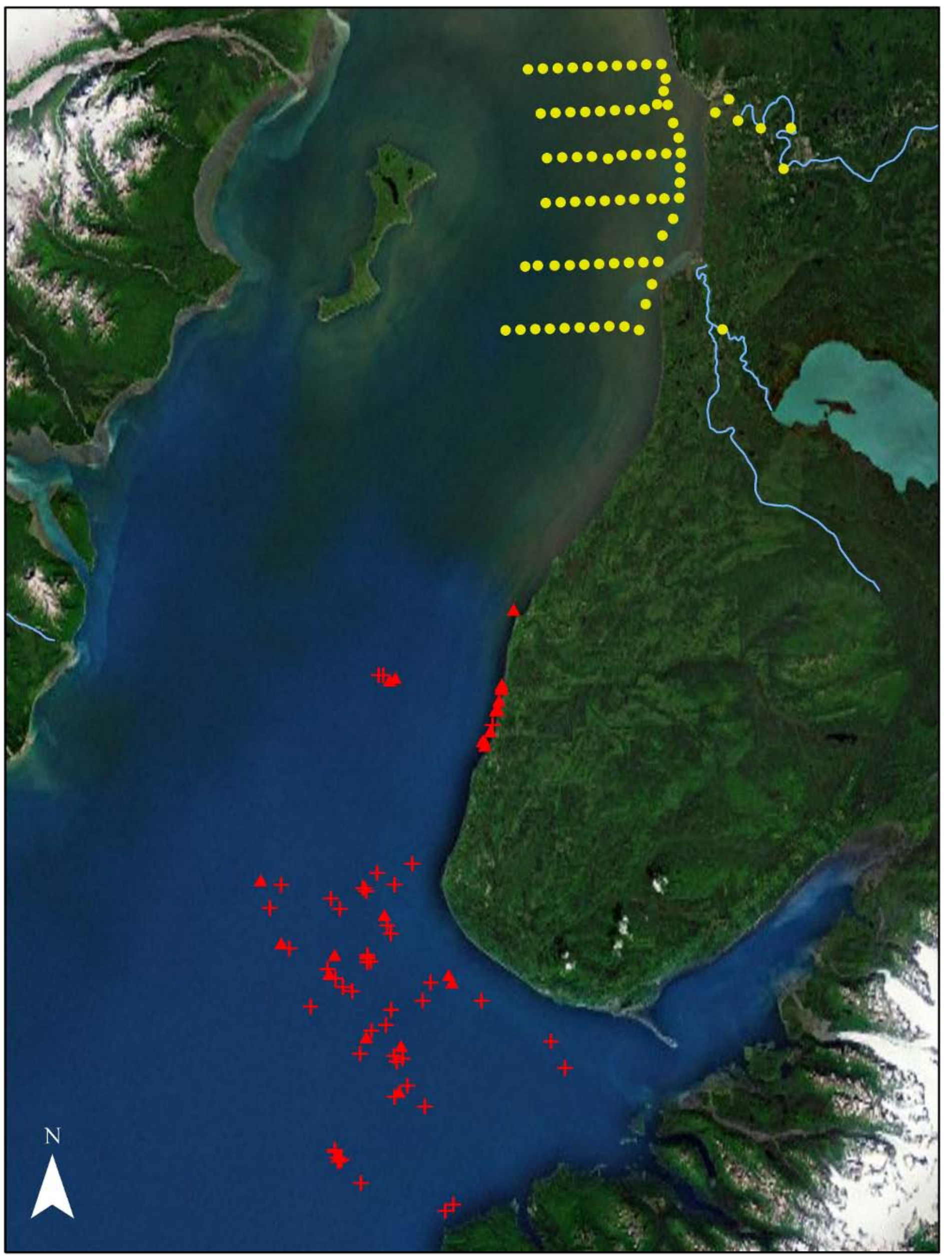
# Chinook and Sockeye Salmon Migration Patterns in Cook Inlet, 2013.

Report to the State of Alaska, Department of Fish and Game, Division of Commercial Fisheries

By Kintama Research Services Ltd.

Publication Date: 20 December 2013




**Location of the acoustic-tracking array (yellow dots) and the release sites of acoustic-tagged Chinook (red triangles) and sockeye (red crosses) salmon in Cook Inlet 2013.**

# Chinook and Sockeye Salmon Migration Patterns

# in Cook Inlet, 2013.

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Publication Date: 20-December-2013

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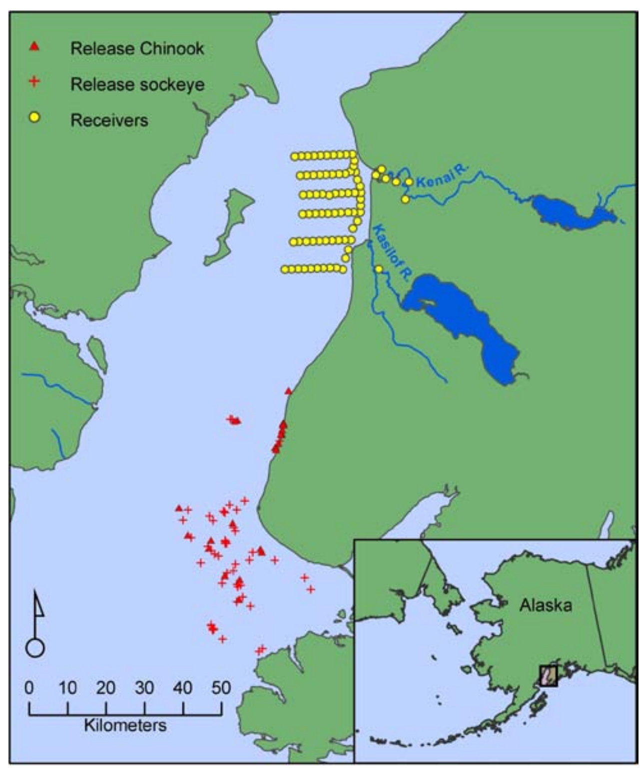
# Summary

## *Introduction*

Steadily worsening returns of Chinook salmon are occurring over a wide range of Alaskan rivers, including Cook Inlet's Kenai River Chinook population. The widespread nature of the decline suggests that the likely cause of the problem lies in the ocean—but with the marine phase of the life history poorly understood, questions of "where and when" significant declines are established remain unclear. The reduced productivity of Kenai River Chinook complicates attempts to manage the still productive sockeye stocks while ensuring escapement goals are achieved for both species. Because the sockeye fisheries also catch Chinook, an ability to identify biological differences between the two species that could potentially reduce Chinook catch when sockeye fisheries are underway would be useful in refining management strategies. The primary goal of this study was to identify species-specific differences in migration depth or other movement patterns for adult sockeye and late-run Kenai & Kasilof Chinook returning to spawn that could provide a stronger biological basis for management decisions.

## *Methods*

To address these questions, a marine telemetry array consisting of 70 receivers was deployed in a sparse grid starting at the western (offshore) edge of the eastside set net (ESSN) fishery area and extending westward approximately 1/3$^{rd}$ of the way across Cook Inlet (Summary Figure 1). Additional receivers were placed in the Kasilof and Kenai Rivers to monitor the freshwater phase of the migration. Acoustic receivers record the unique serial number transmitted by each acoustically-tagged fish along with the date and time of the detection. All acoustic tags used in this study were equipped with a pressure sensor reporting fish depth at the



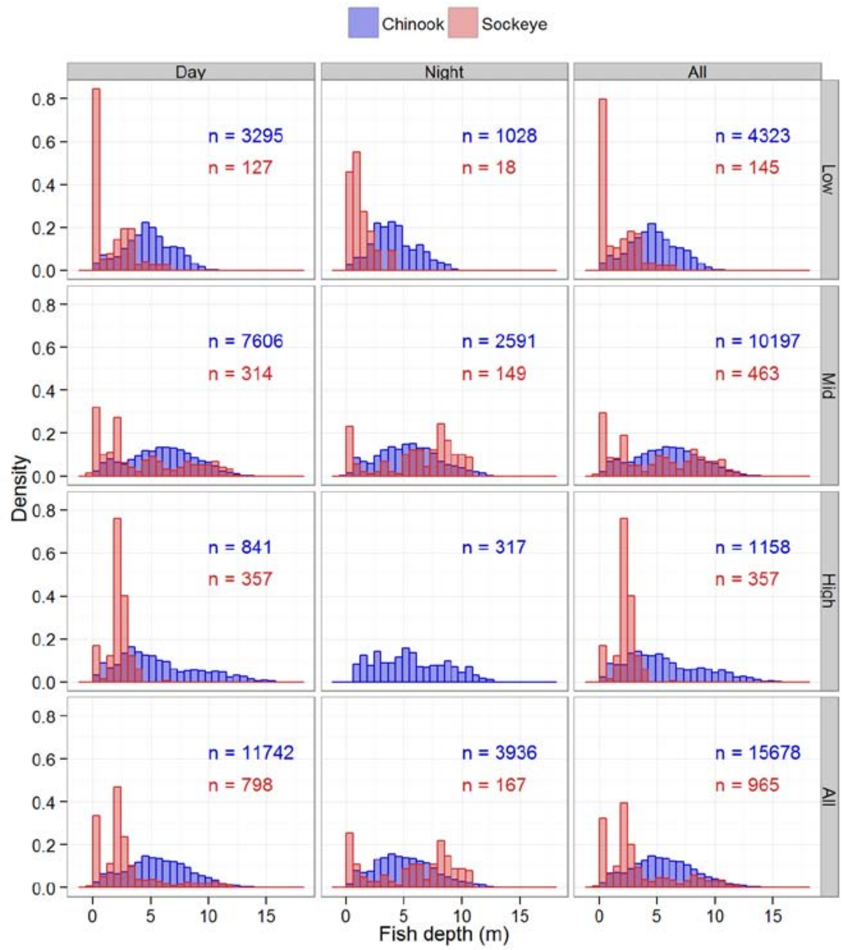

**Summary Figure 1. Location of the acoustic telemetry array and release sites for tagged adult sockeye and Chinook salmon in Cook Inlet, 2013.**

time of transmission. A total of 25 adult Chinook and 51 adult sockeye were caught in Lower Cook Inlet and tagged with paired external disc tags and internal acoustic tags. The fish were then released to continue their migration northwards over the acoustic array.

## *Key Results*

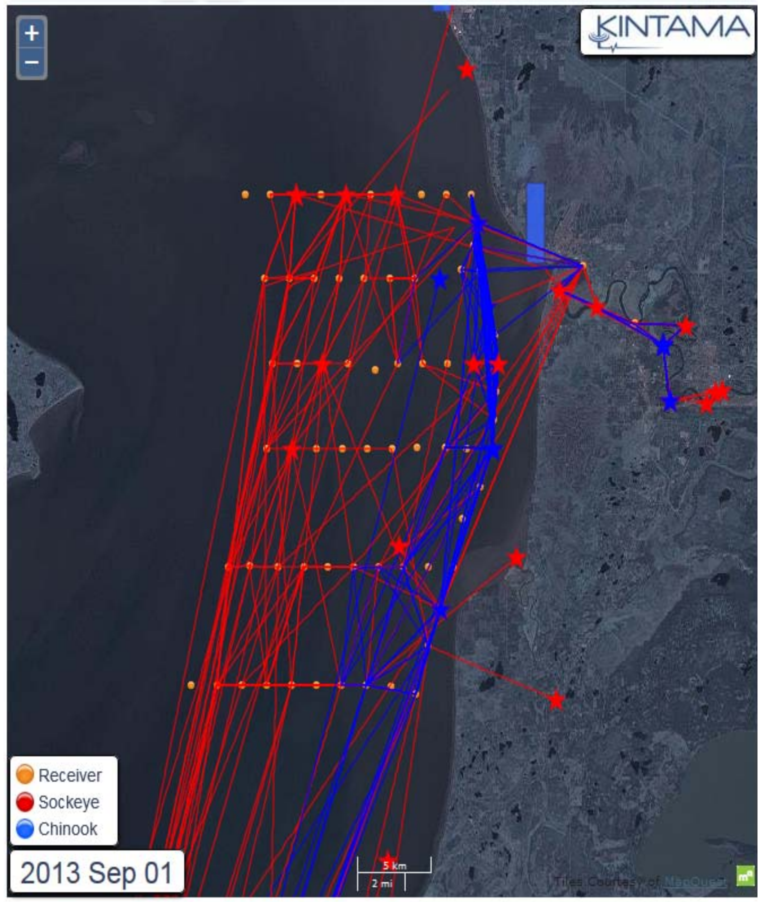
**1) Establish the depth distributions of Chinook and sockeye salmon as they enter the ESSN fishing district**.

The marine receivers recorded 16,608 depth measurements for Chinook and 3,389 depth measurements for sockeye. When depth data are restricted to those receivers sited just along the western boundary of the ESSN, the number of detections remains very similar for Chinook (15,678), but drops to only 965 for sockeye, reflecting the fact that most sockeye spent their time well offshore of the ESSN. The median depth of the sockeye and Chinook when calculated using data for the entire marine array was 1.21 m and 4.85 m, respectively; when restricted to receivers sited along the western boundary of the ESSN, these median depths were 1.82 m for sockeye and 4.85 m for Chinook. Although Chinook occasionally rose to near-surface waters, a clear difference in water column use was evident (Summary Figure 2).




**Summary Figure 2. Distribution of migration depths of adult sockeye and Chinook salmon along the western edge of the ESSN fishing district in 2013.**

2) **Establish the differences in entry patterns of Chinook and sockeye salmon into the ESSN fishing district in relation to date, tide stage, and wind velocity.**

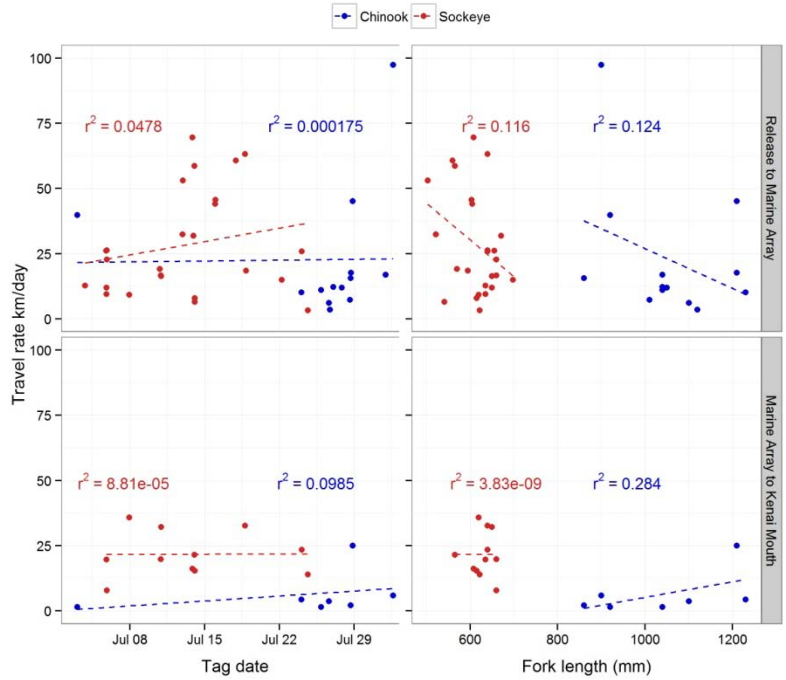



**Summary Figure 3. Screen clip from the animation of the Cook Inlet project in 2013 showing the inshore distribution of Chinook relative to sockeye. Lines indicate the movement path of each fish as represented by detections on the acoustic array and tags recovered by the fishery. Stars indicate the last known location of each fish. The animation can be accessed at www. http://kintama.com/animator/CookInlet2013/. (The vertical blue bars on the animation show how tide height changes with time for locations within Cook Inlet).**

Chinook and sockeye were found to have strikingly different marine behaviors, with Chinook repeatedly "patrolling" north-south almost exclusively along the western boundary of the ESSN, and sockeye found mainly farther offshore (Summary Figure 3). (An animation of the movements of the tagged salmon that can be dynamically zoomed, panned, and queried is available on the Kintama website: www. http://kintama.com/animator/CookInlet2013/). The observed behavior suggests that Chinook may spend a significant portion of their time within the ESSN and beyond the maximum detection range of the receivers. As receivers were not placed within the 1.5 nautical mile (2.5 km) wide ESSN, the length of time Chinook may spend in this area cannot be quantified at this time. No evidence was found that entry into the ESSN was strongly related to date, stage of the tide or wind.

**3) Establish the differences in migration rates of Chinook and sockeye salmon in relation to tagging date and fish length.**

There was no evidence that the migration rates of sockeye or Chinook were affected by either tagging date or fish length. Salt-water travel rates from 1) release to first detection on the marine array, and 2) from first detection on the marine array to river entry showed little relationship with release date or fish size in either species (r2<0.3; Summary Figure 4).




**Summary Figure 4. Comparison of the effect of release data and fish length on the travel rate of Chinook and sockeye from (top) release to first detection on the marine array and (bottom) from the marine array to river entry.**

4) **Establish whether tidal fluctuations affect milling behavior of Chinook and sockeye salmon in the Kenai River estuary.**

The majority of Chinook and sockeye initially entered the river and migrated upstream on either a flood or slack tide. At RKm 2 (Snug Harbor), only two fish had detections while the tide was ebbing significantly; one of these fish did not migrate upriver and the other logged only a single detection on a falling tide as it milled back and forth between the detection sites at RKm 2 and 4.5. At RKm 4.5, (Inlet Fish), neither species was recorded during ebbing tides. The influence of tide dropped by RKm 8.2 (Kenai Bridge), as 62% of Chinook and 81% of sockeye detections were recorded during flooding tides.

Only two fish showed evidence of milling in the Kenai River estuary. Fish 9484 moved back and forth three times between the two lowest receivers in the Kenai River; fish 9535 was detected once at the Kenai River mouth and then disappeared for 7 hours before being detected at the river mouth again and then proceeding upstream. Most of these upriver movements occurred during flooding tides. All other tagged salmon migrated directly up the Kenai River after river entry.

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# 1. Methods

## 1.1. Acoustic array

Acoustic-tagged salmon were detected by VEMCO VR2W acoustic receivers deployed in Central Cook Inlet, and in the Kenai and Kasilof rivers (Figure 1). In Cook Inlet, we deployed 70 receivers in early June in a sparse grid starting at the western (offshore) edge of the eastside set net (ESSN) fishery area and extending westward approximately 15 km or 1/3rd of the way across the channel. The grid consisted of a series of 6 east-west lines spaced ca. 5 km apart. We deployed 10 receivers in each line. We also sited 2 receivers midway between each line (for a total of 10 units) to provide greater resolution along the outer boundary of the ESSN fishing zone. We recovered and successfully uploaded 54 of these receivers Aug 27th-September 5th. Four of the remaining 16 receivers did not respond when polled and are considered lost. An additional 8 receivers did respond when polled (i.e., they were in their deployed position) but did not rise to the surface and were possibly held down by the strong tidal currents. The last 4 receivers were displaced by fishing activities or other causes and then returned to Kintama by members of the public. We downloaded these units and screened the detections to estimate the date and time they were pulled from their deployed positions (see section B.4).

To monitor the freshwater phase of the migration, we worked with ADF&G to deploy 11 receivers in the Kenai River between June 9th and July 2nd. Single receivers were installed at Snug Harbor and Inlet Fisheries (RKms 2 and 4); and paired receivers were installed at RKm 8.2 (the Kenai River Bridge), RKm 13.8 (lower Chinook sonar site), RKm 22.0 (upper Chinook sonar site), RKm 25.3 (Harry Gaines Fish Camp), and RKm 30.6 (sockeye sonar site). On June 19th, ADF&G deployed an additional 2 receivers in the Kasilof River at RKm 12.1 on the mountings for the ADF&G sonar. All freshwater deployments were successfully recovered and downloaded Aug 8th-24th.

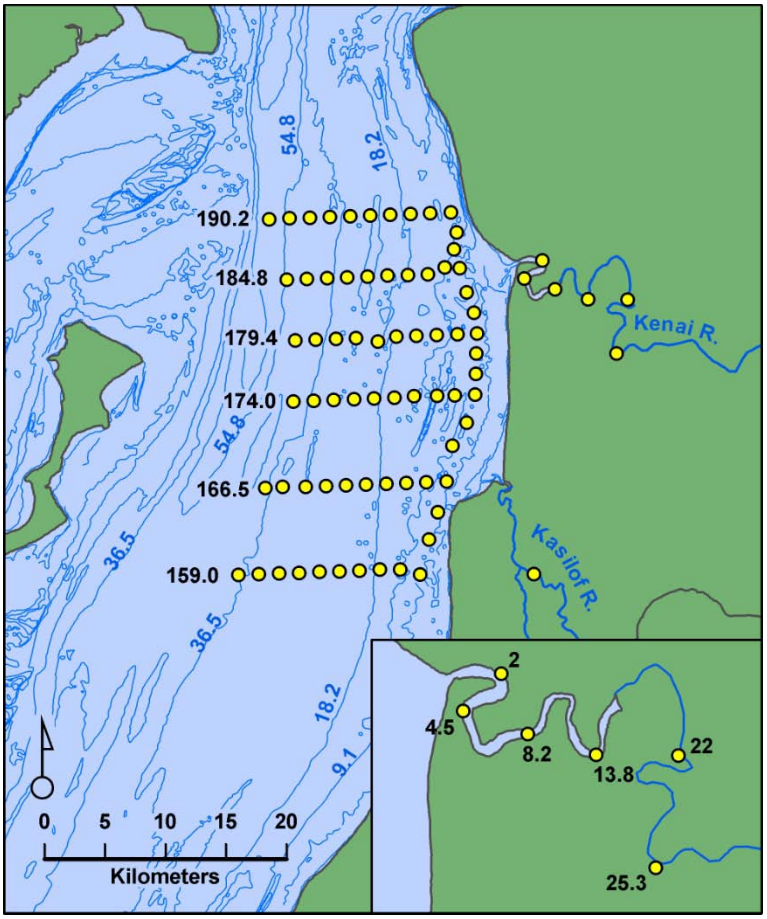


**Figure 1. The acoustic array deployed in Cook Inlet and the Kenai and Kasilof rivers in 2013. Yellow circles represent individual acoustic receivers. Number labels to the left of east-west receiver lines are the distance in kilometers from the mouth of Cook Inlet. Inset: numbers beside receiver deployments are the river kilometer (RKm) from the mouth of the Kenai River. The receiver deployed in the Kasilof River was at RKm 12.1.**

## 1.2. Tagging

### 1.2.1. Tagging procedure

Maturing Chinook and sockeye salmon were captured and tagged in southern Cook Inlet between July 1st and August 1st 2013. In order to obtain a representative sample of the Kenai River salmon, tags were applied approximately in proportion to the abundance of each species as the run entered Cook Inlet. Capture efforts were initially conducted with commercial troll gear and focused on offshore waters where it was thought that the majority of Kenai River Chinook likely migrate[1]. Because

[1] ADF&G (2013). Request For Proposal: Chinook and Sockeye Migration Patterns in Cook Inlet. Page 24.

the captures of tagged Chinook were very low offshore (see Results), we began capturing Chinook using sport troll gear in the inshore near Anchor Point in late July.

Salmon were tagged with paired external disc tags and internal acoustic tags. External tags were numbered orange Petersen disc tags; internal tags were VEMCO V16P-3H acoustic transmitters (16 mm diameter; 67 mm length; 26 g weight in air). The acoustic tags transmitted the unique ID code of the tag and the current depth. (These data along with the date and time of transmission are recorded by the acoustic receiver.) Both tag types were labeled "Return for Reward" in case of capture by the fishery. The disc tags were attached through the musculature below the dorsal fin. We implanted acoustic tags into the abdominal cavity of the first three sockeye using surgical techniques (July 1st and 2nd, 2013); however, we switched to using a gastric implantation technique for the remainder of the tagging (from July 2nd) when we found that the surgical incision tended to gape. After tagging, each fish was measured, and a DNA tissue sample was taken from the axillary process of the pelvic fin. Fish were then released to the ocean close to their capture location (Figure 2).

Detailed handling and tagging methods are available in Appendix A.

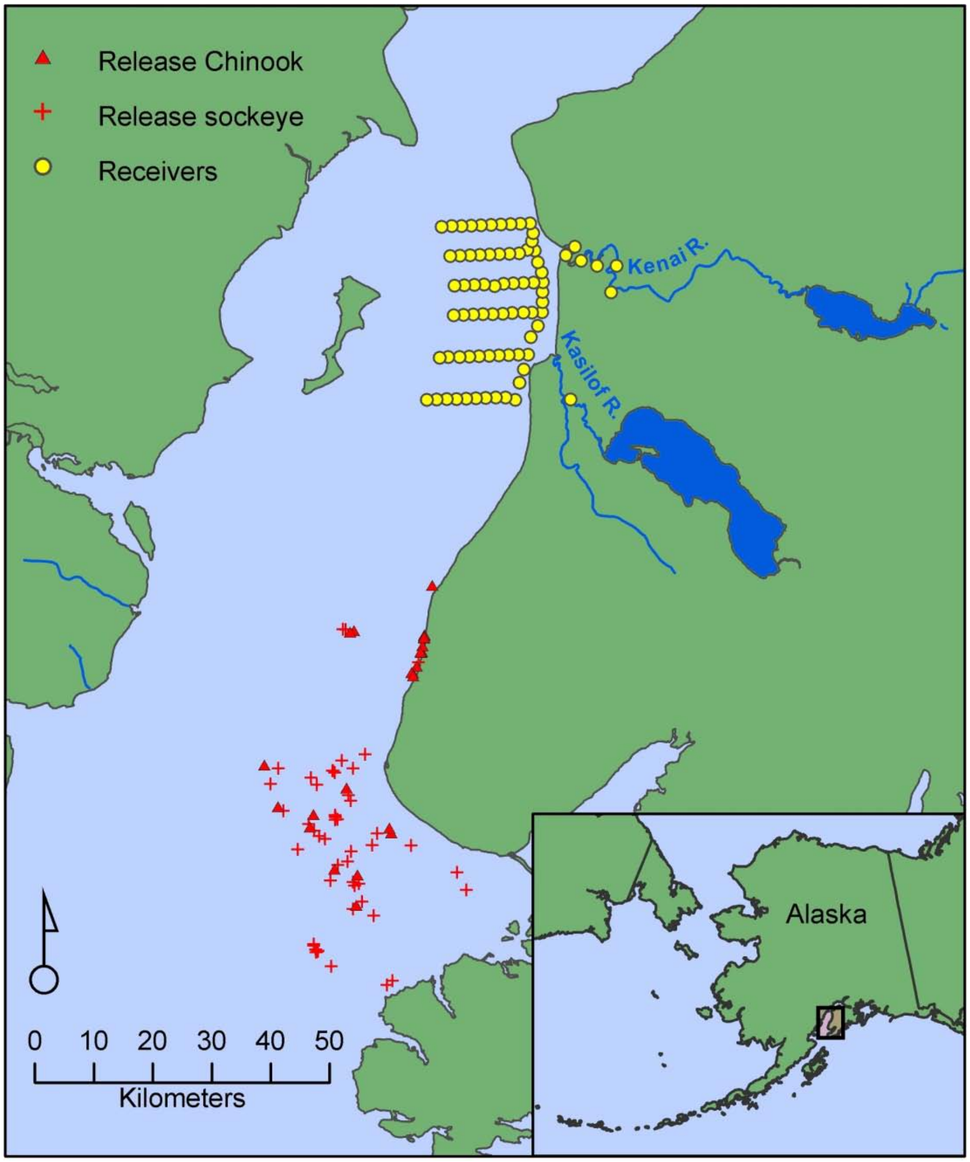


**Figure 2. Location of release sites for tagged Chinook and sockeye relative to the telemetry array.**

### *1.2.2. Sensor accuracy*

In order to assess the accuracy of the pressure sensors in the acoustic tags, we deployed six tags previously returned from the fishery and eight receivers in Sproat Lake, B.C., between Oct 23rd and Dec 4th. Three tags were deployed at each of 5.2 or 3.0 m below the surface (close to the mean recorded depth of the Chinook and sockeye—see Results 2.5) on a taut mooring with all floatation placed sub-surface to reduce the risk of vandalism. Three major rainfall events occurring while this study was running increased the water level in the lake and thus the depth of the tags. A water level gauge[2] at the outflow of Sproat Lake (only a few km from the study site) indicated that water levels there changed by a maximum of 0.9 m and thus should be closely correlated to water level changes above the tags. To limit the effect of water level changes, we used only sensor transmissions on days where the water level at the gauge was within 0.25 m of its level on the day the tags were deployed (Oct 23rd). The results show that one depth sensor failed (although the tag continued transmitting; see Appendix B.6 for other failed sensors), and one tag stopped transmitting before the end of the study. Apparently the tag that stopped transmitting had not been turned off when originally recovered from the fishery and the programmed kill time of 150 days post-activation was exceeded during the lake deployment. The maximum average difference between the approximate deployed depth of the tags and the reported depth by the remaining sensors was 0.58 m. Because the tags were programmed to have a depth resolution of 0.6 m, this indicates that the tags were generally within 1 interval of true depth and that instrument errors were substantially smaller than the difference in species-specific mean depths measured in this study. There was also no indication that the accuracy of the tags' depth sensors changed over time.

**Table 1. Comparison between the approximate depth (m) of VEMCO V16 tags deployed in Sproat Lake B.C. and the depth values reported by pressure sensors in the tags.**

| | | | Transmitted Depth (m) | | | |
|---|---|---|---|---|---|---|
| **Deployed Depth (m)** | **Tag** | **N** | **Mean** | **SE** | **SD** | **Difference between deployed and transmitted depths (m)** |
| 5.2 | 9485 | 69583 | 4.75 | 0.004 | 0.95 | -0.45 |
| | 9487 | 71519 | 4.83 | 0.004 | 1.17 | -0.37 |
| | 9524 | 61921 | 5.21 | 0.004 | 0.95 | 0.01 |
| 3.0 | 9491 | 70389 | 3.04 | 0.002 | 0.59 | 0.04 |
| | 9499 | 50166 | 3.58 | 0.002 | 0.47 | 0.58 |

[2] Environment Canada hydrometric station 08HB008: http://www.wateroffice.ec.gc.ca/index_e.html

### 1.3. Data screening

The detections data are screened in various ways prior to analysis. Details on these screens are available in Appendix B.

### 1.4. Data analysis

For simplicity in the main report, analytical methods are described in Appendix C.

## 2. Results

### 2.1. Tagging

A total of 26 Chinook and 51 sockeye were tagged and released as part of the 2013 study. Tagging locations are shown in Figure 2.  Because offshore Chinook catches were low using the commercial troller f/v West Bank (Figure 3), beginning on July 23rd Kintama (at its own cost) supplemented tagging efforts by chartering two sport fishing boats to troll in the very shallow waters (1.5-2.7 m; 5’-9’) just off the beach north of Anchor Point, where most Kenai Chinook are known to be caught.  (Offshore tagging operations were partially or completely shut down from 18-20 July because of bad weather; fishing near the beach then had to wait further before starting because the water was heavy with debris from the storm).

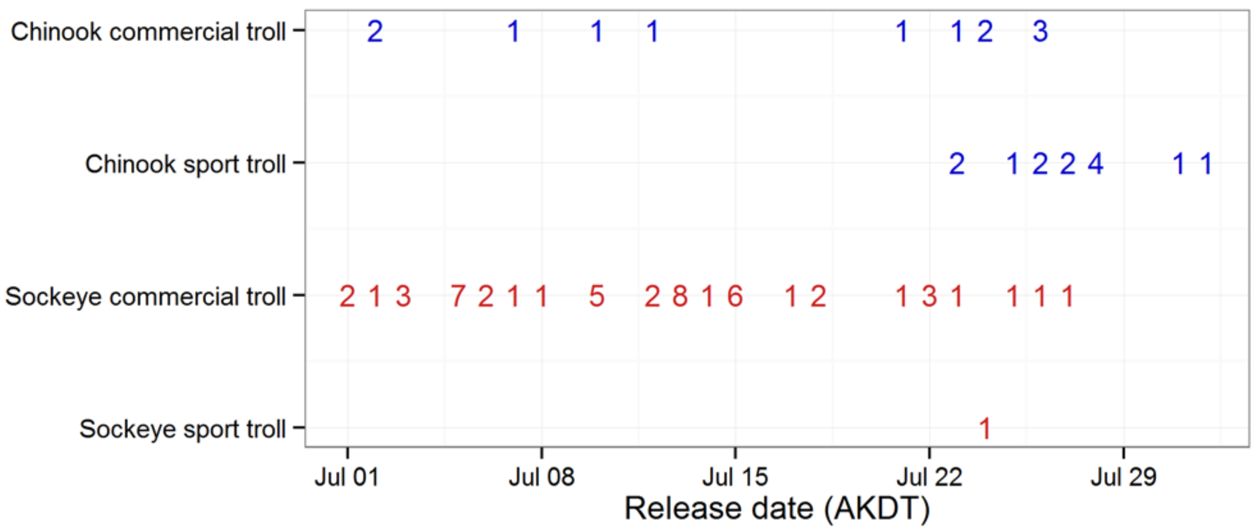


**Figure 3. Number of acoustic-tagged, adult Chinook and sockeye grouped by capture method and capture/release date.**

Capture depths varied by location for maturing Chinook (as well as immature "feeders"; Figure 4). Adult Chinook were consistently caught only on the bottom lures by the troller in maximum water depths of 30-35 m (100'-120') despite substantial proportions of the other lures on each troll line also being rigged for Chinook. (Each of the 6 troll wires was rigged with flashers and lures spaced approximately 2 fathoms apart; the total number of hooks fished therefore depended upon water depth, but was typically 4-6 vertically spaced lures/troll wire, yielding a total of 24-36 lures). In the inshore, maturing Chinook were captured at <5 m. Maturing sockeye were widely distributed in the water column offshore with most fish captured at water depths between 3.5-11 m. The single sockeye captured with the inshore sport gear was caught at ~2.5 m depth.

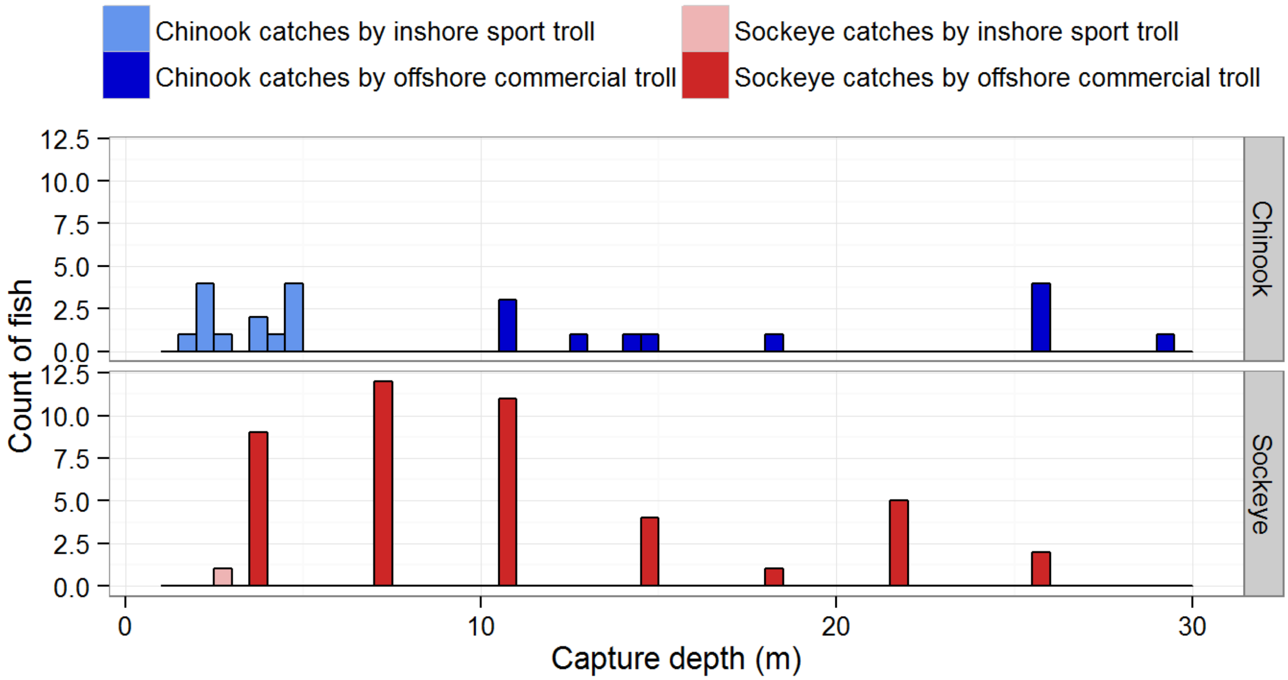


**Figure 4. Capture depth by capture location (fishing method) for maturing Chinook and sockeye tagged in southern Cook Inlet 2013.**

Although daily catch rates for maturing Chinook were low in the offshore region of southern Cook Inlet, maturing Chinook were likely widely distributed across at least the eastern and central parts of lower Cook Inlet, a region 40 nautical miles wide. The estimated run size of ca. 22,000 Kenai Chinook (17,000 escapement[3] + 5,000 harvest[4]) yields a migration density of 550 Kenai Chinook per mile per month, or a daily migration of ca. 18 Chinook crossing per linear mile across the Inlet. These low densities (plus the fact that Chinook would only typically bite just after the change to the ebb tide) strongly suggest that maturing Chinook are not just confined to the nearshore region off Anchor Point where most sports fishermen operate, but that they are difficult to catch in the offshore because they are thinly distributed near-bottom over a wide region.

Sockeye catch rates were also lower than the planned target of 70 adults, but for a different reason. Early catches using the offshore troll vessel were ample to provide the target of 70 sockeye for

[3] http://www.adfg.alaska.gov/sf/FishCounts/index.cfm?ADFG=main.kenaiChinook

[4]ADF&G reports a preliminary 2013 commercial Chinook harvest in lower Cook Inlet of 5,098 king salmon. www.adfg.alaska.gov/static/applications/dcfnewsrelease/371793118.pdf

tagging if these catch rates had continued, unfortunately, catches dropped to virtually nothing after 18 July (Figure 3).

Overall, there were four reasons for the shortfall in tagging numbers. We outline these issues here to document them and to suggest how the study design could be modified in future years.

1. The original direction in the RFP required tagging across lower Cook Inlet in order to ensure that salmon were tagged from all regions of Cook Inlet (in case salmon migrating through other parts of the inlet had different behaviors); this resulted in some fishing effort being expended in western or west-central Cook Inlet where few or no Chinook (and very little other animal life) was present. In general, we found the region farther to the west biologically unproductive (no birds or sea mammals seen at the surface, no sign of plankton or fish on the echo sounder, and no salmon catches when trolling).

2. It was challenging to tag fish in proportion to abundance because future catch rates were unknown. When sockeye were abundant early in July, we reserved substantial tag numbers for use later in the run; unfortunately, sockeye catches dropped sharply after mid-July, leaving us with insufficient numbers to meet the tagging goal.

3. Bad weather. Fishing was shut down (or terminated early during the day) several times because of storms.

4. The exposed nature of Cook Inlet and the poor bottom for secure anchoring made it necessary to steam for 2-3 hrs at the beginning and end of each day in order to find a safe anchorage (typically near Seldovia) on all but the most favorable weather days. Because the salmon were biting primarily near the turn to the ebb tide, potentially productive fishing time was often lost to the logistics of moving to and from the fishing ground.

In future years, additional fishing vessels could be used to increase the numbers of tagged salmon in the offshore. For sockeye, an additional offshore troller would be needed because of the limitations imposed by the timing of tides, poor weather, and the short periods that salmon actively fed each day. Additional fishing using one or more smaller boats fishing very near to shore off Anchor Point would yield substantial increases in catch for Chinook in a region where substantial proportions of the maturing Chinook appear to be returning to the Kenai River. Offshore, a second troller would also improve Chinook tagging rates because only the near-bottom troll hooks catch Chinook, and bottom lures were often rendered ineffective by halibut captures.

## 2.2. Technical performance

Detection efficiency on both the marine and freshwater components of the tracking array was 100%, with all tagged animals detected in the Kenai or Kasilof Rivers previously detected on one or more of the receivers forming the marine array, and all tagged animals detected on up-river receivers in the Kenai River previously detected on the lower river receivers[5]. It was not possible to evaluate detection efficiency of the two Kasilof River receivers deployed on opposite sides of the river at the ADF&G Didson site because no receivers were placed farther upstream, but their detection efficiency may have been poor; only one sockeye was detected (three detections) and on only one of the two receivers, despite the river being relatively narrow.

## 2.3. Detections

For both species, approximately 50% of tagged fish were detected on the marine array, and approximately 25% were detected entering the Kenai and Kasilof rivers (Table 2). We discuss these numbers further in section 2.11 Apparent survival. Because we released more sockeye than Chinook, these percentages mean that more sockeye were detected by the acoustic array. However, differences in the migration behavior of the two species resulted in far more detections for individual Chinook than sockeye (see section 2.4 Movements) and thus provided a stronger dataset per individual.

[5]This does not mean that every tagged fish was detected by every receiver when the fish were within the theoretical detection range.

**Table 2. Detections recorded by the acoustic array deployed in Cook Inlet in 2013. First columns report the count of maturing Chinook and sockeye detected; second columns report the count of detections recorded for these fish. (A total of 25 tagged Chinook and 51 tagged sockeye were released in lower Cook Inlet).**

| | | Number of Fish Detected[6] | | Number of Detections | |
|---|---|---|---|---|---|
| | | **Chinook** | **Sockeye** | **Chinook** | **Sockeye** |
| **Entire Marine Array (includes ESSN Boundary)** | | 13 | 27 | 18,232 | 3,422 |
| **ESSN Boundary** | | 12 | 17 | 17,190 | 969 |
| **Kenai River** | **RKm 2 Snug Harbor** | 7 | 11 | 169 | 175 |
| | **RKm 4.5 Inlet Fish** | 7 | 10 | 207 | 176 |
| | **RKm 8.2 Bridge** | 7 | 9 | 304 | 368 |
| | **RKm 13.8 Lower King Sonar** | 5 | 9 | 35 | 301 |
| | **RKm 22 Upper King Sonar** | 3 | 7 | 10 | 13 |
| | **RKm 25.3 Gaines Dock** | 7 | 9 | 386 | 71 |
| | **RKm 30.6 Sockeye Sonar** | 3 | 7 | 28 | 73 |
| **Kasilof R.** | **RKm 12.1 Sockeye Sonar** | 0 | 1 | 0 | 3 |

## *2.4. Movements*

Animation of the detection data (http://kintama.com/animator/CookInlet2013/) revealed major differences in the pattern of movement of the two species, with tagged Chinook migrating almost exclusively as close to shore as our instrumentation was deployed (the western offshore boundary of the ESSN), and then repeatedly "patrolling" north and south along the offshore boundary for up to 20 days before river entry (Figure 5; Figure 6; Figure 7). In contrast, the marine distribution of tagged sockeye was much broader in the eastern third of Cook Inlet (where instrumentation was emplaced). Sockeye migrated primarily offshore and then moved rapidly past the western boundary of the ESSN fishing district with all but one sockeye present near the ESSN boundary for one day or less before entering the Kenai River. In general, both species were detected evenly along the ESSN boundary (Figure 6), although more Chinook were detected at the receivers 6.5 and 10 km south from the Kenai River, which some individual Chinook used as the southern limit before turning around and swimming north again while milling near the river mouth.

[6] Totals include several fish that were not included in the assessment of migration depth: 2 Chinook and 1 sockeye with faulty depth sensors; and 1 sockeye that was detected entering the Kasilof River. The sockeye with the faulty depth sensor was detected on the outer array before being recovered in the fishery near Kodiak Island.

A lack of receivers within the first 1.5 nautical miles (2.7 km) of the eastern shore of Cook Inlet, where the ESSN operates, is a limitation in the observational power of the 2013 array design for Chinook because the majority of Chinook detections are from receivers sited along the outer edge of the ESSN. This suggests that undetected Chinook may simply have remained farther inshore, beyond the range of our instrumentation (a maximum of roughly 700 m). Similarly, the limited western extent of the marine sub-arrays likely prevented complete detection of sockeye, which were more abundant on the offshore half of the marine array.

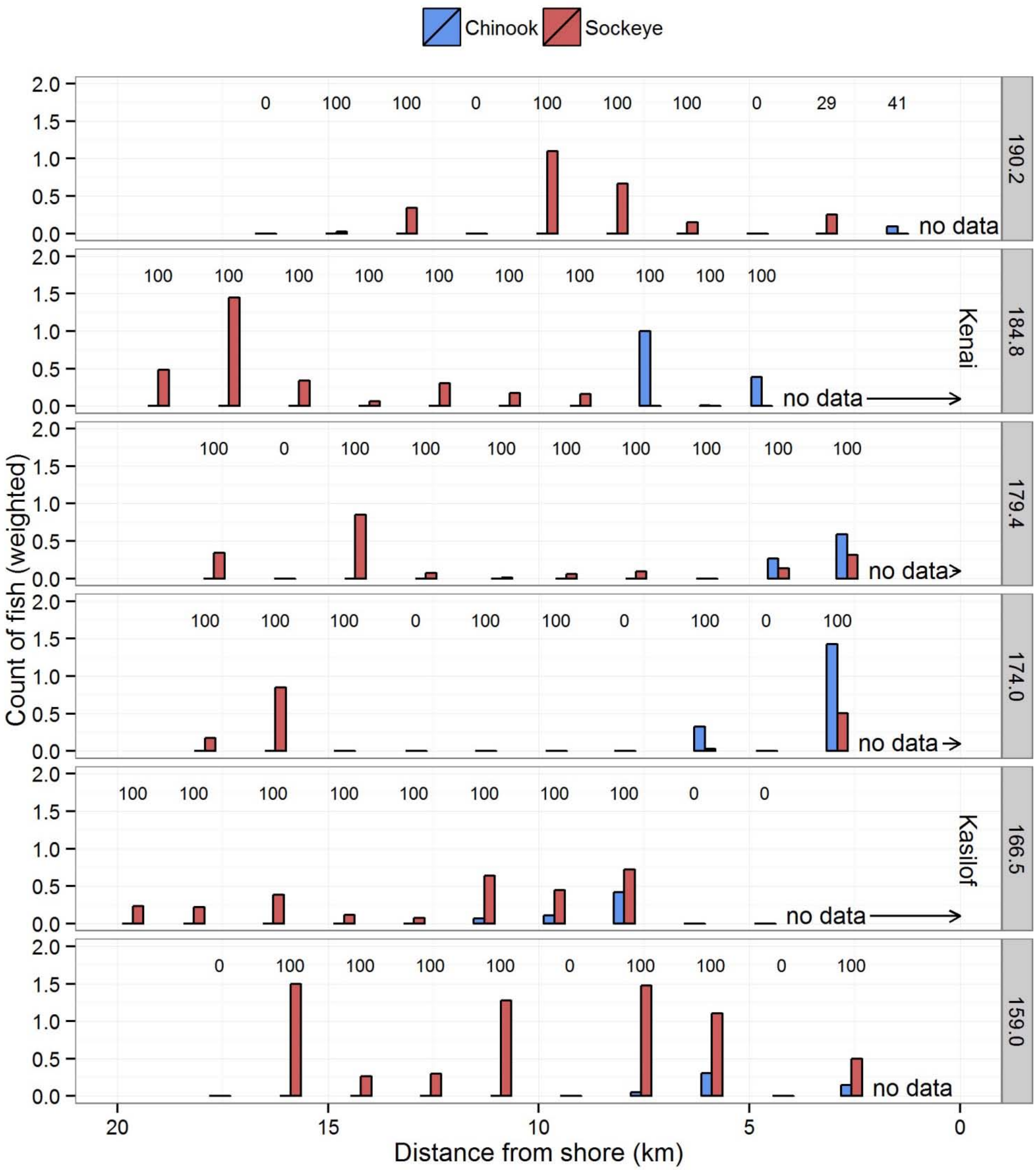


**Figure 5. Distribution of adult sockeye and Chinook salmon migrating over the marine array. If a fish was detected at more than one receiver, a proportion was allocated to the receiver, e.g., if an ID code was detected on two receivers, each receiver was assigned a value of 0.5. The values above the bars indicate the proportion of time that the receiver was operational during the season. "No data" indicates the extent of the inshore region (within the ESSN) lacking instrumentation.**


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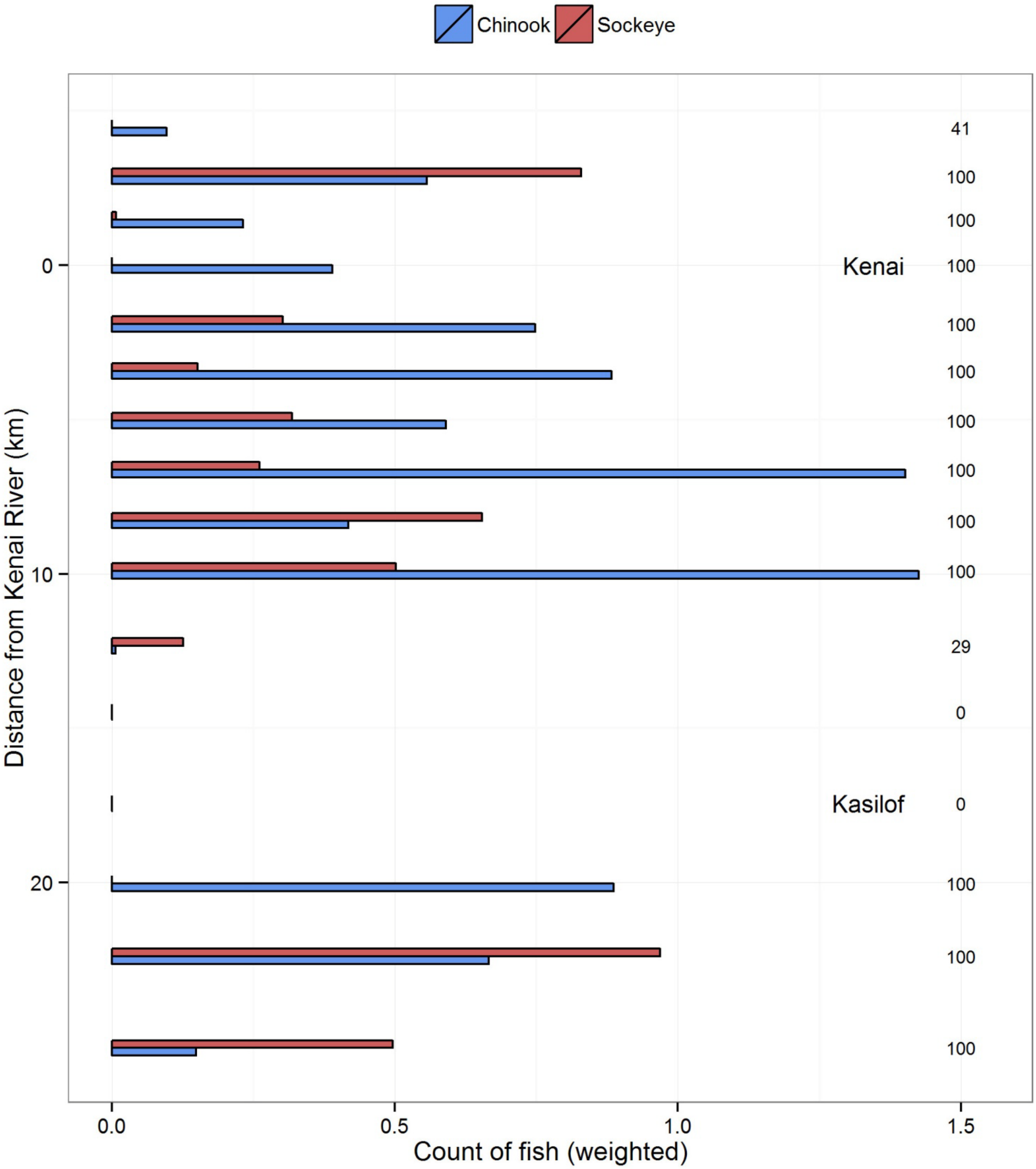


**Figure 6. Distribution of adult sockeye and Chinook salmon as they migrated over the north-south row of acoustic receivers bordering the western edge of the ESSN fishery in Cook Inlet 2013. If a fish was detected at more than one receiver, a proportion was allocated to the receiver, e.g., if an ID code was detected on two receivers, each receiver was assigned a value of 0.5. The values to the right of the bars indicate the proportion of time that the receiver was operational during the season.**

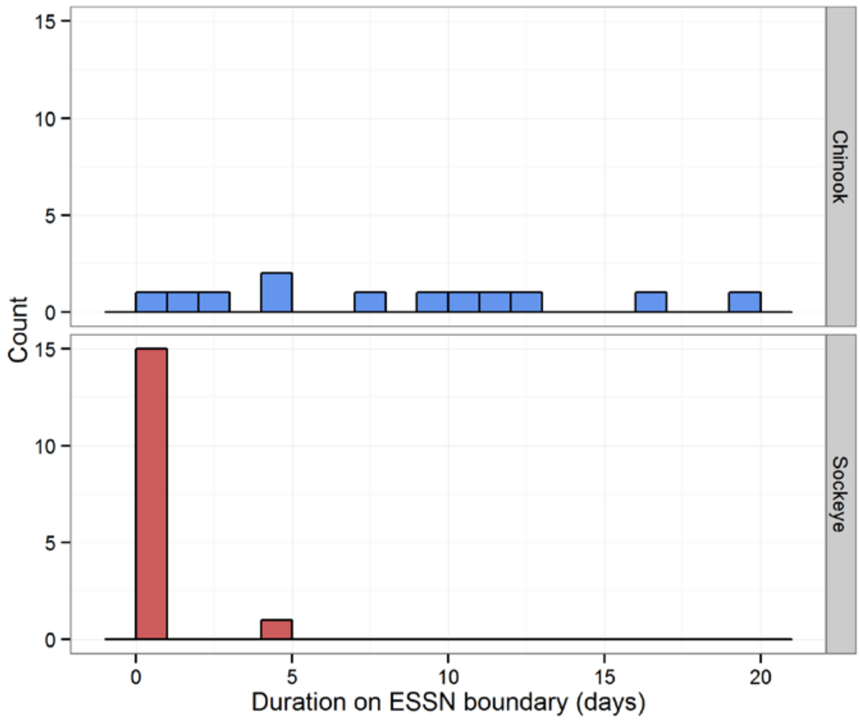


**Figure 7. Time between first and last detection (duration) of adult sockeye and Chinook salmon on the north-south row of acoustic receivers bordering the western edge of the ESSN fishing district.**

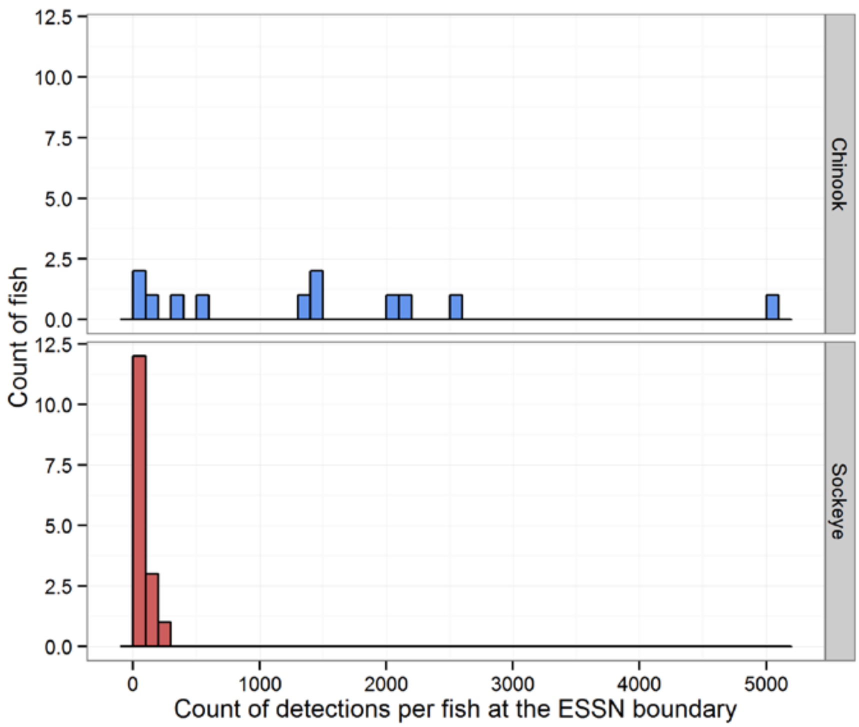


**Figure 8. Distribution of the number of detections recorded for individual adult sockeye and Chinook salmon on the north-south row of acoustic receivers bordering the western edge of the ESSN fishing district.**

## 2.5. Depth distributions near the ESSN

Chinook and sockeye detected on the receivers sited along the offshore boundary of the ESSN showed significant differences in the depth of migration. At the boundary, the receivers recorded a total of 15,678 depth measurements for 10 individual Chinook, and 965 depth measurements for 16 individual sockeye. The median depths were 4.8 and 1.8 m respectively, a 3 m difference. Over the broader area represented by the marine array as a whole, the receivers recorded 16,608 depth measurements for 11 individual Chinook and 3,389 depth measurements for 25 individual sockeye. The large increase in the number of detections for sockeye relative to the count along the ESSN boundary reflects their mostly offshore distribution. The Chinook migrated closer to shore and were mainly detected along the ESSN boundary. Despite their distribution over deeper offshore water, the median depth for sockeye over the full marine array was slightly shallower than along the ESSN boundary (1.2 m); the median depth for Chinook was unchanged (4.8 m).

To better assess the amount of time tagged Chinook and sockeye spent at each depth along the western boundary of the ESSN, we calculated the relative depth distribution using all observations collected over the receivers forming the ESSN boundary (Figure 9) after excluding the data from three failed depth sensors (Appendix B). We then calculated the proportion of the total detections that occurred between the surface and different maximum depths (the cumulative depth distribution), as this measurement reflects the proportion of time each species spends near the surface (Figure 10).

These summaries show that sockeye spent 50% of their time in the top 1.8 m (6’) of the water column, while Chinook spent only ca. 12% of their time at such shallow depths (Table 3). For both species, depth in the water column bore little relationship to bottom depth (Figure 11).

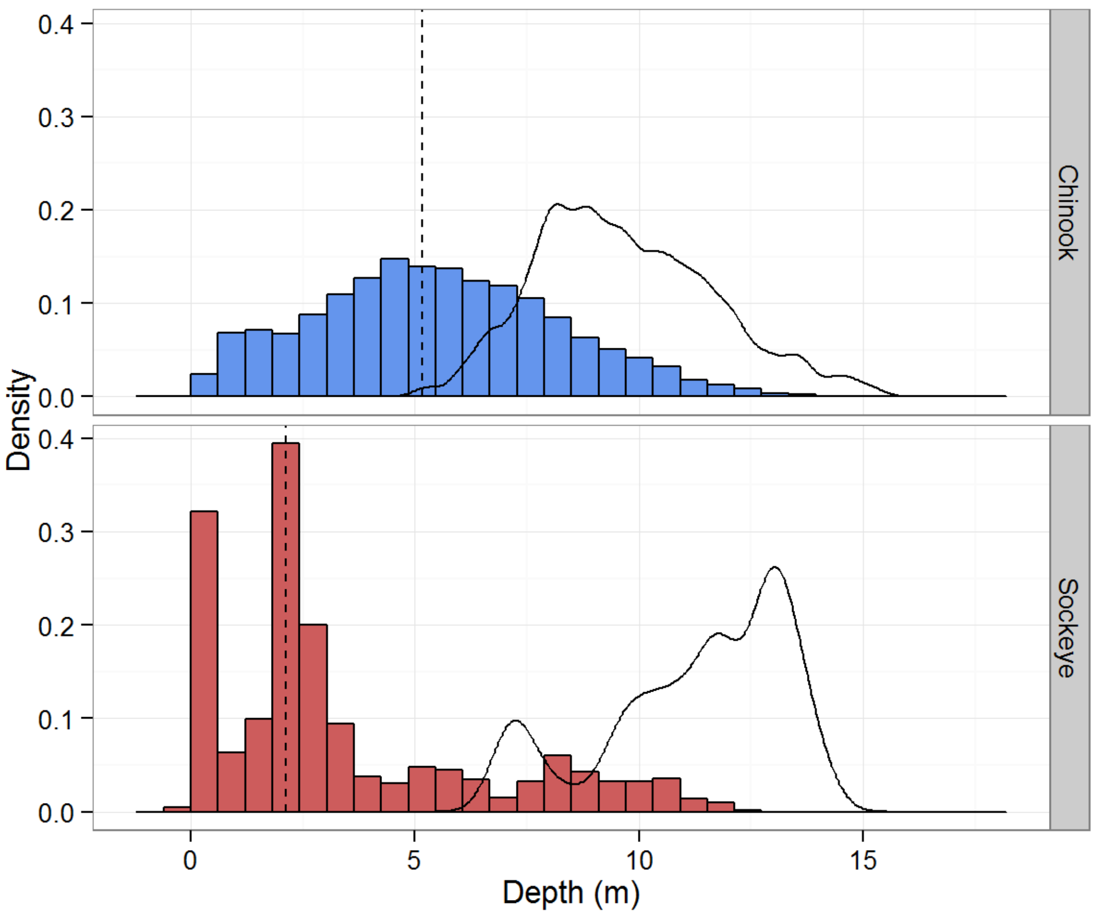


**Figure 9. Depth distribution (m) of adult sockeye and Chinook salmon migrating over the row of acoustic receivers bordering the western edge of the ESSN fishing district. Colored bars indicate the depth distributions of acoustic-tagged fish. Black lines indicate the distribution of seafloor bottom depths at the time (i.e. adjusted for tide level) and location (i.e. receiver site) each fish was detected. Distributions were calculated using all depth measurements pooled by species. Vertical dashed lines indicate the median depth.**

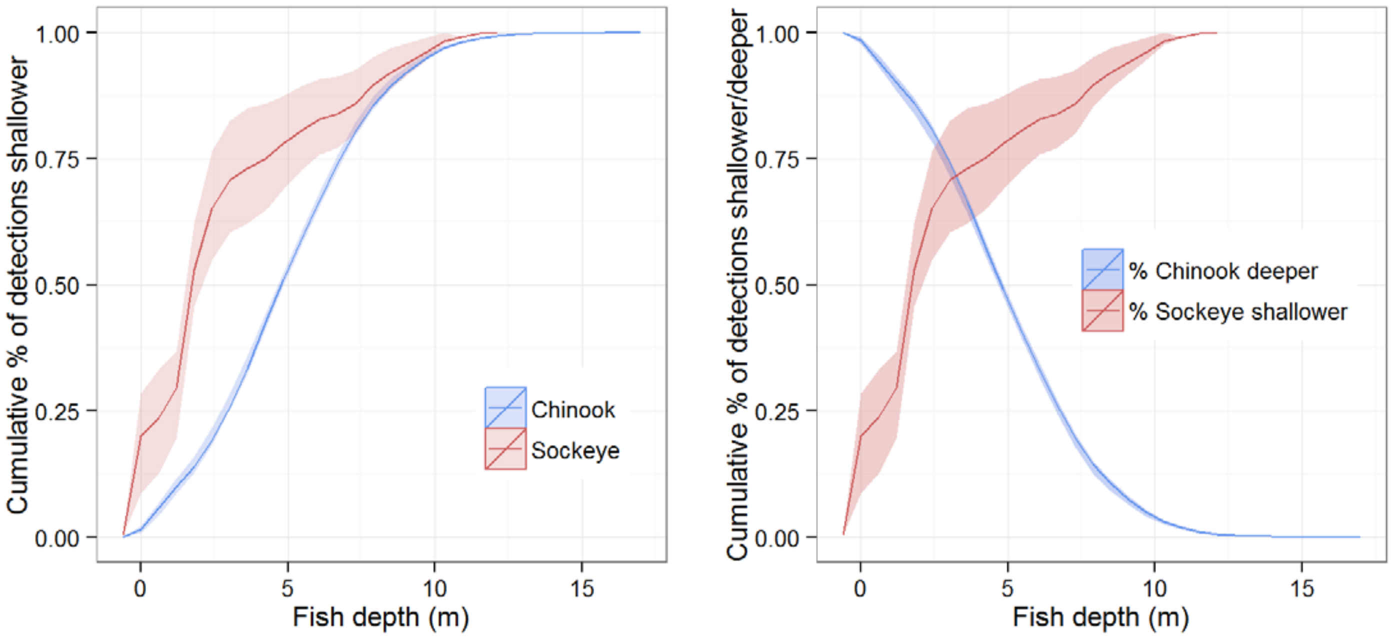


**Figure 10. (Left) Cumulative depth distribution of tagged sockeye (red) and Chinook (blue) near the ESSN. (Right) The same data, but showing for Chinook the proportion of time Chinook spent deeper than a given depth. The lines show the jackknifed mean and the shaded areas span the minimum and maximum of the jackknifed replicates (see Appendix C Data Analysis).**

**Table 3. Cumulative depth distribution of tagged sockeye and Chinook near the western boundary of the ESSN fishing district.**

| Depth (m) | Cumulative percent of detections shallower | |
|---|---|---|
| | Chinook | Sockeye |
| 1 | 6% | 24% |
| 2 | 14% | 54% |
| 3 | 19% | 66% |
| 4 | 34% | 74% |
| 5 | 51% | 78% |
| 6 | 59% | 81% |
| 7 | 74% | 84% |
| 8 | 86% | 90% |
| 9 | 89% | 92% |
| 10 | 95% | 96% |

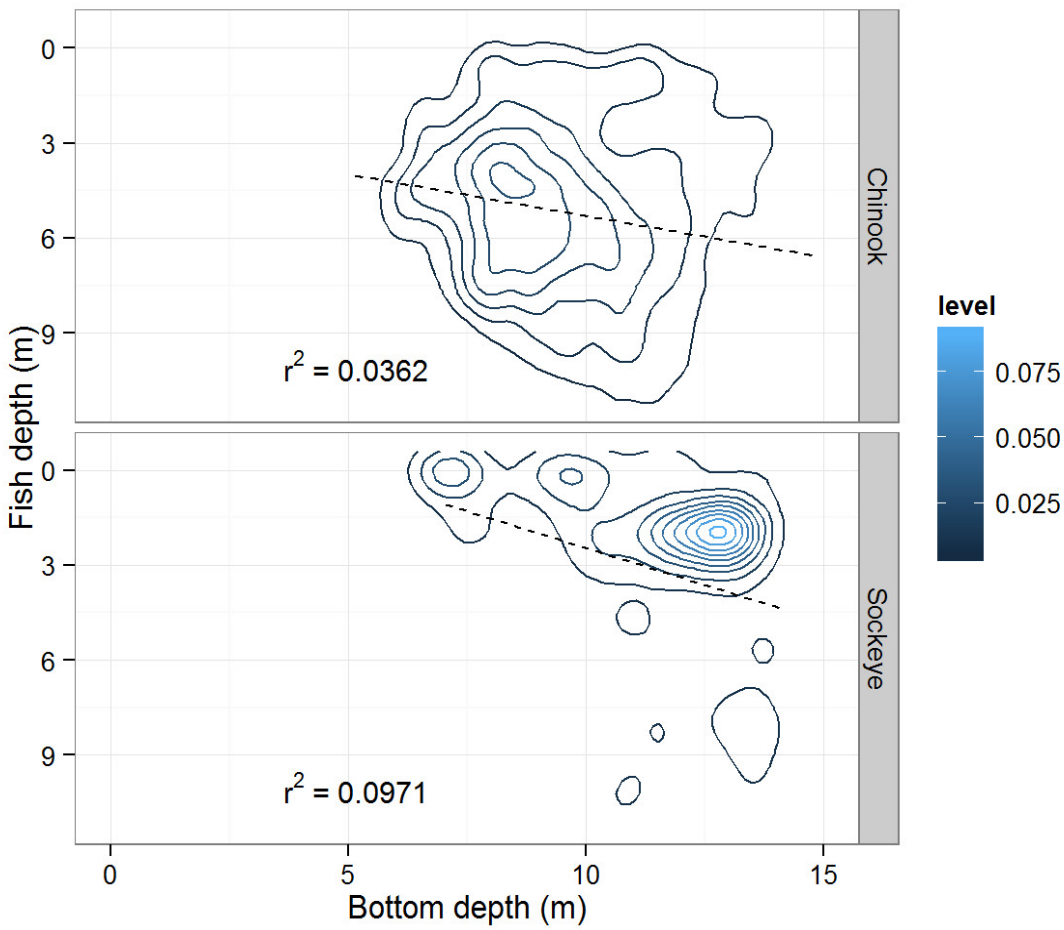


**Figure 11. Depth distribution (m) of adult sockeye and Chinook salmon relative to seafloor bottom depth (m) near the ESSN fishing district. Seafloor bottom depths are specific to the time (i.e. adjusted for tide level) and location (i.e. receiver site) each fish was detected. Distributions were calculated using all depth measurements pooled by species.**

As a final step, we examined the relationship between the fork length and migration depth near the ESSN (Figure 12). There was no evidence that fork length influenced migration depth for either species.

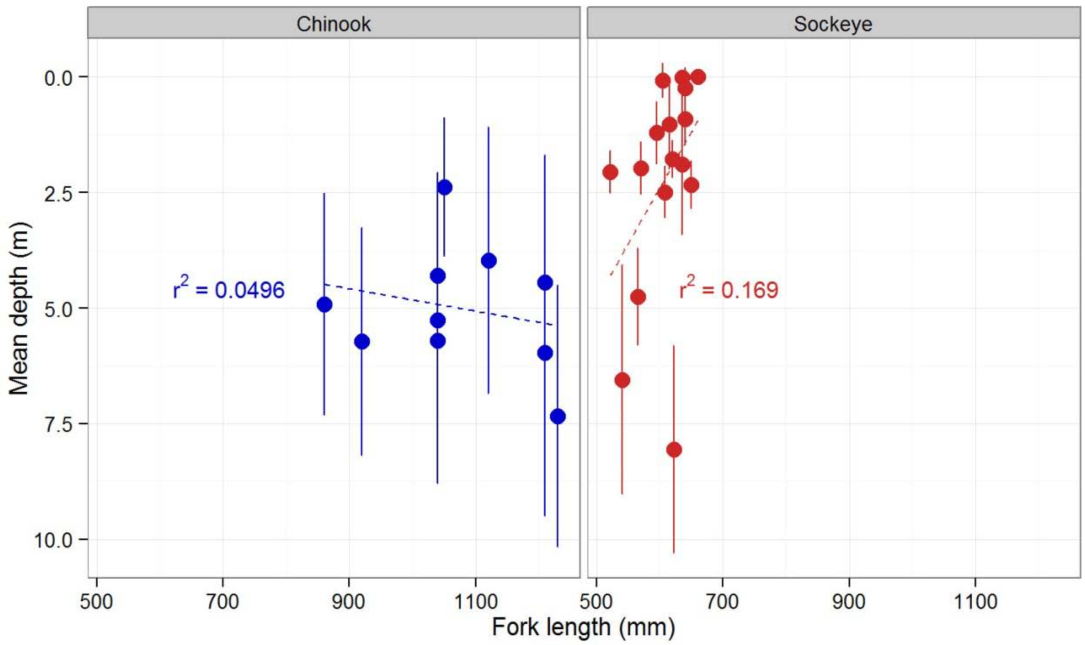


**Figure 12. Mean migration depth (m) relative to fork length (mm) for individual Chinook and sockeye adult salmon near the ESSN fishing district. Error bars show the standard deviation of the mean.**

Appendix D provides supplementary figures and tables as well as a supporting analysis focused on the depth distribution for each tagged individual.

## *2.6. Effect of tides and time of day on depth distributions near the ESSN*

To examine the effect of time of day and tidal stage on migration depth (and to look for possible interactions between tide and light level) we compared the depth distribution of Chinook and sockeye using trellis plots, where the rows divide the available depth data by the stage of the tide[7] at the time depth was recorded, and the columns divide the data by day or night[8]. We used a density histogram to

[7] We defined 'high' tides as those ≥ the 80th percentile of tide heights predicted for the Kenai River mouth during the interval the tagged fish were migrating over the marine array, and 'low' tides as those≤ the 20 th percentile of tide heights during this same interval (see Appendix C).
[8] We defined 'day' as the interval between sunrise and sunset, and 'night' as the interval between sunset and sunrise (see Appendix C).

show the relative distribution of the detections for each species (Figure 13). Then to more simply assess the proportion of time sockeye spent shallower than a given depth versus the proportion of time Chinook spent deeper than a given depth, we plotted the Chinook cumulative depth distribution (CDD) as its complement (1-CDD; Figure 14).

The difference between the median depth of the two species (vertical lines) provides a useful measure of the depth separation possible at different times of day or stages of the tide. At night, the difference in median depth was reduced because the sockeye moved deeper while Chinook moved slightly (average 0.8 m) towards the surface. Although the depth distribution of sockeye in the offshore region of the array was similar to the sockeye depth distribution near the western boundary of the ESSN, data for the latter are quite limited and considerable caution should be used in interpreting the effect of the tides on depth. Additionally, the number of detections recorded during mid-tide may not accurately reflect the occurrence of tagged fish near the ESSN boundary because the detection range of the receivers is expected to drop when the tidal currents are strong; it is not known if this effect applies equally over all depths. Perhaps the most confident conclusion is that during daylight hours different stages of the tides appeared to have at best only a minor effect on the depth difference between Chinook and sockeye.

Some circumstantial evidence that Chinook spent much of their time in shallower waters within the ESSN comes from an assessment of the number of tag detections collected by the nearshore array receivers at different stages of the tide (Figure E-4). Fewer Chinook detections were recorded at high tides than at low tides. This suggests that the Chinook moved farther inshore on the rising tide and away from the receivers, thus decreasing the opportunity to detect them at the western edge of the ESSN where the receivers were sited. In contrast, sockeye detections were few (reflecting their presence primarily offshore), but slightly greater at high tides, perhaps suggesting that during high tides they staged near the ESSN prior to their migration into the river. (We show in the next section that there is clear evidence that both species entered the river on either flood tides or slack water).

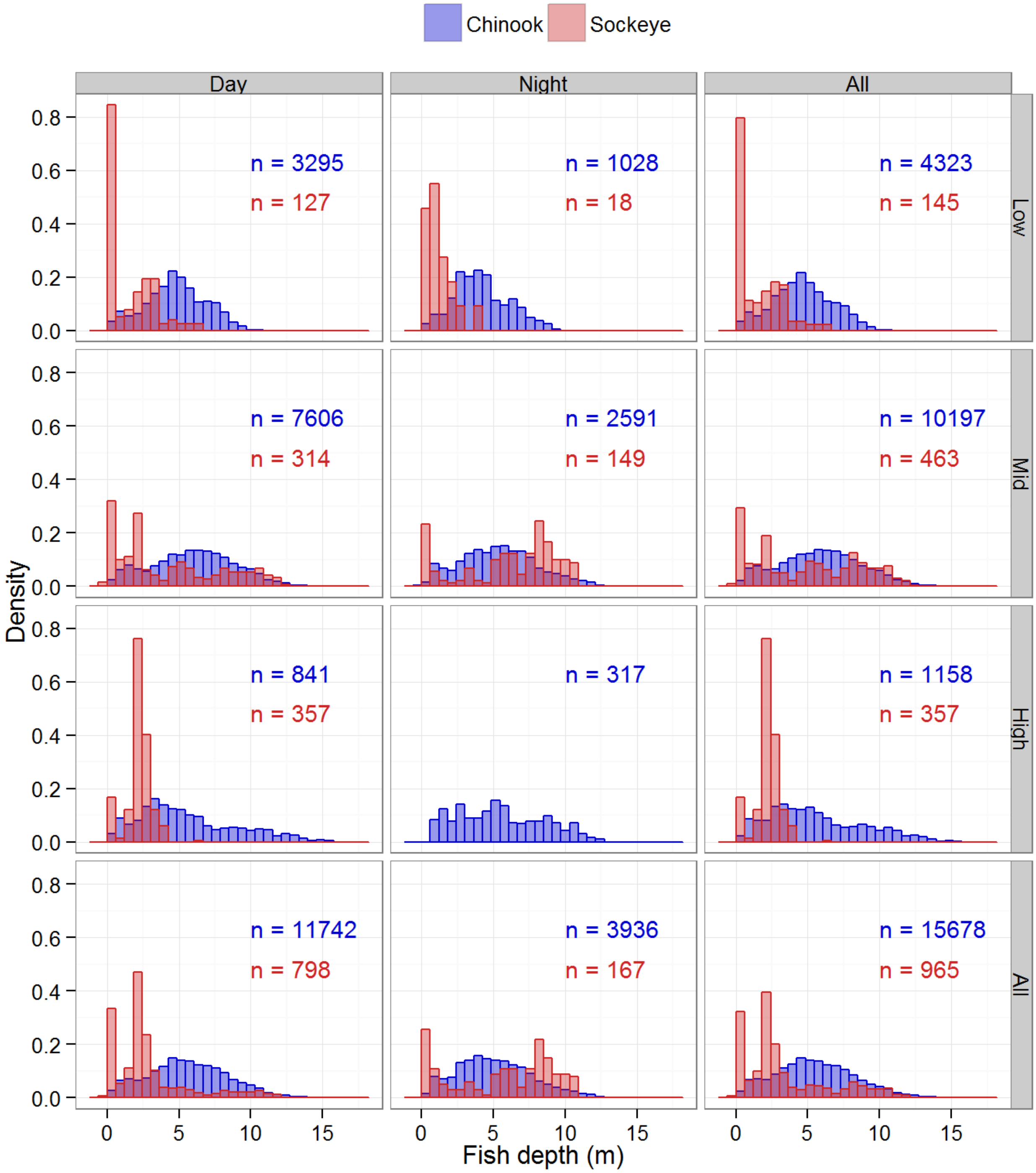


**Figure 13. Depth distributions (m) of adult sockeye and Chinook salmon along the western edge of the ESSN fishing zone; n: sample size.**

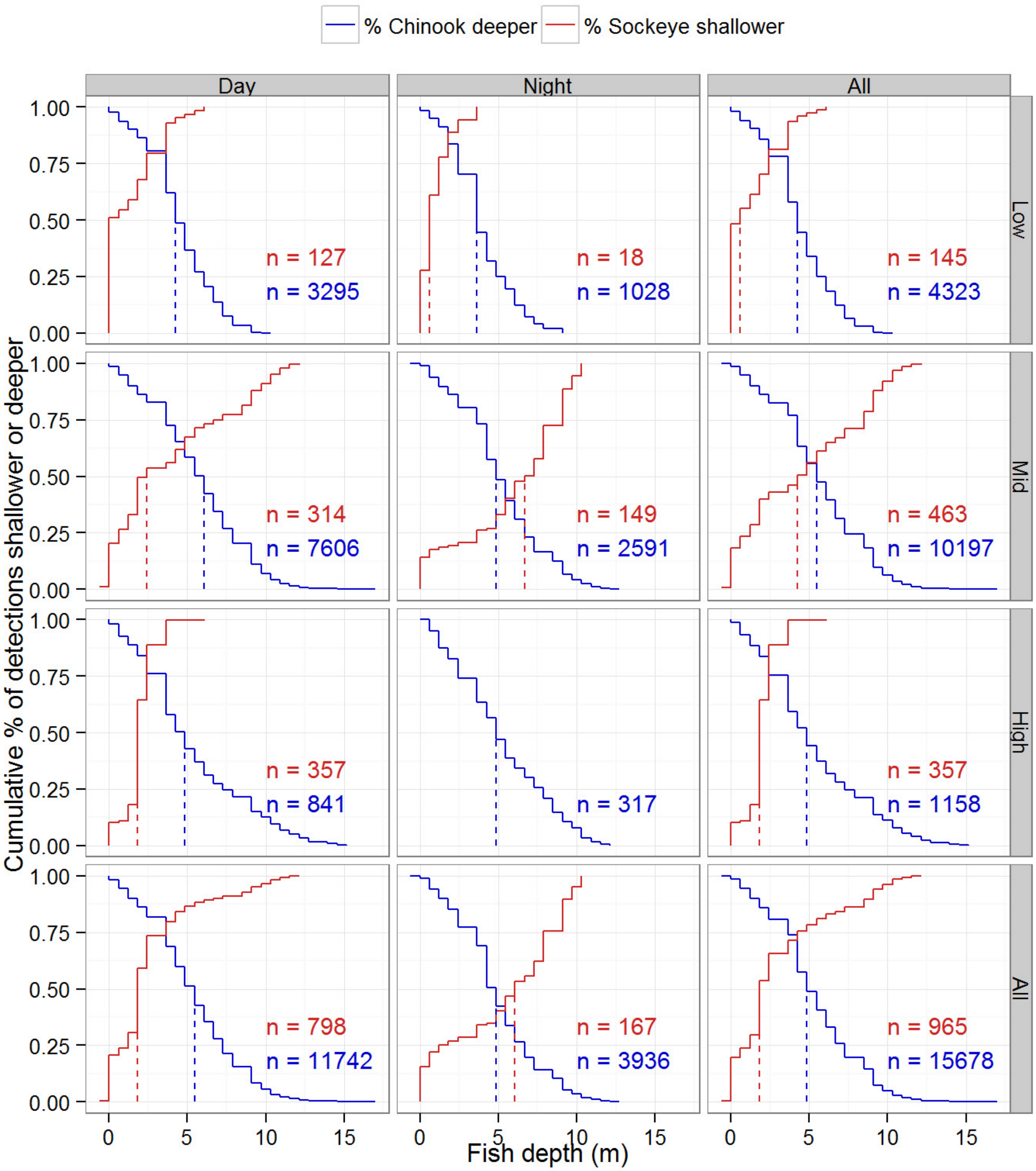


**Figure 14. Cumulative depth distributions (m) of adult sockeye and Chinook along the western edge of the ESSN fishing district; n: sample size. Distributions show the proportion of time sockeye spent shallower than a given depth and the proportion of time Chinook spent deeper than a given depth. The vertical lines show the median depths.**

## 2.7. *Entry patterns into the ESSN and Kenai River in relation to time of day, tide stage, and wind velocity*

There was little evidence that entry into the ESSN was strongly related to date, stage of the tide or wind. For river entry, the majority of Chinook and sockeye initially entered the Kenai River and migrated upstream on either a flood tide or slack water (Table 4). At RKm 2 (Snug Harbor), 74% of Chinook detections and 78% of sockeye detections were recorded as the tide was rising. Of the remaining detections at this site most were recorded at slack water or on a tide that was still ebbing, but nearly slack (classed as Ebbing in Table 4). Only 14 detections (of 2 individuals) were recorded at RKm 2 while the tide was falling significantly; one of these fish did not migrate upriver and the other logged only a single detection on a falling tide as it milled back and forth between the detection sites at RKm 2 and 4.5. At the next site upstream (RKm 4.5, Inlet Fish), no detections of either species were recorded during ebbing tides. The influence of tide dropped somewhat by RKm 8.2 (the Kenai Bridge), as 62% of Chinook detections and 81% of sockeye detections were recorded during flooding tides, suggesting that both species took advantage of tidal conditions primarily to move past the river mouth as quickly as possible and then continued migrating upriver irrespective of the stage of the tide once past the river mouth.

Appendix E provides figures that present the environmental conditions during entry to the ESSN.

**Table 4. Number of detections (number of individual fish in brackets) recorded at the detection sites in the lower Kenai River during different tidal stages. Ebb, slack, and flood tides were defined based on whether the tide height predicted for the Kenai River mouth was lower, equal, or higher than in the preceding half hour, respectively.**

| | Site | RKm | Ebbing | Flooding | Slack |
|---|---|---|---|---|---|
| **Chinook** | Snug Harbor | 2 | 2 (2) | 125 (6) | 42 (1) |
| | Inlet Fish | 4.5 | 0 | 186 (6) | 21 (1) |
| | Kenai Bridge | 8.2 | 114 (3) | 190 (6) | 0 |
| **Total** | | | **116 (5)** | **501 (18)** | **63 (2)** |
| **Sockeye** | Snug Harbor | 2 | 38 (4) | 137 (8) | 0 |
| | Inlet Fish | 4.5 | 0 | 176 (10) | 0 |
| | Kenai Bridge | 8.2 | 71 (2) | 297 (7) | 0 |
| **Total** | | | **109 (6)** | **610 (25)** | **0** |

## 2.8. Migration rates

Travel rates were slow in the ocean, sped up on river entry, and then gradually slowed again as the fish migrated upriver (Figure 15). Marine travel rates reflect milling behavior; the fish travelled an unknown distance further than the straight line distance used to calculate the travel rates. The extensive milling the Chinook displayed before entry to the Kenai River reduced their travel rate both relative to sockeye and to the other migration segments. As well, travel rates were somewhat slower for Chinook than sockeye between release and arrival at the marine array, indicating that Chinook may have also milled more along southern areas of the ESSN fishery. Both species moved from the array directly into the Kenai River mouth, although Chinook made this transition more rapidly. Once in the river, almost all fish migrated directly upstream without evidence of milling. At upriver sites, the influence of river current may have contributed to reduced travel rates.

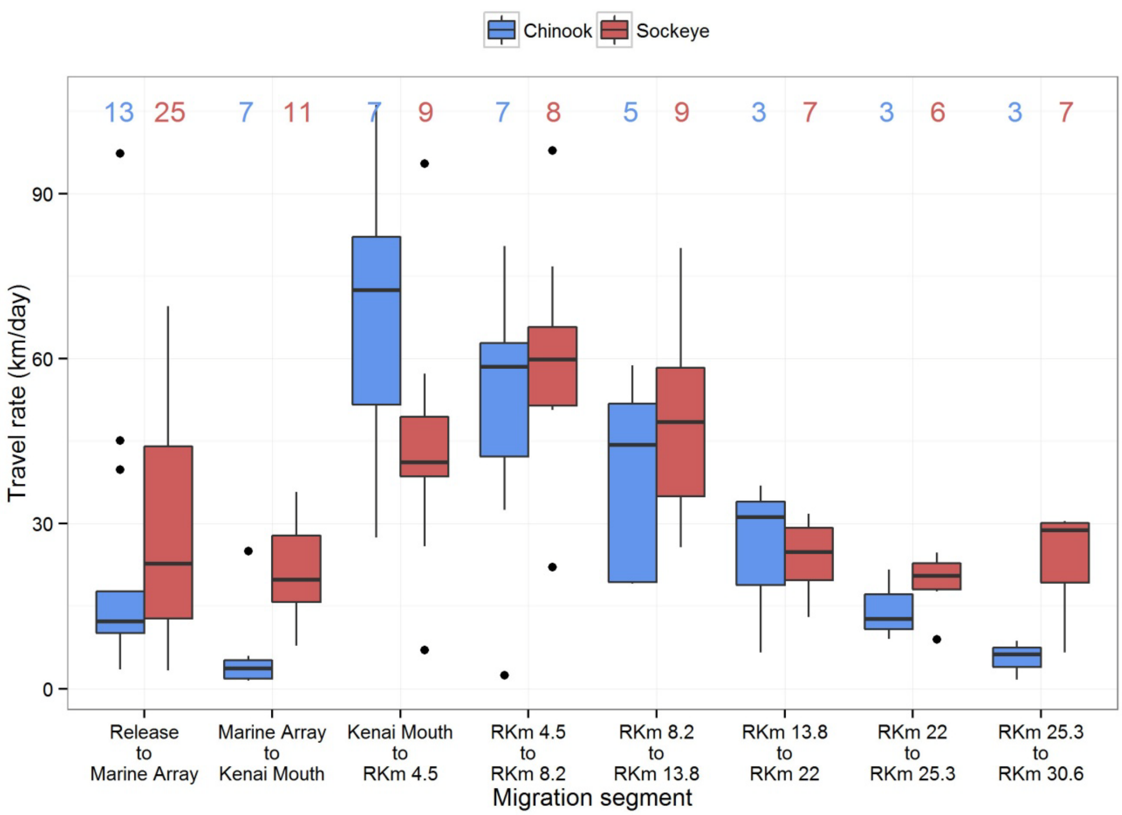


**Figure 15. Travel rates (km/day) of tagged adult sockeye and Chinook salmon during different phases of the migration.**



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Travel rates from release to arrival at the marine array and from the marine array to freshwater entry of both sockeye and Chinook showed little relationship with release date or fish size (Figure 16). One possible exception was that a few (4 of 5) sockeye tagged mid-month may have travelled more quickly between release and arrival at the southern-most line of marine receivers (line 159; circle symbols in top left corner of Figure 16; $r^2$=0.52). To increase sample size and further assess this possible relationship, we also plotted travel rates for those fish first detected on more northerly regions of the marine array (instead of only those detected on the southern line); however, once these fish were included there is little evidence that the time of tagging or fish size had a substantial influence on subsequent travel rate. Similarly, there was no evidence that once either species reached the marine array that their subsequent entry into freshwater was related to tagging date or fish size.

Appendix F provides supplementary figures and tables on travel times and rates.

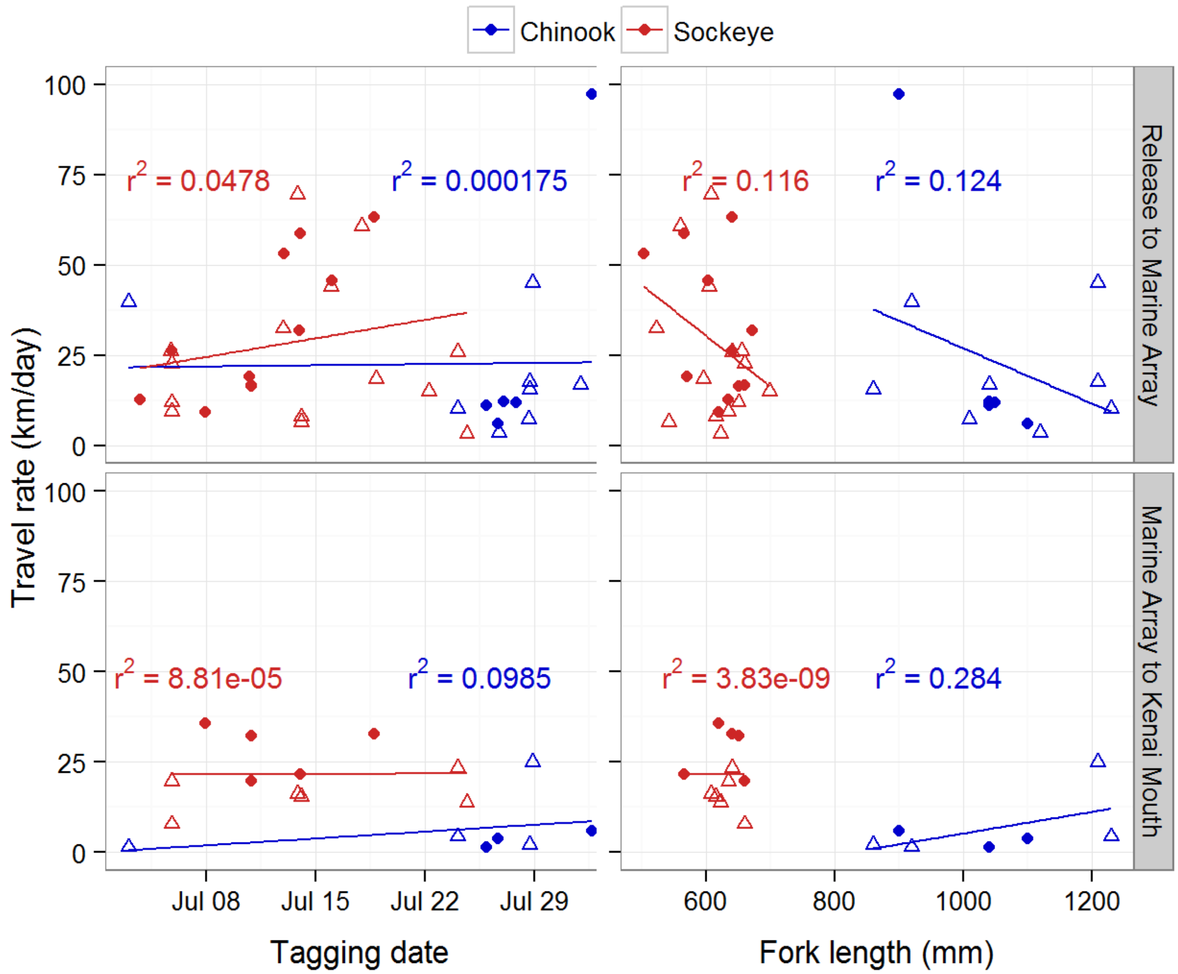
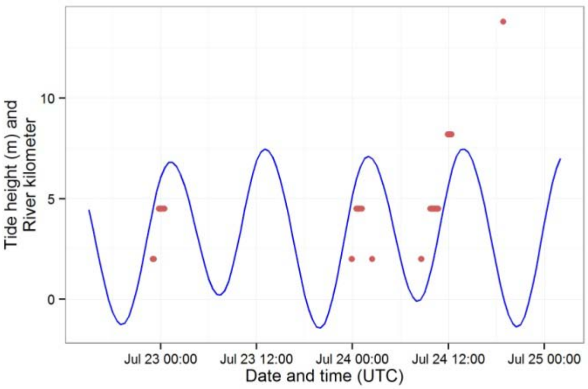



**Figure 16. Marine travel rates (km/day) for adult sockeye and Chinook in relation to tagging date and fork length (mm). Rates were calculated for two migration segments:(top) between release and arrival at the marine array, and (bottom) from first arrival at the marine array until entry into the Kenai River (river kilometer 2). Circles show fish first detected on the most southern line of receivers in the marine array (line 159); triangles show fish first detected on any other marine line. The r-squared values were calculated across all rate estimates for each species in each segment.**

## *2.9. Effect of tides on milling behavior in the estuary*

Most tagged salmon migrated directly up the Kenai River after river entry; only two showed evidence of milling in the Kenai River estuary (Figure 17). Fish 9484 (a Chinook) was detected moving back and forth three times between the two lowest receivers in the Kenai River; fish 9535 (a sockeye) was detected once at the Kenai River mouth and then disappeared for 7 hours before being detected at the river mouth again and then proceeding upstream. These movements appear to be coordinated with tides; however, the sample size is small. All other tagged salmon migrated directly up the Kenai River after river entry.



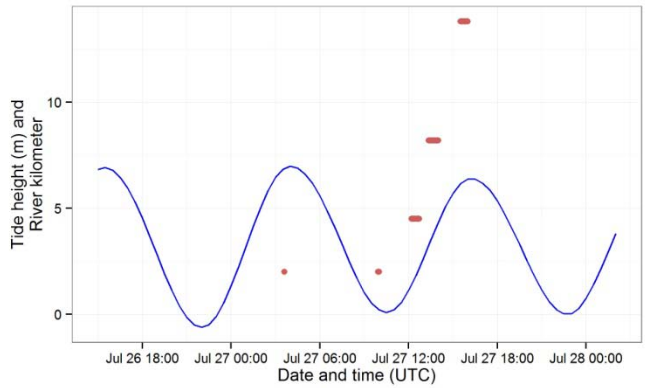




**Figure 17. Detections of the two fish that milled in the Kenai River estuary displayed with tide height (m) as estimated at the Kenai River mouth. Red dots represent detections recorded at four sites in the Kenai River; blue lines indicate tide height; tag 9484 is on the left and tag 9535 is on the right. Note the y-axis represents both tide height (m) and location of detection sites by river kilometer.**

## *2.10.DNA analysis*

Tissues samples were collected from 25 Chinook and 50 sockeye salmon that received an acoustic tag. Mixed stock analyses (MSA) were conducted for the Chinook using a baseline for Upper Cook Inlet Chinook salmon similar to that reported in Barclay et al. (2012). MSA results for Chinook were inconclusive, likely due to the small sample size and the presence of fish in the sample from populations not present in the baseline. (DNA analysis of sockeye tissue samples was not complete at the date of writing). The acoustic tagging results suggested that some Chinook salmon tagged in the offshore area of Cook Inlet may not have been from Upper Cook Inlet populations. Out of the 12 Chinook tagged offshore, 8 were never detected by the acoustic array and 2 of these tagged Chinook were later reported caught in areas outside of Upper Cook Inlet (Jakolof Bay and Columbia River). Conversely, out of 13 fish caught and tagged in the nearshore off Anchor Point, 11 were later relocated in Upper Cook Inlet. Because the genetics results were equivocal, it is not possible to confidently exclude from the analyses Chinook that were not from Cook Inlet populations.

## 2.11. Apparent survival

Fish not detected by the marine array do not necessarily die. Properly designed telemetry arrays measure what is technically referred to as "*apparent survival*", or the progressive disappearance of tagged fish after release as they migrate over elements of the tracking array. For simplicity, we refer to this as "*survival*"; however, "*apparent survival*" is more accurate because several factors can reduce the number of tagged salmon in addition to mortality. In the present study, these factors are (i) sockeye and Chinook from stocks not originating from the Kenai or Kasilof Rivers which were tagged but would never migrate to these rivers[9]; (ii) tag loss from extrusion (in surgically implanted individuals) or regurgitation (in individuals whose tag was inserted in the stomach); iii) incomplete detection by the receiver array; (iv) tag failure; and, (v) mortality occurring as a result of tagging (fish capture, handling, tagging or release procedures).

Just over half the tagged Chinook and sockeye released in southern Cook Inlet were detected on the marine array (Figure 18; Figure 19; Table 2; Table 5). Half of the animals detected on the marine array were then detected entering the Kenai or Kasilof Rivers, providing an overall apparent survival to river entry of 25%. Within the Kenai River, where multiple sets of receivers allowed us to track the upstream movements of the tagged salmon, all 7 Chinook detected entering the Kenai River mouth were detected as high up as RKm 25 (River Mile 15; Harry Gaines' Fish Camp), so had excellent in-river survival[10]. The sockeye also had good in-river survival, with 9 of the 12[11] fish (75%) initially reaching the Kenai River mouth detected at RKm 25.

[9] We partially addressed this concern by removing fish from the apparent survival calculations (n=2 Chinook; n=2 sockeye) that were recovered south of the release site (see Appendix B); however, we could only remove individuals whose tags were returned.

[10] Only three of these 7 Chinook were subsequently detected at the final detection site, the ADF&G Didson sonar site at RKm 30.6 (mile 18). The number of detections of each of the tagged animals was lower than at the preceding detection site (Harry Gaines), suggesting that harmonic coupling of the electronics with the Didson sonar may have reduced the sensitivity of the receivers.

[11] One additional sockeye was detected in the Kasilof River.

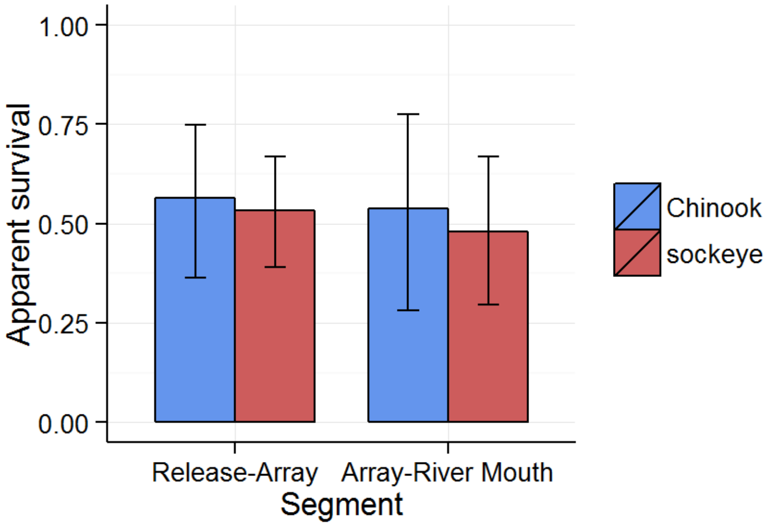



**Figure 18. Apparent survival of acoustic tagged Chinook and sockeye between release and arrival on the marine array, and from the arrival on the array until entry into the Kenai River mouth. Error bars are 95% confidence intervals. Survival rates calculated using standard Cormack-Jolly-Seber methods in R. We excluded fish recovered by the fishery south of the release site from these calculations as well as one sockeye detected in the Kasilof River because the detection efficiency of the Kasilof receivers is unknown.**

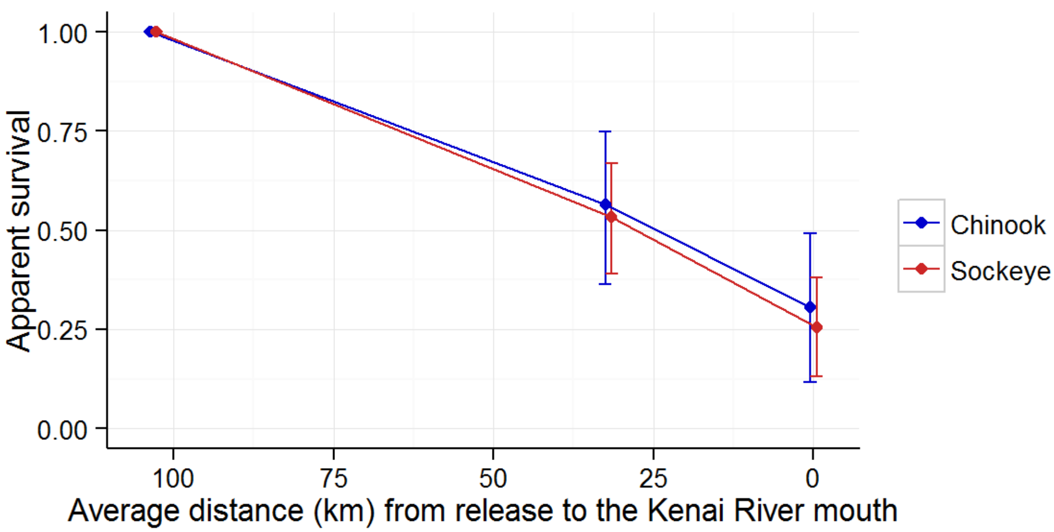



**Figure 19. Apparent marine survival for acoustic tagged Chinook and sockeye by distance from release. The points represent apparent survival at release; between release and arrival at the marine array; and between release and arrival at the Kenai River mouth. Error bars are 95% confidence intervals. Survival rates calculated using standard Cormack-Jolly-Seber methods in R. We excluded fish recovered in fisheries south of the release site from these calculations as well as one sockeye detected in the Kasilof River because the detection efficiency of the Kasilof receivers is unknown. Distance from the Kenai River mouth was calculated for each fish for the shortest in-water path and then averaged across all fish (see section C Data Analysis).**

**Table 5. Apparent survival over the marine and freshwater components of the array (standard error in brackets). We excluded from these calculations fish recovered by the fishery south of the release site and the sockeye that was detected in the Kasilof River because the detection efficiency of the Kasilof receivers is unknown12. Numbers detected at each detection site are available in Table 2. N=sample size.**

| Species | N Released | N for Survival[13] | Release to Marine Array[14] | Marine Array to Kenai R. Mouth[15] | Release to Kenai R. Mouth |
|---|---|---|---|---|---|
| Chinook | 25 | 23 | 57% (10%) | 54% (14%) | 30% (10%) |
| Sockeye | 51 | 47 | 53% (7%) | 48% (10%) | 26% (6%) |

Although apparent survivals in the ocean appear low post-release (see Discussion), they were higher for Chinook captured and tagged in shallow waters near Anchor Point (46% survival to the Kenai R mouth), than for Chinook tagged offshore (10%[16] to the Kenai R mouth; Figure 20). Chinook released inshore had a shorter distance to travel to the Kenai River mouth (average of 73 km versus 102 for the offshore fishery), but survivals for the inshore fish were still higher when scaled by distance (inshore: 90% survival/km; offshore: 80% survival/km). However, sample sizes were small when subdivided by capture site.

[12] Kasilof River had two receivers placed at the Didson Sonar site, and detected only 1 tagged salmon (3 detections total), suggesting that detection data for the Kasilof River may be poor.
[13] We excluded fish recovered by the fishery south of the release site from these calculations (see Appendix B). We also excluded one sockeye detected in the Kasilof River because the detection efficiency of the Kasilof receivers is unknown.
[14] Detection efficiency of the marine sub-arrays was perfect; no tagged salmon were detected on the freshwater (river) array without first being detected on the marine array.
[15] Detection efficiency of the Kenai River freshwater sub-array was also perfect; at most Kenai River receiver sites no tagged salmon were detected upstream that were not first detected on the downstream sites.
[16] Excludes two Chinook caught and tagged in offshore Cook Inlet that were later recovered by the fishery south of the release site: 1 recovered in the Columbia River; 1 recovered from Seldovia.

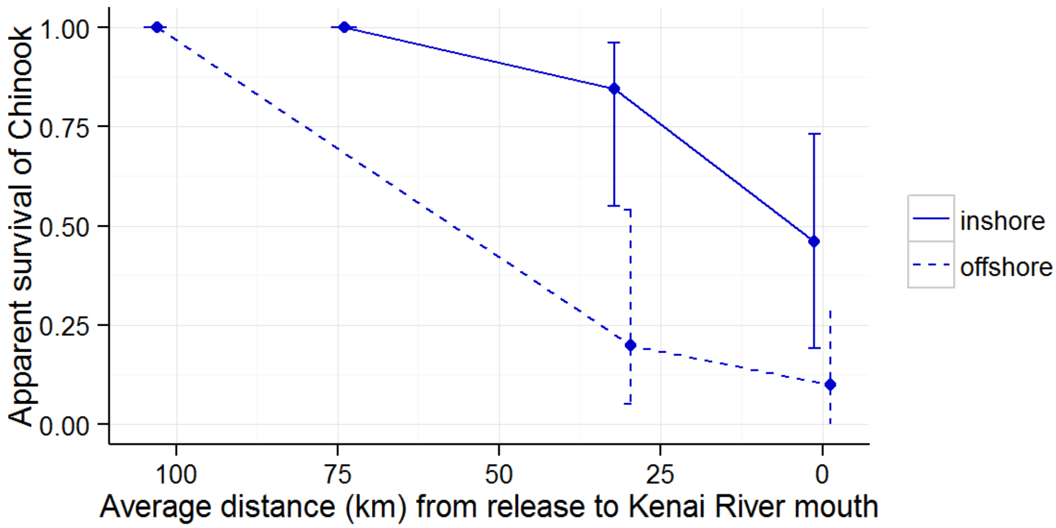



**Figure 20. Apparent marine survival for Chinook captured and tagged in southern Cook Inlet either offshore or inshore near Anchor Point. Points represent apparent survival at release; between release and arrival at the marine array; and between release and until arrival at the Kenai River mouth. Error bars are 95% confidence intervals. Apparent survival rates calculated using standard Cormack-Jolly-Seber methods in R. We excluded fish recovered by the fishery south of the release site from these calculations. Distance from the Kenai River mouth was calculated for each fish for the shortest in-water path and then averaged across all fish by capture location (see section C, Data Analysis).**

# 3. Discussion

The technical aspects of the 2013 Cook Inlet telemetry study were generally successful; the marine array detected 100% of the tagged sockeye and Chinook that were subsequently recorded entering the Kenai or Kasilof Rivers, and most freshwater receivers in the Kenai River also detected 100% of all tagged animals migrating upstream. These results were probably due to the tag programming chosen, which partially compensated for the sparse grid of ocean receivers (1.5 km spacing). A few simultaneous detections of a tagged animal on adjacent receivers demonstrated that this specialized programming allowed detection ranges≥700 m when circumstances were favorable. Only one pair of receivers was placed in the Kasilof at the ADF&G Didson SONAR site, precluding assessment of performance, but performance may have been poor; just one sockeye was detected (3 times) and by only one of the two paired receivers. Local conditions can degrade sound transmission and it seems likely that mounting some of the tracking receivers on the ADFG Didson sonars may have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degraded performance of the receiver. If the study is to be repeated, it would be useful to place a foam sleeve around the receivers to dampen possible resonant coupling.

The major identified limitations on the 2013 results are the small number of salmon tagged and the lack of reliable genetic assignment from the DNA samples collected. Although the number of tagged salmon was substantially lower than the target of 70 tagged adults per species, the large number of depth measurements collected for these tagged fish provided enough information to calculate reasonable depth distributions for Chinook and sockeye in the ocean. The near perfect detection efficiency of both the marine and Kenai River sub-arrays also gives high statistical confidence in the proportions of tagged fish first reaching the areas covered by the marine array, and then entering the Kenai River.

A novel result stemming from the present study was the detailed information on the behaviour and distribution of Chinook in the ocean, especially the repeated north-south marine movements of Chinook recorded in the nearshore prior to river entry. In contrast to Chinook, tagged sockeye were distributed further offshore and transited rapidly through the ESSN to reach the river. Both species then migrated directly through the river mouth at high speeds (primarily on flood tides or at slack water) before slowing down again upriver. The timing and speed of river entry may have evolved to allow the fish to avoid predators congregating at the choke point formed by the river mouth.

Migration depths were surprisingly shallow at the ESSN boundary for both species (median depth for sockeye: 1.8 m; Chinook: 4.8 m), as well as over the entire marine array (median depth sockeye: 1.2 m; Chinook: 4.8 m). The similarity in the depth distributions across these two zones is most interesting for sockeye because the majority of sockeye detections were recorded away from the ESSN boundary in deeper water (while most Chinook were detected along the ESSN).

In general, the Chinook migrated ~3 m deeper than the sockeye and were deeper in the water column than sockeye under all tidal conditions and particularly during daylight hours. For both species, depth in the water column bore little relationship to bottom depth. These results apply primarily to approximately the outer 500 m of the ESSN region, where most Chinook were detected and where receivers could effectively monitor tagged salmon.

Prior to the start of our study, the expectation was that essentially all maturing Chinook tagged in 2013 would return to the Kenai River, similar to 2012. Consistent with that view, no tagged Chinook were detected in the Kasilof River. However, even after excluding two Chinook captured to the south of the array in Jakolof Bay (southern Cook Inlet) and the lower Columbia River, the low apparent Chinook survival rate of 30% (7/23) between release and Kenai River entry is surprising, but close to the sockeye apparent survival rate of 26% (12/47; Figure 21)[17]. Both species had high in-river survival: all Chinook and the majority of sockeye (9 of 12 entering the Kenai) were subsequently detected well upstream. The three apparent sockeye losses are consistent with several sockeye tags being returned from fishermen fishing within the river.

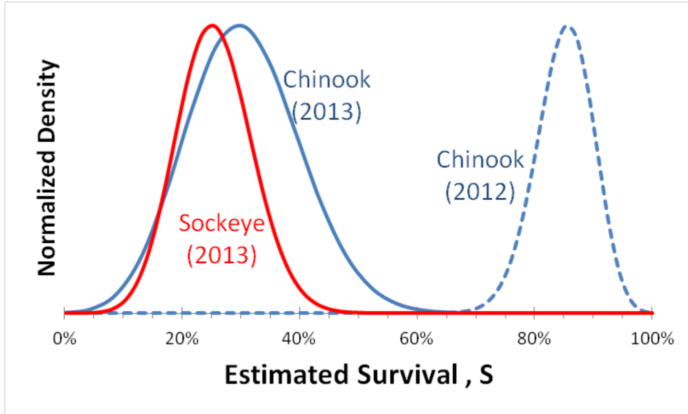


**Figure 21. Probability density functions showing apparent survival from release near Anchor Point to river entry for Chinook in 2012 (dashed blue; ADFG study) & 2013 (solid blue) and sockeye in 2013 (red).**

**The x-axis shows survival and the y-axis shows relative density. Note that sockeye and Chinook survival were very similar in 2013. Calculations assume perfect detection of all surviving tagged adults reaching freshwater, which may not be true in 2012. The effect of poorer in-river detection would be to increase survival in 2012 but also widen the statistical uncertainty as to the true survival.**

The 2013 apparent survival rates from release to river entry based on 23 tagged Chinook[18] can be compared with the reported 2012 results when ADF&G tagged and released 49 radio-tagged and 5 acoustic-tagged Chinook near Anchor Point[19]. In total, 87% of the radio-tagged and 60% of the acoustic-tagged adult Chinook were detected in either the Kenai or Kasilof Rivers, yielding a minimum 2012 combined survival estimate to river entry of 85% (SE=9.7%)[20], or a 95% confidence interval of 75%-95%. This is far higher than our apparent survival rate for Chinook of 30% (SE=9.6%), despite

[17] Sockeye survival increases to 27% (13/48) if the fish detected in the Kasilof River is included.
[18] 25 Chinook were tagged, but one tagged Chinook was reported caught in the lower Columbia River and a second was caught in Jakolof Bay south of the release site. A complete 2013 survival estimate for Kenai & Kasilof River Chinook would require excluding other tagged Chinook not from these two river systems but is not possible because of problems with the DNA analysis.
[19] ADF&G (2012). Chinook Salmon Migration Patterns in Upper Cook Inlet-- Summary of First-Year Pilot Study acoustic tag study. Unpublished Report. 4 pp.
[20] (49*87% + 5*60%)/(49+5)=85%. An approximate 95% confidence interval on this value can be calculated as twice the standard error on this proportion, or $\pm 2*(S(1-S)/N)^{0.5}$, or ±9.7%.

apparently perfect detection on the array and perfect in-river survival over the Kenai receivers during upstream migration.

The cause of the large difference between the 2012 and 2013 Chinook survival estimates is unclear. It seems unlikely that the lower survivals in 2013 were an artifact of the tagging procedure because fish were not noticeably affected by tagging in either year. Also, if Kintama's tagging protocols were at fault (as opposed to the methods used in 2012), we would expect that sockeye marine survival would be substantially lower than Chinook (since the sockeye are targeted by the commercial fishery), and that in-river survival of tagged Kenai River Chinook would be less than 100% (assuming tagging effects persist). Neither effect was observed.

Other possible explanations for the poor apparent marine survival rates are poor performance of the single detection site in the Kasilof River, and higher-than-expected tagging of maturing Chinook ultimately migrating to rivers other than the Kenai. Unfortunately, given problems with the Chinook DNA analysis in 2013, it is not possible to distinguish between these factors at the time of writing.

There is evidence that Chinook tagged farther offshore in Cook Inlet may have included a greater proportion of non-Cook Inlet origin Chinook. Apparent survival to the marine array was 85% for inshore releases and only 16% for offshore releases, while survival for both release zones was close to 50% between arriving at the array and Kenai River entry. Although some of this difference can possibly be accounted for by the shorter average migration distance of the inshore releases to the marine array (43 km vs 72 km), the large difference in apparent survival after release suggests that at least some offshore tagged Chinook were destined for other rivers. This conclusion is further supported by the fact that two Chinook tagged offshore were subsequently recovered from southern Cook Inlet (Jakolof Bay) or entirely outside Cook Inlet (Columbia River). A broader array would be needed to address these issues, both by identifying the movement of tagged salmon into other parts of Cook Inlet (or their emigration out of Cook Inlet entirely), and by measuring the post-release survival of tagged salmon just before they reached the ESSN.

# 4. **Future Work**

The magnitude of the disappearance of the tagged Chinook and sockeye suggests that a more extensive telemetry array would be a valuable addition to the study design. Telemetry lines stretching eastward into the ESSN and westward fully across Cook Inlet would better allow identification of Chinook and sockeye movements north of the tagging site. In addition, a telemetry line situated just south of the ESSN would be useful for evaluating whether there was poor post-release survival prior to reaching the main marine telemetry array to the north. Finally, without reliable genetic results to identify Kenai River Chinook, a southern sub-array sited somewhere near the Barren Islands to monitor the exit from Cook Inlet of tagged animals migrating to other regions of the coast would be useful, but costly.

In future years, fish capture protocols should also be modified to focus on tagging fish in those areas and times where they are most abundant, in order to increase the number of tagged salmon released. The capture rates achieved in 2013 suggest that two or more vessels would be required in the offshore Cook Inlet area plus at least one small boat fishing the very nearshore off Anchor Point. Post-season, the behavior of tagged salmon from different tagging groups could then be compared to try to identify possible differences in behavior between different tagging groups and areas.

Finally, the expansion of acoustic arrays around Alaska would allow a much broader look at survival of Chinook during all phases of their marine life history, and allow a quantitative assessment of when and where the poor survival affecting many Alaskan Chinook stocks is occurring in the ocean. Such data will be critical to moving beyond speculation as to the causes of the current decline in adult returns of Chinook to many of Alaska's rivers. A large-scale Alaskan telemetry array would also have broad utility to many of Alaska's other valuable fisheries.

# 5. **Acknowledgements**

We thank ADF&G staff, particularly Mr Mark Willette, for support and advice during this study, and particularly for agreeing to mount acoustic receivers at their Kenai & Kasilof sonar sites—this allowed us to deploy substantially more tracking receivers in freshwater than would otherwise be the case. We thank Captain Dave Beam (Cordova; Montague Marine Research, LLC), Casey Pape, and other crew for their able assistance in deploying and recovering the marine array, Mr Ritchie Davis

(Juneau; F/V West Bank) for his incredible skills and assistance trolling for Chinook, and Mr Steve Walli (Anchor Point) and Dan Calhoun (Homer) for their agreement and great willingness to assist on very short notice with additional nearshore sportfish trolling to supplement the number of tagged Chinook when contacted in the middle of July.  Without all of you this study would not have been successful.

# 6. Appendices

# A. Fish Handling and Tagging Methods

## A.1. Summary statistics

### A.1.1. Total salmon tagged

Maturing Chinook: 25
Maturing Sockeye: 51

### A.1.2. Fishing effort

Total fishing effort: 317.25 hours.
Full Fishing: 28 June-02 August 2013
Minimal Fishing: July 18 – due to weather
No Fishing: July 09, 19, 20 – due to weather

## A.2. Tagging operations

Most fishing for adult salmon used a 53' commercial troller, F/V West Bank, but from July 23rd- August 2nd, two smaller sport fishing boats were also hired to help increase catch rates of maturing Chinook by fishing in very shallow waters along the beach off Anchor Point. Fish were captured using commercial or sport troll gear.

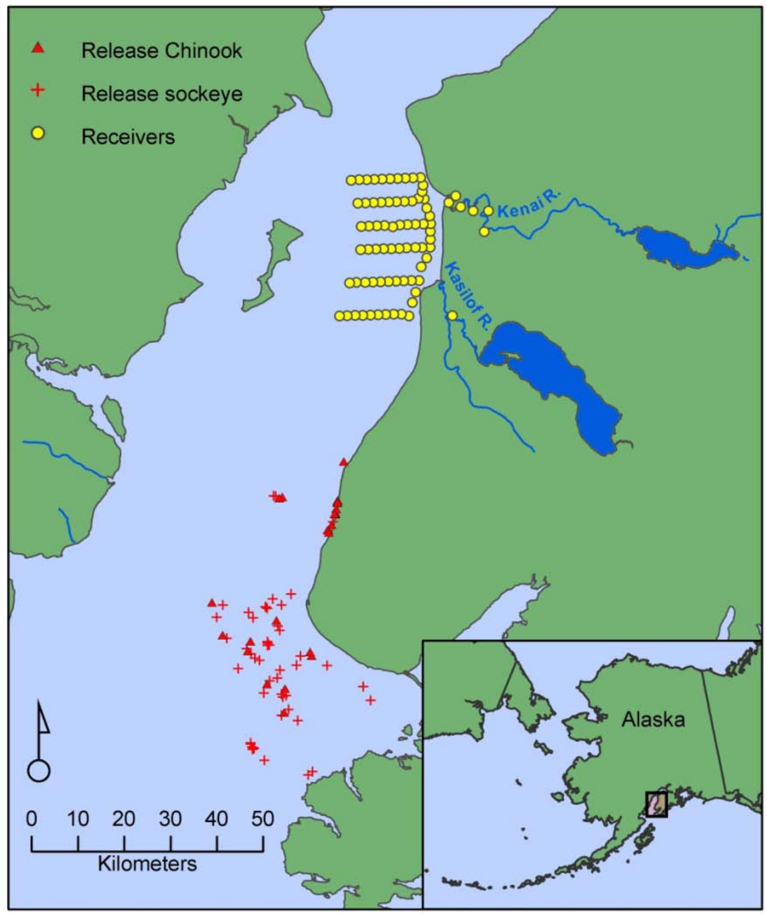


**Figure A-1.** **Map showing 2013 study. Red triangles show release locations; yellow dots show the location of telemetry receivers.**

Two tagging tanks were set up with independent power and controls for the recirculating pumps and aeration systems. A light sedative dose of an approved fisheries anesthetic (AQUI-S® 20E[21]) was put in the tank water to produce an average AQUI-S® 20E working concentration of 104.4 ppm for Chinook and 128.6 ppm for sockeye[22]. Because the adult Chinook and sockeye were found to be quite docile in the tagging sling once they were inverted and a hood covered their eyes, a decision was made in late July that the use of AQUI-S® 20E was unnecessary for most gastric tagging of sockeye and Chinook[23] (Table A-1). Finally, artificial fish slime (Vidalife) was introduced into the tank water and spread over tagging surfaces that would come in contact with the fish to minimize damage to the mucous layer.

We implanted acoustic tags into the abdominal cavity of the first three sockeye using surgical techniques on June 1st and 2nd, 2013 (Table A-2). However, the surgical incision tended to gape, probably due to pressure from the developing gonads on the abdominal wall. As a result, we switched to using a gastric implantation technique starting July 2nd for the majority of Chinook and sockeye that were tagged, N=25 and N=48 respectively.

Sockeye and smaller Chinook were lifted directly from the water into the tagging tank, while larger Chinook were netted and transferred using a long-handled landing net. Fish were quickly and carefully positioned upside-down in a neoprene sling. A rubber mouthpiece was then inserted into the mouth to irrigate the gills with recirculating oxygenated water. A neoprene hood was placed over the head eyes to help calm the fish. The acoustic tag was placed into a flexible PVC tube, which was inserted through the mouth and esophagus into the stomach. A plunger inside the tube was depressed to dislodge the tag, placing it in the stomach. DNA tissue samples (5-10 mm clipped from the axillary process of the pelvic fin) were then collected from every acoustically tagged salmon except one sockeye (July 10th, 2013), placed into individually labeled vials with ethanol, and given to ADF&G staff for analysis. Finally, paired numbered Petersen disc tags stating "*Return for Reward*" and listing Kintama's toll-free telephone number and email address were attached to both sides of the back using a nickel pin

[21] AQUI-S® 20E is approved under the Investigational New Animal Drug (INAD) program run by the Aquatic Animal Drug Approval Partnership (AADAP) Program.
[22] The three sockeye with tags surgically implanted were anesthetized with a heavier dose (Table A-2).
[23] Some informal experiments using incidentally-caught coho demonstrated that coho were much less docile, and strongly fought being turned on their backs and hooded; it is likely that AQUI-S® 20E would be required if a future study included coho.

run through the back musculature and between the fin rays approximately 2/3rds back from the leading edge of the dorsal fin.

Nine of the first 11 sockeye and the first two Chinook tagged were released directly into the ocean immediately following the procedure (Figure A-1; Figure A-2; Table A-3). Part way through tagging operations on July 5th, a decision was made to implement a revival tank, where fish were held in fresh, flow-through seawater until recovery from the anesthetic.  Prior to, and certainly after the implementation of the revival tank, tagged fish were lively and swimming actively at the time of release.

Procedure times are summarized in Table A-4 and Table A-5, with individual times listed Table A-8.

## A.3. Tagging results

A variety of data were recorded throughout the procedure:

- Date and time of capture, as well as capture coordinates.
- Capture depth (if available; Table A-5).
- Fork length (FL), and mid-eye fork length (MEFL) (Figure A-3; Table A-5).
- Sex (if determinable with confidence). Chinook: 2 male, 8 female, 15 undetermined; sockeye: 10 male, 4 female, 37 undetermined.
- Time of induction (capture time), time out of induction (Table A-8).

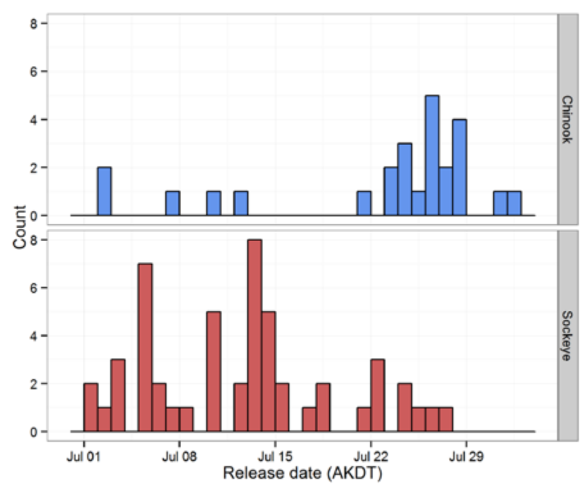


**Figure A-2. Daily count of tagged Chinook and sockeye released between July 1st and August 2nd (start and end of tagging operations).**

- Date and time of release, and release coordinates (Table A-3). Table A-5 provides a summary of 'handling times'.
- Water quality in the tagging tank at the time of tagging (Table A-6).
- Observations on fish condition and disposition were also recorded if merited;
  - not fully revived (after the first few immediate releases, the revival tank was implemented as previously documented),
  - bleeding slightly from mouth (N=8; as a result of capture on fishing tackle),
  - evidence of old injuries (N=4) or fresh injury (N=1); assessed as non-detrimental to fish health and survival after tagging)

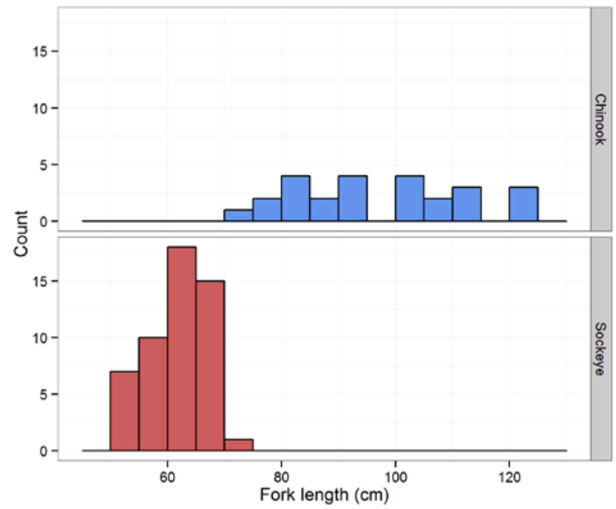


**Figure A-3.** **Fork length frequency histogram of tagged salmon.**

## *A.4. Bycatch*

All bycatch was released at the side of the boat, as quickly as possible, taking care to minimize harm. Daily bycatch by species is summarized in Table A-9.

## *A.5. Tables*

**Table A-1. AQUI-S® 20E use.**

| | Chinook | Sockeye |
|---|---|---|
| Tagged with Sedative | 19 | 47 |
| Tagged without Sedative | 6 | 4 |

**Table A-2. Concentration of AQUI-S® 20E and handling particulars of the first 3 heavily anesthetized sockeye, into each of which an acoustic tag was surgically implanted.**

| | Duration (minutes) | | |
|---|---|---|---|
| Anesthetic Concentration (ppm) | Induction | Recovery | Handling |
| 888.9 | 11 | 209 | 220 |
| 733.3 | 12 | 0 | 12 |
| 888.9 | 12 | 87 | 99 |

**Table A-3. Release locations (decimal degrees) and release date/time (AKDT)**

| Species | Release Latitude | Release Longitude | Local Release Date/Time | Species | Release Latitude | Release Longitude | Local Release Date/Time |
|---|---|---|---|---|---|---|---|
| SOCKEYE | 59.77399 | -152.19007 | 01-Jul-2013 14:19 | SOCKEYE | 59.75887 | -152.09126 | 15-Jul-2013 12:25 |
| SOCKEYE | 59.65341 | -151.91340 | 01-Jul-2013 19:46 | SOCKEYE | 59.66518 | -152.05407 | 15-Jul-2013 13:49 |
| SOCKEYE | 59.70971 | -152.17808 | 02-Jul-2013 13:18 | SOCKEYE | 59.59287 | -151.96909 | 15-Jul-2013 15:25 |
| CHINOOK | 59.77957 | -152.23172 | 02-Jul-2013 17:08 | SOCKEYE | 59.59875 | -151.97447 | 15-Jul-2013 15:50 |
| CHINOOK | 59.71572 | -152.19422 | 02-Jul-2013 20:43 | SOCKEYE | 59.55765 | -151.97587 | 15-Jul-2013 16:34 |
| SOCKEYE | 59.66951 | -152.07198 | 03-Jul-2013 10:44 | SOCKEYE | 59.54676 | -151.91550 | 15-Jul-2013 17:43 |
| SOCKEYE | 59.67838 | -152.08681 | 03-Jul-2013 10:56 | SOCKEYE | 59.58101 | -151.63357 | 17-Jul-2013 14:16 |
| SOCKEYE | 59.68822 | -152.10248 | 03-Jul-2013 11:08 | SOCKEYE | 59.65140 | -151.79595 | 18-Jul-2013 10:19 |
| SOCKEYE | 59.50614 | -152.09827 | 05-Jul-2013 10:26 | SOCKEYE | 59.60821 | -151.65944 | 18-Jul-2013 12:44 |
| SOCKEYE | 59.50376 | -152.09778 | 05-Jul-2013 10:34 | SOCKEYE | 59.62489 | -152.01774 | 21-Jul-2013 21:11 |
| SOCKEYE | 59.49800 | -152.09290 | 05-Jul-2013 11:06 | CHINOOK | 59.56298 | -151.96630 | 21-Jul-2013 21:23 |
| SOCKEYE | 59.49597 | -152.08532 | 05-Jul-2013 11:21 | SOCKEYE | 59.56849 | -151.94892 | 22-Jul-2013 10:56 |
| SOCKEYE | 59.49523 | -152.08655 | 05-Jul-2013 11:28 | SOCKEYE | 59.60200 | -152.04226 | 22-Jul-2013 12:10 |
| SOCKEYE | 59.49397 | -152.09120 | 05-Jul-2013 11:45 | SOCKEYE | 59.65070 | -152.13770 | 22-Jul-2013 13:40 |
| SOCKEYE | 59.47181 | -152.04746 | 05-Jul-2013 11:58 | CHINOOK | 59.60880 | -151.96013 | 23-Jul-2013 16:45 |
| SOCKEYE | 59.44116 | -151.88194 | 06-Jul-2013 10:23 | CHINOOK | 59.94458 | -151.74363 | 23-Jul-2013 17:13 |
| SOCKEYE | 59.44745 | -151.86515 | 06-Jul-2013 11:48 | CHINOOK | 59.94313 | -151.74547 | 23-Jul-2013 17:37 |
| CHINOOK | 59.74093 | -151.98556 | 07-Jul-2013 11:18 | SOCKEYE | 59.98168 | -151.97270 | 23-Jul-2013 18:10 |
| SOCKEYE | 59.79151 | -151.92558 | 07-Jul-2013 14:16 | SOCKEYE | 59.92820 | -151.75502 | 24-Jul-2013 07:58 |
| SOCKEYE | 59.77083 | -151.96306 | 08-Jul-2013 16:16 | CHINOOK | 59.97932 | -151.94828 | 24-Jul-2013 20:24 |
| CHINOOK | 59.67132 | -151.85438 | 10-Jul-2013 05:32 | CHINOOK | 59.97683 | -151.96000 | 24-Jul-2013 20:40 |
| SOCKEYE | 59.67115 | -151.89633 | 10-Jul-2013 11:00 | SOCKEYE | 59.62993 | -151.98845 | 25-Jul-2013 13:30 |
| SOCKEYE | 59.76512 | -152.01951 | 10-Jul-2013 13:12 | CHINOOK | 59.92222 | -151.76035 | 25-Jul-2013 13:36 |
| SOCKEYE | 59.76854 | -152.02620 | 10-Jul-2013 13:21 | CHINOOK | 59.70253 | -152.08776 | 25-Jul-2013 17:05 |
| SOCKEYE | 59.76817 | -152.02383 | 10-Jul-2013 14:00 | CHINOOK | 59.96465 | -151.73493 | 26-Jul-2013 07:07 |
| SOCKEYE | 59.78338 | -151.99673 | 10-Jul-2013 15:43 | CHINOOK | 59.95310 | -151.74058 | 26-Jul-2013 09:20 |
| SOCKEYE | 59.72186 | -151.97336 | 12-Jul-2013 14:19 | SOCKEYE | 59.59583 | -151.95705 | 26-Jul-2013 12:08 |
| SOCKEYE | 59.73019 | -151.97955 | 12-Jul-2013 15:07 | CHINOOK | 59.61868 | -152.02890 | 26-Jul-2013 13:45 |
| CHINOOK | 59.67849 | -151.85985 | 12-Jul-2013 23:23 | CHINOOK | 59.68367 | -152.09950 | 26-Jul-2013 15:12 |
| SOCKEYE | 59.64513 | -151.97743 | 13-Jul-2013 12:34 | SOCKEYE | 59.74802 | -152.07430 | 26-Jul-2013 16:05 |
| SOCKEYE | 59.64708 | -151.98191 | 13-Jul-2013 12:44 | CHINOOK | 59.91293 | -151.77321 | 27-Jul-2013 12:28 |
| SOCKEYE | 59.69360 | -152.02285 | 13-Jul-2013 14:44 | CHINOOK | 59.96924 | -151.73386 | 27-Jul-2013 17:36 |
| SOCKEYE | 59.69773 | -152.02120 | 13-Jul-2013 17:12 | CHINOOK | 59.94375 | -151.74746 | 28-Jul-2013 06:50 |
| SOCKEYE | 59.69901 | -152.02160 | 13-Jul-2013 17:27 | CHINOOK | 59.96784 | -151.73506 | 28-Jul-2013 08:12 |
| SOCKEYE | 59.70024 | -152.02174 | 13-Jul-2013 17:41 | CHINOOK | 59.96543 | -151.73484 | 28-Jul-2013 08:43 |
| SOCKEYE | 59.70086 | -152.02190 | 13-Jul-2013 17:49 | CHINOOK | 59.91269 | -151.77712 | 28-Jul-2013 12:35 |
| SOCKEYE | 59.69456 | -152.01520 | 13-Jul-2013 18:28 | CHINOOK | 59.90810 | -151.77218 | 31-Jul-2013 14:55 |
| SOCKEYE | 59.75092 | -152.21450 | 14-Jul-2013 11:51 | CHINOOK | 60.04397 | -151.70480 | 01-Aug-2013 07:40 |

**Table A-4. Handling times of tagged fish that were released immediately after the tagging procedure without a recovery interval. Times reported in mm:ss.**

| | | Chinook | Sockeye | Species Combined |
|---|---|---|---|---|
| Count of Tagged Fish (N) | | 6 | 9 | 15 |
| After Sedation | Average | 11:00 | 10:53 | 10:56 |
| | Minimum | 06:00 | 05:00 | |
| | Maximum | 13:00 | 17:00 | |
| Count of Tagged Fish (N) | | 6 | 4 | 10 |
| No Sedation | Average | 10:30 | 07:00 | 09:06 |
| | Minimum | 07:00 | 05:00 | |
| | Maximum | 20:00 | 10:00 | |

**Table A-5. The duration of each stage of the tagging procedure, broken down by species, and troll method. Times reported in mm:ss**

| | | Chinook | | | Sockeye | | | Species Combined | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Commercial | Sport | Combined | Commercial | Sport | Combined | Commercial | Sport | Combined |
| Count of Fish Tagged (N) | | 7 | 12 | 19 | 43 | 1 | 44 | 50 | 13 | 63 |
| Induction Duration | Average | 06:43 | 08:55 | **08:04** | 07:59 | 05:00 | **07:55** | 07:48 | 08:37 | **07:58** |
| | Minimum | 04:00 | 04:00 | | 03:00 | N/A | | 03:00 | 04:00 | |
| | Maximum | 10:00 | 13:00 | | 25:00 | N/A | | 25:00 | 13:00 | |
| Recovery Duration | Average | 04:43 | 02:45 | **03:28** | 06:25 | 03:00 | **06:20** | 06:11 | 02:46 | **05:31** |
| | Minimum | 00:00 | 00:00 | | 00:00 | N/A | | 00:00 | 00:00 | |
| | Maximum | 11:00 | 07:00 | | 34:00 | N/A | | 34:00 | 07:00 | |
| Handling Duration | Average | 11:26 | 11:40 | **11:35** | 14:24 | 08:00 | **14:15** | 13:16 | 11:23 | **13:27** |
| | Minimum | 06:00 | 05:00 | | 05:00 | N/A | | 05:00 | 05:00 | |
| | Maximum | 17:00 | 18:00 | | 40:00 | N/A | | 40:00 | 18:00 | |

*Excluding fish tagged without using anesthetic; excluding first 3 surgically implanted sockeye.

**Table A-6. Water quality conditions during tagging.**

| | | Chinook | Sockeye |
|---|---|---|---|
| Sedative Concentration (ppm)* | Average | 104.4 | 128.6 |
| | Minimum | 66.7 | 88.3 |
| | Maximum | 183.3 | 133.3 |
| Water Temp (°C) | Average | 11.8 | 9.3 |
| | Minimum | 9.0 | 6.5 |
| | Maximum | 15.0 | 11.5 |
| Dissolved Oxygen (ppm) | Average | 11.5 | 10.6 |
| | Minimum | 9.0 | 8.2 |
| | Maximum | 12.3 | 12.6 |

***Excluding the first 3 sockeye surgically implanted using a heavy sedative dose. Also excludes fish tagged without sedative (Chinook, N=19; Sockeye, N=44).**

**Table A-7. Capture statistics by the capture vessel/method. All fish caught using the sport fishing vessels were captured in shallow, nearshore waters. Capture depth of sockeye caught by commercial troll calculated on N=44.**

| | | Chinook | | | Sockeye | | |
|---|---|---|---|---|---|---|---|
| | | Commercial | Sport | Combined | Commercial | Sport | Combined |
| Count of Tagged Fish (N) | | 12 | 13 | 25 | 50 | 1 | 51 |
| FL (mm) | Average | 853 | 1075 | 968 | 612 | 622 | 612 |
| | Minimum | 700 | 860 | | 503 | N/A | |
| | Maximum | 1040 | 1230 | | 710 | N/A | |
| MEFL (mm) | Average | 764.6 | 960.8 | 866.6 | 561 | 565 | 561.2 |
| | Minimum | 620 | 790 | | 456 | N/A | |
| | Maximum | 940 | 1040 | | 650 | N/A | |
| Capture Depth (m) | Average | 18.7 | 3.5 | 10.8 | 10.9 | 2.7 | 10.7 |
| | Minimum | 11 | 1.8 | | 3.7 | N/A | |
| | Maximum | 29.3 | 4.9 | | 25.6 | N/A | |

**Table A-8. Induction, recovery, and retention durations for tagged individuals. Times reported in h:mm.**

| Species | Induction Duration | Recovery Duration | Overall Handling Duration | Species | Induction Duration | Recovery Duration | Overall Handling Duration |
|---|---|---|---|---|---|---|---|
| SOCKEYE | 0:11 | 3:29 | 3:40 | SOCKEYE | 0:25 | 0:05 | 0:30 |
| SOCKEYE | 0:12 | 0:00 | 0:12 | SOCKEYE | 0:08 | 0:26 | 0:34 |
| SOCKEYE | 0:12 | 1:27 | 1:39 | SOCKEYE | 0:06 | 0:07 | 0:13 |
| CHINOOK | 0:11 | 0:00 | 0:11 | SOCKEYE | 0:05 | 0:05 | 0:10 |
| CHINOOK | 0:06 | 0:00 | 0:06 | SOCKEYE | 0:08 | 0:04 | 0:12 |
| SOCKEYE | 0:05 | 0:00 | 0:05 | SOCKEYE | 0:07 | 0:12 | 0:19 |
| SOCKEYE | 0:11 | 0:00 | 0:11 | SOCKEYE | 0:04 | 0:10 | 0:14 |
| SOCKEYE | 0:09 | 0:00 | 0:09 | SOCKEYE | 0:10 | 0:09 | 0:19 |
| SOCKEYE | 0:08 | 0:00 | 0:08 | SOCKEYE | 0:05 | 0:08 | 0:13 |
| SOCKEYE | 0:16 | 0:00 | 0:16 | SOCKEYE | 0:12 | 0:09 | 0:21 |
| SOCKEYE | 0:06 | 0:00 | 0:06 | CHINOOK | 0:04 | 0:03 | 0:07 |
| SOCKEYE | 0:14 | 0:00 | 0:14 | SOCKEYE | 0:05 | 0:16 | 0:21 |
| SOCKEYE | 0:17 | 0:00 | 0:17 | SOCKEYE | 0:04 | 0:08 | 0:12 |
| SOCKEYE | 0:06 | 0:06 | 0:12 | SOCKEYE | 0:06 | 0:04 | 0:10 |
| SOCKEYE | 0:10 | 0:05 | 0:15 | CHINOOK | 0:04 | 0:11 | 0:15 |
| SOCKEYE | 0:06 | 0:02 | 0:08 | CHINOOK | 0:13 | 0:05 | 0:18 |
| SOCKEYE | 0:08 | 0:02 | 0:10 | CHINOOK | 0:10 | 0:07 | 0:17 |
| CHINOOK | 0:06 | 0:03 | 0:09 | SOCKEYE | N/A | 0:00 | 0:10 |
| SOCKEYE | 0:05 | 0:04 | 0:09 | SOCKEYE | 0:05 | 0:03 | 0:08 |
| SOCKEYE | 0:08 | 0:04 | 0:12 | CHINOOK | N/A | 0:00 | 0:09 |
| CHINOOK | 0:10 | 0:07 | 0:17 | CHINOOK | N/A | 0:00 | 0:08 |
| SOCKEYE | 0:10 | 0:04 | 0:14 | SOCKEYE | N/A | 0:00 | 0:05 |
| SOCKEYE | 0:08 | 0:04 | 0:12 | CHINOOK | 0:10 | 0:06 | 0:16 |
| SOCKEYE | 0:07 | 0:05 | 0:12 | CHINOOK | N/A | 0:00 | 0:10 |
| SOCKEYE | 0:07 | 0:03 | 0:10 | CHINOOK | 0:06 | 0:03 | 0:09 |
| SOCKEYE | 0:05 | 0:05 | 0:10 | CHINOOK | 0:06 | 0:05 | 0:11 |
| SOCKEYE | 0:12 | 0:03 | 0:15 | SOCKEYE | N/A | 0:00 | 0:08 |
| SOCKEYE | 0:05 | 0:12 | 0:17 | CHINOOK | N/A | 0:00 | 0:09 |
| CHINOOK | 0:06 | 0:09 | 0:15 | CHINOOK | N/A | 0:00 | 0:07 |
| SOCKEYE | 0:08 | 0:07 | 0:15 | SOCKEYE | N/A | 0:00 | 0:05 |
| SOCKEYE | 0:09 | 0:05 | 0:14 | CHINOOK | 0:04 | 0:01 | 0:05 |
| SOCKEYE | 0:06 | 0:03 | 0:09 | CHINOOK | 0:05 | 0:01 | 0:06 |
| SOCKEYE | 0:03 | 0:03 | 0:06 | CHINOOK | 0:04 | 0:05 | 0:09 |
| SOCKEYE | 0:04 | 0:05 | 0:09 | CHINOOK | 0:13 | 0:00 | 0:13 |
| SOCKEYE | 0:09 | 0:08 | 0:17 | CHINOOK | 0:13 | 0:00 | 0:13 |
| SOCKEYE | 0:06 | 0:34 | 0:40 | CHINOOK | 0:13 | 0:00 | 0:13 |
| SOCKEYE | 0:06 | 0:17 | 0:23 | CHINOOK | N/A | 0:00 | 0:20 |
| SOCKEYE | 0:04 | 0:12 | 0:16 | CHINOOK | 0:10 | 0:00 | 0:10 |

**N/A in the 'Induction Duration' column indicates that <u>NO</u> anesthetic (AQUI-S® 20E) was used**

**Table A-9. Bycatch recorded and released.**

| | SPECIES | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | SOCKEYE (UNTAGGED) | SOCKEYE (UNFIT) | IMMATURE CHINOOK | MATURE CHK <400mm | COHO | PINK | CHUM | HALIBUT | PACIFIC COD | WALLEYE POLLOCK | DOLLY VARDON | IRISH LORD | GREENLING | VESSEL |
| 29-Jun-13 | | | 1 | | | | | | 2 | 3 | | | | F/V WEST BANK |
| 30-Jun-13 | 1 | 1 | | | | 1 | | 21 | | | | | | F/V WEST BANK |
| 01-Jul-13 | 1 | 2 | | | | | | 9 | | | | | | F/V WEST BANK |
| 02-Jul-13 | 3 | | | | | 2 | | 30 | | | | | | F/V WEST BANK |
| 03-Jul-13 | 2 | 1 | | | | 1 | 1 | 17 | | | | | | F/V WEST BANK |
| 04-Jul-13 | | | | | | 1 | | 19 | | 1 | 1 | | | F/V WEST BANK |
| 05-Jul-13 | 7 | 3 | 3 | | 5 | 17 | 6 | 18 | | | | | | F/V WEST BANK |
| 06-Jul-13 | 2 | | 4 | | 6 | 5 | | 1 | 3 | 5 | | | | F/V WEST BANK |
| 07-Jul-13 | | | 2 | | | 1 | | 18 | 1 | 2 | | | | F/V WEST BANK |
| 08-Jul-13 | | | 2 | | 2 | 1 | | 13 | | | | | | F/V WEST BANK |
| 09-Jul-13 | | | | | | | | | | | | | | F/V WEST BANK |
| 10-Jul-13 | 1 | 1 | 1 | | 7 | 9 | | 27 | 5 | | 1 | | | F/V WEST BANK |
| 11-Jul-13 | | | | | | | | 4 | | | | | | F/V WEST BANK |
| 12-Jul-13 | | 2 | 1 | | 1 | 2 | | 10 | 2 | | | | | F/V WEST BANK |
| 13-Jul-13 | 11 | 1 | 2 | | | | | 23 | | | | | | F/V WEST BANK |
| 14-Jul-13 | | | | | | 5 | 3 | 3 | | | | | | F/V WEST BANK |
| 15-Jul-13 | | 7 | | | 2 | 14 | 3 | 22 | | 3 | | | | F/V WEST BANK |
| 16-Jul-13 | | | | | | | | | | | | | | F/V WEST BANK |
| 17-Jul-13 | | | 2 | | | 2 | 4 | | | 4 | | | | F/V WEST BANK |
| 18-Jul-13 | | 2 | | | 2 | 5 | | 3 | | 2 | | | | F/V WEST BANK |
| 19-Jul-13 | | | | | | | | | | | | | | F/V WEST BANK |
| 20-Jul-13 | | | | | | | | | | | | | | F/V WEST BANK |
| 21-Jul-13 | | | | | 1 | 21 | | 15 | | 5 | 1 | | | F/V WEST BANK |
| 22-Jul-13 | | | 2 | | | 17 | 2 | | | | | | | F/V WEST BANK |
| 23-Jul-13 | | 2 | 1 | | 4 | 60 | | 9 | | | | 1 | | COMBINED (ALL 3 VESSELS) |
| 24-Jul-13 | | | 3 | | 2 | 20 | | 3 | | | 1 | 1 | 1 | COMBINED (ALL 3 VESSELS) |
| 25-Jul-13 | | | 1 | | 2 | 15 | 1 | 11 | 1 | | 1 | | | COMBINED (ALL 3 VESSELS) |
| 26-Jul-13 | | | 1 | | 2 | 12 | | 12 | | 1 | | | | COMBINED (ALL 3 VESSELS) |
| 27-Jul-13 | | | 2 | | 3 | | | 12 | | | | | 1 | COMBINED (ALL 3 VESSELS) |
| 28-Jul-13 | | | | | | 1 | | 14 | | | | | | COMBINED (ALL 3 VESSELS) |
| 29-Jul-13 | | | | | | | | | | | | | | M/V REFLECTIONS & SERENITY |
| 30-Jul-13 | | | | | | | | | | | | | | M/V REFLECTIONS & SERENITY |
| 31-Jul-13 | | | | | | | | | | | | | | M/V REFLECTIONS & SERENITY |
| 01-Aug-13 | | | | | | | | | | | | | | M/V REFLECTIONS & SERENITY |
| 02-Aug-13 | | | | | | | | | | | | | | M/V REFLECTIONS & SERENITY |
| **TOTALS** | **28** | **22** | **28** | **0** | **39** | **212** | **20** | **314** | **14** | **26** | **5** | **2** | **2** | |

## B. Detections Data Screening

Prior to analysis, we screen the data to identify 1) false detections; 2) single transmissions that were recorded on more than one receiver; 3) the date of displacement for receivers that were pulled from position (likely by fishing activities) and returned to us by the public; and 4) fish that were likely not of Kenai River origin.

### *B.1. Clock-drift correction*

VEMCO submerged receivers rely on crystal oscillators to keep track of time. Due to manufacturing variations, the frequency of the crystal oscillators varies slightly between receivers. Over time, the clock drifts and loses or gains time. A receiver may drift up to 4 seconds per day. Some of the time drift is due to changes in temperature, however, the majority of the drift is due to the variations in the oscillator. Therefore, the drift is highly linear and can be corrected (http://vemco.com/wp-content/uploads/2013/10/vue_manual.pdf).

We corrected the receivers for clock drift using the automatic correction function in VEMCO's VUE software.

### *B.2. False detection screening*

We identified and excluded any detection likely to be false (as a result of aliasing or tag collisions) using the First and Second Acceptance Criteria recommended by VEMCO (Pincock 2008; see http://www.vemco.com/pdf/false_detections.pdf) with a modification to the Second Criteria. Detections met the first criteria if there was at least one short interval (<0.5 hour) between successive detections of an ID code on a receiver and if there were more short intervals (<0.5 hour) between detections than long ones (>0.5 hour). Detections not meeting the first criteria were then examined individually (second criteria) to determine if they were supported by detections on other sub-arrays in a temporally logical sequence (including release) along the migratory path and if they were recorded when the probability of collision between multiple tags was low (i.e., at times when there was a silent interval of >5 minutes on at least one side of the detection in question). VEMCO acoustic tags generally have a very low false positive rate: we identified four of 24573 detections as false.

## *B.3. Duplicate detections*

The VEMCO V16 acoustic tags we used in the Cook Inlet study in 2013 are powerful and a single transmission was occasionally detected by more than one receiver. We removed these duplicates from the marine detections.

We used the following criteria to identify duplicate detections:

1) the tag numbers must match;

2) the depth measurements must match;

3) the receiver serial numbers must be different; and

4) the detections must be recorded within the minimum transmission interval of the tag (<15 s).

This screen identified 205 duplicate detections.

## *B.4. Last date of valid detection screening*

When receivers are accidentally displaced from their deployment position (usually by fishing activity), they are sometimes returned to Kintama by members of the public. We are usually able to download the data from these units; however, we do not always know the date and time they were displaced. Fishing crews are often able to provide dates when units were caught in their nets, providing us with accurate displacement dates, but receivers found floating or washed ashore may have been displaced much earlier.

When the date of displacement is not available, we estimate it by comparing the date and time of each tag ID logged with the date and time of the same tag ID on neighboring units that remained in position throughout the study period. The last date with a difference of less than one hour between tag detections on neighboring receivers is accepted as the last date of valid detection, and otherwise valid detections recorded for later dates are excluded from any analysis that is sensitive to receiver position. This process can only be used for receivers that have data (empty units cannot be screened) and that have neighboring units that also recorded detections.

In 2013, there were 4 receivers returned to Kintama by members of the public. From these, we identified 35 detections of 4 individual fish as being recorded after the receiver was displaced.

### *B.5. Stock of origin screening*

This study focuses on Chinook and sockeye from the Kenai and Kasilof rivers; however, fish were captured at sea and we do not know the stock of origin. Tissue samples were collected from each acoustic-tagged fish for genetic stock analysis, but results were not conclusive for Chinook, and were not yet available for sockeye at the time of writing. Prior to the start of our study, it was assumed that most fish captured in lower Cook Inlet in 2013 would return to the Kenai or Kasilof rivers, similar to 2012. However, there is now some evidence that fish from other stocks were included in our sample (see Discussion). These fish were unlikely to be detected by the acoustic array and would appear to be mortalities.

To partially address this concern, we removed fish from the analyses (n=2 Chinook; n=3 sockeye) that were recovered south of the release site; however, we could only remove individuals whose tags were returned in the fishery. To further focus the results on the Kenai River, we also removed the one sockeye that was detected in the Kasilof River. Removal of the Kasilof sockeye was particularly important for the survival analysis because the detection probability of the single detection site in the Kasilof River was unknown.

We removed 6 fish:

1) 1 Chinook caught in the Columbia River;
2) 1 Chinook caught near Seldovia;
3) 1 sockeye caught near Seldovia;
4) 1 sockeye caught near Kodiak Island;
5) 1 sockeye caught in Kachemak Bay; and
6) 1 sockeye caught in the Kasilof River.

### *B.6. Failed depth sensors*

All depth measurements for three tags read 2.5 m above the water surface, indicating that the pressure sensors were broken:

1) 9563 was a Chinook detected 1529 times between Aug 2nd and 9th;
2) 9572 was a Chinook detected 95 times between Aug 2nd and 6th; and
3) 9501 was a sockeye detected 15 times over 1.5 hours on July 19th.

Acoustic tag 9501 was returned by the fishery and VEMCO confirmed that the sensor had failed. We removed all three of these fish from the depth analysis.

VEMCO reports that the pressure sensors used in this study are their most reliable model and they have had no previous failures reported from the field. That we had 3 of these sensors fail out of 76 tags (39 with detections) is a cause for concern. Both Kintama and VEMCO are running various assessments using additional tags. In particular, Kintama has deployed multiple tags at the mean migration depths of the Chinook and sockeye measured in this study to evaluate their accuracy and precision. These results were not complete at the time this report was prepared.

# C. Data Analysis

## *C.1. Distribution on marine array*

To identify possible migratory pathways within Cook Inlet, we plotted the number of fish that were detected at each receiver on each of the six east-west lines deployed in the marine array. We also assessed the distribution of fish detected entering the ESSN by plotting fish counts at each receiver along the eastern boundary of the marine array. Because individual fish are usually heard at more than one receiver on a line, we allocated a proportion of each fish to each of the receivers on which it was detected (i.e., if a fish was heard once at each of three positions, each unit was allocated 0.33 of a fish).

## *C.2. Vertical distributions on entry to the ESSN fishing district*

We assessed the vertical distributions of Chinook and sockeye on entry to the ESSN and in relation to daylight and stage of tide. Entry to the ESSN was represented by all detections recorded on the north-south line of receivers bounding the western edge of the ESSN district (and the eastern edge of the marine array). Note that fish detected at this boundary may not actually be 'entering' the ESSN at the detection site; they may be anywhere within detection range of these receivers (~700 m) either inside or outside the ESSN fishing district.

We classified detections as occurring during day or night using the sunrise and sunset times specific to the day they were recorded. Sunrise/sunset times were obtained for at the Kenai Municipal Airport using the calculator provided by Horizon Network Security (http://www.cmpsolv.com/cgi-bin/sunset?page=bob&exper=new97&loctype=City&loc=Kenai%2C+AK&date=28%2F06%2F2013&tz=Zulu&tzcustom=&q=d2&aviation=yes&astro=yes&colors=white&datefmt=3). We defined 'day' as the interval between sunrise and sunset, and 'night' as the interval between sunset and sunrise.

We obtained estimates of tide level at the Kenai River Mouth from Nobeltec software Tides and Currents Professional version 3.5.107. The tidal data were for the interval between July 1st and August 20th which corresponds to the release of the first acoustic-tagged fish and the last detection on the marine array. They were reported with a 30 minute resolution and relative to the Mean Lower Low Water datum. Each detection was associated with the tide level predicted closest to the time the detection was recorded. We defined 'low' tides as tides ≤ the 20th percentile of tide heights (≤ 1.4 m), ‘high’ tides as tides $\geq$ the 80th percentile of tide heights ($\geq$ 5.4 m), and intermediate tides as tides between the 20th and 80th percentiles.

Because the number of depth measurements varied by individual fish, there was the possibility that unique behaviour by one or a few individuals who were detected frequently could bias the results. Accordingly, we present the depth distributions data for each species in two ways: 1) with depth transmissions as the unit of replication, and 2) with individual fish as the unit of replication. In the first approach, we simply summarized all the depth transmissions by species regardless from which fish they originated. In the second approach, we allocated a proportion of each fish to each of its depth transmissions (i.e., if a fish was detected 100 times, each detection was weighted as 0.01). Thus, the total number of detections for each individual summed to one. Using the fish as the unit of replication in this manner reduced the influence of individuals with high detection counts, but in exchange, individuals for which we have little information were weighted the same as those whose depth distributions are well known.

To further investigate the influence of individual animals on the cumulative depth distributions, we calculated the jackknife distribution for the $m$ fish of each species that were detected by resampling the data $m$ times while successively leaving out all the detections from one individual fish. We then calculated the mean, minimum, and maximum values at each depth across these resampled cumulative distributions.

There was little difference in results between the methods where the unit of replication was 1) the detection, or 2) the fish. For simplicity, the main report body presents results based on detections. Results based on individual fish are included in Appendix D.

## *C.3. Entry patterns into the ESSN fishing district in relation to time of day, tide stage, and wind velocity*

We assessed if entry of tagged Chinook and sockeye to the ESSN was related to time of day, tide stage, or wind velocity (wind speed and direction). We did not assess if entry to the ESSN was related to date (as specified in the RFP) because date was confounded by release timing after tagging (Figure E-1) and, therefore, reflects both run-timing and our fishing schedule rather than a variable that can be used to inform fishery management.

Entry to the ESSN was represented by all detections recorded on the north-south line of receivers bounding the western edge of the ESSN district (and the eastern edge of the marine array). Note that fish detected at this boundary may not actually be ‘entering’ the ESSN at the detection site; they may be anywhere within detection range of these receivers (~700 m) either inside or outside the ESSN fishing district.

Sources for sunrise/sunset times and tide levels are provided in section C.2. We defined ‘day’ as the interval between sunrise and sunset, and ‘night’ as the interval between sunset and sunrise. We defined ‘low’ tides as tides ≤ the 20th percentile of tide heights (≤ 1.4 m), ‘high’ tides as tides ≥ the 80th percentile of tide heights (≥ 5.4 m), and intermediate tides as tides between the 20th and 80th percentiles. We further defined ebb, slack, and flood tides defied based on whether the tide height predicted for the Kenai River mouth was lower, equal, or higher than in the preceding half hour, respectively (tides were predicted at ½ hour intervals).

We used hourly wind speed and direction measurements for the NOAA meteorological station at Nikiski (Station number: 09455760) to represent wind conditions at the western boundary of the ESSN fishing district (http://tidesandcurrents.noaa.gov/met.html?id=9455760). Each detection was associated with the wind speed and direction measurements recorded closest to the time the detection was recorded.

Because the number of detections varied by individual fish, there was the possibility that unique behaviour by one or a few individuals who were detected frequently could bias the results. Accordingly, we assessed entry to the ESSN for each species in two ways: 1) with each detection the unit of replication, and 2) with individual fish as the unit of replication. In the first approach, we simply summarized (by species) the environmental conditions occurring when each detection was recorded regardless of the fish from which it originated. In the second approach, we allocated a proportion of each fish to each of its detections (i.e., if a fish was detected 100 times, the environmental conditions occurring when the detection was recorded were weighted as 0.01). Thus, the total number of detections for each individual summed to one. Using the fish as the unit of replication in this manner reduced the influence of individuals with high detection counts, but in exchange, individuals for which we have little information were weighted the same as those whose depth distributions are well known.

There was little difference in results between the methods where the unit of replication was 1) the detection, or 2) the fish. Results from both methods are included in Appendix E.

### C.4. Travel times and rates

Travel time (days) was calculated for each fish from release until first detection on the marine array, from this first detection on the marine array until arrival at the Kenai River Mouth at RKm 2 (Snug Harbor), and from arrival at one detection site until arrival at the next for all sites in the Kenai River (RKms 2, 4.5, 8.2, 13.8, 22, 25.3, and 30.6). These estimates could only be made for fish detected at both detection sites bracketing the segment in question. Arrival was defined as the first detection at each detection site.

Travel rate was calculated for each fish as follows:

$$Travel\ rate = \frac{Distance}{Travel\ time}.$$

For this equation, distance was measured for each fish along the shortest route in water. We present travel rates in both kilometers/day and body lengths/second (BL/sec). We used fork length at tagging as the body length measure.

### C.5. Migration rates in relation to tagging date and fish length

Travel rates were calculated as described in section C.4. Fish length (fork length) and tag date were recorded at time of tagging.

### C.6. Milling behavior of Chinook and sockeye salmon in the Kenai River estuary in relation to tidal fluctuations

We used the three detection sites at or below the Kenai River Bridge (RKms 2, 4.5, and 8.2) to investigate the influence of tidal fluctuations on milling behaviour in the Kenai River estuary. Estimates of tide level at the Kenai River Mouth were from Nobeltec software Tides and Currents Professional version 3.5.107. These data were reported with a 30 minute resolution and relative to the Mean Lower Low Water datum. We defined 'milling' in the following ways:

1. a gap in the detection sequence at a single detection site of >1 hour; or
2. detection at a detection site upstream followed by detection at a site downstream.

For each fish that displayed milling behaviour, we plotted its detection sequence overlaid with the time series of tide levels.

## *C.7. Survival analysis*

Estimates of survival and detection probabilities were calculated using the Cormack-Jolly-Seber[24] (CJS) model for live-recaptured animals implemented with Program MARK (White and Burnham 1999) through the R[25] package RMark[26]. This model estimates survival ($\phi$) and detection probabilities ($p$) within a likelihood framework.

The survival estimates are termed "apparent survival" and represent the joint probability of migration to the Kenai River and survival through each segment of the array. Any fish that did not migrate to the Kenai River were counted as mortalities. For simplicity, we have abbreviated "apparent survival" as "survival".

We estimated survival for acoustic-tagged Chinook and sockeye in two segments of their migration: 1) between release and arrival at the marine acoustic array at line 159.0 (Figure 1), and 2) from there until arrival at the Kenai River mouth. Fish were considered to have survived to reach line 159 if they were detected anywhere on the marine array. They were then considered to have survived to reach the Kenai River Mouth if they were detected at either of the receivers deployed at RKms 2 or 4. Detections upstream were used to estimate the detection probability at the River Mouth.

The method of using the entire marine array to represent detection at line 159 has the potential to bias the survival estimates if fish swam over a portion of the marine array undetected and died before reaching the river mouth. In this case, the mortality would appear to have occurred between release and line 159 rather than in the next segment over the marine array. We used a more complex CJS model[27] to

[24] 1) Cormack RM (1964) Estimates of survival from the sighting of marked animals. Biometrika 51:429-438
2) Jolly GM (1965) Explicit estimates from capture-recapture data with both death and immigration- Stochastic model. Biometrika 52:225-247
3) Seber GAF (1965) A note on the multiple recapture census. Biometrika 52:249-259

[25] R Core Team (2013). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL http://www.R-project.org/.

[26] Laake, J.L. (2013). RMark: An R Interface for Analysis of Capture-Recapture Data with MARK. AFSC Processed Rep 2013-01, 25p. Alaska Fish. Sci. Cent., NOAA, Natl. Mar. Fish. Serv., 7600 Sand Point Way NE, Seattle WA 98115.

[27] We added a digit to the capture history sequence by dividing the marine array into 2 segments: 1) line 159 represented arrival at the marine acoustic array because it formed the southern edge of the grid; and 2) the rest of the marine receivers

investigate this possible source of bias: the survival estimates for Chinook were unchanged and the survival estimates for sockeye were increased by only 3% which is well within 1 standard error.

We estimated cumulative survival from release to the Kenai River mouth as the product of the two segment estimates. Because detection probability was 100% at the River mouth (i.e., all fish detected upstream were also detected at the Mouth), we calculated the standard error of the cumulative survival estimates as the standard error of a proportion[28].

$$Standard\ error = \sqrt{\frac{Survival(1 - Survival)}{Number\ released}}.$$

were combined and used to boost the number of fish detected beyond line 159. Given the study design, this method provided the largest possible sample size to estimate detection probability and survival to line 159.

[28] When detection probability is 100%, the CJS model returns the same results as the following expression:

$$Survival = \frac{Number\ detected}{Number\ released}$$

## D. Sections 2.5 Depth distributions near the ESSN; and 2.6 Effect of tides and time of day on depth distributions near the ESSN– Supplementary

Because the number of depth measurements varied by individual fish, it was possible that unique behavior by one or a few individuals who were detected frequently could bias the results. To investigate this prospect, we present the depth distributions data for each species in two ways: 1) with depth transmissions as the unit of replication, and 2) with individual fish as the unit of replication. In the first approach, we summarized all the depth transmissions by species regardless from which fish they originated. In the second approach, we allocated a proportion of each fish to each of its depth transmissions (i.e., if a fish was detected 100 times, each depth measurement was weighted as 0.01). Because the results were similar between the two methods, we reported only the results based on detections in the main report body. This appendix presents the results based on individual fish.

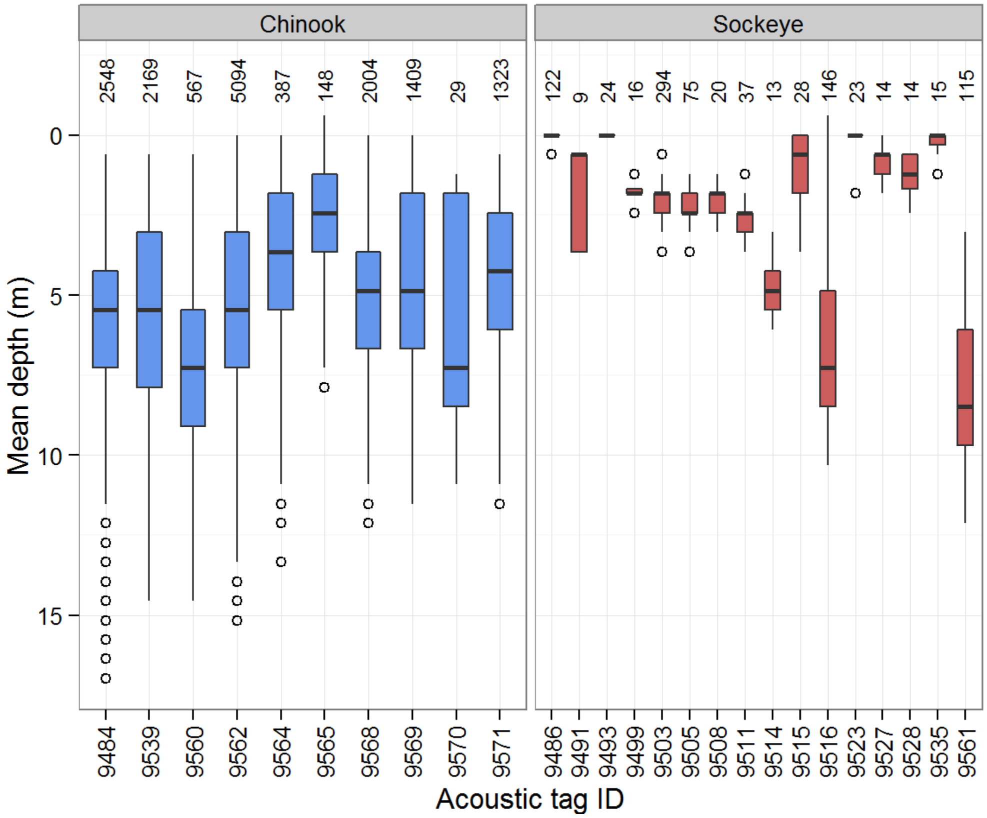


**Figure D-1. Depth distribution (m) of individual adult sockeye and Chinook salmon migrating over the row of acoustic receivers bordering the western edge of the ESSN fishery. Numbers along the top of the plots are the sample size. The top and bottom of each box are the 25th and 75th percentiles, the central band is the median, and the whiskers extend to the minimum and maximum values exclusive of outliers which are shown as circles.**

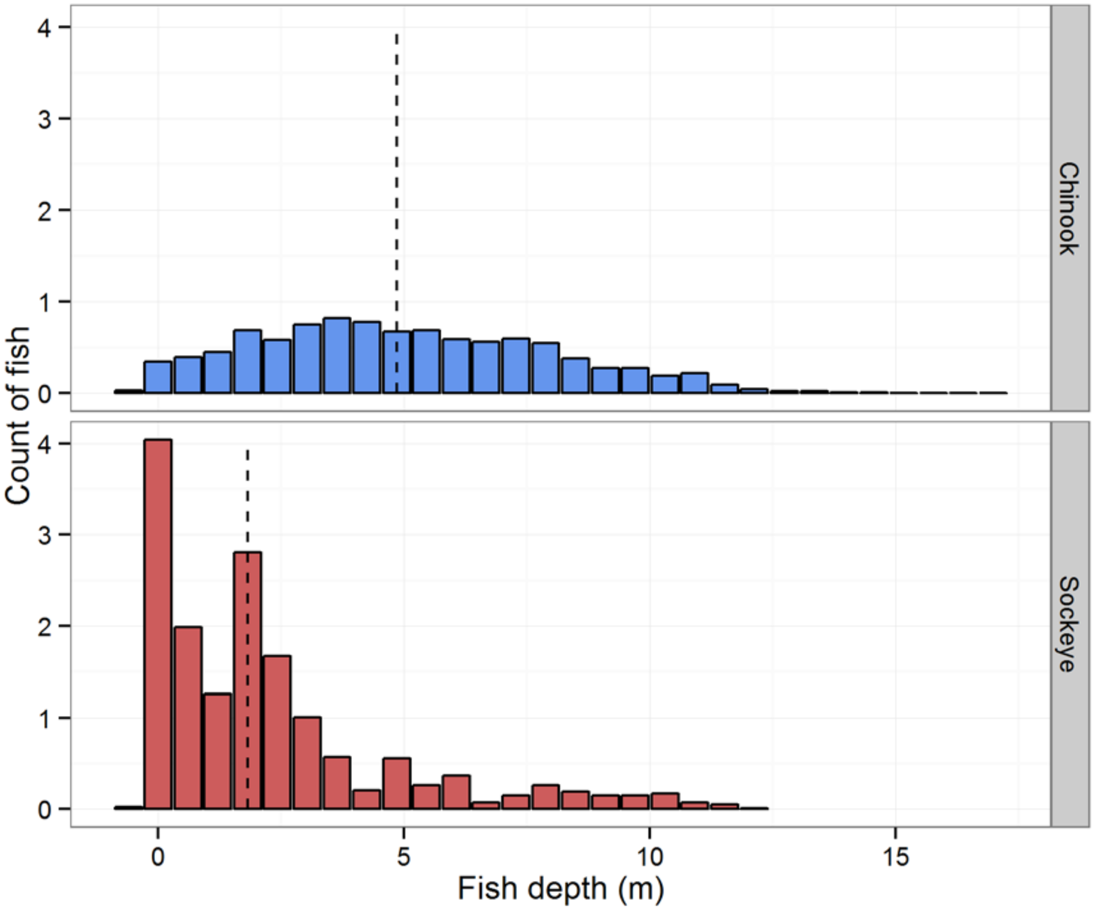


**Figure D-2. Depth distribution (m) of adult sockeye and Chinook salmon migrating over the row of acoustic receivers bordering the western edge of the ESSN fishery. Distributions were calculated by weighting each depth measurement by the number of depth measurements recorded by each individual fish (i.e., if a fish was detected 100 times, each depth measurement was weighted as 0.01). The vertical lines show the median depth.**

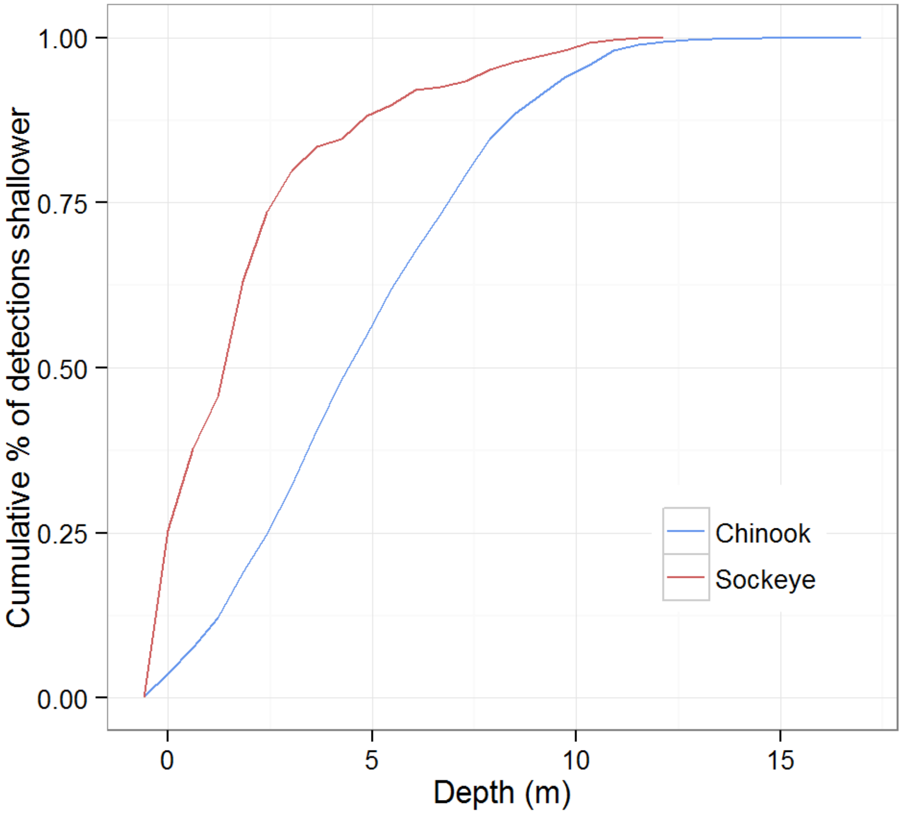


**Figure D-3. Cumulative depth distribution of tagged sockeye (red) and Chinook (blue) near the western boundary of the ESSN. Distributions were calculated by weighting each depth measurement by the number of depth measurements recorded by each individual fish (i.e., if a fish was detected 100 times, each depth measurement was weighted as 0.01).**

**Table D-1. Cumulative depth distribution of tagged sockeye and Chinook near the western boundary of the ESSN fishing district. Distributions were calculated by weighting each depth measurement by the number of depth measurements recorded by each individual fish (i.e., if a fish was detected 100 times, each depth measurement was weighted as 0.01).**

| Depth (m) | Cumulative percent of detections shallower | |
|---|---|---|
| | Chinook | Sockeye |
| 1 | 8% | 38% |
| 2 | 19% | 63% |
| 3 | 25% | 74% |
| 4 | 41% | 83% |
| 5 | 55% | 88% |
| 6 | 62% | 90% |
| 7 | 73% | 93% |
| 8 | 85% | 95% |
| 9 | 89% | 96% |
| 10 | 94% | 98% |

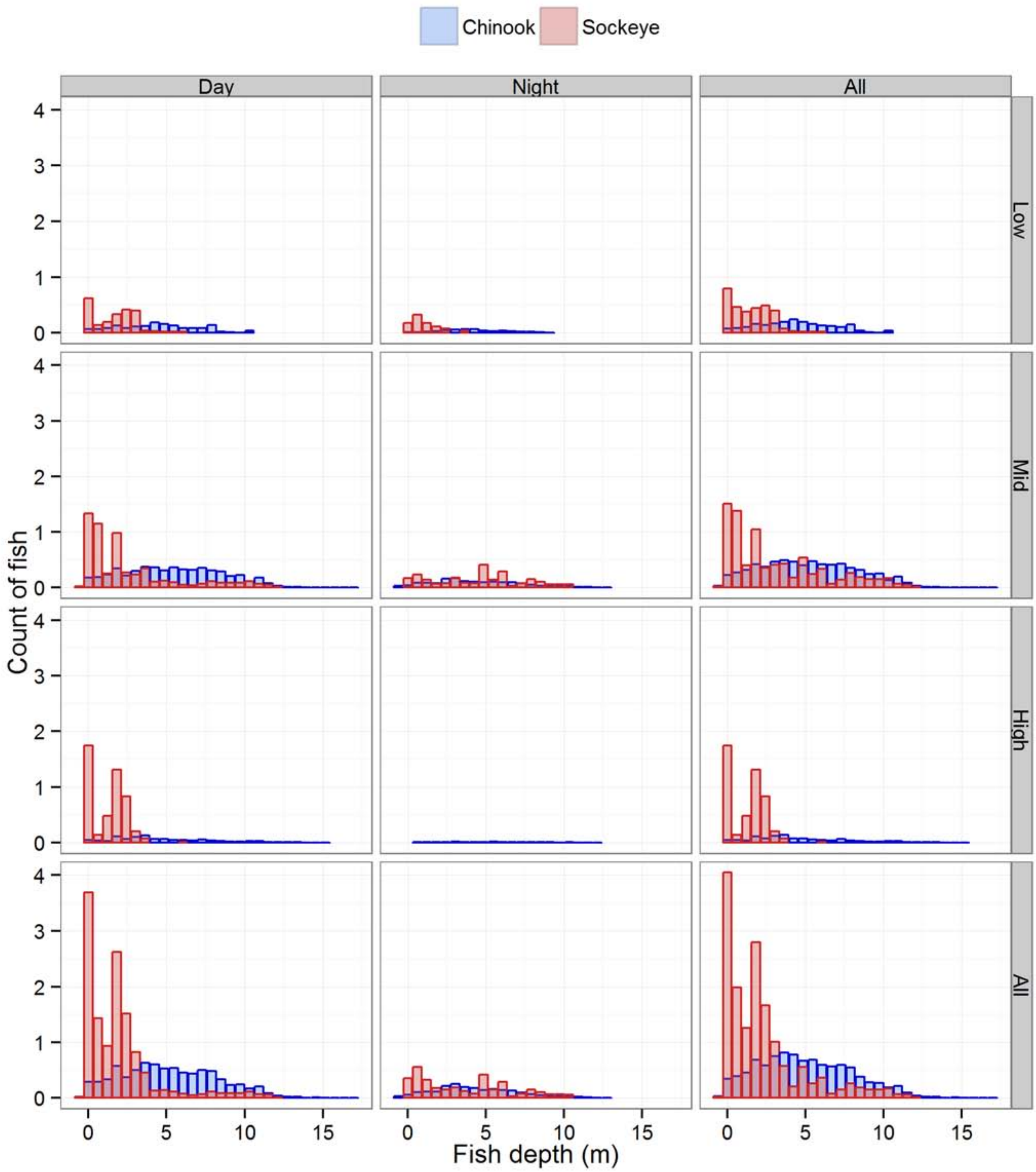


**Figure D-4. Depth distributions (m) histograms of adult sockeye and Chinook salmon along the western edge of the ESSN fishing zone. Distributions were calculated by weighting each depth measurement by the number of depth measurements recorded by each individual fish (i.e., if a fish was detected 100 times, each depth measurement was weighted as 0.01).**

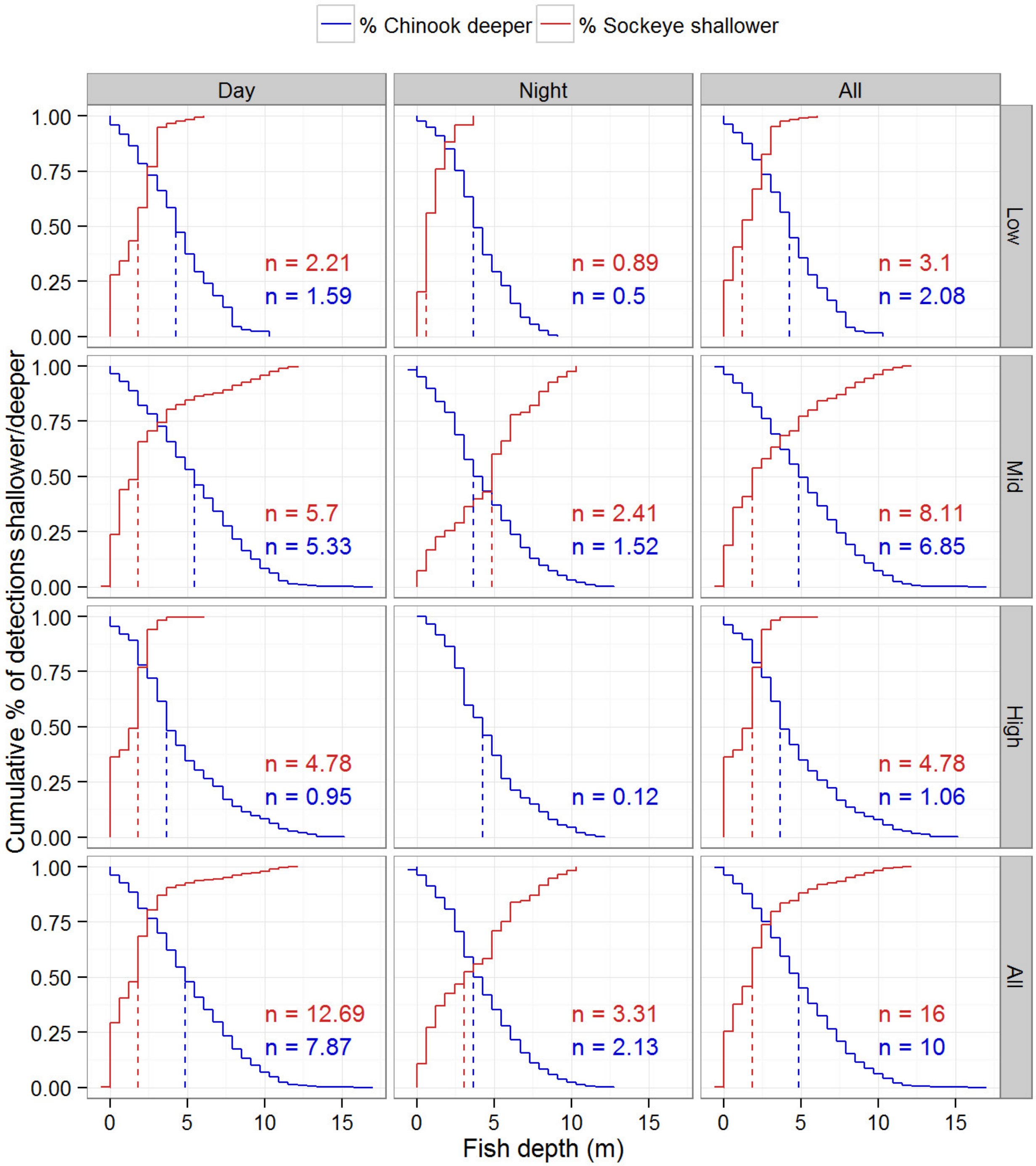


**Figure D-5. Cumulative depth distributions (m) of adult sockeye and Chinook along the western edge of the ESSN fishing district; n: sample size. Distributions show the proportion of time sockeye spent shallower than a given depth and the proportion of time Chinook spent deeper than a given depth. Distributions were calculated by weighting each depth measurement by the number of depth measurements recorded by each individual fish (i.e., if a fish was detected 100 times, each depth measurement was weighted as 0.01).**

## E. Section 2.7 Entry patterns into the ESSN and Kenai River in relation to time of day, tide stage, and wind velocity—Supplementary

This appendix presents supplementary figures for the investigation into the effects of environmental conditions on entry to the ESSN fishing district. "Entry" to the ESSN was represented by all detections by all detections recorded on the north-south line of receivers bounding the western edge of the ESSN district (and the eastern edge of the marine array). Note that fish detected at this boundary may not actually be 'entering' the ESSN at the detection site; they may be anywhere within detection range of these receivers (~700 m) either inside or outside the ESSN fishing district.

Several of the figures in this appendix are presented twice using 1) the detection as the unit of replication and 2) the fish as the unit of replication. In the first approach, we simply summarized the environmental conditions by species when each detection was recorded. In the second approach, we allocated a proportion of each fish to each of its depth transmissions (i.e., if a fish was detected 100 times, the environmental condition when each detection was recorded were weighted as 0.01). Thus, the total number of detections for each individual summed to one. Using the fish as the unit of replication in this manner reduced the influence of individuals with high detection counts, but in exchange, individuals for which we have little information were weighted the same as those whose distributions are well known.

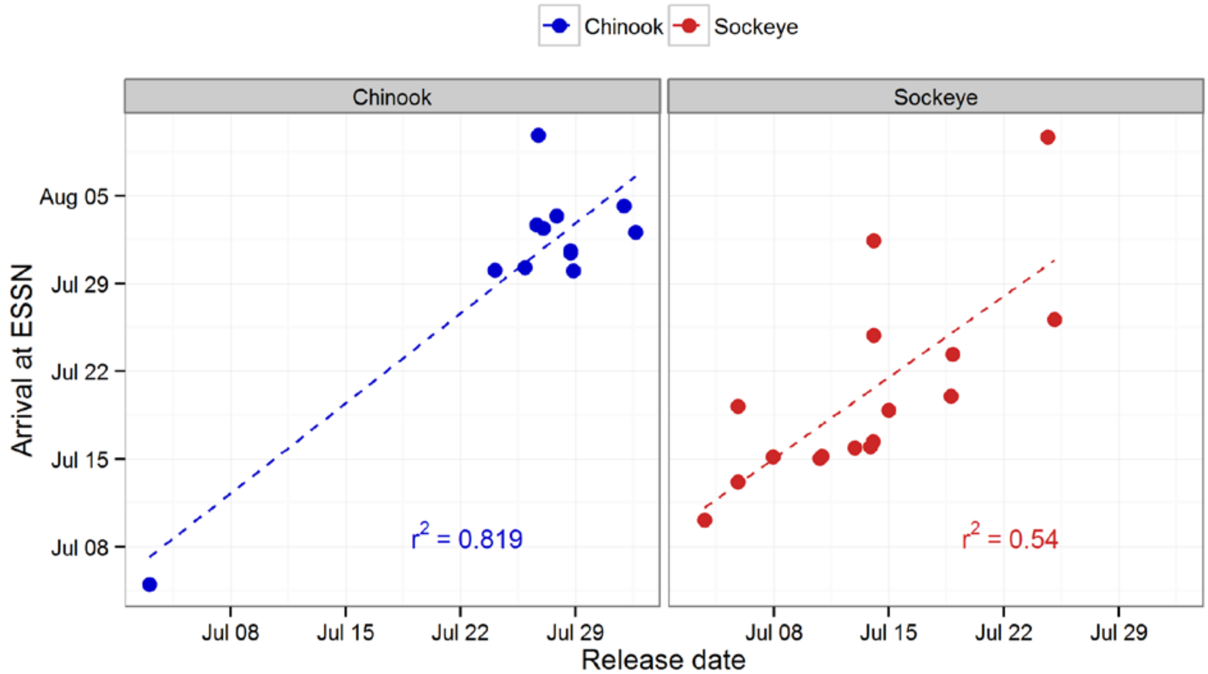


**Figure E-1. Relationship between release date and arrival of tagged adult sockeye and Chinook salmon at the western boundary of the ESSN fishing district.**

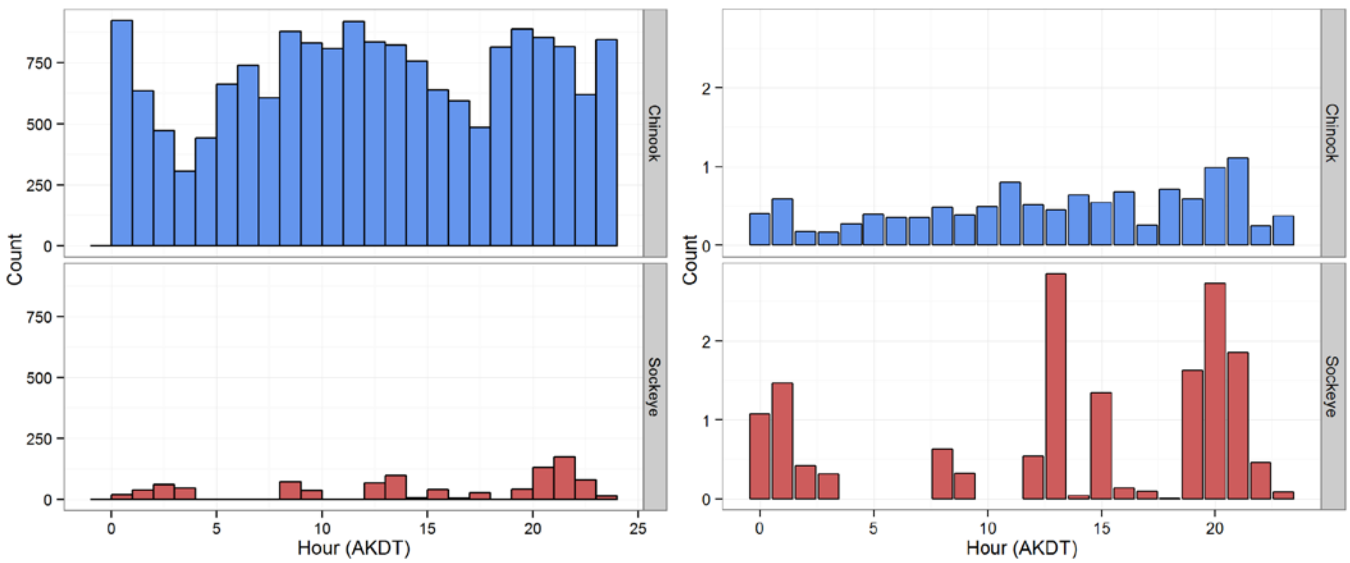


**Figure E-2. Distribution of the number of detections recorded by hour (all days combined) for adult Chinook and sockeye salmon as they migrated over the north-south line of acoustic receivers along the western edge of the ESSN fishing district. Left: by detection; right: by fish.**

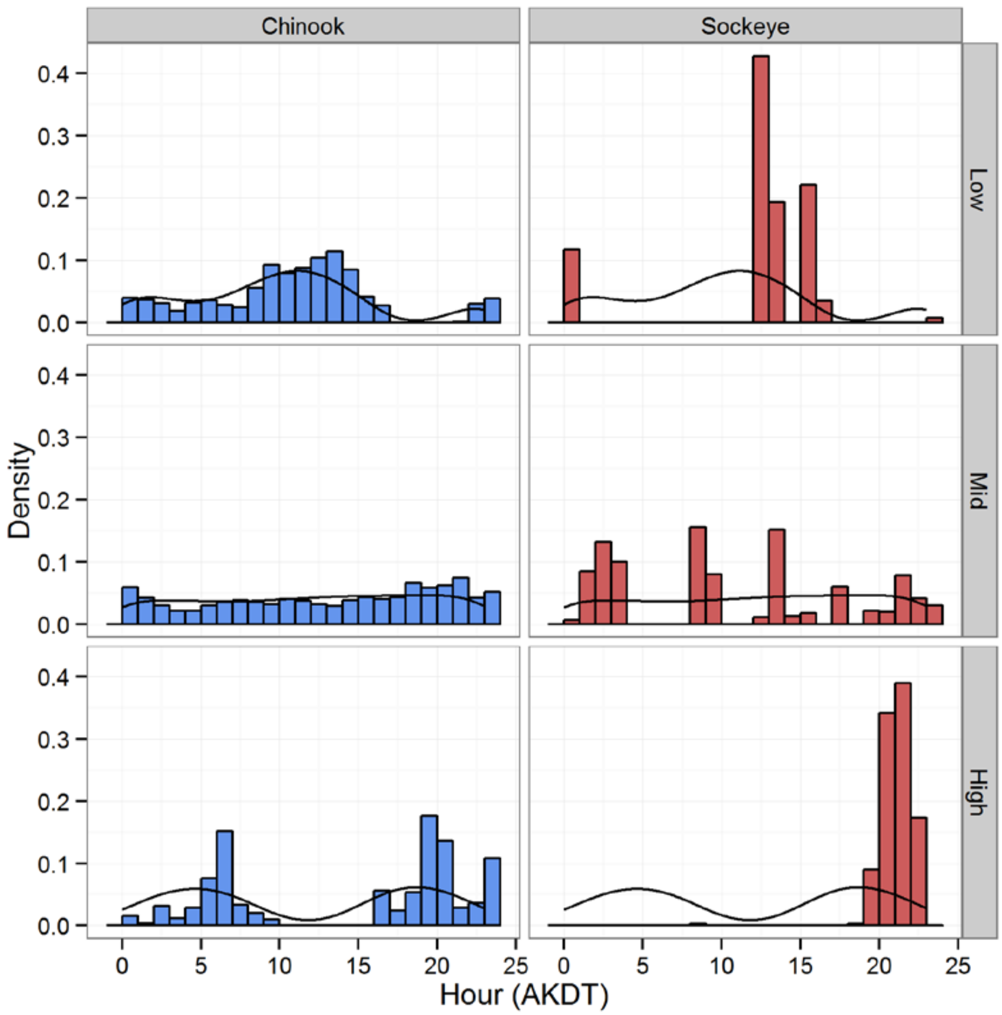


**Figure E-3. Density distribution of detections recorded by time of day (AKDT) and binned by tide height for adult Chinook and sockeye salmon as they migrated along the western edge of the ESSN fishing district. The black line represents the hourly distribution of tides predicted for the migration period and binned by tide height (i.e., these are the tide heights that were available to the salmon).**

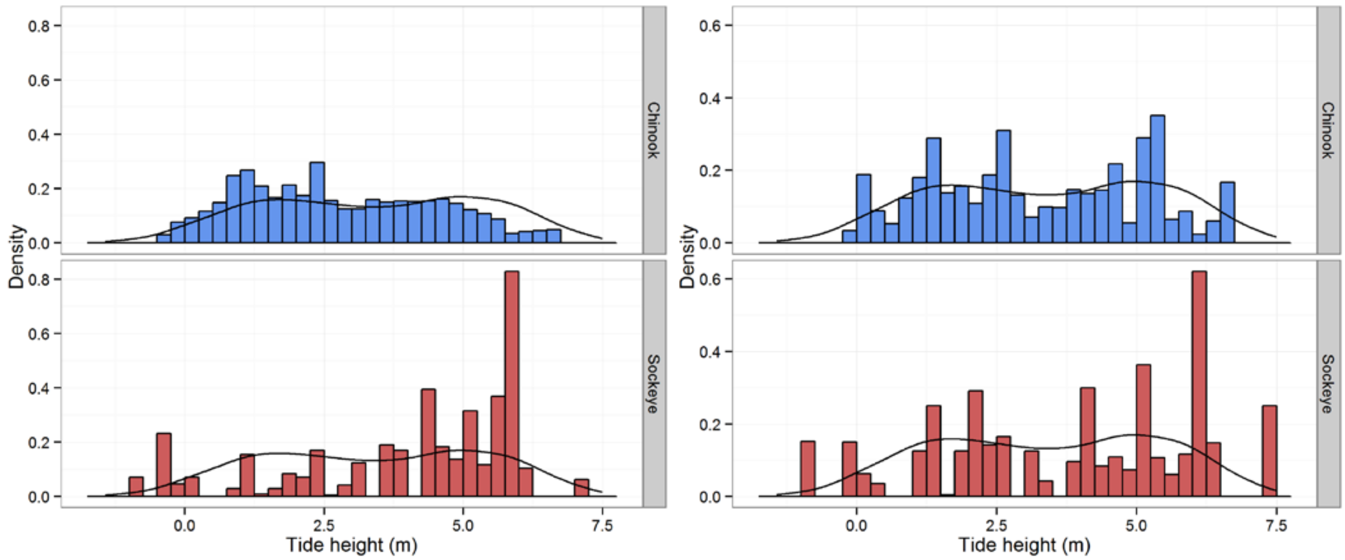


**Figure E-4. Density distribution of detections recorded by tide height (m) for adult Chinook and sockeye salmon as they migrated over the north-south line of acoustic receivers along the western edge of the ESSN fishing district. Left: by detection; right: by fish. The black line represents the distribution of tide height during the migration period (i.e., these are the tide heights that were available to the salmon). Tide heights were predicted for the Kenai River mouth at 0.5 hour intervals and relative to Mean Lower Low water.**

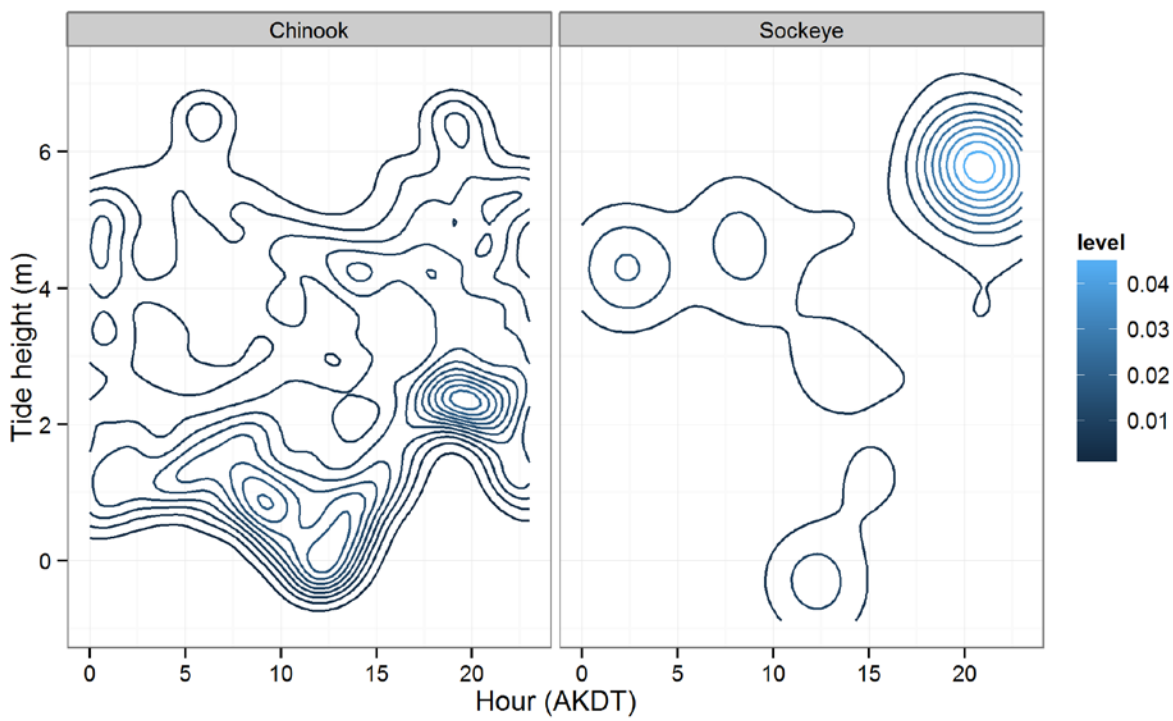


**Figure E-5. Contour plot of adult sockeye and Chinook detections relative to tide height (m) and hour of day (AKDT) along the western edge of the ESSN fishing district. Tide heights were predicted for the Kenai River mouth and are relative to Mean Lower Low water.**

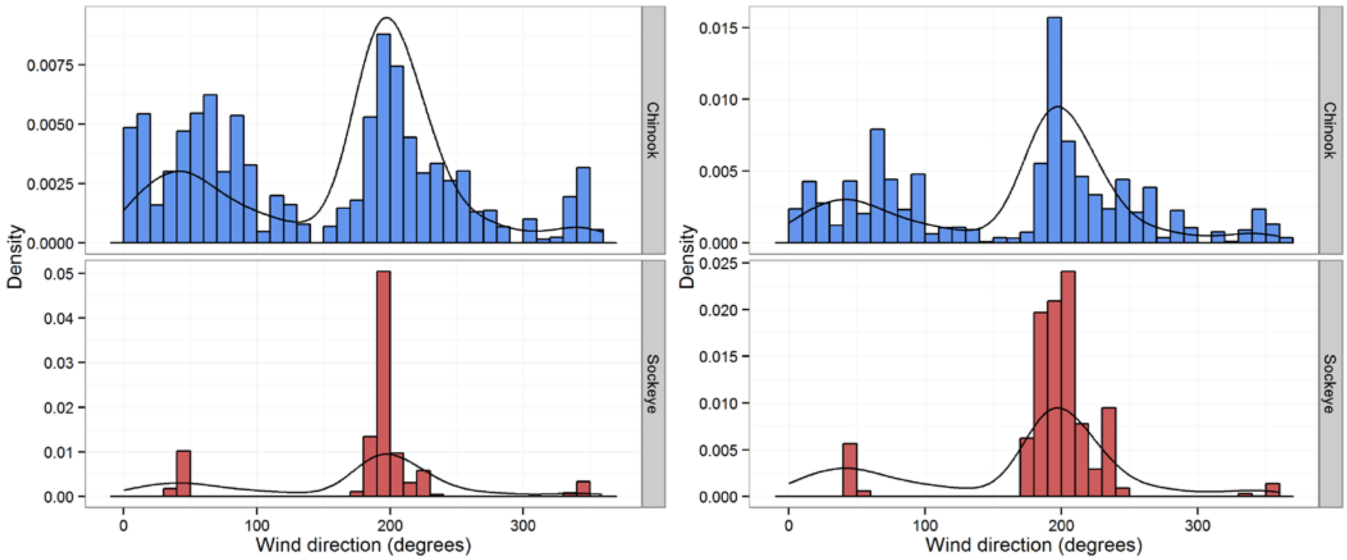


**Figure E-6. Density distribution of detections recorded by wind direction (degrees) for adult Chinook and sockeye salmon as they migrated over the north-south line of acoustic receivers along the western edge of the ESSN fishing district. Left: by detection; right: by fish. Wind blows from the direction indicated. North is at 0 degrees; east is at 90 degrees; south is at 180 degrees, and west is at 270 degrees. The black line represents the distribution of wind direction during the migration period (i.e., these are the wind directions that were available to the salmon). Wind direction was measured at hourly intervals at the NOAA meteorological station at Nikiski.**

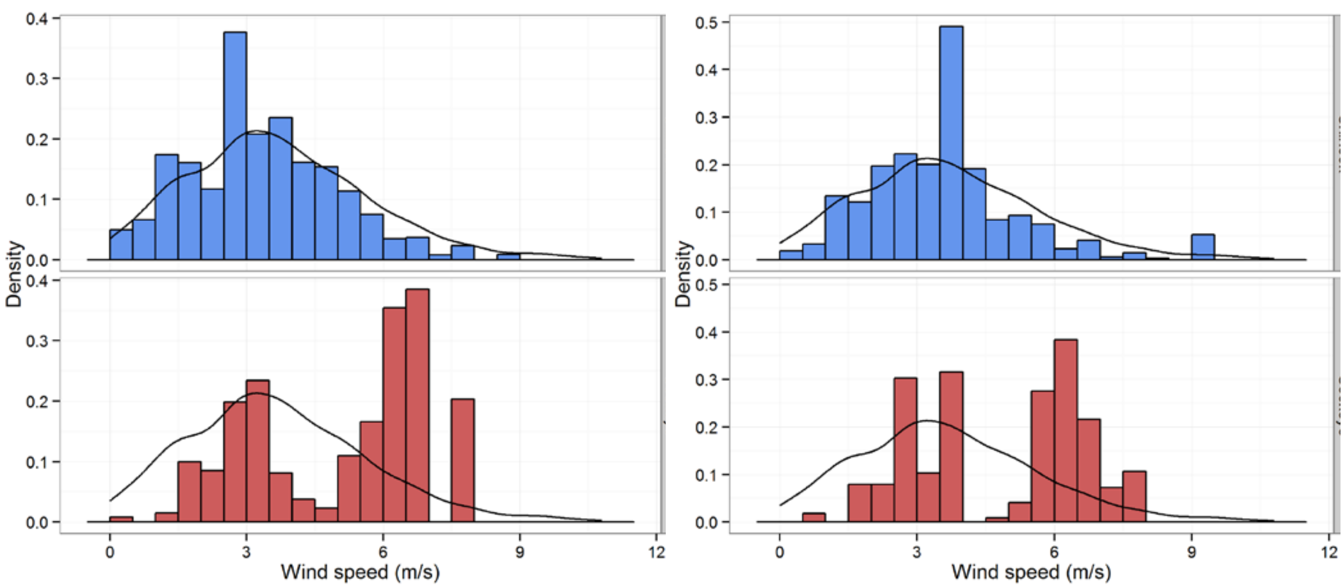


**Figure E-7. Density distribution of detections recorded by wind speed (m/s) for adult Chinook and sockeye salmon as they migrated over the north-south line of acoustic receivers along the western edge of the ESSN fishing district. Left: by detection; right: by fish. The black line represents the distribution of wind speed during the migration period (i.e.,**

**these are the wind speeds that were available to the salmon).Wind speed was measured at hourly intervals at the NOAA meteorological station at Nikiski.**

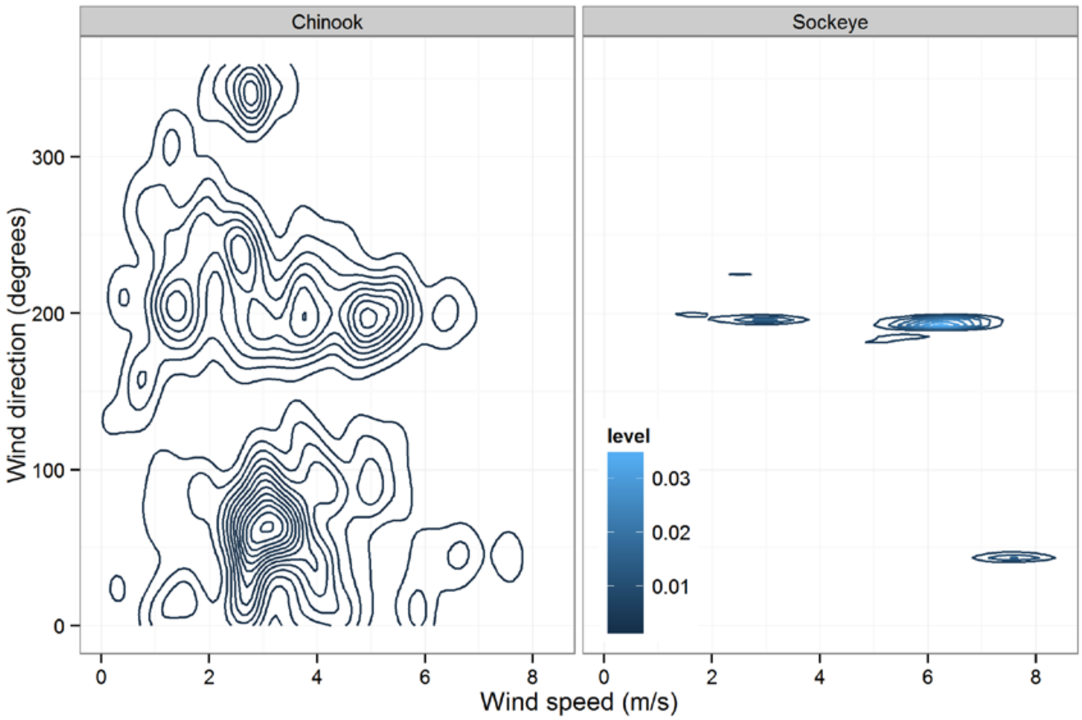


**Figure E-8. Contour plot of adult sockeye and Chinook detections relative to wind speed (m/s) and direction (°N) along the western edge of the ESSN fishing district. Wind variables were measured at hourly intervals at the NOAA meteorological station at Nikiski.**

# F. Section 2.8 Migration rates— Supplementary

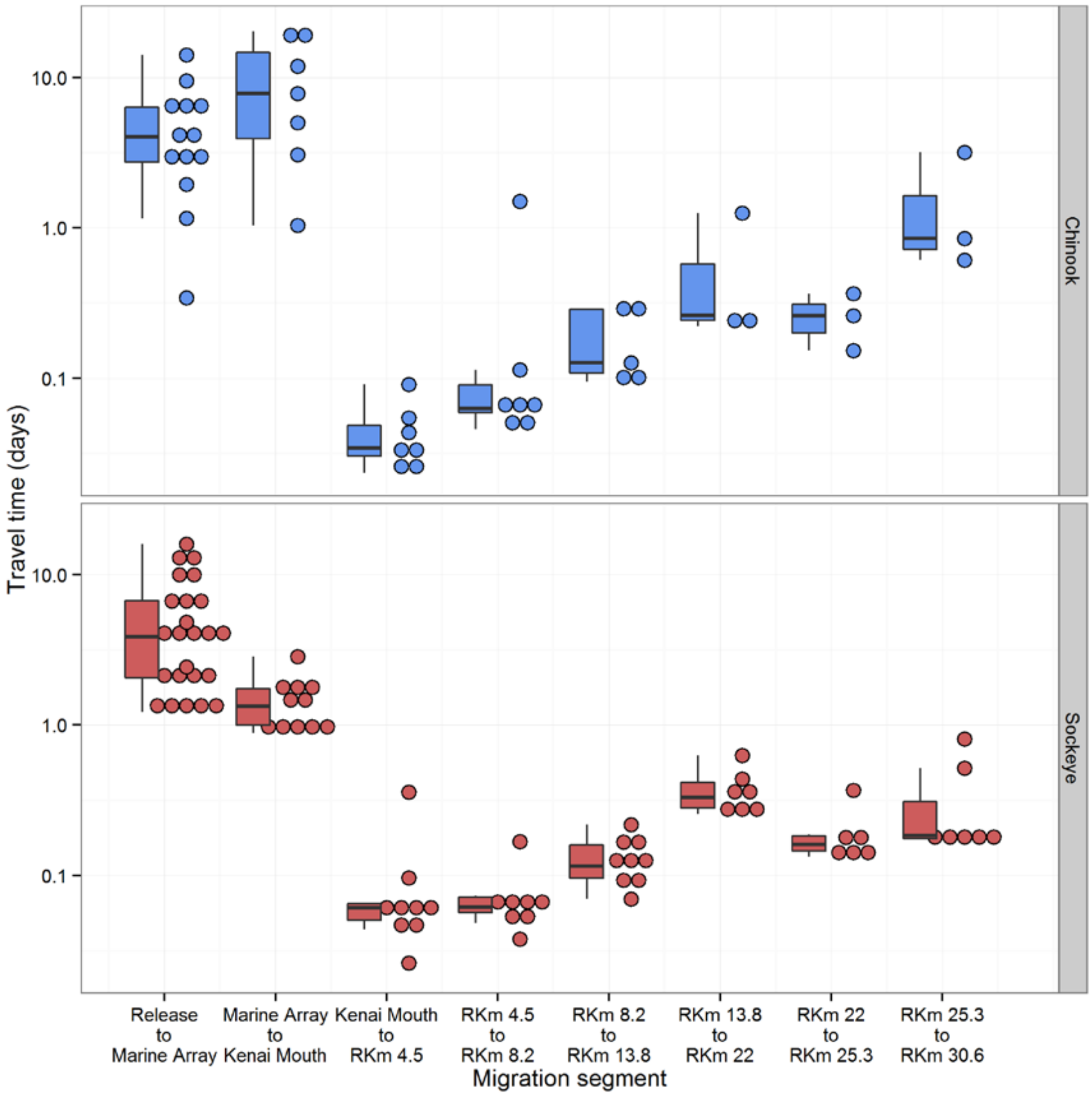


**Figure F-1. Travel time (days) distribution for adult sockeye and Chinook migrating between segments of the acoustic array. Travel times were calculated from release to the first detection on the marine array, from the marine array to RKm 2 in the Kenai River, and then between all detection sites in the Kenai River. The top and bottom of each box are the 25th and 75th percentiles, the central band is the median, and the whiskers extend to the minimum and maximum values exclusive of outliers.**

**Table F-1. Travel time (days) for adult sockeye and Chinook migrating between segments of the acoustic array. Travel times were calculated from release to the first detection on the marine array, from the marine array to RKm 2 in the Kenai River, and then between all detection sites in the Kenai River. Travel times are listed beside the end of the segment.**

| | | | | | | Percentiles | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Species** | **Detection Site** | **N** | **Mean** | **SE** | **SD** | **Min** | **10th** | **25th** | **Median** | **75th** | **90th** | **Max** |
| Chinook | Marine Array | 13 | 4.90 | 1.04 | 3.77 | 0.34 | 1.32 | 2.73 | 4.03 | 6.35 | 9.03 | 14.12 |
| | RKm 2 Snug Harbor | 7 | 9.57 | 2.80 | 7.40 | 1.04 | 2.25 | 4.02 | 7.81 | 14.93 | 18.86 | 20.22 |
| | RKm 4.5 Inlet Fish | 7 | 0.04 | 0.01 | 0.02 | 0.02 | 0.03 | 0.03 | 0.03 | 0.05 | 0.07 | 0.09 |
| | RKm 8.2 Kenai Bridge | 7 | 0.27 | 0.21 | 0.54 | 0.05 | 0.05 | 0.06 | 0.06 | 0.09 | 0.67 | 1.51 |
| | RKm 13.8 Lower King Sonar | 5 | 0.18 | 0.04 | 0.10 | 0.10 | 0.10 | 0.11 | 0.13 | 0.29 | 0.29 | 0.29 |
| | RKm 22 Upper King Sonar | 3 | 0.58 | 0.34 | 0.58 | 0.22 | 0.23 | 0.24 | 0.26 | 0.76 | 1.06 | 1.26 |
| | RKm 25.3 Gaines Dock | 3 | 0.26 | 0.06 | 0.11 | 0.15 | 0.17 | 0.21 | 0.26 | 0.31 | 0.35 | 0.37 |
| | RKm 30.6 Sockeye Sonar | 3 | 1.54 | 0.81 | 1.41 | 0.61 | 0.66 | 0.73 | 0.85 | 2.01 | 2.70 | 3.17 |
| Sockeye | Marine Array | 25 | 5.14 | 0.84 | 4.19 | 1.22 | 1.33 | 2.06 | 3.87 | 6.71 | 11.53 | 16.01 |
| | RKm 2 Snug Harbor | 11 | 1.46 | 0.18 | 0.60 | 0.88 | 0.90 | 1.00 | 1.32 | 1.74 | 1.88 | 2.85 |
| | RKm 4.5 Inlet Fish | 9 | 0.09 | 0.03 | 0.10 | 0.03 | 0.04 | 0.05 | 0.06 | 0.06 | 0.15 | 0.36 |
| | RKm 8.2 Kenai Bridge | 8 | 0.07 | 0.01 | 0.04 | 0.04 | 0.05 | 0.06 | 0.06 | 0.07 | 0.10 | 0.17 |
| | RKm 13.8 Lower King Sonar | 9 | 0.13 | 0.02 | 0.05 | 0.07 | 0.09 | 0.10 | 0.12 | 0.16 | 0.18 | 0.22 |
| | RKm 22 Upper King Sonar | 7 | 0.37 | 0.05 | 0.13 | 0.26 | 0.26 | 0.28 | 0.33 | 0.42 | 0.51 | 0.63 |
| | RKm 25.3 Gaines Dock | 6 | 0.19 | 0.04 | 0.09 | 0.13 | 0.14 | 0.15 | 0.16 | 0.18 | 0.28 | 0.37 |
| | RKm 30.6 Sockeye Sonar | 7 | 0.32 | 0.09 | 0.25 | 0.17 | 0.17 | 0.18 | 0.18 | 0.35 | 0.63 | 0.81 |

**Table F-2. Cumulative travel time (days) for adult sockeye and Chinook migrating over the acoustic array. Travel times were calculated from release to the first detection on the marine array, and from release to all detection sites in the Kenai River. Note that these travel times do not increase continuously along the migratory pathway because the number of fish detected at different points in the river varies.**

| | | | | | | Percentiles | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Species** | **Detection Site** | **N** | **Mean** | **SE** | **SD** | **Min** | **10th** | **25th** | **Median** | **75th** | **90th** | **Max** |
| Chinook | Marine Array | 13 | 4.90 | 1.04 | 3.77 | 0.34 | 1.32 | 2.73 | 4.03 | 6.35 | 9.03 | 14.12 |
| | RKm 2 Snug Harbor | 7 | 12.95 | 3.00 | 7.93 | 2.20 | 4.08 | 7.20 | 14.83 | 17.39 | 21.74 | 24.49 |
| | RKm 4.5 Inlet Fish | 7 | 13.00 | 2.99 | 7.92 | 2.29 | 4.15 | 7.24 | 14.86 | 17.43 | 21.77 | 24.52 |
| | RKm 8.2 Kenai Bridge | 7 | 13.27 | 3.07 | 8.13 | 2.35 | 4.24 | 7.32 | 14.92 | 18.21 | 22.69 | 24.56 |
| | RKm 13.8 Lower King Sonar | 5 | 10.86 | 3.42 | 7.64 | 2.64 | 3.84 | 5.63 | 9.24 | 15.03 | 19.06 | 21.74 |
| | RKm 22 Upper King Sonar | 3 | 11.79 | 5.35 | 9.27 | 3.90 | 5.01 | 6.68 | 9.46 | 15.73 | 19.49 | 22.00 |
| | RKm 25.3 Gaines Dock | 7 | 15.09 | 3.01 | 7.98 | 4.26 | 6.50 | 8.86 | 15.45 | 21.51 | 23.36 | 25.18 |
| | RKm 30.6 Sockeye Sonar | 3 | 13.59 | 5.24 | 9.08 | 4.87 | 6.48 | 8.88 | 12.89 | 17.95 | 20.98 | 23.00 |
| Sockeye | Marine Array | 25 | 5.14 | 0.84 | 4.19 | 1.22 | 1.33 | 2.06 | 3.87 | 6.71 | 11.53 | 16.01 |
| | RKm 2 Snug Harbor | 11 | 7.27 | 1.54 | 5.11 | 2.10 | 2.72 | 2.97 | 5.69 | 9.77 | 13.55 | 17.71 |
| | RKm 4.5 Inlet Fish | 10 | 6.92 | 1.51 | 4.78 | 2.17 | 2.70 | 3.78 | 5.44 | 7.72 | 12.51 | 17.80 |
| | RKm 8.2 Kenai Bridge | 9 | 8.49 | 1.68 | 5.04 | 2.82 | 3.34 | 5.19 | 7.69 | 11.96 | 14.50 | 17.87 |
| | RKm 13.8 Lower King Sonar | 9 | 8.62 | 1.68 | 5.04 | 2.96 | 3.44 | 5.29 | 7.81 | 12.03 | 14.66 | 17.99 |
| | RKm 22 Upper King Sonar | 7 | 8.13 | 1.56 | 4.14 | 3.26 | 3.60 | 5.15 | 8.14 | 10.50 | 13.29 | 14.23 |
| | RKm 25.3 Gaines Dock | 9 | 8.25 | 1.68 | 5.04 | 3.39 | 3.87 | 4.59 | 6.84 | 8.48 | 15.20 | 18.36 |
| | RKm 30.6 Sockeye Sonar | 7 | 7.64 | 1.35 | 3.57 | 4.17 | 4.19 | 5.12 | 7.36 | 8.56 | 11.03 | 14.60 |

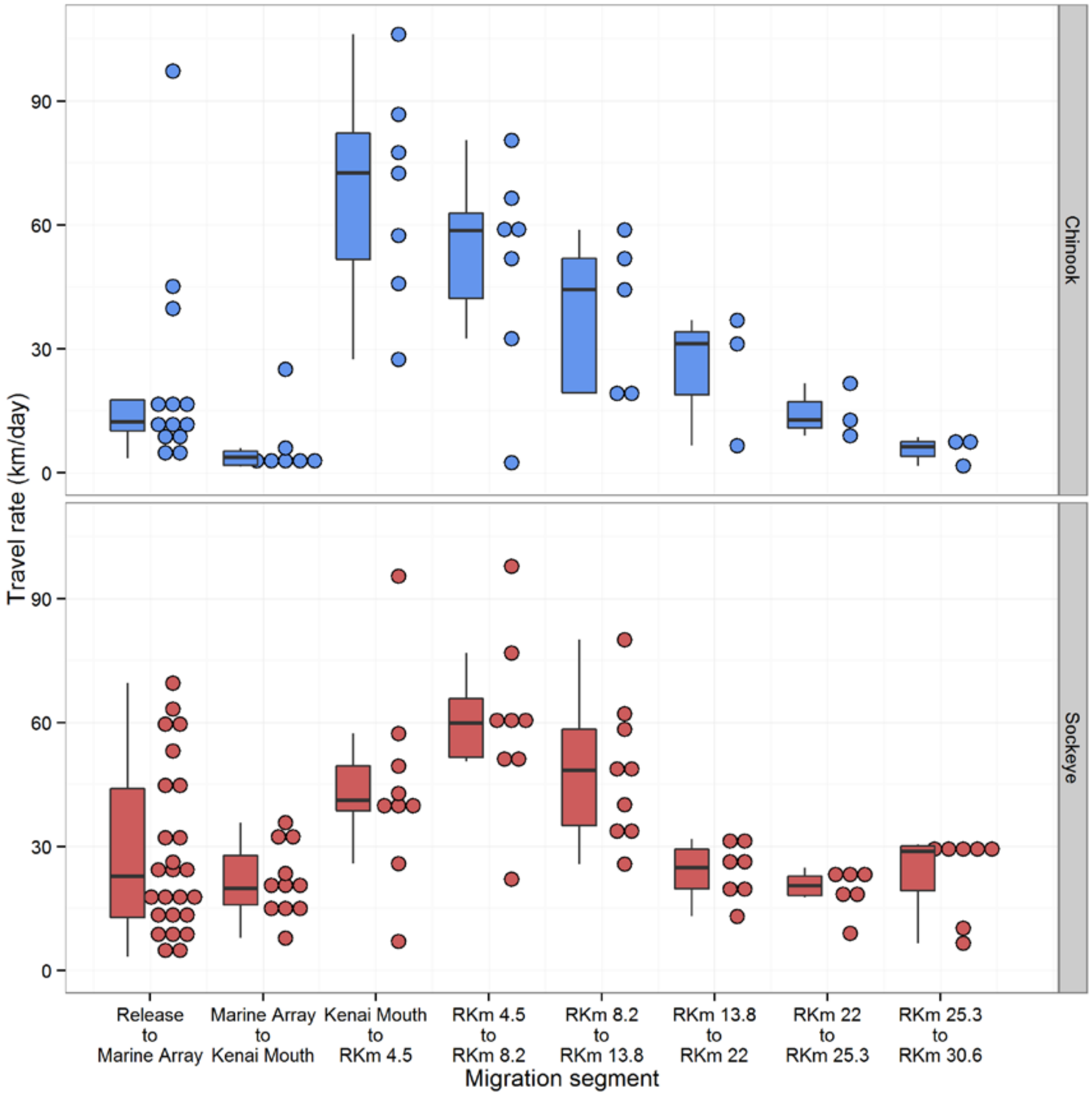


**Figure F-2. Travel rate (km/day) distribution for adult sockeye and Chinook migrating between segments of the acoustic array. Rates were calculated from release to the first detection on the marine array, from the marine array to RKm 2 in the Kenai River, and then between all detection sites in the Kenai River. The top and bottom of each box are the 25th and 75th percentiles, the central band is the median, and the whiskers extend to the minimum and maximum values exclusive of outliers.**

**Table F-3. Travel rates (km/day) for adult sockeye and Chinook migrating between segments of the acoustic array. Rates were calculated from release to the first detection on the marine array, from the marine array to RKm 2 in the Kenai River, and then between all detection sites in the Kenai River. Travel rates are listed beside the end of the segment.**

| | | | | | | Percentiles | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Species** | **Detection Site** | **N** | **Mean** | **SE** | **SD** | **Min** | **10th** | **25th** | **Median** | **75th** | **90th** | **Max** |
| Chinook | Marine Array | 13 | 22.66 | 7.10 | 25.60 | 3.52 | 6.33 | 10.15 | 12.25 | 17.66 | 44.03 | 97.29 |
| | RKm 2 Snug Harbor | 7 | 6.31 | 3.18 | 8.41 | 1.44 | 1.46 | 1.83 | 3.70 | 5.18 | 13.58 | 25.00 |
| | RKm 4.5 Inlet Fish | 7 | 67.67 | 9.95 | 26.33 | 27.48 | 38.51 | 51.68 | 72.46 | 82.15 | 94.55 | 106.14 |
| | RKm 8.2 Kenai Bridge | 7 | 50.22 | 9.67 | 25.58 | 2.46 | 20.49 | 42.20 | 58.56 | 62.83 | 72.05 | 80.48 |
| | RKm 13.8 Lower King Sonar | 5 | 38.68 | 8.26 | 18.46 | 19.10 | 19.22 | 19.40 | 44.30 | 51.84 | 56.00 | 58.78 |
| | RKm 22 Upper King Sonar | 3 | 24.87 | 9.32 | 16.14 | 6.53 | 11.46 | 18.85 | 31.17 | 34.04 | 35.76 | 36.91 |
| | RKm 25.3 Gaines Dock | 3 | 14.44 | 3.75 | 6.50 | 9.00 | 9.74 | 10.84 | 12.68 | 17.16 | 19.85 | 21.64 |
| | RKm 30.6 Sockeye Sonar | 3 | 5.53 | 2.05 | 3.56 | 1.67 | 2.59 | 3.96 | 6.24 | 7.46 | 8.19 | 8.68 |
| Sockeye | Marine Array | 25 | 28.27 | 3.98 | 19.90 | 3.28 | 8.50 | 12.76 | 22.73 | 44.03 | 59.85 | 69.58 |
| | RKm 2 Snug Harbor | 11 | 21.67 | 2.63 | 8.74 | 7.85 | 13.90 | 15.77 | 19.77 | 27.81 | 32.67 | 35.81 |
| | RKm 4.5 Inlet Fish | 9 | 44.11 | 8.00 | 24.01 | 6.99 | 22.10 | 38.63 | 41.17 | 49.45 | 64.94 | 95.45 |
| | RKm 8.2 Kenai Bridge | 8 | 60.12 | 7.69 | 21.74 | 22.10 | 42.08 | 51.51 | 59.84 | 65.79 | 83.10 | 97.82 |
| | RKm 13.8 Lower King Sonar | 9 | 47.93 | 5.66 | 16.98 | 25.69 | 31.10 | 34.99 | 48.45 | 58.35 | 65.70 | 80.08 |
| | RKm 22 Upper King Sonar | 7 | 23.95 | 2.58 | 6.82 | 13.05 | 16.49 | 19.75 | 24.86 | 29.23 | 31.17 | 31.82 |
| | RKm 25.3 Gaines Dock | 6 | 19.26 | 2.31 | 5.66 | 8.96 | 13.32 | 18.07 | 20.50 | 22.77 | 23.95 | 24.78 |
| | RKm 30.6 Sockeye Sonar | 7 | 23.52 | 3.93 | 10.40 | 6.57 | 8.79 | 19.27 | 28.77 | 30.12 | 30.36 | 30.50 |

**Table F-4. Travel rates (body lengths/second) for adult sockeye and Chinook migrating between segments of the acoustic array. Rates were calculated from release to the first detection on the marine array, from the marine array to RKm 2 in the Kenai River, and then between all detection sites in the Kenai River. Travel rates are listed beside the end of the segment.**

| | | | | | | Percentiles | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Species** | **Detection Site** | **N** | **Mean** | **SE** | **SD** | **Min** | **10th** | **25th** | **Median** | **75th** | **90th** | **Max** |
| Chinook | Marine Array | 13 | 0.26 | 0.09 | 0.33 | 0.04 | 0.07 | 0.10 | 0.14 | 0.21 | 0.49 | 1.25 |
| | RKm 2 Snug Harbor | 7 | 0.07 | 0.03 | 0.08 | 0.02 | 0.02 | 0.02 | 0.04 | 0.06 | 0.14 | 0.24 |
| | RKm 4.5 Inlet Fish | 7 | 0.77 | 0.12 | 0.31 | 0.26 | 0.46 | 0.60 | 0.82 | 0.97 | 1.06 | 1.18 |
| | RKm 8.2 Kenai Bridge | 7 | 0.55 | 0.11 | 0.28 | 0.03 | 0.26 | 0.48 | 0.57 | 0.71 | 0.83 | 0.90 |
| | RKm 13.8 Lower King Sonar | 5 | 0.45 | 0.10 | 0.22 | 0.18 | 0.21 | 0.24 | 0.55 | 0.57 | 0.65 | 0.70 |
| | RKm 22 Upper King Sonar | 3 | 0.27 | 0.10 | 0.18 | 0.06 | 0.12 | 0.20 | 0.35 | 0.37 | 0.38 | 0.39 |
| | RKm 25.3 Gaines Dock | 3 | 0.16 | 0.06 | 0.10 | 0.09 | 0.09 | 0.10 | 0.12 | 0.20 | 0.24 | 0.27 |
| | RKm 30.6 Sockeye Sonar | 3 | 0.06 | 0.02 | 0.04 | 0.02 | 0.03 | 0.05 | 0.08 | 0.08 | 0.08 | 0.08 |
| Sockeye | Marine Array | 25 | 0.55 | 0.08 | 0.41 | 0.06 | 0.16 | 0.23 | 0.40 | 0.84 | 1.21 | 1.32 |
| | RKm 2 Snug Harbor | 11 | 0.40 | 0.05 | 0.16 | 0.14 | 0.26 | 0.30 | 0.36 | 0.51 | 0.59 | 0.67 |
| | RKm 4.5 Inlet Fish | 9 | 0.81 | 0.15 | 0.45 | 0.13 | 0.41 | 0.68 | 0.74 | 0.87 | 1.23 | 1.78 |
| | RKm 8.2 Kenai Bridge | 8 | 1.10 | 0.15 | 0.42 | 0.39 | 0.74 | 0.94 | 1.10 | 1.22 | 1.52 | 1.84 |
| | RKm 13.8 Lower King Sonar | 9 | 0.88 | 0.11 | 0.32 | 0.45 | 0.56 | 0.61 | 0.90 | 1.04 | 1.20 | 1.51 |
| | RKm 22 Upper King Sonar | 7 | 0.44 | 0.05 | 0.12 | 0.25 | 0.30 | 0.35 | 0.46 | 0.54 | 0.56 | 0.56 |
| | RKm 25.3 Gaines Dock | 6 | 0.35 | 0.04 | 0.11 | 0.16 | 0.24 | 0.33 | 0.38 | 0.41 | 0.44 | 0.47 |
| | RKm 30.6 Sockeye Sonar | 7 | 0.43 | 0.07 | 0.19 | 0.13 | 0.16 | 0.34 | 0.52 | 0.54 | 0.55 | 0.57 |