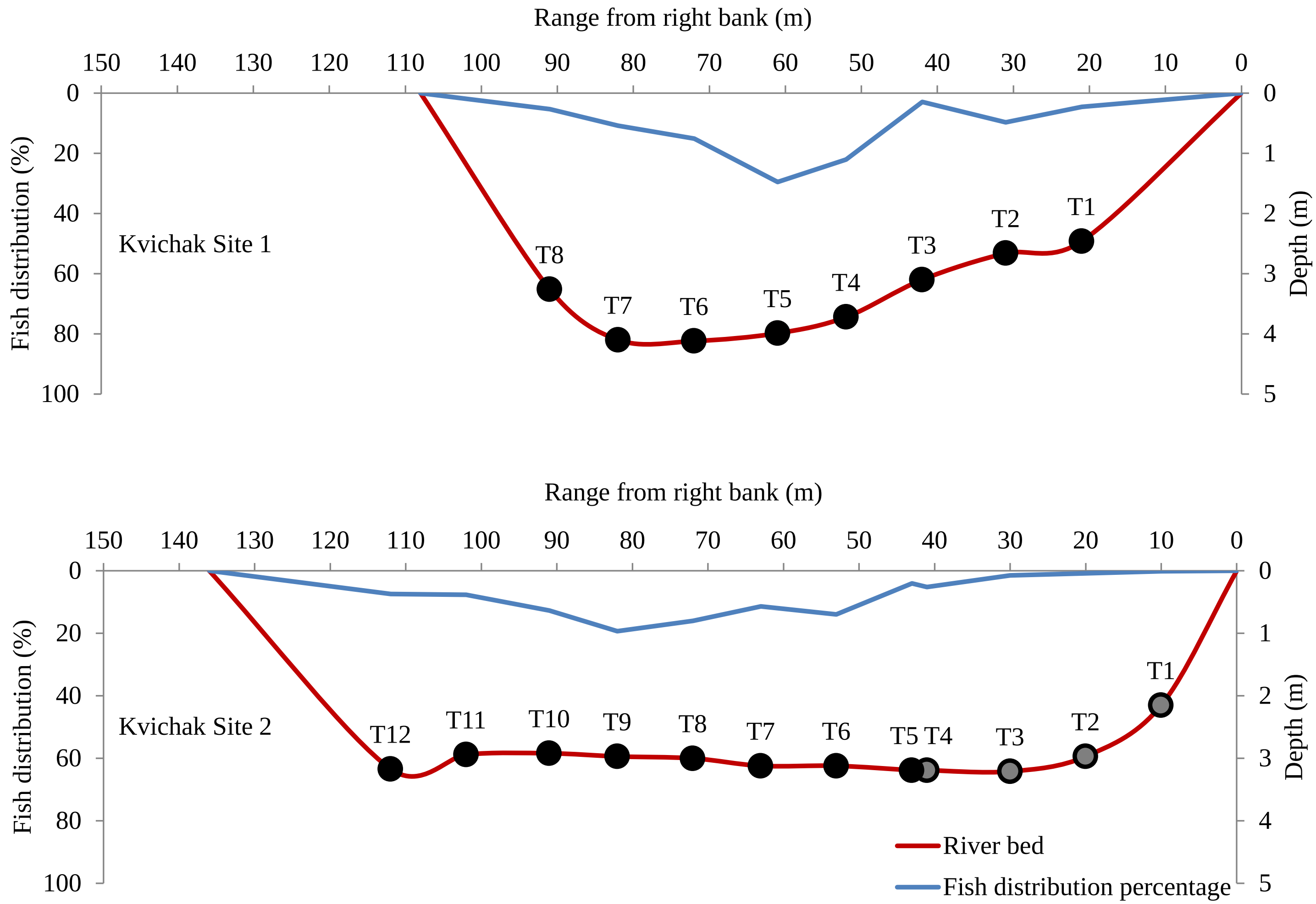


Figure 6. Cross river distribution of sockeye salmon smolts, interpolated river bed profile, and transducer locations in the Kvichak River, 2014. Smolt distribution is for total estimated abundance in 2014.

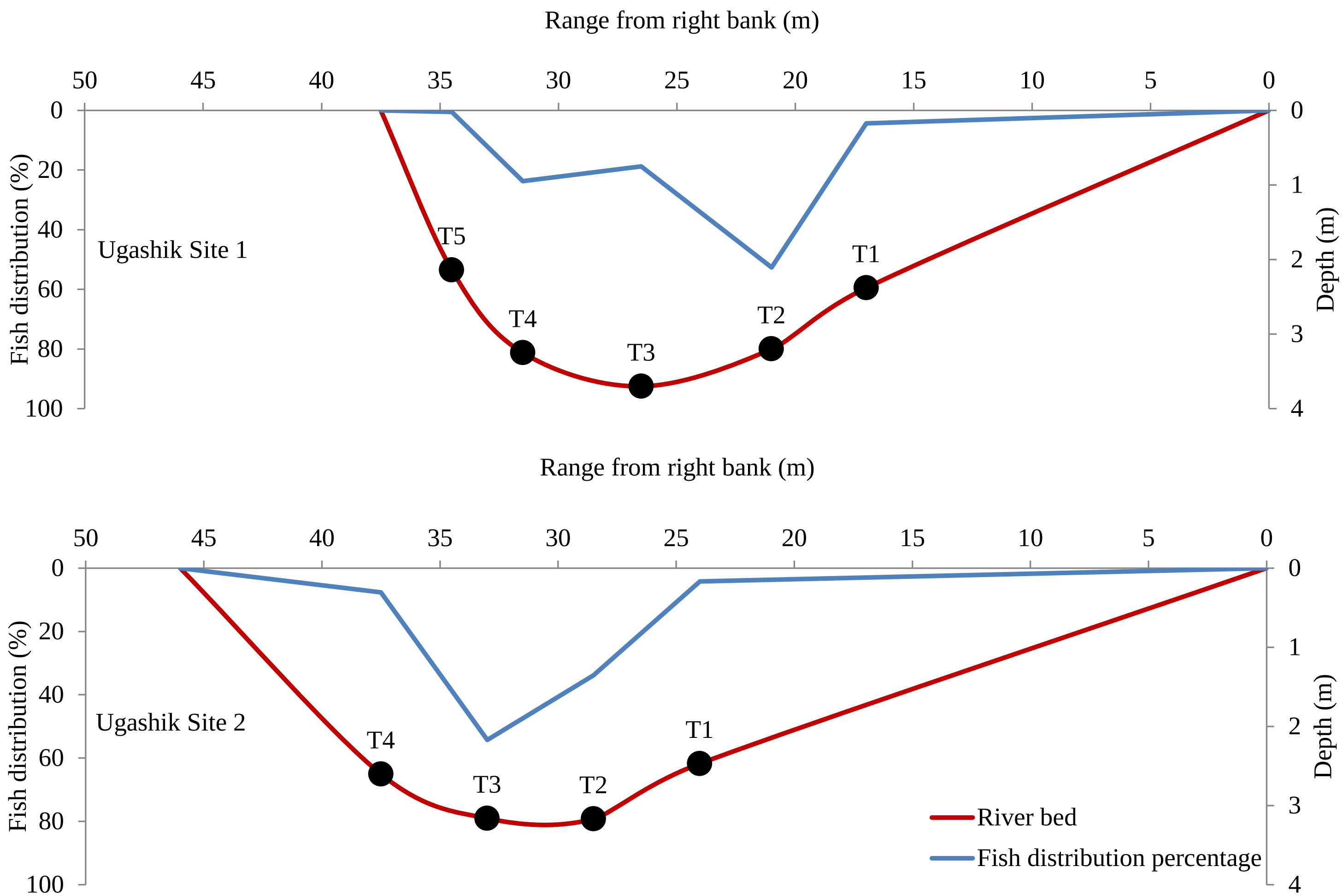


Figure 7. Cross river distribution of sockeye salmon smolts, interpolated river bed profile, and transducer locations in the Ugashik River, 2014. Smolt distribution is for total estimated abundance in 2014.

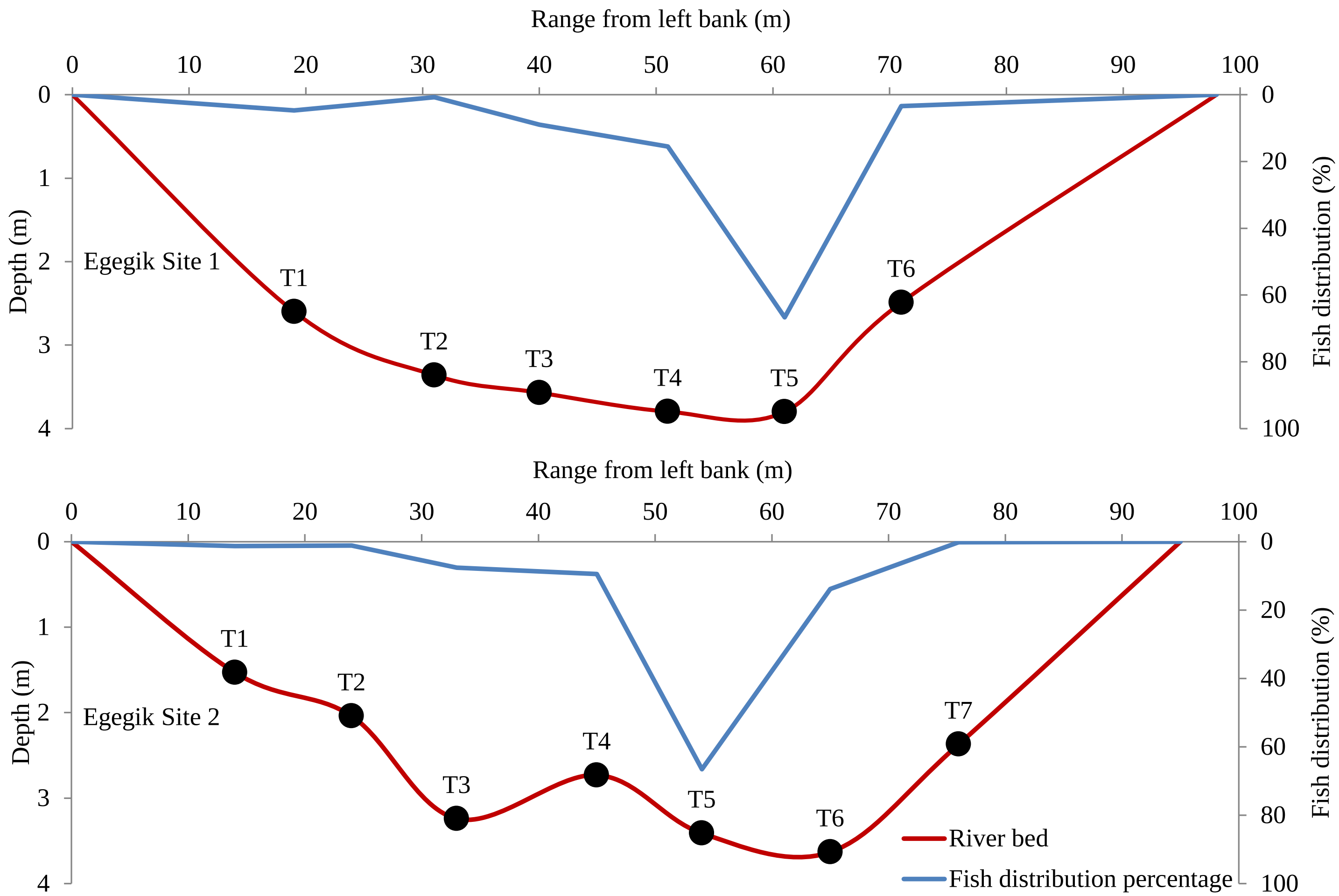


Figure 8. Cross river distribution of sockeye salmon smolts, interpolated river bed profile, and transducer locations in the Egegik River, 2014. Smolt distribution is for total estimated abundance in 2014.

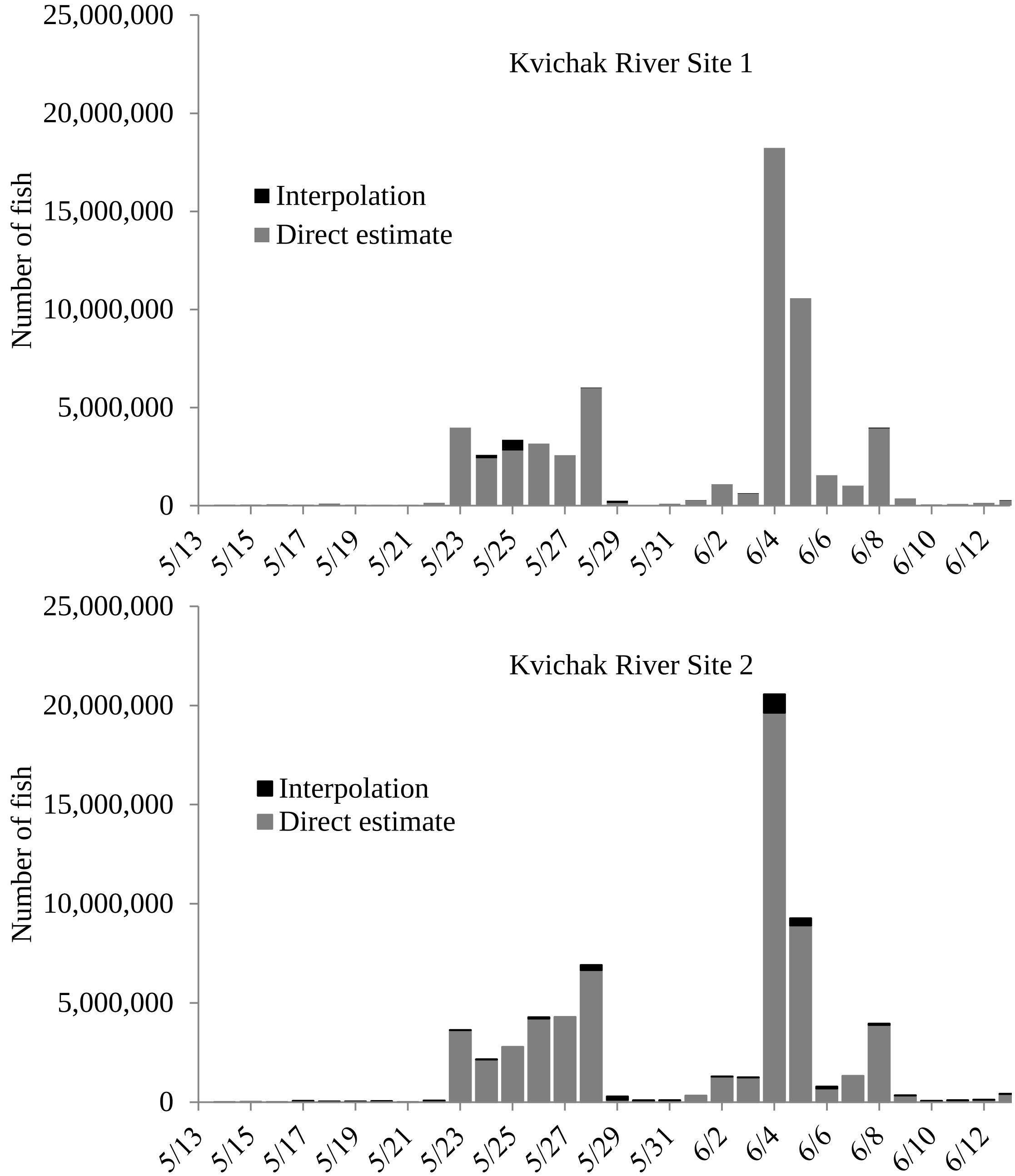


Figure 9. Daily interpolations and direct estimates of abundance of sockeye salmon smolts on the Kvichak River, 2014.

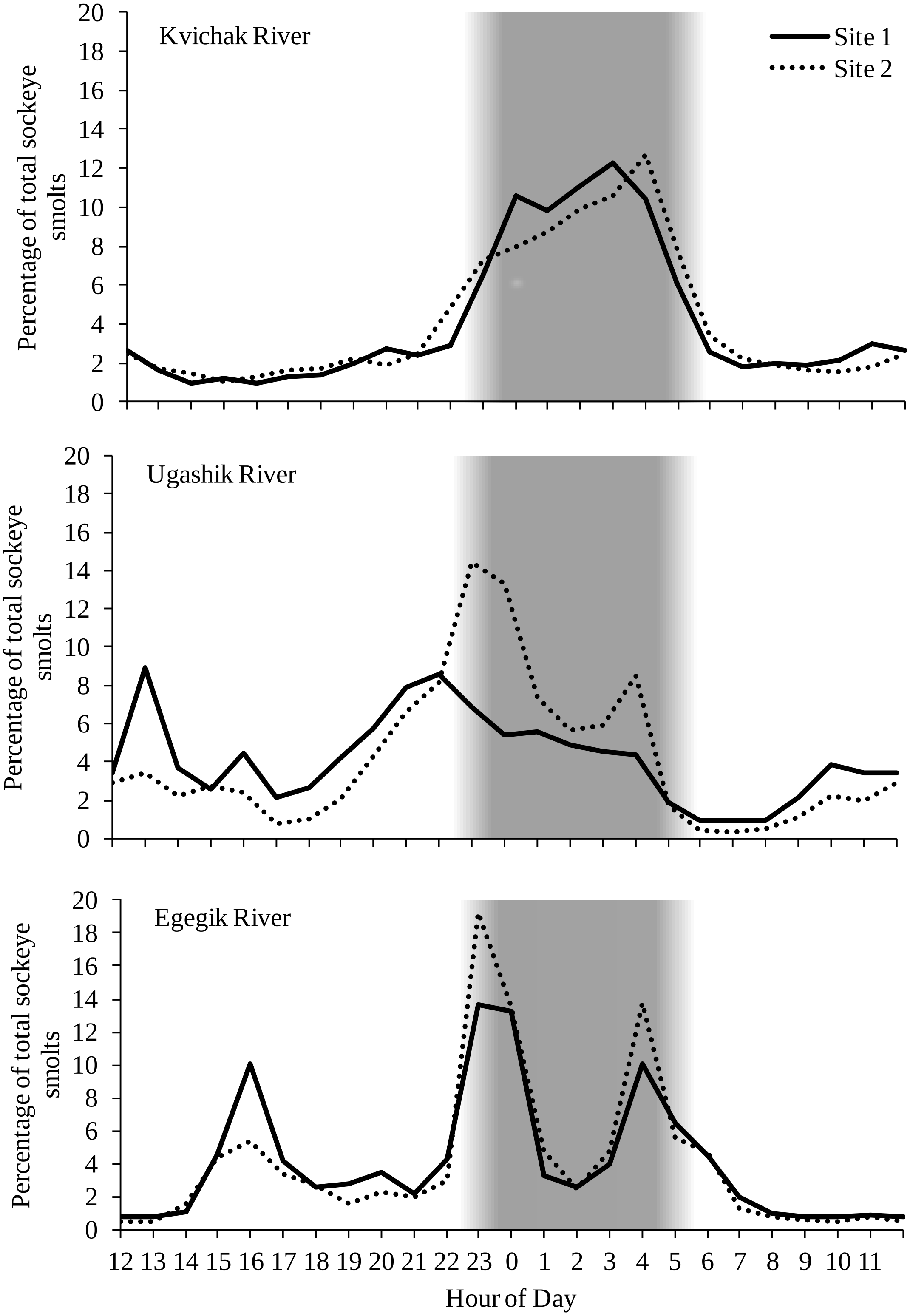


Figure 10. Proportion of total smolts by hour of the day at sonar sites on the Kvichak, Ugashik, and Egegik rivers in 2014. Shading shows hours considered nighttime (2300–0500) during the study period.

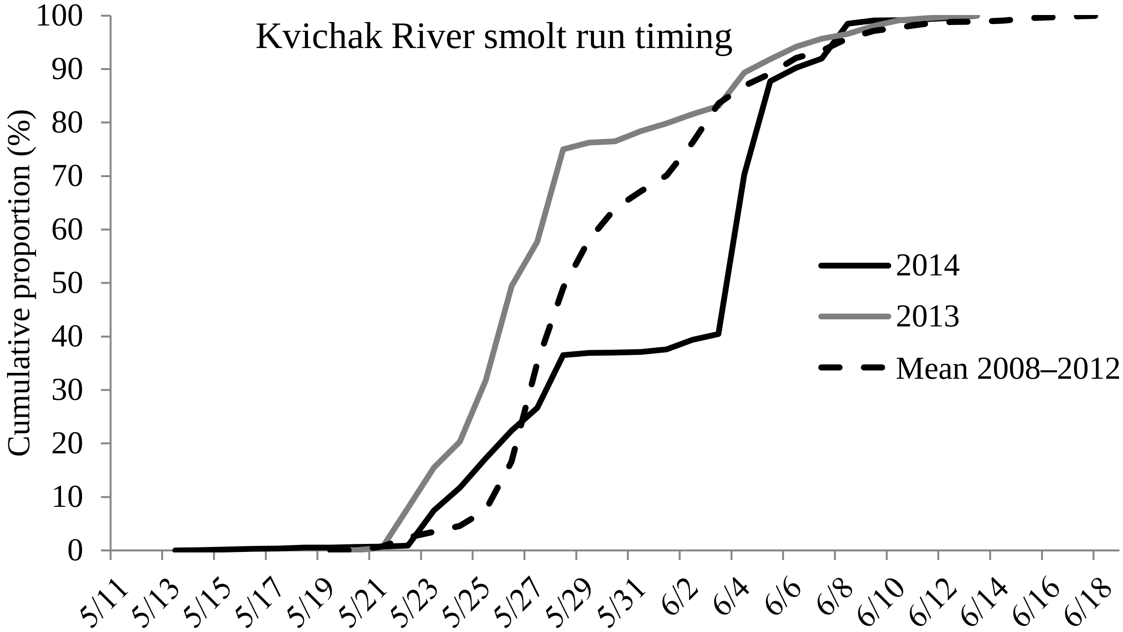


Figure 11. Annual run timing of sockeye salmon smolts at Site 1 on the Kvichak River in 2014, 2013, and the 2008–2012 mean.

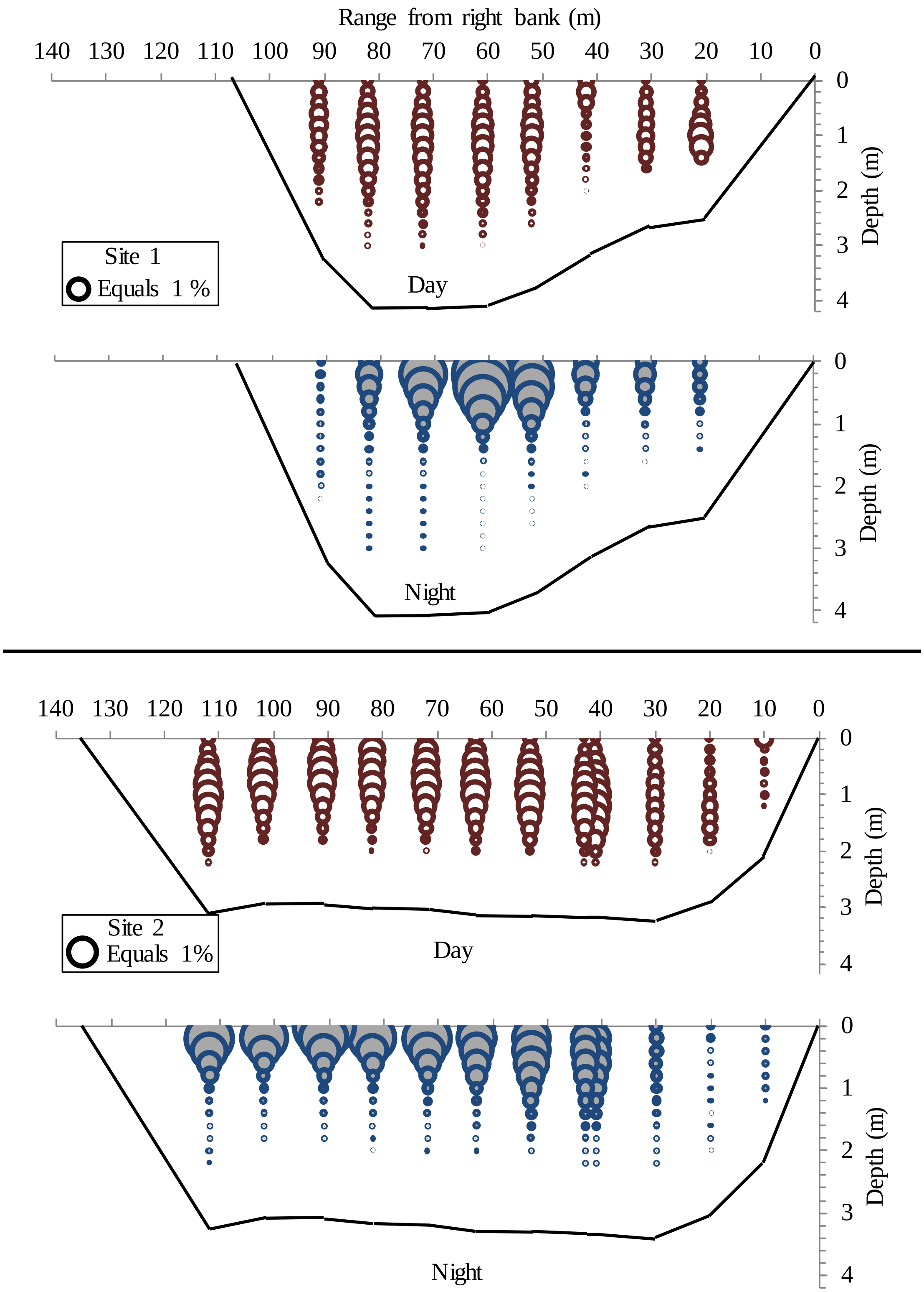


Figure 12. Vertical distribution of sockeye salmon smolts among Kvichak River transducers in 2014. Distributions are raw detections (not expanded for total abundance) and thus only comparable for vertical distribution. For horizontal comparisons among transducers, see Figures 6–8.

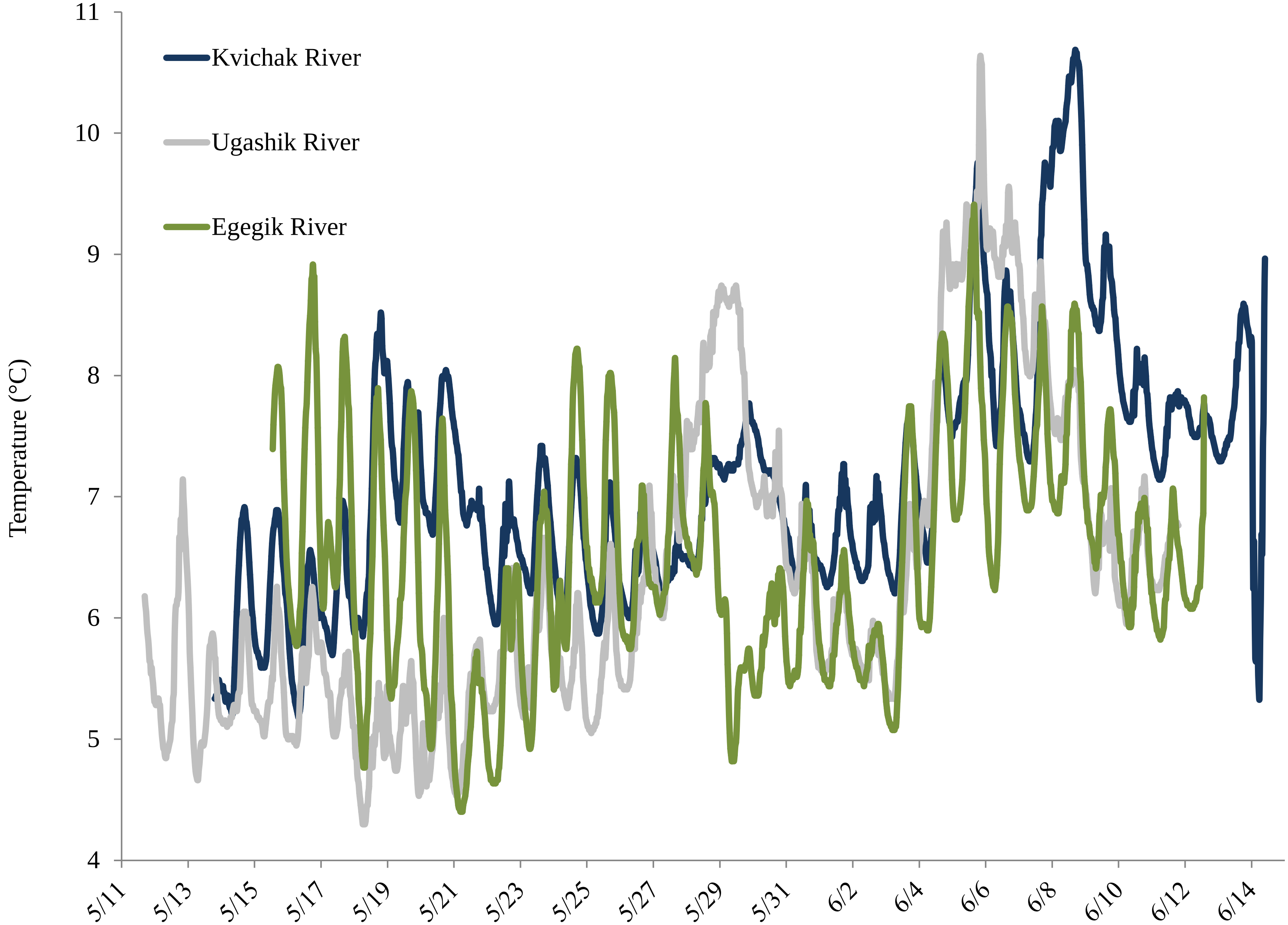


Figure 13. Season long water temperatures in the Kvichak, Ugashik, and Egegik rivers, 2014.

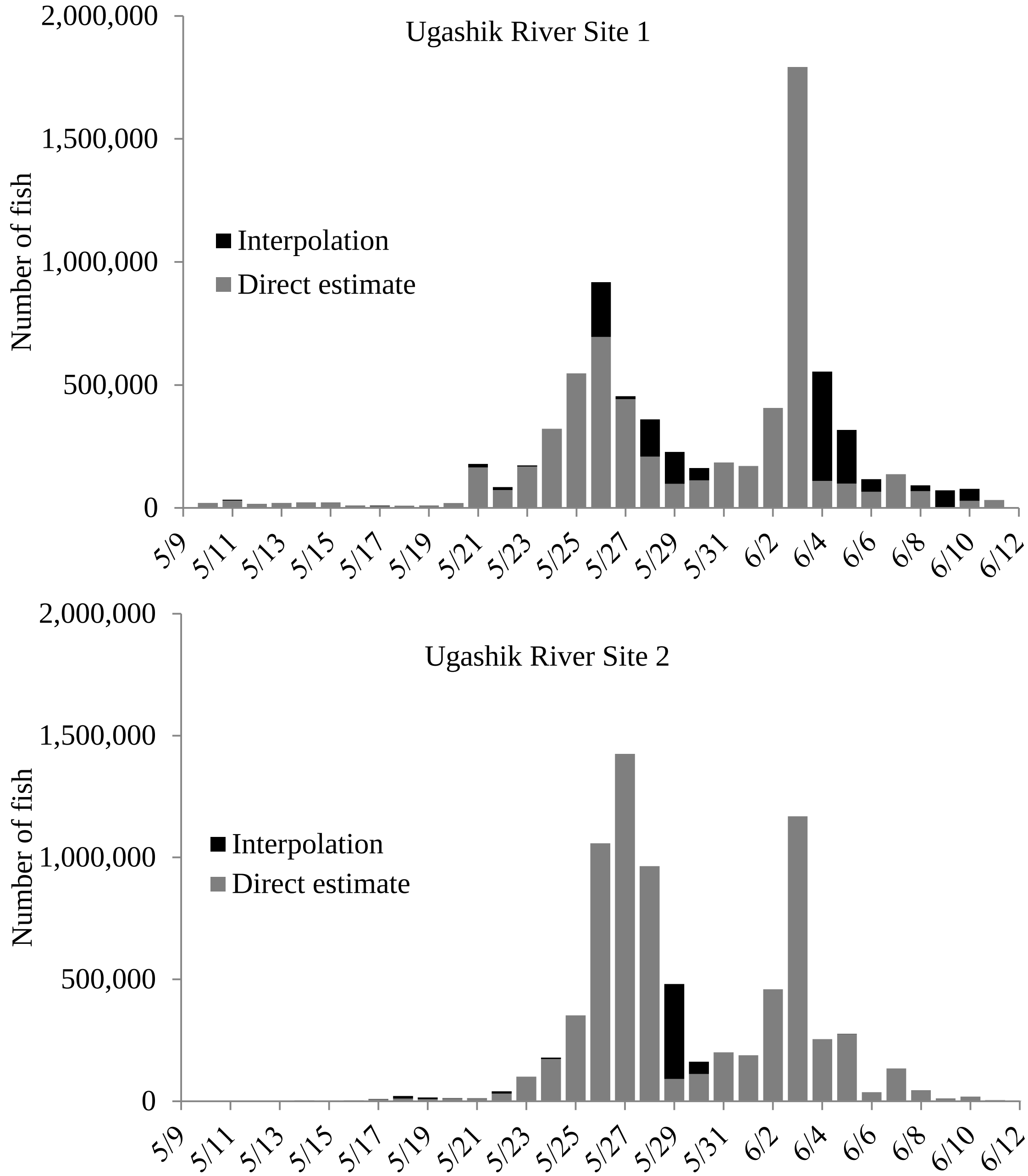


Figure 14. Daily interpolations and direct estimates of abundance of sockeye salmon smolts on the Ugashik River, 2014.

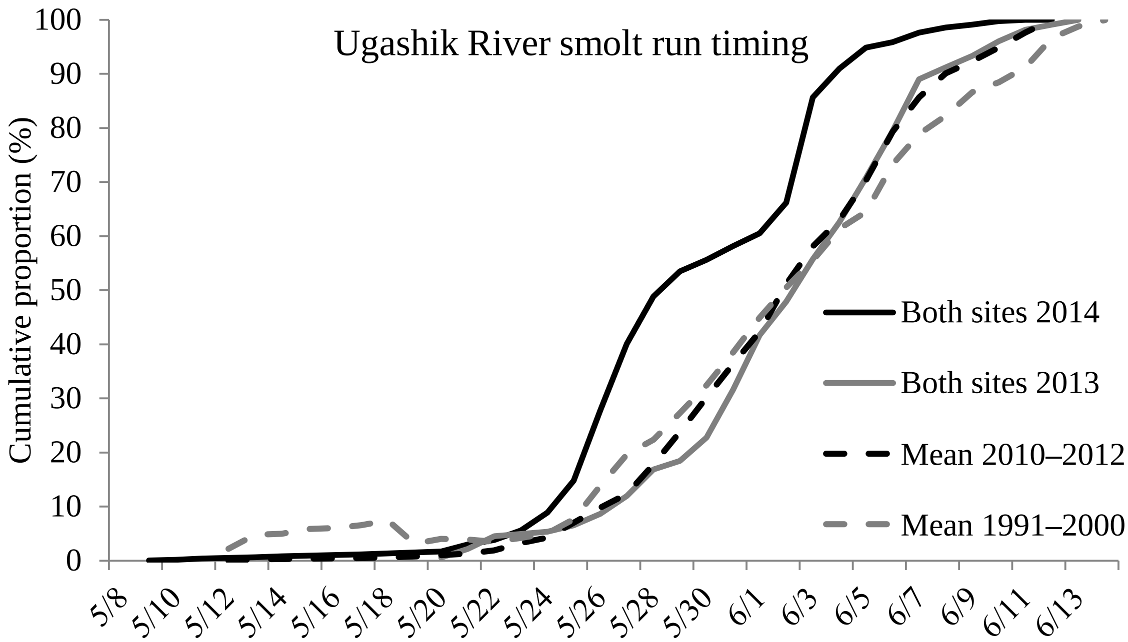


Figure 15. Annual run timing of sockeye salmon smolts on the Ugashik River in 2014, 2013, 2010–2012 mean, and 1991–2000 mean which utilized a Bendix sonar system. 2013 and 2014 data are for both sonar sites combined.

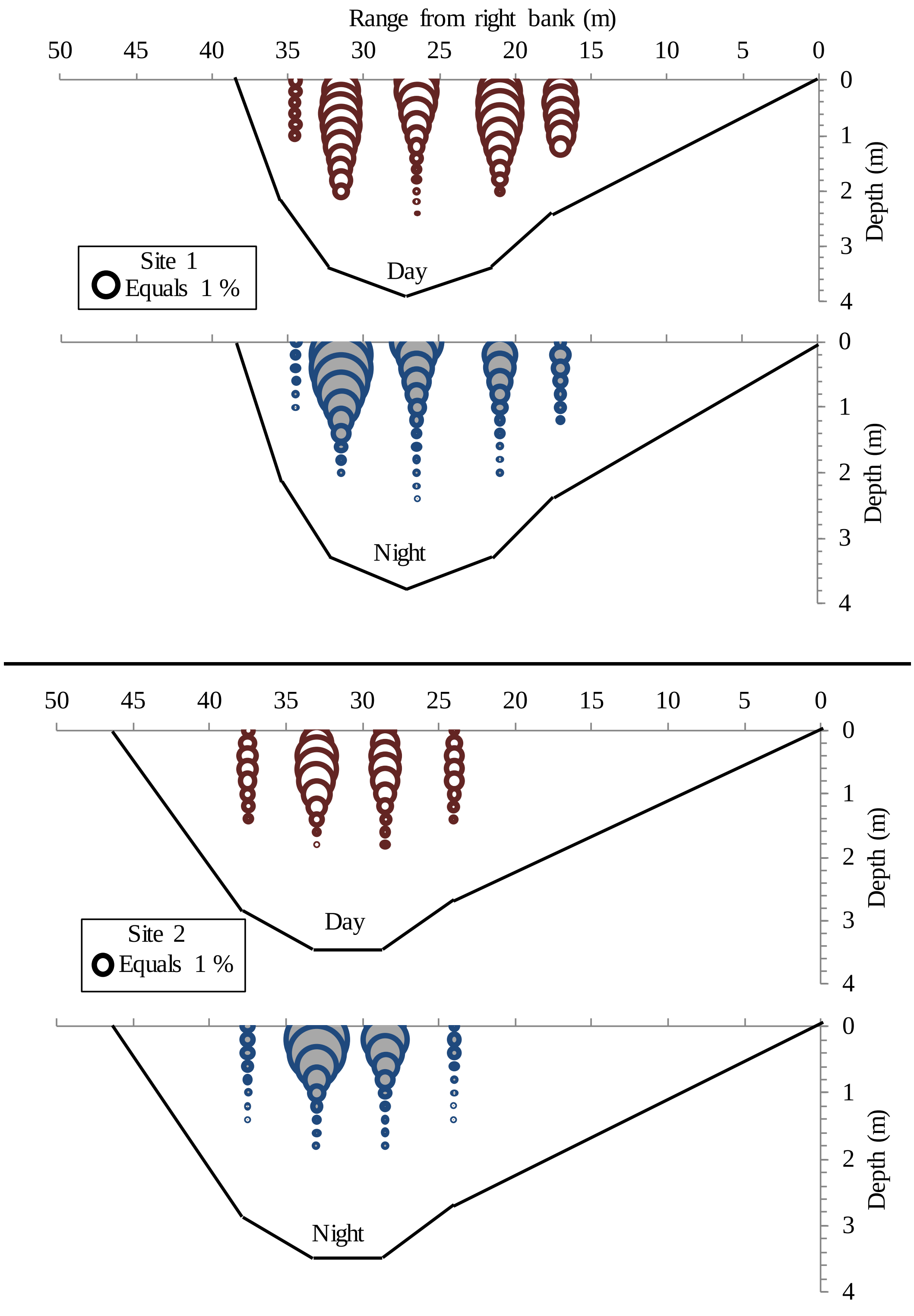


Figure 16. Vertical distribution of sockeye salmon smolts among Ugashik River transducers in 2014. Distributions are raw detections (not expanded for total abundance) and thus only comparable for vertical distribution. For horizontal comparisons among transducers, see Figures 6–8.

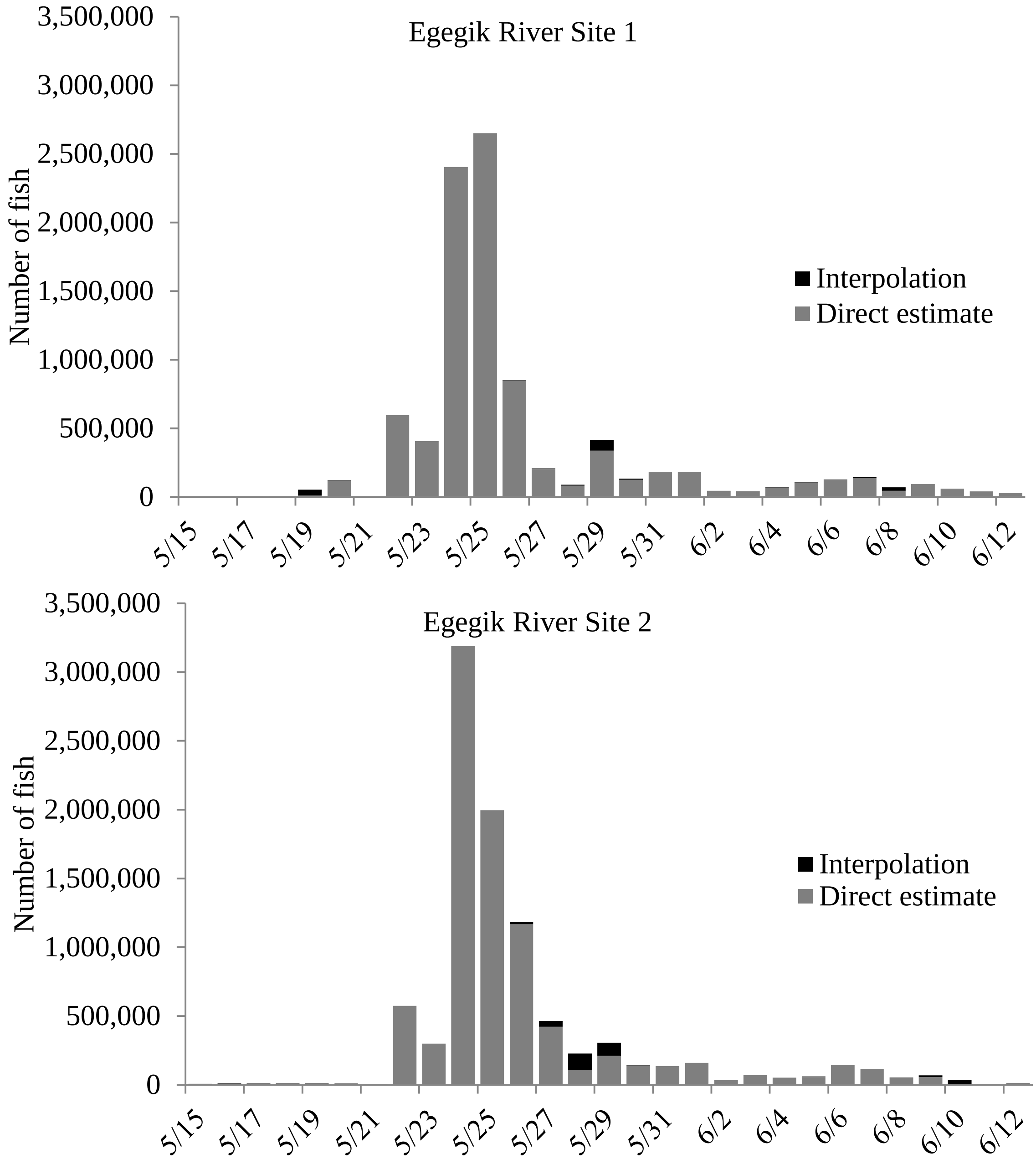


Figure 17. Daily interpolations and direct estimates of abundance of sockeye salmon smolts on the Egegik River, 2014.

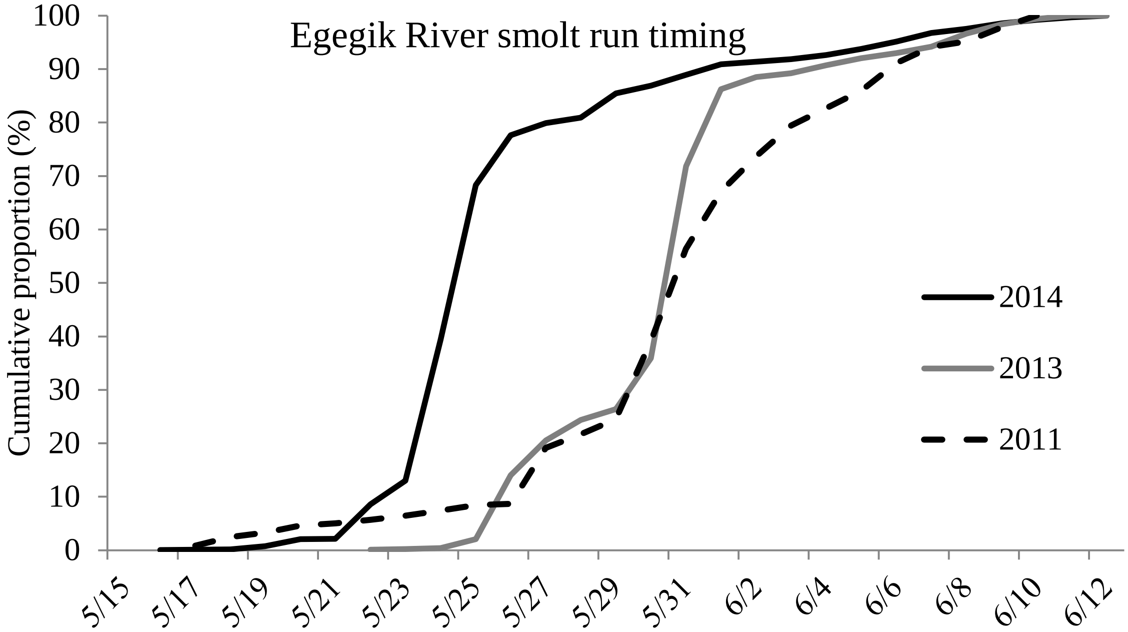


Figure 18. Annual run timing of sockeye salmon smolts at Site 1 on the Egegik River in 2014, 2013, and 2011.

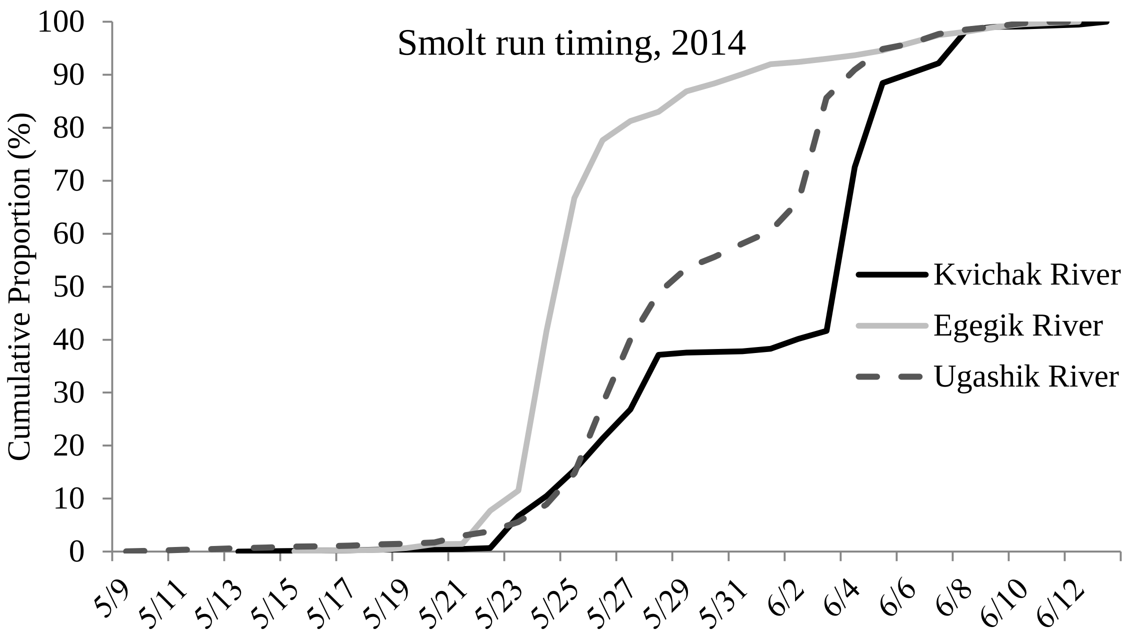


Figure 19. Annual run timing of sockeye salmon smolts on the Kvichak (one site), Ugashik (both sites combined), and Egegik (one site) rivers in 2014.

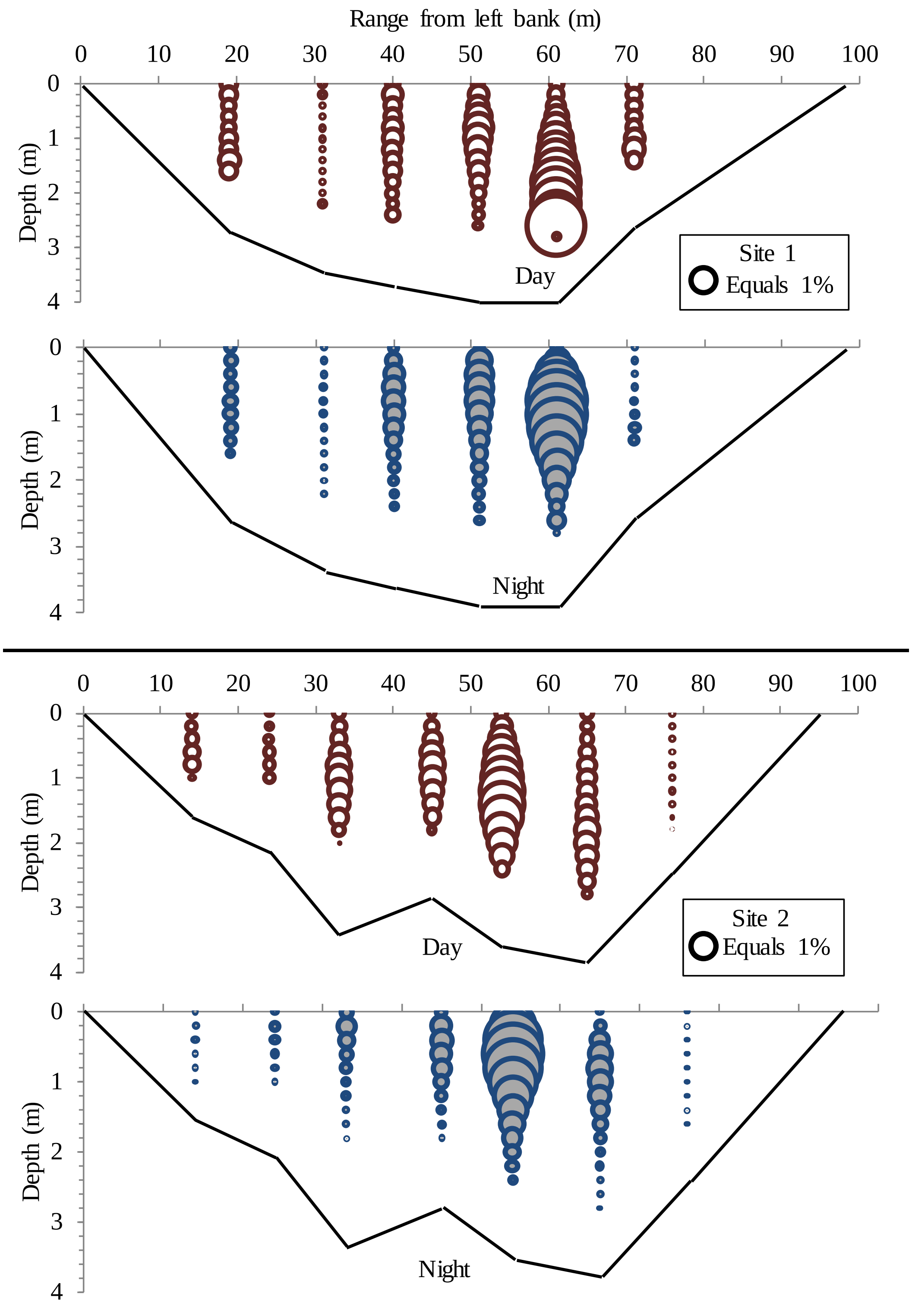


Figure 20. Vertical distribution of sockeye salmon smolts among Egegik River in 2014. Distributions are raw detections (not expanded for total abundance) and thus only comparable for vertical distribution. For horizontal comparisons among transducers, see Figures 6–8.

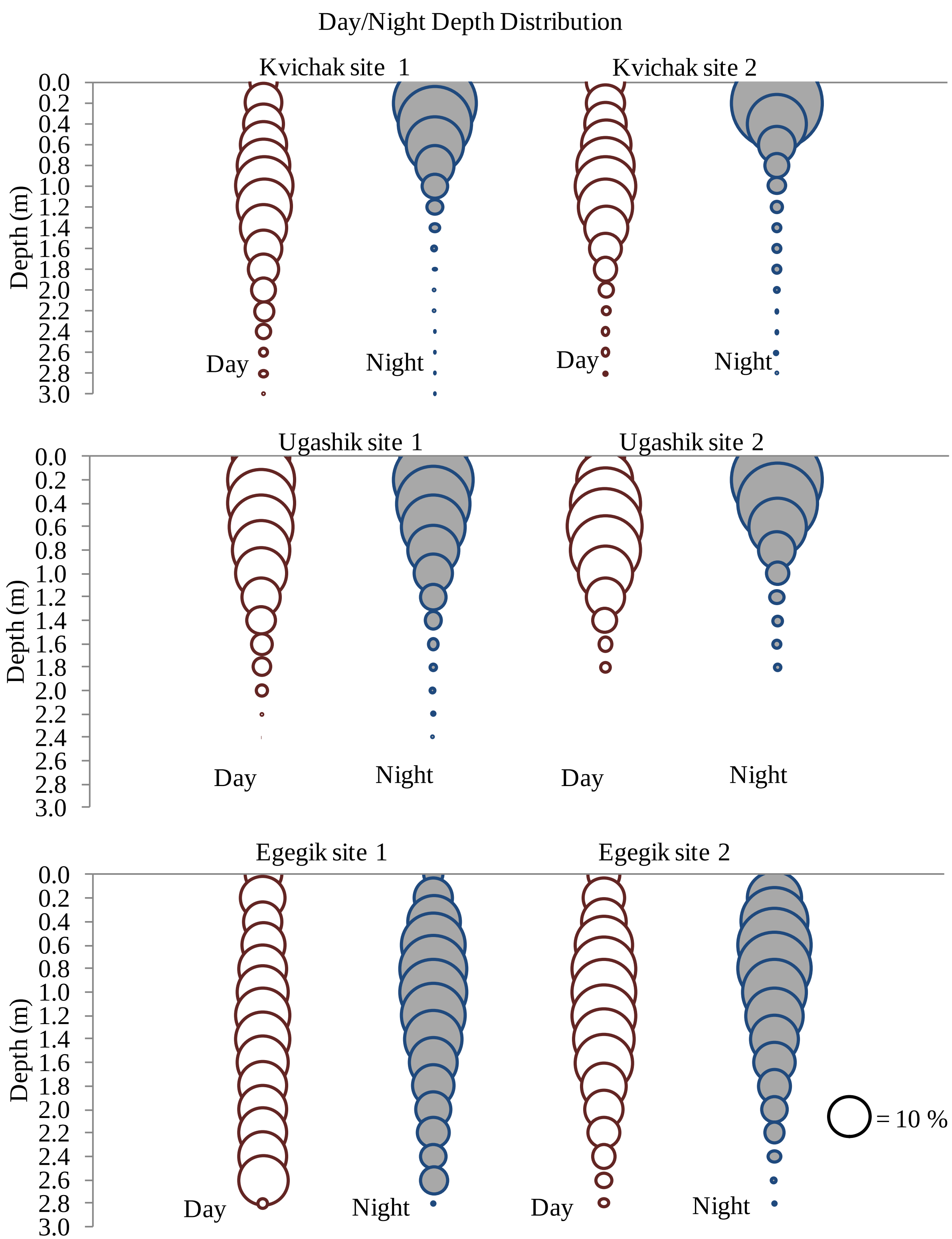


Figure 21. Vertical distribution of sockeye salmon smolts (all transducers combined) migrating in daylight and darkness (2300–0500 hrs) in the Kvichak, Ugashik, and Egegik rivers, 2014.

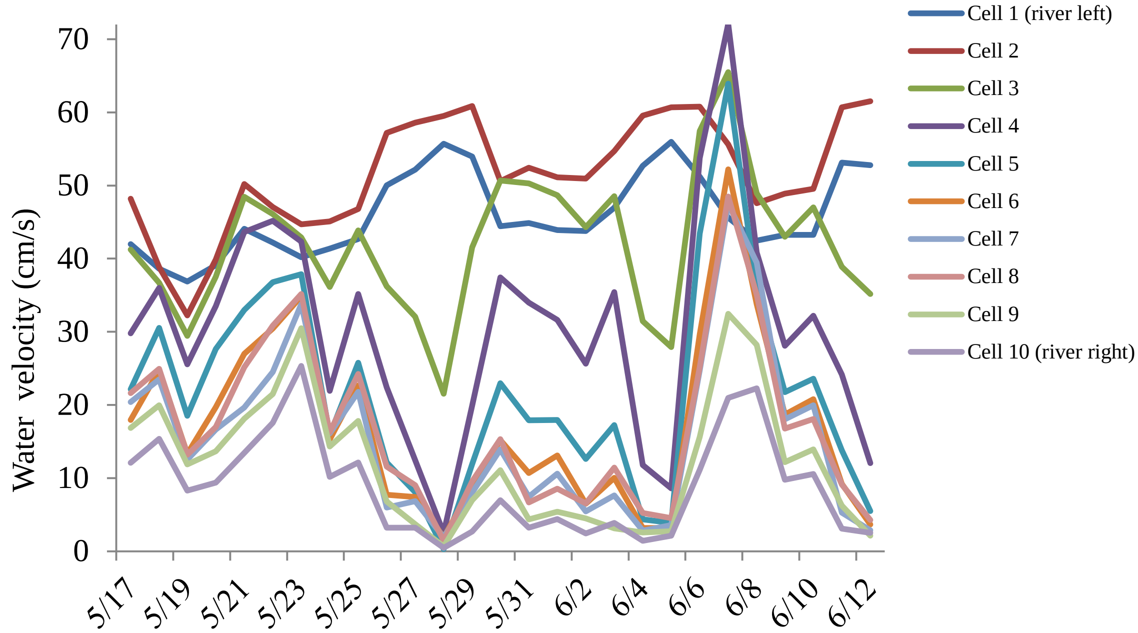
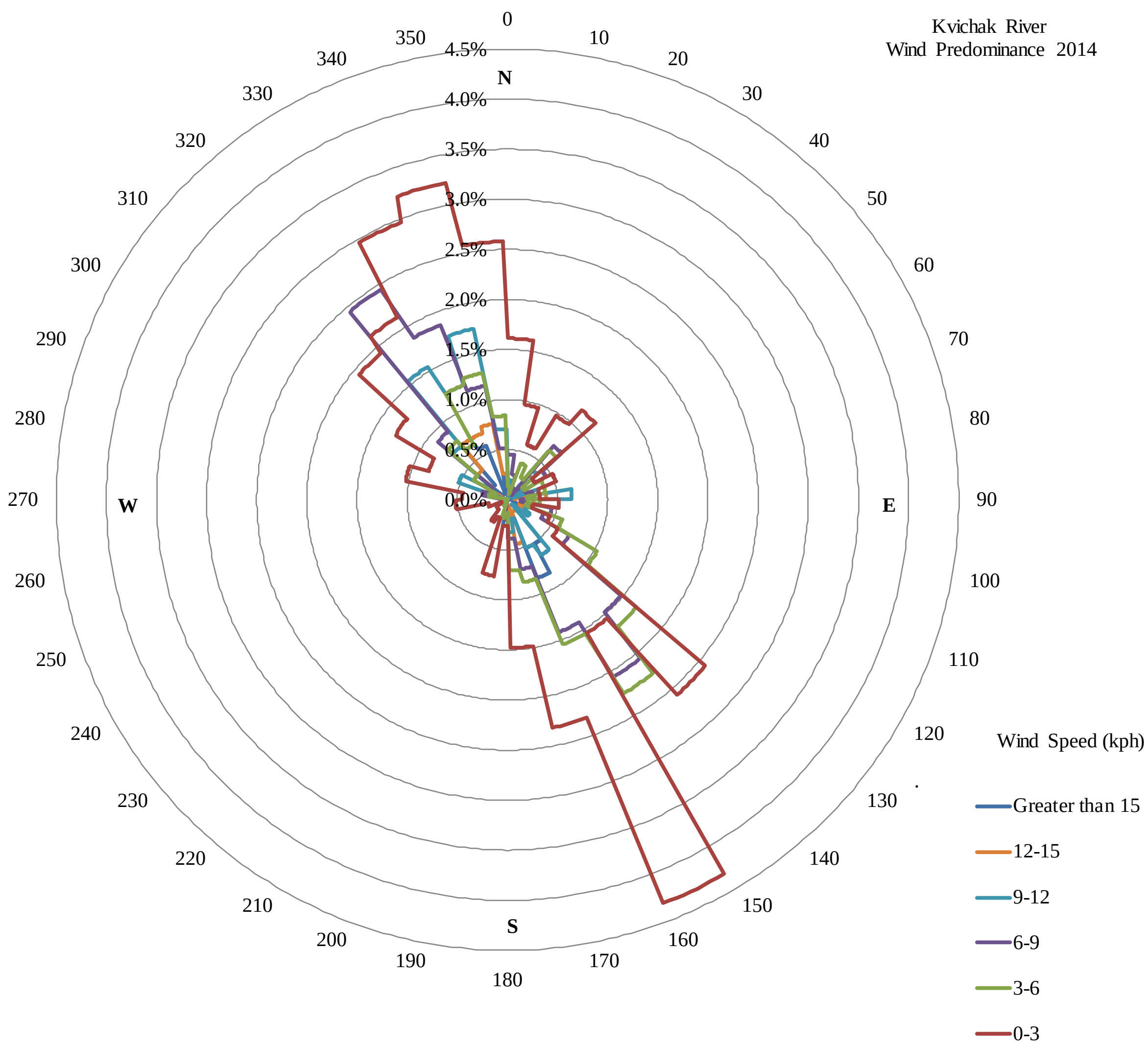
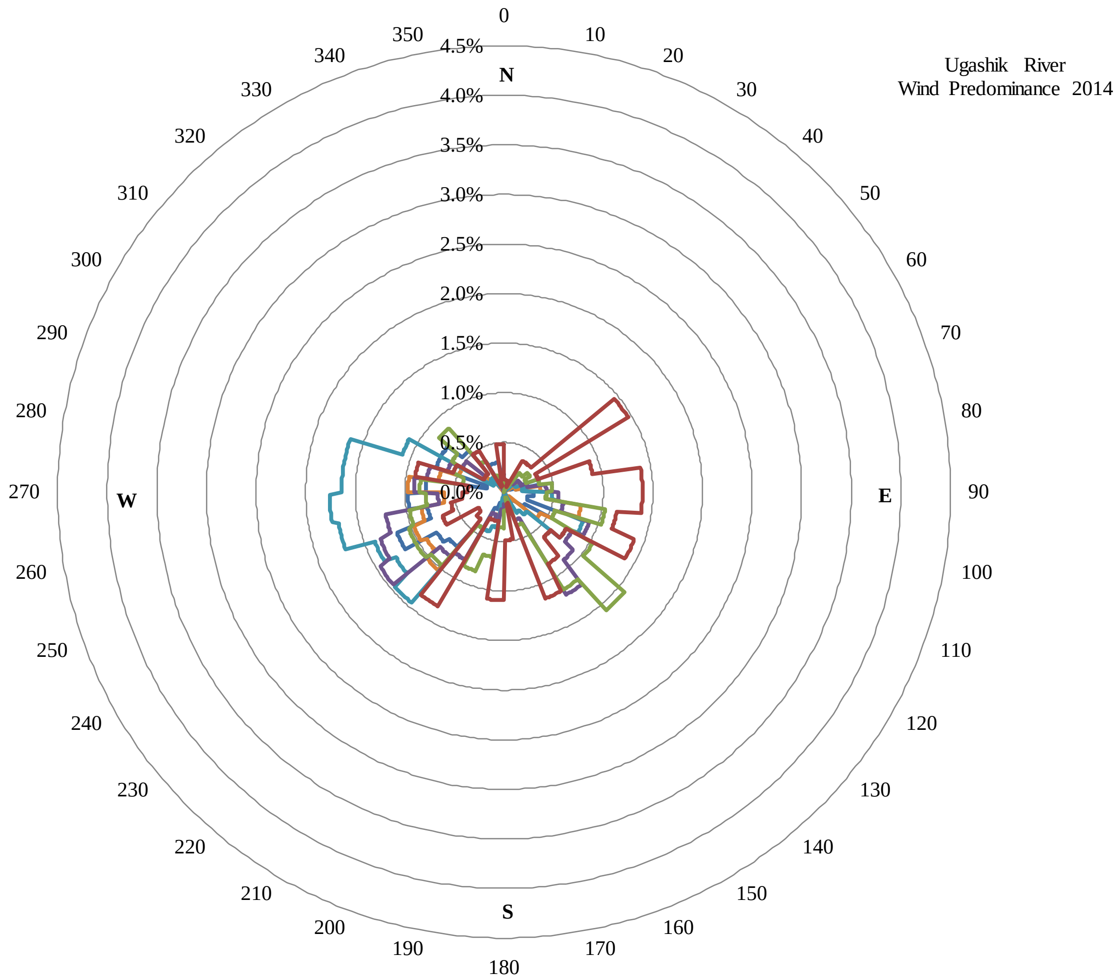


Figure 22. Water velocities recorded by the Acoustic Doppler Current Profiler (ADCP), deployed in the Egegik River, 2014.



0-359 Represents degrees of azimuth
% Represents the relative percentage of time throughout the sampling period that the wind exhibited the given direction and velocity.

Figure 23. Wind predominance at the sonar site on the Kvichak River, 2014.



0-359 Represents degrees of azimuth
% Represents the relative percentage of time throughout the sampling period that the wind exhibited the given direction and velocity.

Figure 24. Wind predominance at the sonar site on the Ugashik River, 2014.

PHOTOS

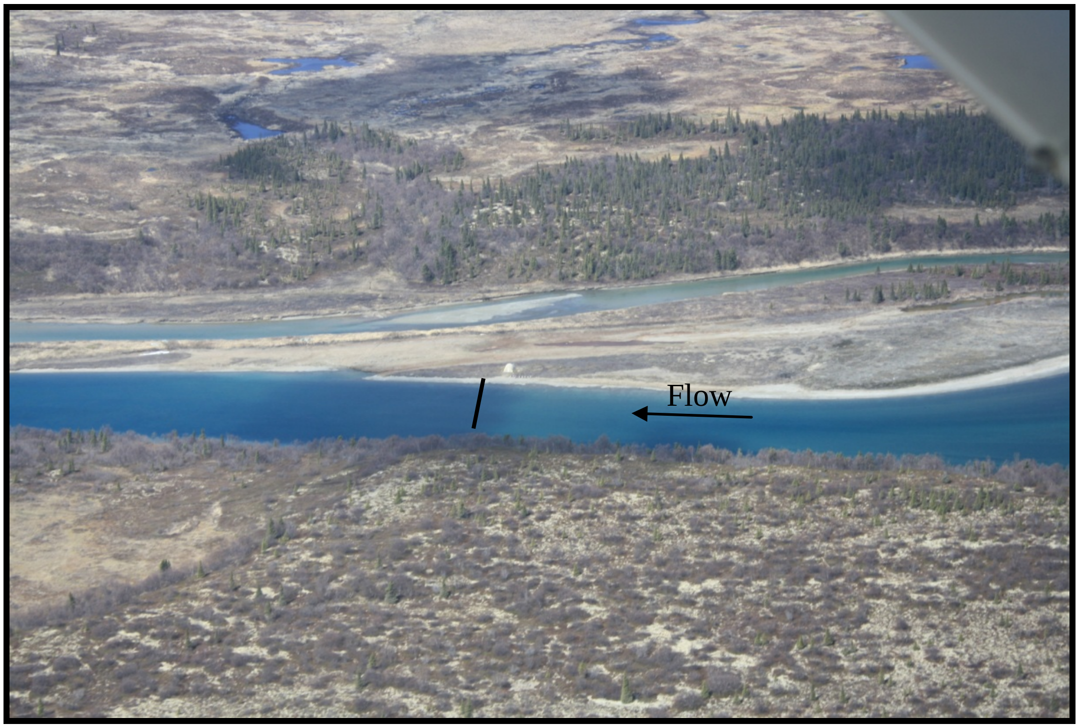


Photo 1. Aerial photo of Site 1 on the Kvichak River. The black line shows the approximate location of Site 1 sonar array used in 2008–2014.

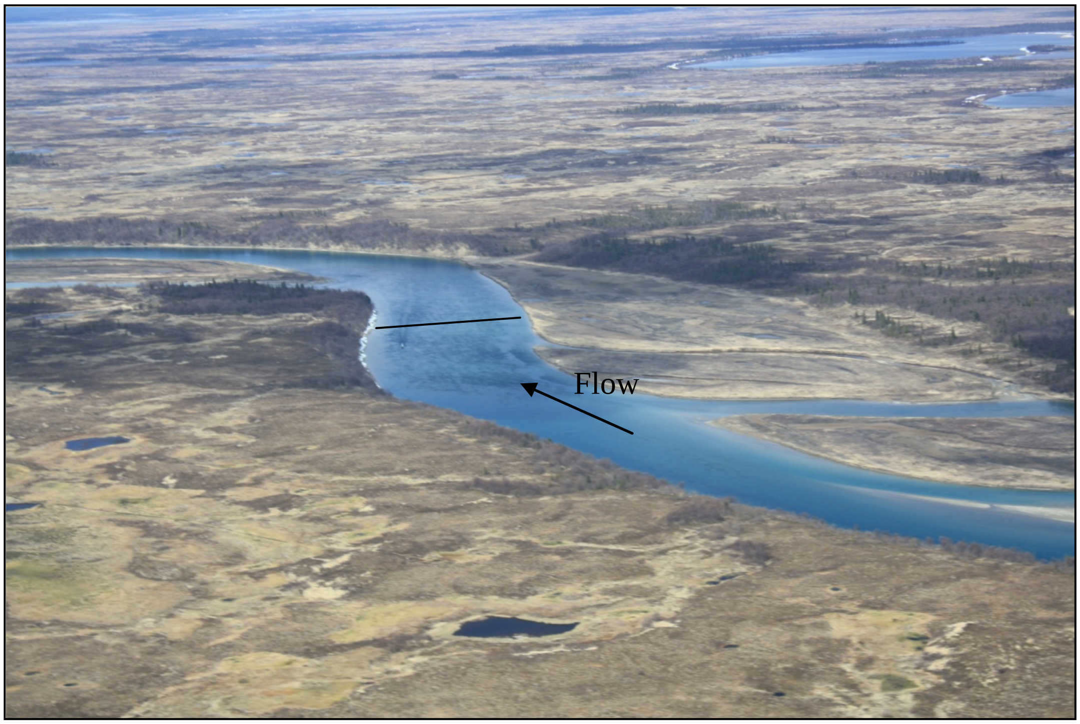


Photo 2. Aerial photo of Site 2 on the Kvichak River. The black line shows the approximate location of the Site 2 sonar array used in 2008 and 2010–2014.

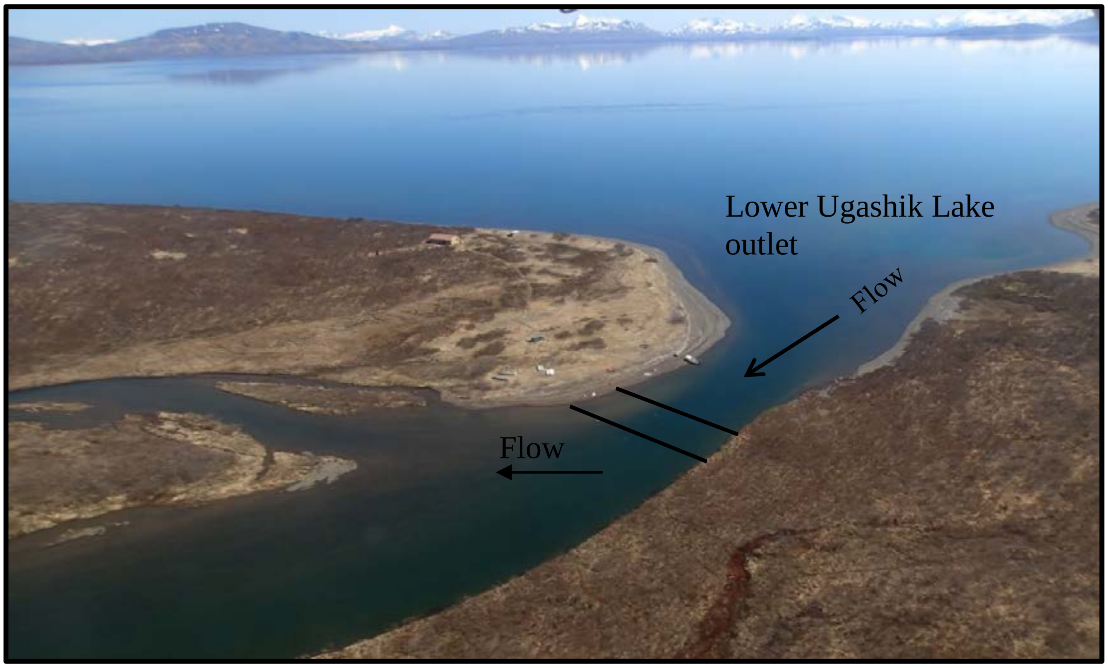


Photo 3. Aerial photo of the Ugashik sonar sites near to the outlet of Lower Ugashik Lake. Site 1 is the upriver line; Site 2 is slightly downriver.

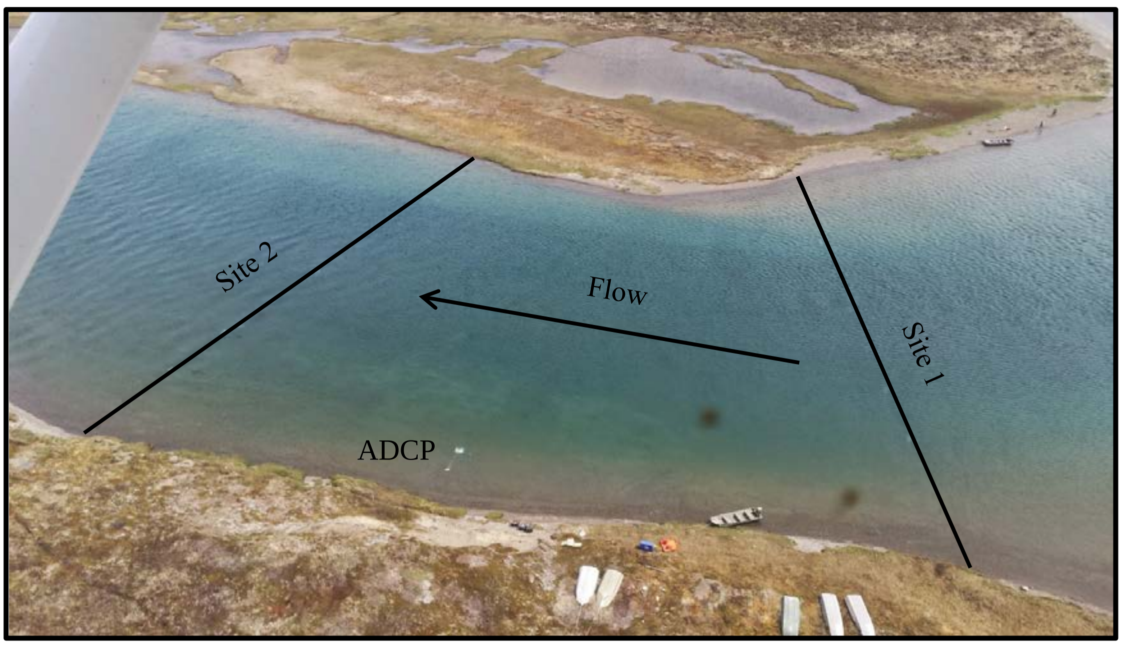


Photo 4. Aerial photo of the Egegik sonar sites in 2014.

Photo 5. Kvichak Site 1 transducer pods are set on the bank prior to deployment. Pods are connected and aligned in order for towing.

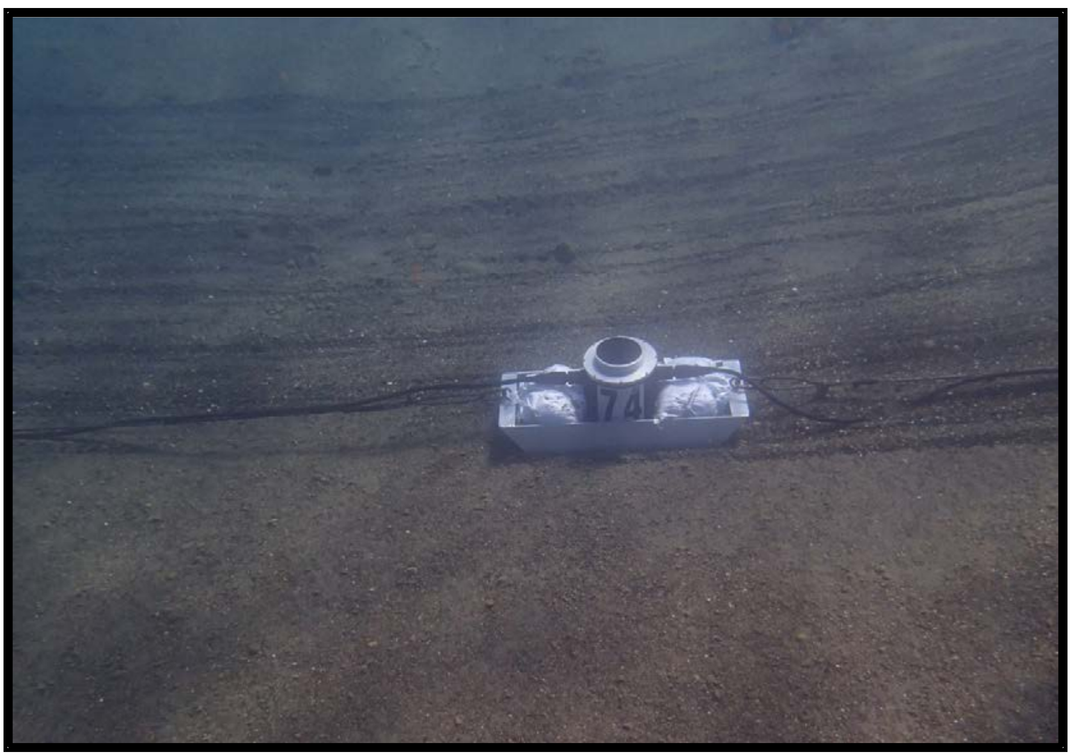


Photo 6. A deployed sonar pod underwater at Egegik Site 1, showing tracks from other sleds have been deployed

Photo 7. The Inclined Plane Trap (IPT) used to capture sockeye salmon smolts on the Kvichak River in 2014. Photo taken in 2013.

Photo 8. Fyke net with a school of sockeye smolt upstream and just outside of the net.

Photo 9. The acoustic current Doppler profiler (ADCP) deployed underwater in the Egegik River in 2014.

APPENDICES

APPENDIX A – AGE AND LENGTH

Appendix A1. Daily age, weight, and length summary of sockeye salmon smolts subsampled from Kvichak River catches in 2014. Weight and length were measured directly; age was estimated from scales sampled from each fish.

Kvichak River catch summary							
	Sample size					Number by age	
Date	AWL	Length only	Total	Mean Weight	Mean Length	Age 1	Age 2
May 12	5		5	12.0	111.6		5
May 13	0		0				
May 14	50		50	14.0	117.6		50
May 15	39		39	12.9	114.3	1	38
May 16	0		0				
May 17							
May 18	100	92	192	14.1	116.7		100
May 19	50	50	100	13.7	117.5	2	47
May 20	98	50	148	14.9	119.8		98
May 21	24		24	13.8	116.8	2	22
May 22	50	14	64	14.9	119.3		49
May 23	100	496	596	15.1	117.7		100
May 24	100	484	584	14.6	114.7		100
May 25	100	501	601	13.1	112.4	5	95
May 26	100	500	600	11.6	109.8	13	87
May 27	100	499	599	11.2	105.9	20	80
May 28	100	493	593	11.5	109.8	19	81
May 29	100	499	599	12.1	108.3	16	83
May 30	3		3	9.1	100.7	2	1
May 31	100	197	297	8.3	97.6	74	26
June 01	100	505	605	7.3	94.1	89	11
June 02	100	499	599	7.8	96.6	86	14
June 03	100	504	604	7.8	94.2	81	19
June 04	100	504	604	8.6	100.2	76	24
June 05	100	500	600	7.9	97.4	78	22
June 06	73	50	123	6.9	92.4	64	9
June 07	100	501	601	6.4	88.8	95	5
June 08	100	497	597	6.3	88.0	97	3
June 09	100	499	599	6.1	87.9	98	2
June 10	100	169	269	6.5	90.1	93	7
June 11	100	498	598	6.7	95.7	93	7
June 12	100	502	602	8.6	97.7	76	24
Total	2,392	9,103	11,495	10.1	101.6	1,180	1,209

Appendix A2. Daily mean length and weight by age class of sockeye salmon smolts from the Kvichak River catches in 2014.

Kvichak River daily age summary										
	Age 1					Age 2				
Date	*n*	Mean Length	SD	Mean Weight	SD	*n*	Mean Length	SD	Mean Weight	SD
May 12						5	111.6	5.5	12.0	1.5
May 13										
May 14						50	117.6	4.5	14.0	1.6
May 15	1	90.0	-	6.4	-	38	115.0	5.0	13.1	1.4
May 16										
May 17										
May 18						100	117.3	4.1	14.1	1.3
May 19	2	90.0	0.0	6.1	0.3	47	117.9	4.8	14.0	1.8
May 20						98	120.0	4.4	14.9	1.4
May 21	2	93.5	6.4	7.3	0.8	22	118.9	2.8	14.4	0.8
May 22						49	120.6	4.2	14.9	1.5
May 23						100	119.2	4.1	15.1	1.5
May 24						100	117.3	5.0	14.6	1.6
May 25	5	91.0	3.4	7.2	1.1	95	114.4	7.0	13.4	2.6
May 26	13	90.4	3.5	6.8	0.8	87	112.5	5.3	12.3	1.6
May 27	20	93.5	4.5	7.4	1.1	80	111.9	5.5	12.2	1.5
May 28	19	90.5	3.1	6.8	0.8	81	113.6	6.1	12.6	1.7
May 29	16	92.4	4.6	7.3	1.0	83	113.0	5.4	13.0	1.7
May 30	2	91.5	0.7	6.8	0.4	1	119.0	-	13.9	-
May 31	74	91.6	4.1	7.3	0.8	26	108.0	7.2	11.1	2.0
June 01	89	89.9	3.7	6.8	0.8	11	107.7	7.7	11.7	2.3
June 02	86	91.7	3.7	7.2	0.8	14	109.1	3.5	11.5	1.3
June 03	81	91.1	3.6	7.0	0.8	19	107.4	8.7	11.1	2.5
June 04	76	92.2	2.9	7.1	0.7	24	115.1	6.7	13.4	2.1
June 05	78	90.3	3.8	6.7	0.8	22	111.8	8.3	12.3	2.5
June 06	64	88.9	3.4	6.3	0.6	9	110.6	7.5	11.1	2.1
June 07	95	87.3	3.6	6.2	0.7	5	97.0	9.6	8.7	2.9
June 08	97	86.5	3.5	6.2	0.6	3	103.7	10.8	10.8	3.0
June 09	98	87.5	4.4	6.0	0.8	2	107.0	1.4	10.0	0.6
June 10	93	88.0	3.7	6.2	0.7	7	105.4	9.8	10.0	2.8
June 11	93	88.4	3.3	6.5	0.7	7	100.4	9.1	9.5	2.3
June 12	76	89.5	3.8	7.0	0.9	24	114.5	5.5	13.7	1.5
Total	1,180	89.5	4.1	6.7	0.9	1,209	115.2	6.6	13.5	2.1

Appendix A3. Daily age, weight, and length summary of sockeye salmon smolts subsampled from Ugashik River catches in 2014. Weight and length were measured directly; age was estimated from scales sampled from each fish.

Ugashik River catch summary							
	Sample size					Number by age	
Date	AWL	Length only	Total	Mean Length	Mean Weight	Age 1	Age 2
May 09							
May 10							
May 11							
May 12							
May 13							
May 14							
May 15	3		3	113	13.5	2	1
May 16							
May 17	77		77	115	13.6	44	31
May 18	17		17	120	16.7	6	11
May 19	11		11	118.4	14.8	5	6
May 20	47		47	123.9	17.1	15	32
May 21	38		38	128.2	19.2	13	25
May 22	62	217	279	124.0	16.8	6	56
May 23	100	51	151	121.2	16.5	5	93
May 24		449	449	122.3			
May 25	100	500	600	113.1	13.0	51	49
May 26							
May 27	46	11	57	106.8	10.8	29	17
May 28	54	429	483	109.3	11.7	43	9
May 29							
May 30	100	500	600	115.2	15.0	41	58
May 31							
June 01	79		79	115.8	15.4	39	40
June 02							
June 03	100	80	180	112.3	14.6	72	27
June 04							
June 05	100	240	340	98.0	10.2	93	6
June 06	100	458	558	101.6	10.4	96	4
June 07	100	106	206	102.9	10.0	90	10
June 08	100	332	432	102.1	11.4	90	10
June 09	72		72	97.6	8.9	71	1
June 10	43		43	107.3	11.3	39	4
June 11	50		50	102.3	10.0	46	1
June 12	46		46	95.6	8.3	46	0
Total	1,445	3,373	4818	110.6	12.8	942	491

Appendix A4. Daily mean length and weight by age class of sockeye salmon smolts from the Ugashik River catches in 2014.

Ugashik River daily age summary										
	Age 1					Age 2				
Date	*n*	Mean Length	SD	Mean Weight	SD	*n*	Mean Length	SD	Mean Weight	SD
May 09										
May 10										
May 11										
May 12										
May 13										
May 14										
May 15	2	108.0	15.56	11.10	4.525	1	123.0	-	18.2	-
May 16										
May 17	44	113.5	10.19	12.94	3.668	31	117.9	9.3	14.4	2.7
May 18	6	114.8	9.75	14.98	3.866	11	122.5	3.7	17.3	2.9
May 19	5	113.0	15.60	13.20	4.792	6	122.8	4.8	16.2	1.7
May 20	15	121.7	9.01	15.82	2.713	32	124.8	5.4	17.7	2.1
May 21	13	124.2	4.41	17.10	1.550	25	130.3	6.7	20.3	3.8
May 22	6	122.0	4.73	15.83	1.631	56	123.6	4.7	16.9	1.9
May 23	5	107.4	6.07	11.66	2.161	93	122.2	3.7	16.7	1.4
May 24										
May 25	51	107.2	3.84	11.13	1.079	49	118.7	5.3	15.0	2.2
May 26										
May 27	29	100.3	9.27	9.56	2.563	17	112.8	7.4	13.0	2.4
May 28	43	104.3	5.11	10.99	1.574	9	119.2	6.1	15.4	3.6
May 29										
May 30	41	105.0	10.20	11.67	2.830	58	120.9	3.9	17.3	1.8
May 31										
June 01	39	108.4	6.40	12.57	1.955	40	123.1	6.4	18.1	2.6
June 02										
June 03	72	109.3	5.46	13.13	1.837	27	122.9	5.2	18.8	2.4
June 04										
June 05	93	100.0	9.09	9.89	2.333	6	121.8	4.7	15.8	2.2
June 06	96	102.8	6.31	10.21	1.893	4	115.0	6.8	14.4	2.6
June 07	90	97.6	10.78	9.25	2.792	10	125.3	3.8	16.7	4.0
June 08	90	103.4	7.11	10.87	2.113	10	120.4	5.5	16.2	2.2
June 09	71	96.1	7.23	8.78	1.867	1	118.0	-	16.7	-
June 10	39	104.2	5.99	10.71	1.654	4	122.0	4.2	16.1	1.8
June 11	46	100.2	5.74	9.79	1.508	1	133.0	-	19.2	-
June 12	46	93.8	6.67	8.34	1.692					
Total	942	103.5	9.80	10.79	2.790	491	121.9	6.2	16.8	2.7

Appendix A5. Daily age, weight, and length summary of sockeye salmon smolts subsampled from Egegik River catches in 2014. Weight and length were measured directly; age was estimated from scales sampled from each fish.

Egegik River catch summary								
	Sample size					Number by age		
Date	AWL	Length only	Total	Mean Length	Mean Weight	Age 1	Age 2	Age 3
May 15								
May 16								
May 17	1		1	67	2.6	1	0	0
May 18								
May 19								
May 20								
May 21	5		5	141.0	26.92	0	4	1
May 22	11		11	126.0	18.94	2	7	1
May 23	119	8	127	118.1	13.81	10	104	4
May 24	18		18	115.6	15.06	5	12	1
May 25	76		76	124.6	18.14	12	45	18
May 26	9		9	154.0	33.16	0	4	4
May 27								
May 28								
May 29	61		61	123.0	17.73	16	37	8
May 30								
May 31	90		90	123.8	18.61	24	55	11
June 01	18		18	106.9	10.14	10	8	0
June 02	20		20	111.5	12.01	15	4	1
June 03	6		6	116.7	14.52	4	2	0
June 04	84		84	131.7	23.33	17	43	21
June 05								
June 06	94	35	129	131.4	24.22	3	57	34
June 07	6		6	115.7	13.82	5	1	0
June 08	11		11	129.5	19.09	1	9	1
June 09	44	29	73	124.5	19.59	2	35	6
June 10	37		37	131.4	22.51	5	25	5
June 11	12		12	136.0	25.13	0	9	1
Total	722	72	794	125.1	19.18	132	461	117

Appendix A6. Daily mean length and weight by age class of sockeye salmon smolts from the Egegik River catches in 2014.

	Egegik River daily age summary															
	Age 1					Age 2					Age 3				
Date	*n*	Mean Length	SD	Mean Weight	SD	*n*	Mean Length	SD	Mean Weight	SD	*n*	Mean Length	SD	Mean Weight	SD
May 15															
May 16															
May 17	1	67.0	-	2.6	-										
May 18															
May 19															
May 20															
May 21						4	134.3	8.5	23.1	5.7	1	168.0	-	42.2	-
May 22	2	87.5	4.9	6.3	0.1	7	130.4	10.4	19.8	3.1	1	156.0	-	32.0	-
May 23	10	104.2	8.2	9.5	2.3	104	119.4	10.9	13.8	4.0	4	139.0	16.1	24.1	11.3
May 24	5	97.4	10.0	8.6	2.2	12	120.8	18.4	16.4	10.1	1	144.0	-	31.8	-
May 25	12	99.5	8.2	8.0	2.1	45	122.6	14.2	16.3	6.9	18	144.7	9.7	28.7	6.6
May 26						4	142.8	16.6	28.1	9.2	4	162.5	20.2	36.8	11.1
May 27															
May 28															
May 29	16	104.4	9.4	9.7	3.1	37	125.4	14.3	18.5	6.6	8	149.4	8.0	30.3	4.0
May 30															
May 31	24	101.5	9.8	9.0	2.2	55	128.7	17.2	20.5	8.5	11	147.8	15.2	30.4	10.1
June 01	10	106.5	4.5	10.0	1.4	8	107.4	5.9	10.4	1.5					
June 02	15	108.3	4.0	10.8	0.9	4	116.8	4.0	12.9	1.8	1	138.0	-	26.0	-
June 03	4	111.8	4.6	11.8	2.6	2	126.5	30.4	20.0	14.1					
June 04	17	102.4	8.0	9.3	2.1	43	134.3	15.4	24.0	7.8	21	150.3	15.3	33.4	10.3
June 05															
June 06	3	107.7	2.5	10.5	0.7	57	132.0	10.6	22.8	5.3	34	140.5	10.4	27.8	6.6
June 07	5	112.4	26.1	12.4	8.5	1	132.0	-	20.9	-					
June 08	1	114.0	-	9.7		9	131.8	5.7	19.9	3.8	1	124.0	-	21.3	-
June 09	2	102.5	4.9	8.3	1.5	35	126.1	8.3	19.7	4.1	6	129.5	6.2	22.4	3.1
June 10	5	115.2	10.5	14.2	4.1	25	132.2	9.5	22.9	5.2	5	141.0	7.3	28.3	4.6
June 11						9	136.0	10.9	25.1	6.0	1	151.0	-	34.8	-
Total	132	104.0	10.4	9.7	3.0	461	126.4	14.0	18.9	7.2	117	144.7	13.3	29.5	8.1

APPENDIX B – SAMPLING SITES

Appendix B1. GPS coordinates (decimal degrees) and dates of operation for the sample sites on the Kvichak, Ugashik, and Egegik rivers, 2014. WGS84 datum.

2014 Sample Site Summary

Location		Latitude	Longitude	Dates of operation
Kvichak River				
	Sonar site 1	59.31398	-155.93101	May 13–June 13
	Sonar site 2	59.30084	-155.96453	May 14–June 13
	Incline plane trap	59.30017	-155.94967	May 12–June 12
Ugashik River				
	Sonar site 1	57.56426	-157.00033	May 9–June 11
	Sonar site 2	57.56450	-157.00044	May 10–June 12
	Fyke net	57.56457	-157.00119	May 11–June 12
	Seine net	57.56410	-156.99668	May 25–June 2
Egegik River				
	Sonar site 1	58.05880	-156.88883	May 13–June 12
	Sonar site 2	58.05979	-156.88665	May 16–June 12
	Fyke net #1	58.05744	-156.88814	May 21–June 11
	Fyke net #2	58.04031	-156.87178	May 21–June 11
	Seine net	58.05744	-156.88814	May 17–21

Appendix B2. Annual sonar pod placements on the Kvichak, Ugashik, and Egegik rivers since project inception in 2008. Depth is water depth in meters, range (R) is distance from shore in meters, and RR and RL are right and left sides of river when facing downstream. Blank cells indicate no pods used; NA indicates pods used but no data available. Page 1, Kvichak River

			2014		2013		2012		2011		2010		2009		2008	
River	Site	Tx	Depth	R	Depth	R	Depth	R	Depth	R	Depth	R	Depth	R	Depth	R
Kvichak River																
	1	RR bank	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	1	1	2.5	21	2.5	17	1.7	19	1.8	13	1.9	15	2.4	29	2.4	19
	1	2	2.7	31	2.8	27	2.3	29	2.1	22	2.2	25	2.9	39	2.5	29
	1	3	3.1	42	3.1	37	2.7	39	2.6	35	2.7	34	3.5	49	3.0	39
	1	4	3.7	52	3.7	47	3.1	49	3.1	45	3.3	44	3.9	59	3.6	49
	1	5	4.0	61	3.9	57	3.6	59	3.5	53	3.6	54	4.4	69	4.0	59
	1	6	4.1	72	3.9	67	3.7	69	3.7	65	3.8	65	3.5	79	4.3	69
	1	7	4.1	82	3.9	77	3.8	79	3.9	74	4.1	75	2.2	89	3.0	79
	1	8	3.3	91	NA	87	3.4	89	3.2	83	3.5	86	NA	NA	1.9	89
	1	RL bank	0	108	0	102	0	114	0	101	0	103	0	103	0	103
	2	RR bank	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	2	1	2.2	10	1.5	4	2.2	15	2.8	35	2.8	41	3.7	37	2.9	42
	2	2	3.0	20	2.7	14	2.9	26	2.6	45	2.6	51	3.8	47	2.7	52
	2	3	3.2	30	3.1	24	3.0	36	2.5	56	2.5	62	4.0	57	2.7	62
	2	4	3.2	41	3.1	34	2.8	46	2.5	66	2.5	72	4.3	67	2.7	72
	2	5	3.2	43	3.3	38	2.7	57	2.4	75	2.6	81	4.3	77	2.6	82
	2	6	3.1	53	3.1	48	2.7	68	2.4	85	2.6	91	2.6	87	2.5	92
	2	7	3.1	63	3.1	58	2.6	78	2.3	95	2.8	101	1.4	97	2.6	102
	2	8	3.0	72	2.9	68	2.5	88	2.7	105	3.4	111	NA	NA	NA	NA
	2	9	3.0	82	2.9	78	2.5	99	NA	NA	NA	NA	NA	NA	NA	NA
	2	10	2.9	91	2.7	88	2.6	110	NA	NA	NA	NA	NA	NA	NA	NA
	2	11	2.9	102	2.7	98	3.3	120	NA	NA	NA	NA	NA	NA	NA	NA
	2	12	3.2	112	3.3	108	3.4	131	NA	NA	NA	NA	NA	NA	NA	NA
	2	RL bank	0	136	0	130	0	146	0	128	0	134	0	119	0	130

Appendix B2. Page 2, Ugashik and Egegik rivers.

			2014		2013		2012		2011		2010		2009		2008	
River	Site	Tx	Depth	R	Depth	R	Depth	R	Depth	R	Depth	R	Depth	R	Depth	R
Ugashik River																
	1	RR bank	0	0	0	0	0	0	0	0	0	0				
	1	1	2.4	17	2.3	20	1.7	22	1.6	35	0.9	16				
	1	2	3.2	21	3.1	25	2.6	27	2.3	40	1.3	18				
	1	3	3.7	26.5	3.3	30	3.2	34	2.4	45	2.5	22				
	1	4	3.3	31.5	2.7	35	3.0	38	2.5	50	2.6	27				
	1	5	2.1	34.5	1.9	40	2.0	42	2.2	55	3.3	32				
	1	6	NA	NA	NA	NA	NA	NA	NA	NA	2.8	37				
	1	7	NA	NA	NA	NA	NA	NA	NA	NA	1.9	42				
	1	RL bank	0	37.5	0	43	0	44	0	60	0	45				
	2	RR bank	0	0	0	0	0	0	0	0						
	2	1	2.5	24	1.8	32	1.8	41	1.3	16						
	2	2	3.2	28.5	2.1	37	2.2	46	1.6	51						
	2	3	3.2	33	2.3	43	2.4	50	2.2	56						
	2	4	2.6	37.5	2.8	48	2.0	54	2.5	60						
	2	5	NA	NA	2.5	53	NA	NA	2.0	64						
	2	RL bank	0	46	0	61	0	57	0	66						
Egegik River																
	1	RL bank	0	0	0	0			0	0						
	1	1	2.6	19	NA	4			0.8	11						
	1	2	3.4	31	3.6	14			1.9	15						
	1	3	3.6	40	3.9	24			2.8	28						
	1	4	3.8	51	4.1	34			3.0	39						
	1	5	3.8	61	4.1	44			3.3	50						
	1	6	2.5	71	4.0	54			3.2	60						
	1	7	NA	NA	3.8	64			3.2	71						
	1	RR bank	0	98	0	80			0	90						
	2	RL bank	0	0					0	0						
	2	1	1.5	14					1.1	15						
	2	2	2.0	24					2.0	26						
	2	3	3.2	33					2.5	37						
	2	4	2.7	45					2.8	47						
	2	5	3.4	54					3.3	57						
	2	6	3.6	65					2.9	68						
	2	7	2.4	76					2.3	79						
	2	RR bank	0	95					0	90						

APPENDIX C – ENVIRONMENTAL CONDITIONS

Appendix C1. Historical ice cover dates on Lake Iliamna, in the Kvichak River drainage.

Winter of	Freeze-up date[a]	Break-up date [b]	Ice cover days
1976 - 1977	Feb 04	April 02	88
1977 - 1978		May 10	
1978 - 1979		May 09	
1979 - 1980		May 20	
1980 - 1981		March 19	
1981 - 1982	Jan 09	May 27	137
1982 - 1983		May 17	
1983 - 1984		May 22	
1984 - 1985	Feb 11	June 05	115
1985 - 1986	Jan 18	May 12	115
1986 - 1987	Feb 13	March 23	39
1987 - 1988	Jan 26		
1988 - 1989	Jan 13		
1989 - 1990	Jan 09	May 22	134
1990 - 1991	Jan 07		
1991 - 1992	Jan 27	May 05	98
1992 - 1993	Jan 22	May 03	102
1993 - 1994	Feb 16	May 05	79
1994 - 1995	Jan 11	May 22	132
1995 - 1996	Jan 12	May 06	114
1996 - 1997	Dec 23	May 08	137
1997 - 1998	Jan 05	April 27	112
1998 - 1999	Dec 30	May 28	150
1999 - 2000	Dec 30	May 06	128
2000 - 2001			
2001 - 2002		April 24	
2002 - 2003			
2003 - 2004		April 25	
2004 - 2005		April 29	
2005 - 2006		May 20	
2006 - 2007		May 22	
2007 - 2008		May 19	
2008 - 2009		May 22	
2009 - 2010		May 19	
2010 - 2011		May 20	
2011 - 2012		May 22	
2012 - 2013		May 17	
2013 - 2014			

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

[b] Data from University of Washington, Fishery Research Institute.

Appendix C2. Historical ice cover dates on Lower Ugashik Lake (Ugashik River drainage) and Becharof Lake (Egegik River drainage).

	Lower Ugashik Lake			Becharof Lake		
Winter of	Freeze-up date[a]	Break-up date	Ice cover days	Freeze-up date[a]	Break-up date	Ice cover days
1981 - 1982		May 12				
1982 - 1983	Jan 18					
1983 - 1984	Jan 16			Jan 16	May 16	121
1984 - 1985	Feb 11	May 14	92	Feb 11	May 03	82
1985 - 1986	Feb 26	May 09	74	Feb 26	Apr 27	61
1986 - 1987	Mar 12			Mar 12		
1987 - 1988	Dec 09	Mar 24	106	Mar 24		
1988 - 1989	Jan 17	May 10	113	Jan 17	Apr 27	101
1989 - 1990	Feb 21	Apr 25	63	Feb 21	Apr 25	64
1990 - 1991	Jan 08			Feb 04	Apr 01	57
1991 - 1992	Jan 27	May 04	97	Jan 27	May 10	104
1992 - 1993	Jan 20	Mar 31	70	Jan 23	Mar 31	68
1993 - 1994	Feb 16	Apr 08	51	Feb 25	Apr 04	39
1994 - 1995	Jan 24	Apr 28	94	Jan 24	Apr 28	95
1995 - 1996	Jan 08	Apr 15	97	Jan 08	Mar 28	80
1996 - 1997	Dec 13	Apr 26	135	Dec 13	Apr 19	128
1997 - 1998	Jan 05	Apr 04	89	Jan 06	Apr 04	89
1998 - 1999	Jan 22	May 19	117	Feb 05	May 28	113
1999 - 2000	Dec 25	Apr 07	104	Jan 02	Apr 12	101
2000 - 2009[b]	-	-				
2009 - 2010		May 10				
2010 - 2011	Dec 10	Feb 08	Lake ice broke 4 times		May 10	
2011 - 2012	Nov 15	May 16	Ice flowed until 22 May			
2012 - 2013						
2013 - 2014						

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

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

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

Appendix C3. Daily climate and hydrological observations made at 0800 and 2000 hours near the Kvichak River sonar sites, 2014.

Kvichak River weather observations, 2014							
Date	Air temperature (°C) @ 0800	Air temperature (°C) @ 2000	Precipitation (mm)	Wind dir @0800 (deg)	Wind speed (kph)	Wind dir @2000 (deg)	Wind speed (kph)
5/9/2014	N/A	N/A	N/A	N/A	N/A	N/A	N/A
5/10/2014	N/A	N/A	N/A	N/A	N/A	N/A	N/A
5/11/2014	N/A	N/A	N/A	N/A	N/A	N/A	N/A
5/12/2014	N/A	20.9	6.10	N/A	N/A	302	0.0
5/13/2014	6.5	20.2	-	344	0.0	53	6.4
5/14/2014	2.8	17.2	-	296	0.0	138	4.8
5/15/2014	5.1	22.5	-	94	0.0	152	1.6
5/16/2014	8.4	25.0	-	317	3.2	62	8.0
5/17/2014	8.3	18.5	-	331	9.7	56	9.7
5/18/2014	7.5	13.1	-	43	1.6	56	9.7
5/19/2014	4.3	14.4	-	79	4.8	96	14.5
5/20/2014	6.7	16.6	-	45	3.2	50	3.2
5/21/2014	7.3	15.2	-	338	0.0	351	4.8
5/22/2014	5.4	16.3	-	321	0.0	135	0.0
5/23/2014	4.9	19.8	-	300	0.0	50	0.0
5/24/2014	5.1	15.0	-	327	11.3	338	12.9
5/25/2014	3.9	13.2	-	327	4.8	341	8.0
5/26/2014	5.2	10.9	1.52	344	0.0	146	3.2
5/27/2014	8.3	10.9	4.83	321	0.0	141	1.6
5/28/2014	8.5	9.2	11.94	152	0.0	175	3.2
5/29/2014	7.7	10.6	27.18	152	4.8	330	8.0
5/30/2014	6.4	5.9	31.50	16	0.0	355	12.9
5/31/2014	3.7	6.2	4.06	324	9.7	310	9.7
6/1/2014	4.6	10.2	2.29	317	6.4	327	11.3
6/2/2014	5.6	11.5	0.25	278	6.4	340	8.0
6/3/2014	6.3	20.1	-	323	1.6	112	3.2
6/4/2014	8.6	17.0	-	314	0.0	145	4.8
6/5/2014	9.9	14.2	-	192	12.9	156	16.1
6/6/2014	10.4	13.5	-	162	14.5	158	17.7
6/7/2014	10.0	14.5	-	138	3.2	163	6.4
6/8/2014	9.1	10.9	16.00	151	0.0	296	9.7
6/9/2014	6.3	9.2	-	338	9.7	328	16.1
6/10/2014	5.0	10.3	0.51	331	6.4	326	16.1
6/11/2014	7.0	9.8	2.79	323	6.4	207	0.0
6/12/2014	8.3	8.2	14.99	152	0.0	139	6.4
6/13/2014	6.7	10.8	9.14	132	9.7	170	0.0

Appendix C4. Daily climate and hydrological observations made at 0800 and 2000 hours near the Ugashik River sonar site, 2014.

Ugashik River weather observations, 2014							
Date	Air temperature (°C) @ 0800	Air temperature (°C) @ 2000	Precipitation (mm)	Wind dir @0800 (deg)	Wind speed (kph)	Wind dir @2000 (deg)	Wind speed (kph)
5/9/2014	N/A	5.8	2.54	N/A	N/A	279	6.4
5/10/2014	1.9	11.3	-	223	0.0	122	9.7
5/11/2014	4.3	12.7	-	107	1.6	146	3.2
5/12/2014	6.0	18.0	-	127	1.6	225	4.8
5/13/2014	6.5	12.9	-	251	1.6	237	8.0
5/14/2014	4.6	17.4	-	282	8.0	321	8.0
5/15/2014	5.2	17.1	-	158	0.0	300	16.1
5/16/2014	6.5	13.8	-	230	4.8	234	11.3
5/17/2014	4.5	7.2	-	227	11.3	241	19.3
5/18/2014	6.8	8.5	-	295	9.7	262	17.7
5/19/2014	3.7	8.2	-	331	11.3	296	20.9
5/20/2014	4.8	12.6	-	227	6.4	302	19.3
5/21/2014	5.8	9.2	-	224	9.7	261	9.7
5/22/2014	5.8	14.1	-	173	3.2	307	16.1
5/23/2014	6.0	12.8	-	227	12.9	248	11.3
5/24/2014	5.3	8.4	-	192	12.9	295	8.0
5/25/2014	3.1	10.5	-	273	0.0	278	16.1
5/26/2014	5.8	8.4	1.78	81	0.0	118	6.4
5/27/2014	7.8	8.0	2.79	79	0.0	138	8.0
5/28/2014	8.8	9.2	4.32	125	0.0	110	12.9
5/29/2014	7.8	9.5	26.16	97	11.3	290	4.8
5/30/2014	6.5	4.5	0.51	292	4.8	240	33.8
5/31/2014	4.8	10.1	0.25	225	9.7	312	6.4
6/1/2014	5.0	7.5	-	196	4.8	268	12.9
6/2/2014	5.0	9.0	-	237	3.2	316	3.2
6/3/2014	6.3	16.0	-	107	3.2	103	4.8
6/4/2014	8.8	12.3	-	114	1.6	118	12.9
6/5/2014	9.5	14.9	-	141	11.3	69	16.1
6/6/2014	10.0	11.2	2.29	70	9.7	124	6.4
6/7/2014	8.7	13.9	1.52	118	0.0	320	11.3
6/8/2014	8.4	7.1	1.27	264	12.9	266	12.9
6/9/2014	4.6	8.9	-	225	8.0	252	12.9
6/10/2014	4.7	9.8	0.51	216	8.0	273	11.3
6/11/2014	6.6	11.0	0.76	80	1.6	94	0.0
6/12/2014	7.5	8.8	5.59	110	0.0	286	0.0
6/13/2014	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Appendix C5. Daily climate and hydrological observations made at 0800 and 2000 hours near the Egegik River sonar site, 2014.

Egegik River weather observations, 2014							
Date	Air temperature (°C) @ 0800	Air temperature (°C) @ 2000	Precipitation (mm)	Wind dir @0800 (deg)	Wind speed (kph)	Wind dir @2000 (deg)	Wind speed (kph)
5/9/2014	N/A	N/A	N/A	N/A	N/A	N/A	N/A
5/10/2014	N/A	N/A	N/A	N/A	N/A	N/A	N/A
5/11/2014	N/A	N/A	N/A	N/A	N/A	N/A	N/A
5/12/2014	N/A	N/A	N/A	N/A	N/A	N/A	N/A
5/13/2014	10.4	16.5	-	90	12	90	15.9
5/14/2014	8.2	18.1	-	0	4.7	315	6.5
5/15/2014	9	18.8	-	90	4.3	315	9.7
5/16/2014	9.6	19.8	-	270	2.9	315	19.2
5/17/2014	12.3	N/A	N/A	270	20.5	N/A	N/A
5/18/2014	11.1	11.9	-	315	20.1	315	26.1
5/19/2014	5.9	10.8	-	0	32.1	270	35.5
5/20/2014	10.2	13	-	0	25.2	0	19.2
5/21/2014	8.3	10.6	5	315	3.2	315	9.9
5/22/2014	6.7	14.9	-	247	4	0	25.9
5/23/2014	10.5	N/A	-	315	6	N/A	N/A
5/24/2014	6.2	8.9	-	315	15.4	315	9.6
5/25/2014	4	13.1	-	270	3.3	315	11.4
5/26/2014	5.9	7	10	90	8.2	90	20.2
5/27/2014	5.8	6.6	8	160	11.8	180	25.7
5/28/2014	6.5	7.3	20	180	18.4	160	18.7
5/29/2014	6.2	9.1	13	90	18.3	270	6.7
5/30/2014	6	6.4	-	0	6.1	270	23.4
5/31/2014	4.8	8.5	-	315	21.3	0	9.6
6/1/2014	6.6	7.8	-	0	8.6	315	11.2
6/2/2014	6	9.5	-	0	4.2	0	4.7
6/3/2014	6.2	13.7	-	0	3.5	180	8.4
6/4/2014	7.7	15.3	-	180	12.8	180	17.2
6/5/2014	8.5	10.6	-	135	12.7	135	30.1
6/6/2014	9.2	9	5	315	4	135	7.9
6/7/2014	10.8	13.3	-	270	2.7	0	15.8
6/8/2014	8.8	8.5	-	315	18.1	0	16.3
6/9/2014	5.6	7.6	3	0	8.1	0	11.3
6/10/2014	5.9	9.1	5	0	12.6	0	11.3
6/11/2014	6.5	8.3	-	180	11	90	10.5
6/12/2014	7.2	N/A	-	90	9.5	N/A	N/A
6/13/2014	N/A	N/A	N/A	N/A	N/A	N/A	N/A