U.S. Fish and Wildlife Service

# Estimation of Chinook Salmon Escapement, Distribution and Run Timing in the Togiak River Watershed Using Radiotelemetry, Togiak National Wildlife Refuge, Alaska, 2012

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# Estimation of Chinook Salmon Escapement, Distribution and Run Timing in the Togiak River Watershed Using Radiotelemetry, Togiak National Wildlife Refuge, Alaska, 2012

**Theresa L. Tanner and Suresh A. Sethi**

## Abstract

Radiotelemetry was used to determine distribution and run timing of Chinook salmon *Oncorhynchus tshawytscha* in the Togiak River watershed. Additionally, mark-recapture techniques were employed to estimate Chinook salmon abundance. In 2012, radio transmitters were implanted into 147 Chinook salmon and another 161 fish were marked with spaghetti tags in the lower 5 km of the Togiak River for the marking event. A total of 106 radio-tagged fish (72%) were successfully tracked to spawning locations. Fifteen radio-tagged fish (10%) had an indeterminate fate, 18 (12%) were known harvests, and 8 (5%) were assigned a fate of dead/regurgitated. Eighty-four percent ($n$ = 57) of the tracked fish selected spawning locations in the mainstem of the Togiak River, and 15% ($n$ = 22) selected spawning locations in the tributaries, primarily in Nayororun River (8%, $n$ = 8) and Kemuk and Ongivinuk rivers (5%, $n$ = 5, each). A resistance-board weir was installed in Gechiak Creek to serve as the primary recapture event for the mark-recapture effort. A total of 283 unmarked and 8 marked Chinook salmon were counted through the weir from 26 June through 2 September. A second recapture event was conducted in the form of 16 carcass surveys, conducted 11 August through 2 September, in which 145 unmarked and 2 marked Chinook salmon carcasses were examined. The spawning population estimate for Chinook salmon that entered the Togiak River in 2012 is 13,050 fish (95% CI = {7,844; 24,762}). Tests to determine differences in run timing between tributary and mainstem spawning populations indicate that tributary fish entered the lower river earlier than mainstem spawning fish. Movement behavior of spawning Chinook salmon, e.g., holding in the lowest mainstem river section for a period of days or weeks, prolongs exposure of in-migrating fish to harvest efforts.

## Introduction

Chinook salmon *Oncorhynchus tshawytscha* returning to spawn in the Togiak River watershed are harvested in subsistence, sport, and commercial fisheries. For the Togiak River watershed, the Alaska Department of Fish and Game (ADF&G) established a Sustainable Escapement Goal threshold of 9,300 Chinook salmon based on aerial surveys (Baker et al. 2009). Average estimated Chinook salmon spawning escapement from 1996 to 2005 was 11,862 fish, and average harvest was 11,273 fish, representing a 49% exploitation rate. In 2007, the harvest included 9,213 fish harvested in the commercial fishery, 902 harvested in the sport fishery, and 1,158 harvested in the subsistence fishery (Sands et al. 2008).

Current monitoring of Chinook salmon escapement into the Togiak River watershed is limited to aerial surveys. Total escapement can be estimated by expanding visual counts with assumed

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correction factors. The accuracy of aerial survey counts is greatly affected by stream life, variable run timing, observer efficiency, weather, water conditions, aircraft characteristics (type, speed, altitude, and pilot experience), and other factors (Bue et al. 1998). Aerial survey estimates within the Togiak River watershed have not been verified or compared with other methods, and the accuracy with which the observations index actual abundance is unknown. A complete aerial survey focused on Chinook salmon escapement for the Togiak drainage has not been completed since 2005 (Salomone et al. 2009). The Office of Subsistence Management (OSM), through its strategic planning process, identified a need to obtain reliable escapement estimates for Chinook salmon in the Togiak River (OSM 2005). The Bristol Bay Regional Advisory Council has voiced support for this need since 2003, and development of a reliable estimate of Chinook salmon escapement into the Togiak River was explicitly requested in the 2008, 2010 and 2012 Request for Proposals for the Fisheries Resource Monitoring Program. Improving long-term escapement monitoring of all species of adult Pacific salmon in the Togiak River has been a top priority issue with the Togiak National Wildlife Refuge, Togiak Traditional Council, and ADF&G. Accurate monitoring of Chinook salmon abundance is needed to ensure that adequate escapements are achieved so that healthy Chinook salmon populations are sustained and subsistence harvests and other needs are maintained. Subsistence harvest and Chinook salmon spawning and rearing habitat in the Togiak River occur within the Federal Conservation System boundaries of the Togiak National Wildlife Refuge. Providing a harvest priority to subsistence users in these waters is mandated under Title VIII of ANILCA. This is the final year of a 3-year radiotelemetry study to estimate Chinook salmon abundance in the Togiak River watershed.

Objectives for the project were to:

1. estimate the proportion of tagged Chinook salmon migrating past a weir on Gechiak Creek;
2. estimate the abundance of Chinook salmon escaping into the Togiak River watershed such that the estimate will have a 90% probability of being within 25% of the true abundance;
3. estimate the weekly age and sex composition of spawning Chinook salmon in Gechiak Creek, such that simultaneous 90% confidence intervals have a maximum width of 0.20;
4. estimate the mean length of Chinook salmon by sex and age;
5. document Chinook salmon spawning locations in the Togiak River watershed; and
6. evaluate the effectiveness of aerial spawning ground surveys for monitoring Chinook salmon abundance in the Togiak River watershed.

Objective 6 was not met in 2010, 2011, or 2012. ADF&G staff obtained only partial aerial counts, and abundance estimates from aerial survey data were not possible.

## Study Area

The Togiak River is located in southwest Alaska and lies within the Togiak National Wildlife Refuge (Figure 1). The watershed encompasses 5,178 km², comprises 9 major lakes and 5 major tributaries, and is bound on the east by the Wood River Mountains and on the west by the Ahklun Mountains. The Togiak River originates at the outlet of Togiak Lake and flows 93 km to Togiak Bay. The watershed upstream of the confluence with Pungokepuk Creek is part of a congressionally designated Wilderness Area. Detailed descriptions of the lakes and tributaries can be found in the Togiak Refuge Fisheries Management Plan (USFWS 1990).

Five species of Pacific salmon *Oncorhynchus* spp. are found in the Togiak River watershed along with rainbow smelt *Osmerus mordax*, rainbow trout *O. mykiss*, Dolly Varden *Salvelinus*

*malma*, Arctic char *S. alpinus*, northern pike *Esox lucius*, Arctic grayling *Thymallus arcticus*, and northern pike *Esox lucius* (USFWS 1990).

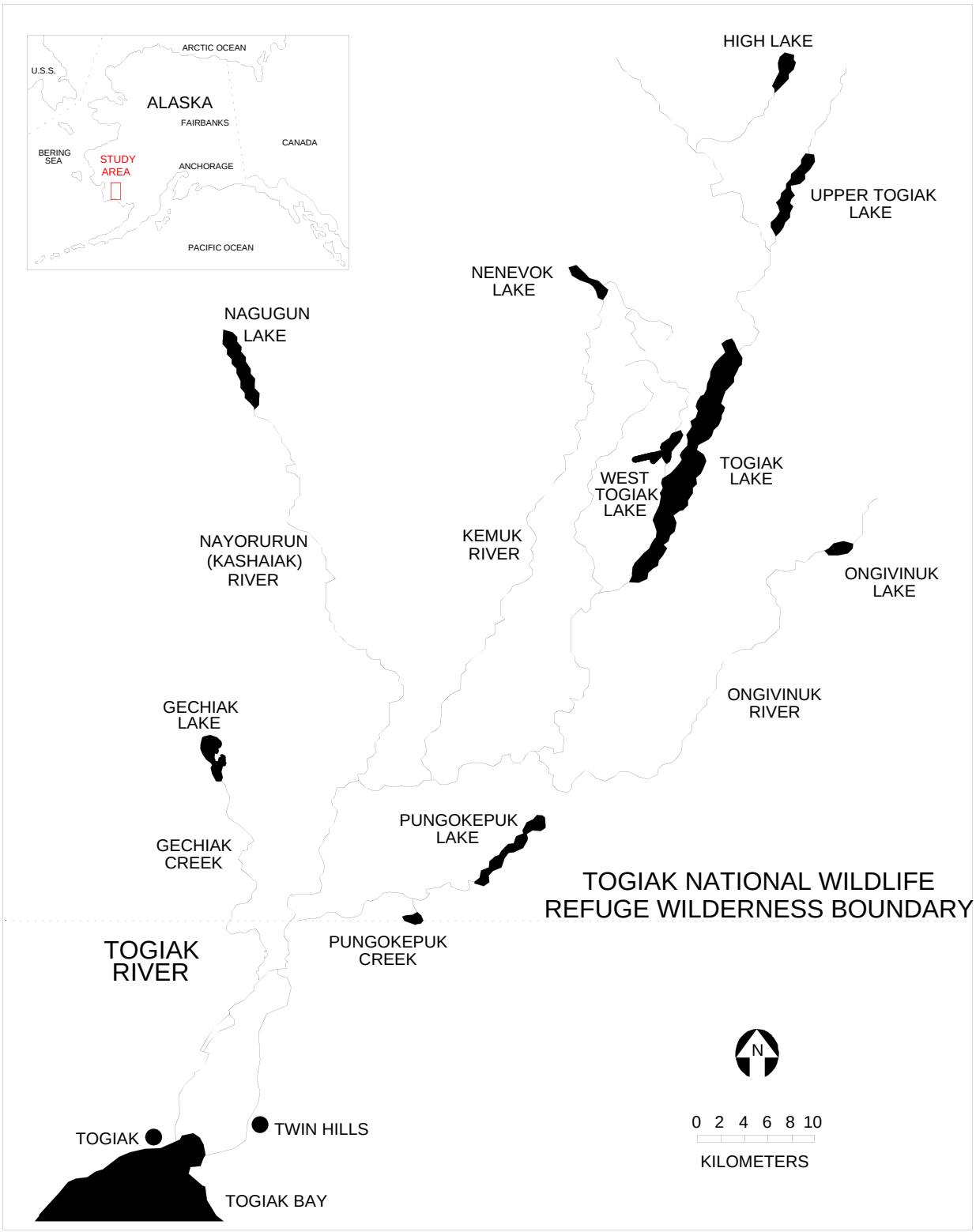


**Figure 1. Map of the Togiak River watershed in Southwest Alaska.**

# Methods

A radiotelemetry experiment was conducted to estimate the abundance, distribution, and run timing of Chinook salmon in the Togiak River watershed. Fish were captured and marked with radio transmitters and spaghetti tags in the lower 5 km of the mainstem. A resistance-board weir was installed in Gechiak Creek to enumerate fish passage and to obtain a proportion of marked to unmarked Chinook salmon. Movements and final spawning destinations of radio-tagged fish were documented using a combination of fixed data logging receiver stations and aerial- and ground-based mobile tracking.

## *Mark-Recapture Procedures*

*Marking event*---A three person crew fished a drift gill net (18.3 m long, 4.6 m deep, 20.3 cm stretched mesh size), with one crew member piloting the boat and the other two positioned in the bow tending the net. The gill net was deployed from the bow of the boat, and the boat motor was idled in reverse to keep the net perpendicular to the shore while drifting downstream in the center or deepest sections of the river. Each sampling area is less than 1 km in length, and fishing continued until the end of the area was reached or a fish became entangled in the net. Drift time was monitored and recorded with a stopwatch. All fish except Chinook salmon caught in the net were identified to species, counted, and immediately released. Statistical weeks defining temporal strata were used for sampling (Table 1). Sampling effort was standardized across temporal strata in order to mark Chinook salmon in proportion to abundance, a sampling feature that was crucial to obtain unbiased mark-recapture estimates of spawning abundance when using a systematic subsample during recapture events (Tanner and Sethi 2012). Gillnet fishing efforts were targeted to 2 hours of soak time per day, for an average of 14 hours soak time in each temporal stratum.

**Table 1. Allocation schedule for Chinook salmon radio transmitters in the Togiak River, 2012.**

| Strata | Dates | Radio Transmitter Allocation | Spaghetti Tag Color |
|---|---|---|---|
| 1 | 21–30 June | 45 | Fluorescent Pink |
| 2 | 1–10 July | 45 | Fluorescent Green |
| 3 | 11–20 July | 45 | Fluorescent Yellow |
| 4 | 21–30 July | 45 | International Orange |
| 5 | 31 July–9 August | 20 | White |
| 6 | 10–12 August | 20 | Florescent Pink/Green |
| | *Total:* | *200* | |

Chinook salmon longer than 450 mm (mid-eye to fork of tail) were tagged with radio transmitters manufactured by Advanced Telemetry Systems, Incorporated® (ATS; Model No. F1840B). Transmitters were encapsulated in a biologically inert polypropylene copolymer and equipped with a stainless steel nylon coated whip antenna. Transmitters weighed 22 g, which never exceeded 2% of the fish's body weight (Winter 1983). Radio transmitters were implanted through the esophagus using a plunger as described by Burger et al. (1985). Two hundred radio

tags consisting of 25 unique pulse digital codes dispersed over eight radio frequencies between 163.3 and 164.0 MHz were used. The combination of codes on each frequency allowed for the identification of individual fish. A mortality code was transmitted after 8 hours of inactivity. Additionally, 30.5 cm serially numbered spaghetti tags (Floy Tag and Manufacturing, Inc.; Model No. FT-4) were applied near the rear base of the dorsal fin between the interneural bones using a hollow needle. The tag was secured to the back of the fish with a Nico press sleeve. The spaghetti tags, or Floy tags, served as a highly visible mark, and each marking strata was represented by a separate color (Table 1). Marking criteria dictated that only healthy, lightly stressed Chinook salmon would receive both a radio tag and a Floy tag. If multiple Chinook salmon were captured in a single net set, only the first fish was implanted with a radio tag. All others were marked solely with a spaghetti tag and released.

We incorporated hook-and-line sampling to complement our gillnet fishing efforts. Hook-and-line sampling entailed letting out line with lead weight and spinner until they 'tapped' along the substrate while the boat driver maintained a slow downstream troll. Fishing effort was timed and standardized to one hour of total line soak time. Chinook salmon captured by hook and line only received Floy tags. All of the spinners were single hook and had the barbs pinched down to minimize injury.

Efforts were made to minimize stress to Chinook salmon during capture and handling. Captured fish were removed from gill nets as quickly as possible, and gillnet meshes were cut if the fish could not be easily removed from the net. Chinook salmon were then placed in a padded tagging cradle alongside the boat to allow the fish to be processed without removal from the water. The general health and appearance of each fish was recorded and mortally injured fish were not marked. Marked Chinook salmon were immediately released into the river after tagging. Total handling time for each marked fish was recorded. Handling time was calculated from the time the fish was first detected hitting the gill net, i.e., the net floats were disturbed, until the fish was sampled and released.

*Recapture events*---A resistance board weir (Tobin 1994; Stewart 2002) was installed in Gechiak Creek (59.2218$^{O}$N, 160.25049 $^{O}$W), approximately 2 rkm upstream from Togiak River. Weir panels were constructed of 2.5 cm inside-diameter schedule 40 polyvinyl chloride electrical conduit. Resistance boards were attached to each panel to aid floatation. Panel dimensions were 5.8 m long by 0.9 m wide with 7.62 cm center to center picket spacing. The panels were attached to the river bottom by way of a steel substrate rail and a 10 mm cable running from bank to bank (Figure 2). A 1.2 m apron of mesh chain link fence served to stabilize the substrate and acted as a barrier to fish passage beneath the rail. A fish passage panel designed as a chute was positioned near the deepest part of the channel, allowing fish to pass into a live trap to facilitate biological sampling and passing adult salmon through the weir. Two panels, not maintained with their resistance boards deployed and marked with orange buoys on either side, were positioned in the thalweg of the creek to allow for boat passage.

The weir served to recapture fish marked in the lower river and to enumerate all fish moving up the creek. Fish were counted intermittently throughout the daylight hours from roughly 0600 through 2400 hours. The duration of each counting session varied depending on the number of fish arriving at the weir. A contrasting substrate was placed on the stream bottom in front of the counting panel to enhance visibility of fish and to facilitate species identification as they were passed through the counting panel. When the weir was unmanned, the live trap was closed to passage. The weir was cleaned of debris and inspected daily for integrity. Repairs were made as needed.

Starting in mid-August, we conducted multiple spawning ground surveys. Surveys continued through the spawning period and ended in early September. Ground surveys were conducted with two or more observers. To prevent bias, surveys were conducted opportunistically and independently from telemetry tracking efforts. Surveys covered all areas accessible by boat to adult salmon in known spawning areas. Surveyors wore polarized glasses to reduce water surface glare. All carcasses were identified to species and Chinook salmon were examined for marks. The following data was recorded for each ground survey: date, time, crew, reach name, GPS coordinates (NAD83 datum) and waypoint, count of marked and unmarked carcasses of Chinook salmon, the color and serial number for each marked fish, count of live Chinook salmon, water clarity (excellent, good, or poor), lighting conditions (sun, partial overcast, overcast), wind generated surface turbulence (calm, moderate, rough), and any other pertinent comments. If a fish could not be positively identified as a Chinook salmon, it was excluded from both counts and counted as "unknown". Once a carcass had been sampled, it was be mutilated by cutting off the caudal fin and marking an operculum to avoid double-counting in future surveys.

**Figure 2. The resistance-board weir installed in Gechiak Creek (photo taken in 2011). A remote telemetry station was co-located with the camp on top of the river left bluff.**

*Biological sampling*--- For all Chinook salmon tagged in the marking event, length was measured to the nearest mm (mid-eye to fork of tail) and sex was determined from external characteristics (Mecklenburg et al. 2002). Three scales from the preferred area on the left side of each fish (Jearld 1983) were removed, cleaned, and mounted on gummed scale cards. After the field season, scale impressions from the gum cards were made on acetate blanks using a heated hydraulic press. Scale impressions were viewed with a microfiche reader and fish age was determined using the standards and guidelines of Mosher (1968). Fish ages were reported according to the European method described by Jearld (1983) and Mosher (1968), where the number of winters the fish spent in fresh water and in the ocean are separated by a decimal. Fish with scales that could not be aged were not included in the age analyses.

Chinook salmon passing through the weir at the recapture event were sampled for age, sex, and length (ASL) data using a temporally stratified sampling design (Cochran 1977), with statistical weeks defining strata. A weekly sample target of 155 fish was drawn for ASL information. Samples were dispersed throughout the week and taken periodically during the day. All fish within the trap were included in the sample to avoid potential bias caused by the selection or capture of individual fish, even if the target number of fish was exceeded. Non-target fishes captured in the live trap were identified to species, enumerated, and released upstream of the weir.

Additionally, genetic tissue samples were collected from the axillary processes of Chinook salmon handled for ASL data collection in both the marking and recapture events. These samples were archived in individual vials for later genetic analysis.

*Data Analysis*

*Radiotelemetry tracking methods*---Radio-tagged Chinook salmon were tracked throughout the Togiak River watershed using a combination of seven fixed monitoring stations (Table 2; Figure 3) and mobile tracking from boats and fixed-wing aircraft. Six of the fixed monitoring stations were located on the mainstem, and one was located on a tributary. One station was co-located at the field camp site and weir on Gechiak Creek. The first fixed station on the mainstem was placed upstream of the capture and tag deployment site to help delineate all of the radio-tagged fish that moved into the study area, which is defined as the bottom of Mainstem A (Figure 4).

Fixed monitoring stations were used to record up- and downstream movement of individual tagged fish. Each fixed station included a single receiver-datalogger (ATS model R4500C or R4520C), a single 4-element Yagi antenna, antenna mast, 12-volt deep cycle battery, solar panel, voltage regulator, and strongbox. Data from fixed receiver stations were downloaded weekly to a notebook computer.

Aerial surveys were used to identify specific spawning locations in the Togiak River and its tributaries. Aerial surveys were conducted from a fixed-wing aircraft equipped with an H-antenna mounted on each wing strut. Aerial surveys were flown at altitudes of approximately 100–400 m above ground along the Togiak River and its tributaries. A global positioning system (GPS) built into the receiver-datalogger (ATS model R4500C or R4520C) was used during aerial surveys to record latitude and longitude coordinates and signal strength of each transmitter located. Two receivers monitoring four separate frequencies each were used to reduce the scan time for aerial surveys.

Boat surveys were used from the river mouth upstream to Togiak Lake to more precisely locate spawning in the mainstem Togiak River. Boat surveys were conducted using a portable receiver-datalogger (ATS model R4500C or R4520C) and a 4-element Yagi antenna. A hand-held GPS

was used during boat surveys to record latitude and longitude coordinates for each transmitter located.

**Table 2. Name and location (decimal degrees) of fixed telemetry stations in the Togiak River watershed, 2012.**

| Station Name | Latitude | Longitude |
|---|---|---|
| Entry | 59.11696 | -160.35397 |
| Second | 59.18352 | -160.27887 |
| Gechiak | 59.22189 | -160.25049 |
| Ranger | 59.26802 | -160.20891 |
| Nayorurun | 59.36012 | -160.09184 |
| Kemuk | 59.36882 | -159.98930 |
| Ongivinuk | 59.40030 | -159.79631 |

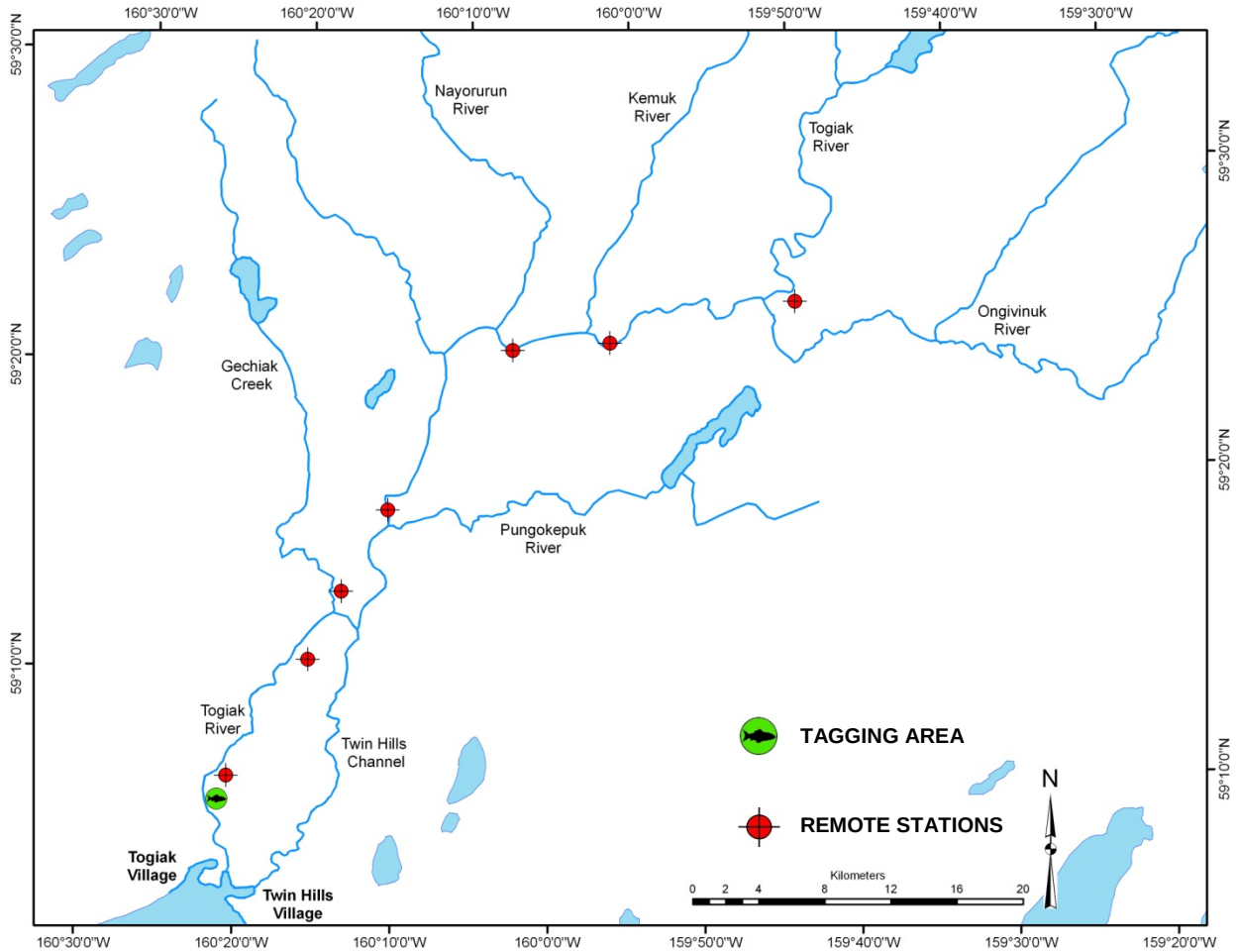


**Figure 3. Remote data logging receiver station locations and tagging areas in the Togiak River, 2012.**

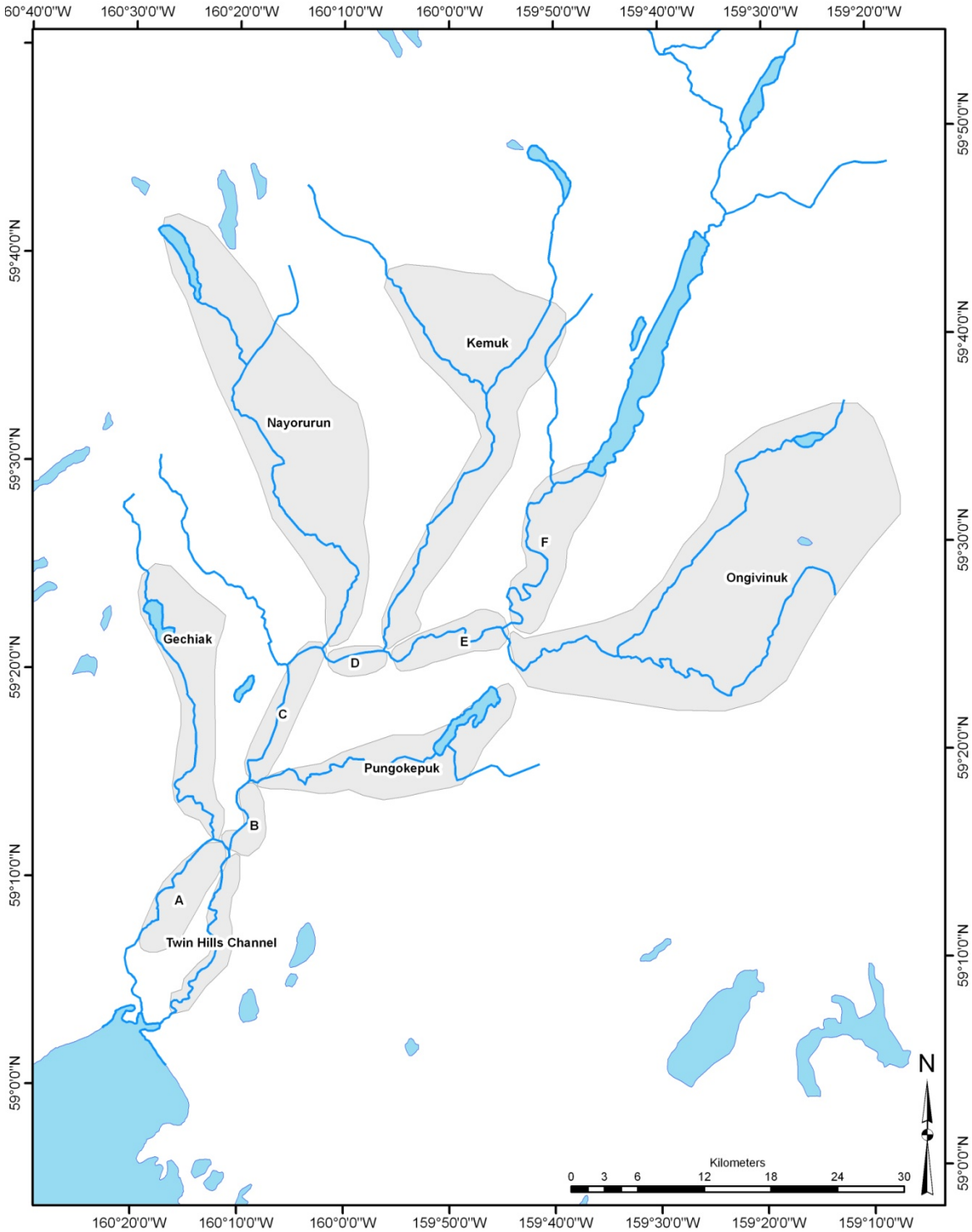


**Figure 4. Mainstem river sections corresponding to ADF&G aerial survey delineations and tributary fates assigned to radio-tagged Chinook salmon in the Togiak River, 2012. The exception is the Twin Hills Channel, which was designated as a possible spawning fate for the first time in 2010.**

*Radiotelemetry data interpretation*---Each radio-tagged Chinook salmon was assigned one of six possible fates based on information collected from mobile and fixed receivers (Table 3). Fish whose spawning locations could be identified based on tracking results were assigned a fate of either mainstem or tributary spawner. Mainstem spawners were assigned to one of six river sections (Figure 4). The boundaries of these (A-F) corresponded with aerial survey segments used by ADF&G (Brookover et al. 1996). Tributary spawners were assigned to one of six tributaries. In addition to the tributary survey areas designated by ADF&G, in 2010 we added the Twin Hills Channel as a possible spawning tributary (Tanner and Sethi 2011). Chinook salmon whose spawning location could not be determined with reasonable certainty were placed into an unknown category. The unknown category was further divided into two groups: fish that were unsuccessfully located post-tagging; and fish that were successfully tracked within the system, but disappeared after at least two to three weeks of movement, indicating possible harvest and removal of that fish from the system. Fish whose radio tags were detected within the local villages or canneries from aerial surveys were also classified as Suspected Harvest. Fish assigned a fate of harvested or dead/regurgitated were censored from the sample.

For fish assigned a spawning fate, the amount of time spent holding in the lower river (defined as locations below or within Mainstem A) was estimated from the date the fish was tagged through the date the fish was first detected beyond the mouth of Gechiak Creek confluence, which defined the upper most portion of Mainstem A (Figure 4). Basic statistics (mean, minimum, and maximum number of days) were calculated for 2012, and a one-way ANOVA was conducted across the 2010–2012 study years to compare the number of days spent holding in the lower river for tributary and mainstem spawners.

**Table 3. Fate of Chinook salmon radio-tagged in the Togiak River, 2012.**

| Fate | Description |
|---|---|
| *Spawning Location:* | |
| Mainstem (1 of 6 river sections) | A fish that spawned in Togiak River. |
| Tributary (1 of 6 tributaries) | A fish that spawned in a tributary of the Togiak River. |
| *Unknown Fate:* | |
| Insufficient location information | A fish that could not be located by either fixed or mobile telemetry tracking. |
| Suspected harvest | A fish that was tracked to multiple locations over a 2-4 week period before disappearing from the system, or a radio tag that was detected within a local village or cannery during an aerial survey. |
| *Removed From Study:* | |
| Harvested | A fish that was reported harvested in either the commercial, sport, or subsistence fisheries. |
| Dead/Regurgitated | A fish that did not complete its spawning migration because it either died or regurgitated its radio tag. |

*Spawning abundance estimation*---Chinook salmon abundance estimation follows methods outlined in Tanner and Sethi (2012); additional details regarding the mark-recapture sampling protocol and defense of modeling assumptions are provided therein. Adult Chinook salmon were tagged in the lower part of the mainstem Togiak River; however, recapture occurred systematically on a single spawning subpopulation at a weir on an upstream tributary (Gechiak Creek), and so opportunistic carcass surveys were conducted to supplement the recapture event. While tagging and recovery occurred over several weeks, release and recovery data were pooled and analyzed with a single release/single recapture closed-population Lincoln-Petersen estimator. We implemented a Bayesian version of the Lincoln-Petersen estimator, $\widehat{N_B}$. In this formulation, modeling both tags and unmarked salmon captured in the second sample session as binomial processes:

$$m_2|n_1\,,p \sim Binomial(n_1\,,p) \qquad 1$$

$$u|U\,,p \sim Binomial(U\,,p) \qquad 2$$

where $p$ is the probability of detection, or catchability, $u$ is the number of unmarked Chinook counted in the recapture event (at the weir), and $U$ is the number of unmarked animals in the overall population. Priors were as follows:

$$\log(U) \sim Uniform(0,14) \qquad 3$$

$$p \sim Beta(1,1) \qquad 4$$

Finally, total abundance, $\widehat{N_B}$, was included as a derived parameter in the model as $m_2 + U$. The Bayesian estimator was implemented in WinBUGS (Spiegelhalter et al. 1999) from R using the R2WinBUGS package (Sturtz et al. 2005). We ran five chains of 1,000,000 iterations, with a burn-in period of 950,000 iterations, and a thin rate of 100, for a total of 2,500 retained joint posterior parameter draws for subsequent inference. The fitted model was monitored for chain convergence by visually examining MCMC trace plots and ensuring that all tracked parameters had Gelman-Brooks-Rubin statistic <1.10 (Brooks and Gelman 1998; Kery and Schaub 2012). Appendix 1 of Sethi and Tanner (2012) provides R code to fit the model.

*Tests for differences in run timing*---Run timing information can be used to ascertain whether subpopulations within the Togiak River passed the tagging site as a well-mixed group, or whether subpopulations entered the river in separate groups. To test for differences in run timing, we used tag release dates of successfully fated fish, where fated spawning location indicates a subpopulation (e.g., Gechiak, Ongivinuk, or Mainstem A spawner).

Following Tanner and Sethi (2012), we examined the following questions associated with run timing of Chinook subpopulations in the Togiak River during the 2012 season:

1. Are there differences in the run timing between pooled tributary and pooled mainstem populations ($H_0$: There is no difference in run timing between tributary and mainstem spawners)?

2. Are there differences in the run timing amongst the tributary subpopulations ($H_0$: There is no difference in run timing between tributary subpopulations)?

3. Are there differences in the run timing amongst the mainstem subpopulations ($H_0$: There is no difference in run timing between mainstem subpopulations)?

4. Are there differences in the run timing between the Gechiak subpopulation and the pooled "rest-of-river" population ($H_0$: There is no difference in run timing between the Gechiak tributary subpopulation and the rest-of-river population)?

Hypotheses were evaluated using "tests of independence" through use of the Fisher exact test implemented in R.

## Results

*Marking event*---Gillnet sampling for Chinook salmon was conducted for a total of 96 hours between 21 June and 6 August, and a total of 331 Chinook salmon were captured (Figure 5). Of the 331 Chinook salmon captured, 147 received radio tags with a secondary spaghetti tag and 154 Chinook were tagged with only a spaghetti tag, for a total of 301 fish marked in gillnet sampling (Table 4). Of the additional 29 fish captured in gill nets, 20 were recaptured marked fish, 8 fish escaped the net or the cradle before they could be marked, and one other Chinook salmon received mortal gill damage. Other species captured included chum *O. keta* ($n$ = 163) and sockeye *O. nerka* ($n$ = 87) salmon, rainbow trout ($n$ = 4), and char *Salvelinus* spp. ($n$ = 10).

Hook-and-line sampling for Chinook salmon was conducted between 26 June and 7 August for a total soak time of 19 hours. Nine Chinook salmon were captured, seven of which received spaghetti tags, and the other two escaped from the cradle before being marked. Other species captured included char ($n$ = 5) and chum salmon ($n$ = 1).

All sampling efforts resulted in a total of 308 marked fish: 147 Chinook salmon with both a radio tag and a Floy tag and 161 fish with only a spaghetti tag (Table 4). The average handling time, from the time the fish was detected hitting the gill net until the fish was sampled, tagged, and released was 3.9 minutes for the first Chinook salmon encountered in the net and 6.1 minutes if a second Chinook was captured and released in the same set. The most Chinook salmon captured in a single drift net set was 5 fish, and the maximum handling time for the fifth Chinook salmon was 13 minutes. The average handling time for all fish in all sets was 4.1 minutes (min = 2, max = 13, mode = 4).

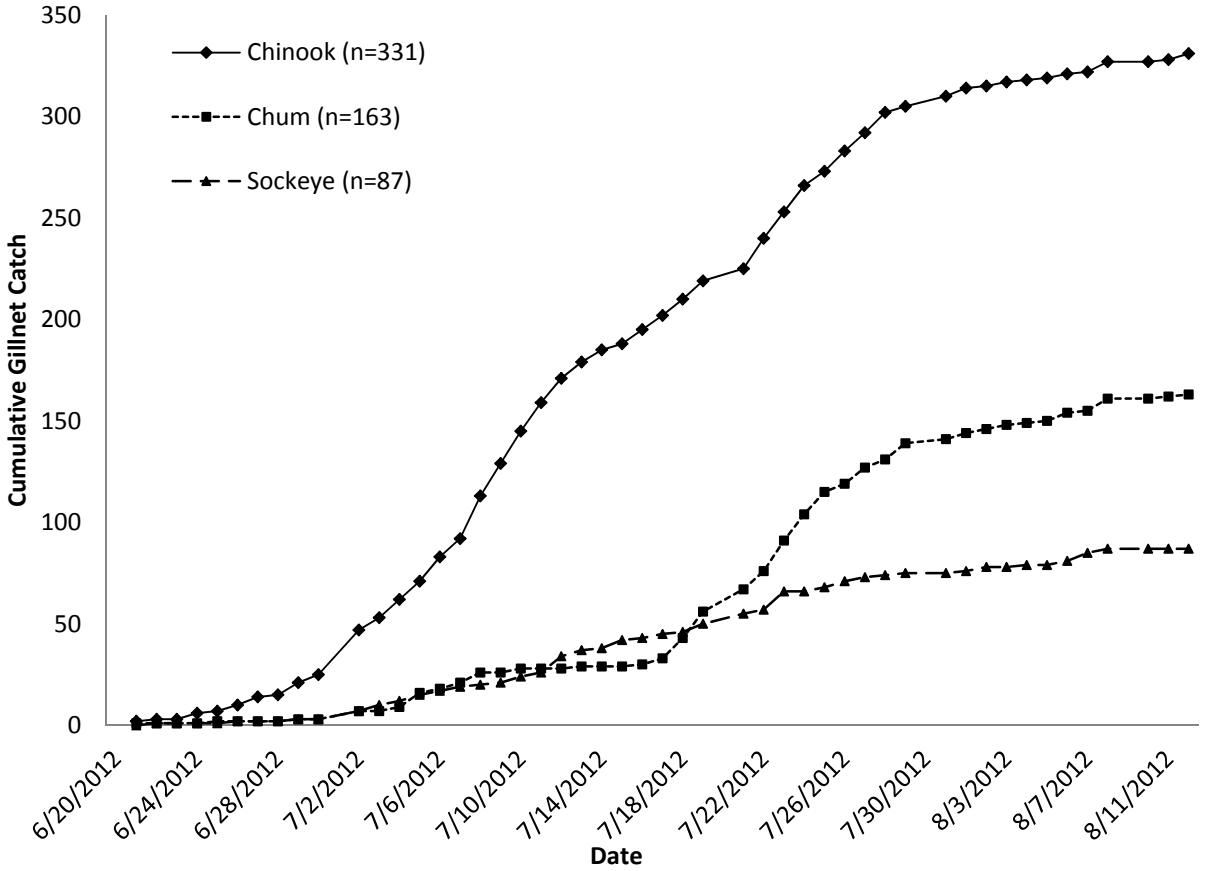


**Figure 5. Cumulative total catch of Chinook (*n* = 331), sockeye (*n* = 87), and chum (*n* = 163) salmon caught by gill net in the lower Togiak River, 2012.**

**Table 4. Radio transmitter and spaghetti tag deployment numbers for determining spawning distribution and population estimate of Chinook salmon. A total of 308 Chinook salmon were marked in the lower Togiak River, 2012.**

| Strata | Dates | Radio Transmitters Deployed | Floy Spaghetti Tags Deployed | |
|---|---|---|---|---|
| | | *Gill Net Only* | *Gill Net* | *Hook & Line* |
| 1 | 21–30 June | 10 | 11 | 3 |
| 2 | 1–10 July | 52 | 59 | 2 |
| 3 | 11–20 July | 29 | 35 | 0 |
| 4 | 21–30 July | 40 | 41 | 2 |
| 5 | 31 July–9 August | 15 | 6 | 0 |
| 6 | 10–12 August | 1 | 2 | 0 |
| | *Total:* | *147* | *154* | *7* |

From the marking event in the lower Togiak River, age data were obtained from 308 Chinook salmon, of which 39 fish could not be aged because of illegible or regenerated scales. Seven age classes were present in 2012, with ages 1.3 (47%) and 1.4 (20%) comprising 67% of the sample (Table 5). Sex was determined for 281 Chinook salmon, with an additional 27 fish sampled who could not be sexed using secondary sexual characteristics. Females comprised 59% of Chinook salmon sampled (Table 6; Figure 6). Lengths were measured from 307 Chinook salmon, and averaged 819 mm (673 min, 988 max) for females and 755 mm for males (355 min, 996 max; Table 7).

**Table 5. Age composition of Chinook salmon marked in the lower Togiak River, 2012.**

| Age | *n* | % | SE (%) |
|---|---|---|---|
| 1.2 | 12 | 4 | 1.1 |
| 1.3 | 145 | 47 | 2.8 |
| 1.4 | 62 | 20 | 2.3 |
| 1.5 | 2 | 1 | 0.5 |
| 2.2 | 4 | 1 | 0.6 |
| 2.3 | 34 | 11 | 1.8 |
| 2.4 | 10 | 3 | 1.0 |
| *Total*[a] | *269* | *100* | |

[a]Total does not include fish sampled whose age could not be determined (*n* = 39).

**Table 6. Sex composition of Chinook salmon radio tagged in the lower Togiak River, 2012.**

| Sex | *n* | % | SE (%) |
|---|---|---|---|
| Female | 167 | 59 | 2.9 |
| Male | 114 | 41 | 2.9 |
| *Total*[a] | *281* | *100* | |

[a]Total does not include fish sampled whose sex could not be determined (*n* = 27).

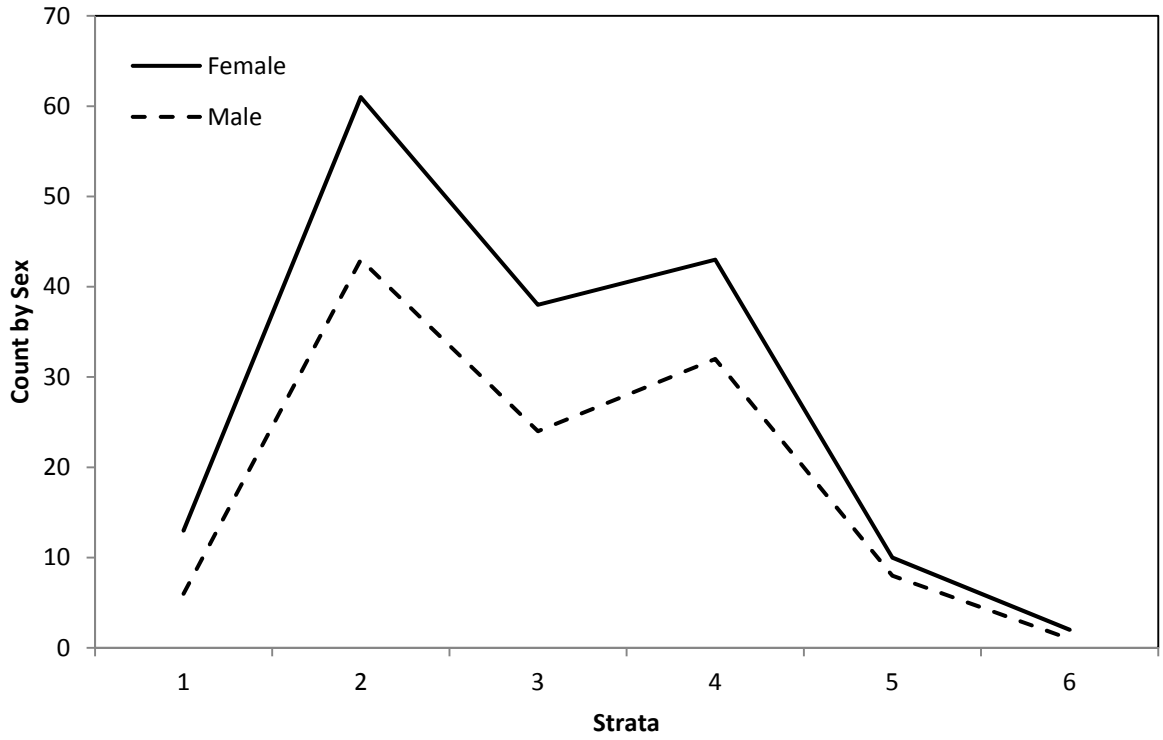


**Figure 6. Sex composition of Chinook salmon radio tagged in the lower Togiak River, 2012, by strata. Total: Female *n* = 167; Male *n* = 144; Unknown Sex *n* = 27.**

**Table 7. Mean length from mid-eye to fork of tail (mm), SE, range, and sample size by age of Chinook salmon radio tagged in the lower Togiak River, 2012.**

| Length | Age Class | | | | | | |
|---|---|---|---|---|---|---|---|
| | 1.2 | 1.3 | 1.4 | 1.5 | 2.2 | 2.3 | 2.4 |
| *n*[a] | 12 | 145 | 62 | 2 | 4 | 34 | 10 |
| Mean | 596 | 786 | 847 | 870 | 700 | 805 | 804 |
| SE | 35.8 | 5.3 | 7.3 | - | 14.1 | 9.6 | 10.0 |
| Minimum | 355 | 646 | 758 | 834 | 675 | 703 | 750 |
| Maximum | 828 | 987 | 996 | 905 | 734 | 911 | 845 |

[a]Does not include fish sampled whose length and age could not be determined (*n* = 39).

*Recapture events*---The resistance-board weir installation in Gechiak Creek was completed on 25 June and began operating on 26 June. Daily operations began at 0600 hours. Weir operation was disrupted due to high water 15–17 July, with partial counts on 29 June, 4 and 14 July, and 2 September. The weir was operated until rising water hindered safety on 3 September. Water levels receded sufficiently for weir removal to be completed 14–15 September.

In total, 291 Chinook salmon were counted through the weir, with the highest daily count occurring on 26 July (Appendix 1). Of the 291 Chinook salmon enumerated, 283 were unmarked and 8 were marked with spaghetti tags. Other species captured included Coho *O. kisutch* ($n$ = 4,553), chum ($n$ = 34,308), and sockeye ($n$ = 6,053) salmon (Figure 7), rainbow trout ($n$ = 69), char ($n$ = 1,237), and round whitefish *Prosopium cylindraceum* ($n$ = 1). An additional 111 fish that were counted through the weir could not be identified to species.

From the recapture event in Gechiak Creek, age data were obtained from 174 unmarked Chinook salmon sampled from the weir, of which 23 fish could not be aged because of illegible or regenerated scales. Nine age classes were present in 2012, with ages 1.3 (38%) and 1.4 (19%) comprising 57% of the sample (Table 8). Sex was determined for 166 Chinook salmon, with 8 additional fish who could not be sexed using secondary sexual characteristics. Females comprised 38% of Chinook salmon sampled (Table 9; Figure 8). Lengths were measured from 174 Chinook salmon, and ranged from 605 mm to 924 mm for females and 331 mm to 981 mm for males (Table 10).

In total, 38 carcass surveys were conducted over 16 days from 11 August to 2 September. Within the mainstem, 18 surveys were completed in sections A and B, 13 surveys were conducted in sections C and D, and 3 surveys done in section E. Carcass surveys accomplished within the tributaries included three surveys in the lower Nayorurun and one survey in the lower Ongivinuk. A total of 152 Chinook salmon were identified, of which 2 were marked fish (one mark each from strata 2 and 4), 145 were unmarked, and 5 were inconclusive regarding marking due to scavenger feeding (Appendix 2).

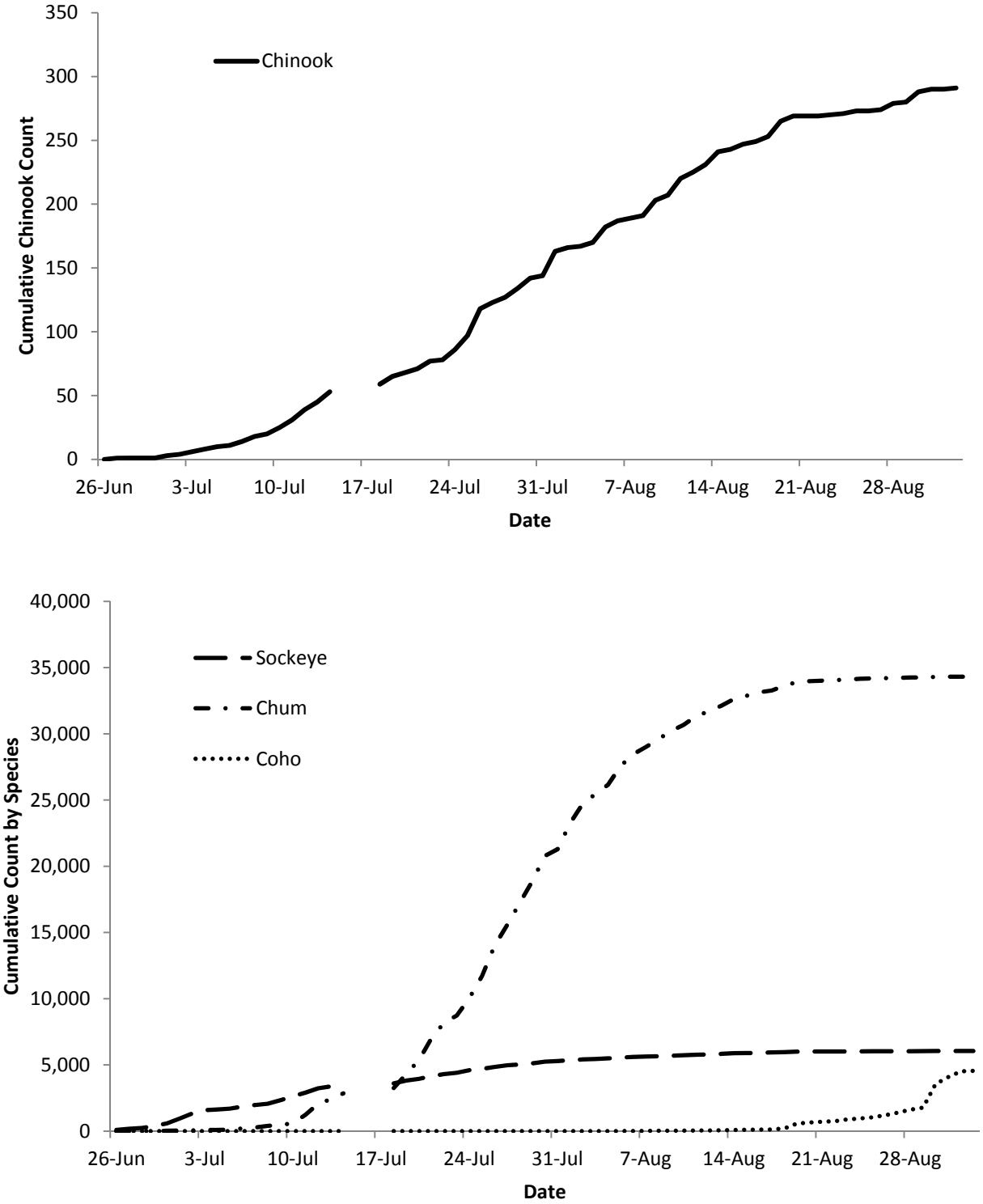


**Figure 7. Cumulative count of Chinook salmon (*n* = 291) counted through the Gechiak Creek weir (top) and cumulative count of sockeye (*n* = 6,053), chum (*n* = 34,308), and coho (*n* = 4,553) salmon counted through the Gechiak Creek weir by species (bottom), 2012. Breaks in data series indicate dates when the weir was inoperable due to high water.**

**Table 8. Age composition of unmarked Chinook salmon sampled through the Gechiak Creek weir, 2012.**

| Age | *n* | % | SE (%) |
|---|---|---|---|
| 1.1 | 8 | 5 | 1.7 |
| 1.2 | 23 | 15 | 2.7 |
| 1.3 | 57 | 38 | 3.7 |
| 1.4 | 29 | 19 | 3.0 |
| 2.1 | 1 | 1 | 0.6 |
| 2.2 | 8 | 5 | 1.7 |
| 2.3 | 15 | 10 | 2.3 |
| 2.4 | 9 | 6 | 1.8 |
| 3.2 | 1 | 1 | 0.6 |
| *Total*[a] | *151* | *100* | |

[a]Total does not include fish whose age could not be determined (*n* = 23).

**Table 9. Sex composition of unmarked Chinook salmon sampled through the Gechiak Creek weir, 2012.**

| Sex | *n* | % | SE (%) |
|---|---|---|---|
| Female | 63 | 38 | 3.8 |
| Male | 103 | 62 | 3.8 |
| *Total*[a] | *166* | *100* | |

[a]Total does not include fish whose sex could not be determined (*n* = 8).

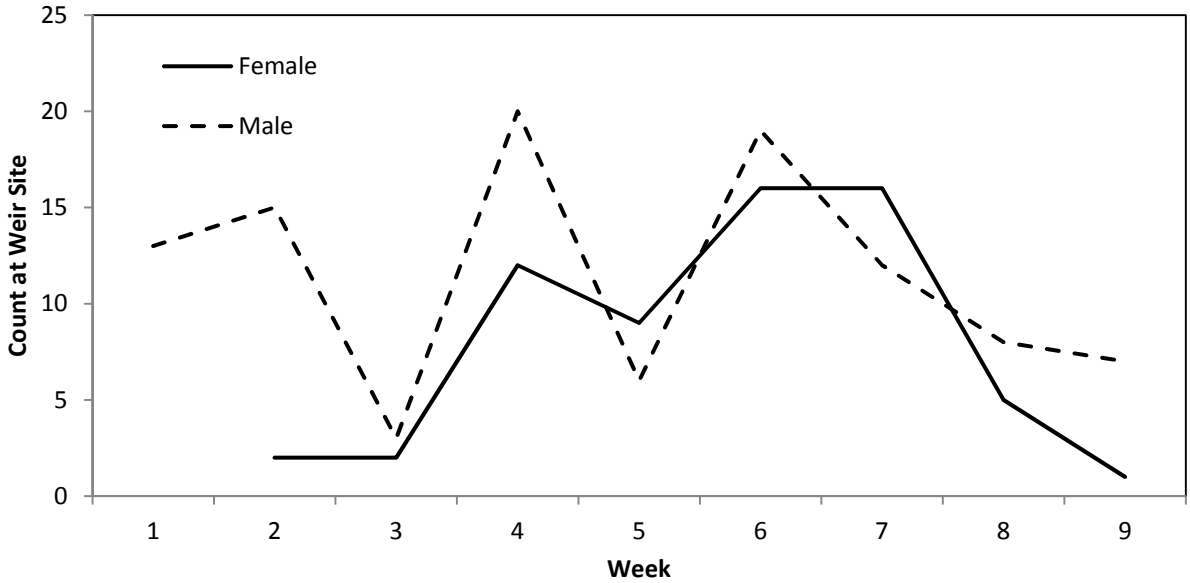


**Figure 8. Weekly sex composition of unmarked Chinook salmon sampled through the Gechiak Creek weir, 2012. Total: Female *n* = 63; Male *n* = 103; Unknown Sex *n* = 8. Sampling occurred 27 June – 2 September in 2012.**

**Table 10. Mean length from mid-eye to fork of tail (mm), SE, range, and sample size by age of unmarked Chinook salmon sampled through the Gechiak Creek weir, 2012.**

| Length | Age Class | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1.1 | 1.2 | 1.3 | 1.4 | 2.1 | 2.2 | 2.3 | 2.4 | 3.2 |
| *n*[a] | 8 | 23 | 57 | 29 | 1 | 8 | 15 | 9 | 1 |
| Mean | 380 | 565 | 776 | 825 | 331 | 603 | 731 | 853 | 755 |
| SE | 14.3 | 17.5 | 10.3 | 12.8 | - | 41.7 | 25.9 | 22.5 | - |
| Minimum | 331 | 381 | 557 | 669 | 331 | 473 | 508 | 760 | 755 |
| Maximum | 447 | 731 | 910 | 981 | 331 | 853 | 870 | 940 | 755 |

[a]Number sampled does not include fish whose age could not be determined (*n* = 23).

*Radiotelemetry*---All seven fixed telemetry stations were operational in time to capture upstream movement by radio-tagged Chinook salmon. The Entry and Second fixed stations were installed on 20 June, one day before the first radio tag was deployed in the lower river. The fixed station co-located with the field camp on Gechiak Creek was installed on 23 June. The Ranger fixed station was installed on 26 June. Kemuk, Nayorurun, and Ongivinuk fixed stations were installed on 4 July. The first radio-tagged fish moved past Ranger station on 14 July.

Four aerial searches were conducted between 25 July and 31 August. Thirty-two boat searches were conducted from 7 July to 9 September. Boat tracking was systematic, with an emphasis placed on locating tagged fish that had not been recorded at fixed stations or were not detected in boat or aerial searches in more than a week.

Radio transmitters were implanted into 147 Chinook salmon between 21 June and 12 August. Of the 147 tagged Chinook salmon, 106 fish (72%) were successfully tracked to spawning areas, 15 (10%) were not successfully tracked to a spawning location, 18 (12%) were harvested, and 8 (5%) were assigned a fate of dead/regurgitated (Table 11, Appendix 3). Seventy-nine percent ($n$ = 84) of the fated spawners selected spawning locations in mainstem areas of the Togiak River, with 43% ($n$ = 45) in the mainstem between Gechiak Creek and Nayorurun River. Twenty-one percent ($n$ = 22) selected spawning locations in tributaries, with only 2% ($n$ = 2) selecting locations in Gechiak Creek (Table 12). In 2012, more radio-tagged fish spawned in the Nayorurun River than any other tributary, including Gechiak Creek.

Based on telemetry data, we determined that radio-tagged fish, regardless of their spawning destination, spent an appreciable amount of time holding within Mainstem A of the lower river before pushing upriver to spawn. This is consistent with the holding behavior previously reported in this system (Tanner and Sethi 2011, 2012). For radio-tagged fish that ultimately spawned in Mainstem B–F in 2012, an average of 19.6 days were spent holding in the mainstem river below the Gechiak Creek confluence (range = 3, 40 days; standard deviation = 8.9). Fish that spawned in the tributaries held for fewer days, with an average of 13.2 days holding time (range = 4, 25 days; standard deviation = 6.2).

Though we did not systematically track radio-tagged Chinook salmon downstream of our capture site for the marking event, we did collect enough data through incidental boat and aerial tracking events to identify fish movement that we refer to as back-out behavior. These were fish radio tagged in the lower river and held near the capture site for two to six days, and then dropped back into Togiak Bay near the river mouth but beyond the commercial drift fishery boundary of 2012. One fish held in the bay for more than a week before moving back upriver to spawn in Mainstem B (Fish ID 17; Appendix 3). We detected similar movements in three other fish (Fish ID 17, 19 and 96; Appendix 3) that were captured in the commercial fishery. Two of the harvested fish were reported to us as being in good or excellent condition, and the third was held on ice when reported to us, such that we were able to examine the intact fish for tagging damage, e.g., damaged/ruptured stomach. In revisiting our harvest data from 2010 and 2011, we were able to identify a few radio-tagged fish from each of those years that also exhibited back-out movement into Togiak Bay. In 2010, fish detected in the bay after tagging returned to Togiak River to spawn (Fish ID 2 in Mainstem F and Fish ID 145 in Pungokepuk Creek), with a third radio-tagged fish reported from the commercial fishery as being in good condition (Fish ID 60; Tanner and Sethi 2011). In 2011, we did not detect any fish that backed out into the bay, returning to the river to spawn; however, three radio-tagged fish located for a week or more within the lower river post-tagging were later captured and reported by the commercial fishery (Fish ID 20, 47 and 78; Tanner and Sethi 2012).

**Table 11. Fate of Chinook salmon radio-tagged in the Togiak River, 2012.**

| Fate | Number | Percentage |
|---|---|---|
| *Spawning Location:* | | |
| Mainstem (1 of 6 river sections) | 84 | 57 |
| Tributary (1 of 6 tributaries) | 22 | 15 |
| *Total* | *106* | *72* |
| *Unknown Fate:* | | |
| Undetermined/insufficient location information | 9 | 6 |
| Undetermined/suspected harvest | 6 | 4 |
| *Total* | *15* | *10* |
| *Removed From Study:* | | |
| Harvested | 18 | 12 |
| Dead/Regurgitated | 8 | 5 |
| *Total* | *26* | *18* |
| Total Tagged: | 147 | 100 |

**Table 12. Distribution of Chinook salmon by river section within the Togiak River drainage based on radio tracking 2008-2012 and ADF&G average aerial survey estimates 1987-2005.**

| | Number (Percent) | | | | | |
|---|---|---|---|---|---|---|
| River Section | 2008 Radio Tracking | 2009 Radio Tracking | 2010 Radio Tracking | 2011 Radio Tracking | 2012 Radio Tracking | 1987-2005 Aerial Surveys[a] |
| | | | *Mainstem* | | | |
| Mainstem A | 26 (34) | 35 (30) | 15 (9) | 22 (19) | 13 (12) | 162 (4) |
| Mainstem B | 11 (14) | 14 (11) | 18 (11) | 20 (18) | 19 (18) | 221 (6) |
| Mainstem C | 17 (22) | 22 (19) | 26 (16) | 23 (20) | 26 (25) | 547 (15) |
| Mainstem D | 0 (0) | 7 (6) | 13 (8) | 13 (12) | 12 (11) | 289 (7) |
| Mainstem E | 2 (3) | 18 (15) | 28 (18) | 13 (12) | 7 (7) | 503 (13) |
| Mainstem F | 1 (1) | 8 (7) | 28 (18) | 8 (7) | 7 (7) | 957 (24) |
| *Total* | *57 (74)* | *104 (88)* | *127 (80)* | *99 (88)* | *84 (79)* | *2,679 (69)* |
| | | | *Tributary* | | | |
| Gechiak Creek | 10 (13) | 6 (5) | 9 (6) | 4 (4) | 2 (2) | 392 (10) |
| Pungokepuk Creek | 2 (3) | 3 (3) | 8 (5) | 1 (1) | 2 (2) | 159 (4) |
| Nayorurun River | 6 (7) | 3 (2) | 6 (4) | 2 (2) | 8 (8) | 213 (5) |
| Kemuk River | 2 (3) | 2 (2) | 4 (3) | 1 (1) | 5 (5) | 274 (7) |
| Ongivinuk River | 0 (0) | 0 (0) | 3 (2) | 6 (5) | 5 (5) | 202 (5) |
| Twin Hills Channel[b] | - | - | 2 (1) | 0 (0) | 0 (0) | - |
| *Total* | *20 (26)* | *14 (12)* | *32 (20)* | *14 (12)* | *22 (21)* | *1,240 (31)* |
| Drainage Total | 77 | 118 | 159 | 113 | 106 | 3,919 |

[a]ADF&G 1987-2005 average aerial survey estimates from Westing et al. (2007).
[b]Twin Hills Channel not included in surveys prior to 2010.
'-' means no data.

*Spawning abundance*---The Bayesian implementation of the pooled Lincoln-Petersen estimator successfully reached convergence (Figure 9), with Gelman-Brooks-Rubin statistic of all tracked parameters <1.002. The abundance estimate was similar to the Chapman point estimate, with a posterior median estimate of total run size of $\widehat{N_B} = 13{,}050$ with a 95% credibility interval of {7,844; 24,762} (Figure 9). The estimated probability of detection was low with a posterior median of 0.037 and a 95% credibility interval of {0.018, 0.057} (Figure 9). Probability of detection during the 2012 field season was nearly identical to that from the 2011 field season, with a posterior median detection probability of 0.034 and 95% credibility interval {0.017, 0.058} (see Tanner and Sethi 2012).

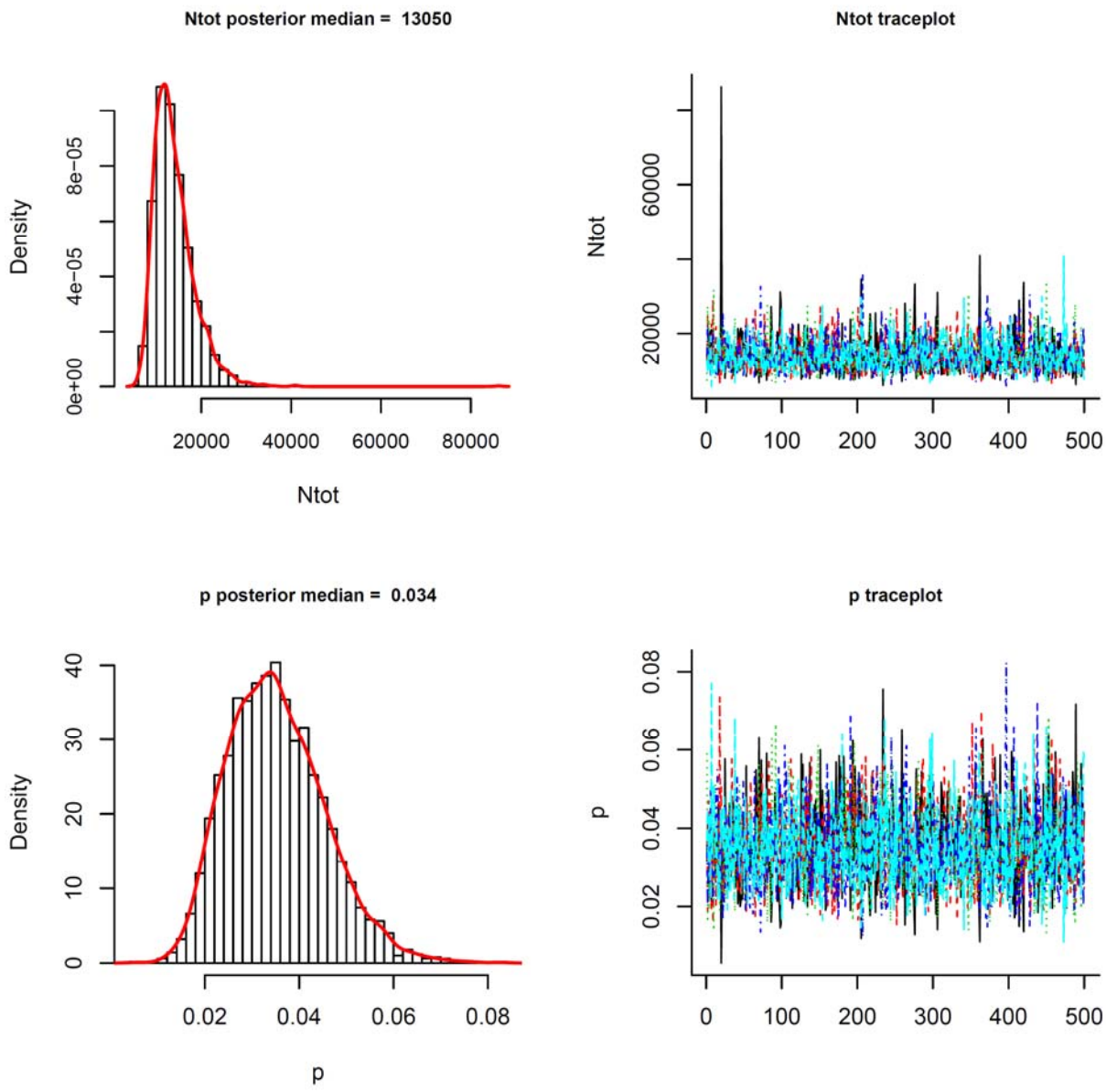


**Figure 9. Marginal posterior distributions (left panels) and trace plots (right panels) for a Bayesian implementation of the pooled Lincoln-Petersen estimator of total Togiak River Chinook salmon abundance in 2012 that escaped past the commercial fishery in Togiak Bay. Distributions are based upon 2,500 posterior draws; red lines represent a kernel smoothed density estimate. Trace plots (right panels) display five MCMC chains overlaid on each plot.**

The 2012 run size was approximately 6,000 fish larger than the 2011 run. From the Bayesian analysis and the conditional pooled Lincoln-Petersen model, we can state that there is a 99% chance that the 2012 run was larger than the 2011 run.

*Run timing*---Results from 2012 were consistent with run timing analyses from 2011 and 2010 (Tanner and Sethi 2011, 2012). Fisher exact tests indicate a significant difference in run timing between the pooled group of mainstem spawning fish versus tributary spawning populations ($p$ = 0.008). Overall, the run transpired slightly earlier in 2012 compared to 2011. In 2012, pooled mainstem and tributary groups had the highest tag releases during the 1-10 July release stratum, whereas these pooled groups had the highest tag releases during the 10-16 July stratum in 2011 (Tanner and Sethi 2012). No fish tagged after the 21-30 July stratum spawned in tributary locations, whereas 14 fish tagged after the 21-30 July stratum spawned in the mainstem river (Table 13), indicating that tributary fish likely entered the river earlier than mainstem spawning fish. There was also a difference in run timing identified among tributary populations ($p$ = 0.041), indicating that Kemuk fish entered later than the other tributary populations in 2012 (Table 13). No difference in run timing was identified among mainstem populations, or in a test between the Gechiak and rest-of-river run, although we caution that these tests likely have low power.

**Table 13. Number of radio-tagged Chinook salmon tracked by strata to spawning enclaves in the Togiak River drainage (*n* = 106), 2012.**

| | River Section | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *Mainstem* | | | | | | *Tributary* | | | | | |
| Strata | A | B | C | D | E | F | Gechiak | Pungokepuk | Nayorurun | Kemuk | Ongivinuk | Twin Hills Channel |
| 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 2 | 0 | 3 | 0 |
| 2 | 3 | 7 | 7 | 6 | 2 | 3 | 1 | 1 | 5 | 1 | 1 | 0 |
| 3 | 4 | 2 | 6 | 4 | 2 | 0 | 1 | 0 | 0 | 0 | 1 | 0 |
| 4 | 3 | 4 | 7 | 2 | 3 | 3 | 0 | 1 | 1 | 4 | 0 | 0 |
| 5 | 2 | 6 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 6 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Total* | *13* | *19* | *25* | *12* | *7* | *8* | *2* | *2* | *8* | *5* | *5* | *0* |

## Discussion

A sonar project stationed on the Pongokepuk River in 1988 and 1990 estimated the Chinook salmon run starts on approximately 25 June (Irving et al. 1995). In 2009, 2011, and 2012, we captured one or two Chinook salmon on our first day of fishing effort, which began between 21 and 25 June (Anderson 2010; Tanner and Sethi 2012). In 2010, we captured eight Chinook salmon on the first day of fishing on 22 June (Tanner and Sethi 2011). In 2008, fishing effort began on 20 June, but the first Chinook salmon was not captured until 26 June (Anderson 2009). We believe that in all years we were able to capture the beginning portion of the Chinook salmon run, except perhaps in 2010, when the earliest portion of the run may have been slightly underrepresented in the tagged population.

To promote unbiased mark-recapture estimates of spawning abundance, we ensured that our sampling effort was standardized across temporal strata in order to mark Chinook salmon in proportion to abundance. Additionally, we conducted opportunistic carcass sampling to supplement our recapture effort beyond the weir recapture, in order to increase the precision of our spawning abundance estimate.

Throughout the life of the project, we maintained low rates of tagging-related mortality and radio tag regurgitation. The number of dead fish or regurgitated tags/total fish radio tagged was 7/127 in 2008, 4/154 in 2009, 6/211 in 2010, 6/171 in 2011, and 8/147 in 2012 (Anderson 2009, 2010; Tanner and Sethi 2011, 2012). Our low mortality rates were due to a combination of concentrated effort to minimize fish stress and handling time, as well as the continuity of our crew across years. Our capture methods ensured that fish remained in the water at all times. Fish were worked and cut from the net while in the river; were sampled from a cradle attached to the exterior of the boat, and had minimal handling from time of capture (i.e., when floats were disturbed) to release. From 2009–2012, most of the crew had experience with esophageal tagging, primarily on the Togiak project, ensuring the crew maintained familiarity and expertise with the study area, fishery, and methods from year to year.

Both the Gechiak Creek weir and the carcass surveys were valid and attainable recapture methods. However, both efforts offered difficulties as well. Throughout weir operations (2010–2012), high water events rendered the weir unsafe to operate, and was not fish tight for at least a few days of each season, leaving gaps in the enumeration of unmarked to marked Chinook salmon spawning in Gechiak Creek. Additionally, the proportion of radio-tagged fish attributed to the Gechiak varied from year to year, from 2% of the tagged population in 2012 to 13% of the tagged population in 2008 (Anderson 2009). The addition of carcass surveys may increase the precision of spawning abundance estimates, but access to a large number of carcasses in this system was more limited than expected. Though 38 carcass surveys were conducted over a 23 day period, only 152 Chinook salmon carcasses were available for examination. We observed that many carcasses flushed through the system or were found in deeper water, rather than in shallows or shorelines, and those carcasses that were readily available in shallows and shorelines were highly scavenged by wildlife. By combining the two recapture methods, we were able to more precisely estimate spawning abundance.

Historical aerial surveys (Westing et al. 2007) indicate that most Chinook salmon utilize the upper mainstem sections for spawning. However, our telemetry data shows that the lower sections in Mainstem A-C had the highest proportion of spawning within the Togiak system. We believe the inversion of the mainstem contribution in the old aerial surveys was due to the difficulty in conducting accurate aerial surveys in areas where the river is deeper, darker and has more channel complexity, such as in Mainstem A. Approximately 80% of spawning occurs in the mainstem, primarily in the lower sections that include areas that cannot be accurately

surveyed in aerial counts using fixed wing aircraft. There is, however, a considerable amount of between-year variability in the use of the spawning enclaves, with shifts between mainstem section use and tributary contribution.

Returning Chinook salmon typically held in the lower reach of the mainstem Togiak River upstream of the tagging site (Mainstem A; Figure 1) for two weeks or longer, with some fish holding as many as 40 days before moving further upstream for spawning. Differences in holding behavior were significant across years for 2010-2012 (one-way ANOVA, $F_{2,319}$=3.11, $p$ = 0.045) and between mainstem versus tributary spawners ($t$-test, $t_{320}$=2.60, $p$ = 0.009). However, the difference in mean holding days across groups was not great, typically 7 days or less, and no clear pattern emerged across time or spawning distribution.

In addition to holding behavior, we found evidence of fish backing out into salt water after moving into lower mainstem reaches through opportunistic aerial surveys which covered the lower mainstem and Togiak Bay near the mouth of the Togiak River. The process of radio tagging may stress fish and lead to slower progressions toward ultimate spawning fates (Bernard et al. 1999; Bromaghin et al. 2007); however, the Togiak system is only 93 rkms long, and we found most tags were ultimately fated as spawning. Due to limited aerial tracking in the salt water of Togiak Bay, we were only able to confirm 10 radio-tagged fish that backed out into salt water after entering Togiak River in 2010-2012. Of these, three fish returned to successfully spawn and seven were harvested in the commercial drift gillnet fishery in Togiak Bay.

From 2008 through 2012, the sex ratios of tagged Chinook salmon in lower river samples had greater percentages of females than males: 69% in 2008, 59% in 2009 (Anderson 2009, 2010), 55% in 2010, 70% in 2011 (Tanner and Sethi 2011, 2012), and 59% in 2012. These findings were consistent with the selectivity of the gill net mesh size used, because it favored capture of larger-bodied Chinook salmon that tends to be female. In 2010 and 2012, most Chinook salmon sampled at the weir were males (55% and 62%, respectively), though in 2011, females comprised more than half (55%) of the fish sampled at the weir.

In all years of this study, the dominate age classes were ages 1.3 and 1.4. The dominate age class in 2010 and 2012 was age 1.3 (2010: 74% of marked fish and 55% of fish sampled through the weir; 2012: 47% of marked fish and 38% of fish sampled through the weir), which is consistent with the 2008 study (Anderson 2009: 54% of marked fish) and with the studies by MacDonald (1997) and MacDonald and Lisac (1997). However, in 2009, age 1.4 fish (49%) dominated the sample of marked fish (Anderson 2010), which is similar to our results in 2011 (Tanner and Sethi 2012), with 71% and 49% of the fish sampled from gill nets and the weir, respectively.

Between 2009 and 2012, the average female Chinook salmon captured in the lower river marking event measured 850 mm, with annual averages of 880 mm, 830 mm, 876 mm, and 819 mm, respectively. The males sampled at the marking event averaged 771 mm overall across all years, with annual average lengths of 688 mm, 798 mm, 806 mm, and 755 mm, respectively (Anderson 2010; Tanner and Sethi 2011, 2012). Comparatively, the average length for females captured in the Gechiak Creek weir 2010-2012 measured 840 mm, with annual averages of 815 mm, 871 mm, and 814 mm, respectively. The Chinook salmon males measured at the weir averaged 658 mm over the 3 years, with annual averages of 626 mm, 667 mm, and 668 mm, respectively (Tanner and Sethi 2011, 2012).

## Recommendations

Due to the declines in Chinook salmon numbers state-wide, we recommend that some monitoring effort of the Togiak spawning abundance need be pursued. Our results show that mark-recapture is a viable approach for estimating Chinook salmon abundance in the Togiak River under appropriate sampling protocols. However, this approach is expensive in both time and resources, and is not viewed as a method for use in long-term annual monitoring. Therefore, we recommend coupling mark-recapture and telemetry sampling studies with aerial surveys to allow for an aerial survey catchability coefficient, $q$, to be estimated, which could be used to translate an aerial index, $I_a$, to an abundance estimate, $N$: $N = I_a/q$. This could help provide a lower cost option for estimating abundance in years with only aerial surveys.

To make inferences about the abundance of a salmon run complex we recommend that study designs using systematic sampling on specific subpopulations be carefully analyzed for potential induced capture heterogeneity, which can occur when tributary and mainstem-spawning stocks exhibit segregated run timing. Sampling protocols which release tags in proportion to abundance provide a solution in such cases. Even when tagging in proportion to abundance, study designs which use systematic recapture samples on subpopulations within the run complex are limited to a maximum recapture sample size equal to the subpopulation size. These designs will lead to imprecise abundance estimates if the targeted recapture subpopulation is small relative to the overall stock complex run size. In such cases, additional recapture sampling may be necessary to improve the precision of abundance estimates. Fortunately, if tagging effort can be administered such that tag releases are in proportion to run abundance, a wide range of recapture sampling schemes will result in valid data for the Lincoln-Petersen model. For example, we found carcass surveys provided additional, low-cost recapture sampling to supplement weir projects.

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**Appendix 1. Daily count of Chinook salmon marked with spaghetti tags and unmarked Chinook salmon through the Gechiak Creek weir, 2012.**

| Date | No. Untagged Counted | No. Tagged Counted | Total Daily Count | Cumulative Total Count |
|---|---|---|---|---|
| 26-Jun | 0 | 0 | 0 | 0 |
| 27-Jun | 1 | 0 | 1 | 1 |
| 28-Jun | 0 | 0 | 0 | 1 |
| 29-Jun* | 0 | 0 | 0 | 1 |
| 30-Jun | 0 | 0 | 0 | 1 |
| 1-Jul | 2 | 0 | 2 | 3 |
| 2-Jul | 1 | 0 | 1 | 4 |
| 3-Jul | 2 | 0 | 2 | 6 |
| 4-Jul* | 2 | 0 | 2 | 8 |
| 5-Jul | 2 | 0 | 2 | 10 |
| 6-Jul | 1 | 0 | 1 | 11 |
| 7-Jul | 3 | 0 | 3 | 14 |
| 8-Jul | 4 | 0 | 4 | 18 |
| 9-Jul | 2 | 0 | 2 | 20 |
| 10-Jul | 5 | 0 | 5 | 25 |
| 11-Jul | 6 | 0 | 6 | 31 |
| 12-Jul | 8 | 0 | 8 | 39 |
| 13-Jul | 6 | 0 | 6 | 45 |
| 14-Jul* | 8 | 0 | 8 | 53 |
| 15-Jul | - | - | - | - |
| 16-Jul | - | - | - | - |
| 17-Jul | - | - | - | - |
| 18-Jul | 6 | 0 | 6 | 59 |
| 19-Jul | 6 | 0 | 6 | 65 |
| 20-Jul | 3 | 0 | 3 | 68 |
| 21-Jul | 3 | 0 | 3 | 71 |
| 22-Jul | 5 | 1 | 6 | 77 |
| 23-Jul | 1 | 0 | 1 | 78 |
| 24-Jul | 8 | 0 | 8 | 86 |
| 25-Jul | 11 | 0 | 11 | 97 |
| 26-Jul | 20 | 1 | 21 | 118 |
| 27-Jul | 5 | 0 | 5 | 123 |
| 28-Jul | 3 | 1 | 4 | 127 |
| 29-Jul | 7 | 0 | 7 | 134 |
| 30-Jul | 8 | 0 | 8 | 142 |
| 31-Jul | 2 | 0 | 2 | 144 |
| 1-Aug | 18 | 1 | 19 | 163 |
| 2-Aug | 3 | 0 | 3 | 166 |
| 3-Aug | 1 | 0 | 1 | 167 |
| 4-Aug | 3 | 0 | 3 | 170 |
| 5-Aug | 12 | 0 | 12 | 182 |
| 6-Aug | 4 | 1 | 5 | 187 |
| 7-Aug | 2 | 0 | 2 | 189 |

**Appendix 1. Continued.**

| Date | No. Untagged Counted | No. Tagged Counted | Total Daily Count | Cumulative Total Count |
|---|---|---|---|---|
| 8-Aug | 2 | 0 | 2 | 191 |
| 9-Aug | 12 | 0 | 12 | 203 |
| 10-Aug | 4 | 0 | 4 | 207 |
| 11-Aug | 13 | 0 | 13 | 220 |
| 12-Aug | 5 | 0 | 5 | 225 |
| 13-Aug | 6 | 0 | 6 | 231 |
| 14-Aug | 9 | 1 | 10 | 241 |
| 15-Aug | 2 | 0 | 2 | 243 |
| 16-Aug | 4 | 0 | 4 | 247 |
| 17-Aug | 2 | 0 | 2 | 249 |
| 18-Aug | 4 | 0 | 4 | 253 |
| 19-Aug | 11 | 1 | 12 | 265 |
| 20-Aug | 4 | 0 | 4 | 269 |
| 21-Aug | 0 | 0 | 0 | 269 |
| 22-Aug | 0 | 0 | 0 | 269 |
| 23-Aug | 1 | 0 | 1 | 270 |
| 24-Aug | 1 | 0 | 1 | 271 |
| 25-Aug | 2 | 0 | 2 | 273 |
| 26-Aug | 0 | 0 | 0 | 273 |
| 27-Aug | 0 | 1 | 1 | 274 |
| 28-Aug | 5 | 0 | 5 | 279 |
| 29-Aug | 1 | 0 | 1 | 280 |
| 30-Aug* | 8 | 0 | 8 | 288 |
| 31-Aug | 2 | 0 | 2 | 290 |
| 1-Sep | 0 | 0 | 0 | 290 |
| 2-Sep | 1 | 0 | 1 | 291 |
| Total | 283 | 8 | 291 | |

'-' denotes days the weir was inoperable due to high water.
* denotes days the weir may not have been fish tight, and the count must be considered a partial count.

**Appendix 2. Daily and cumulative counts of marked and unmarked Chinook salmon in carcass surveys by date and location, 2012.**

| Date | River Section Surveyed | Unmarked Daily Count | Unmarked Cumulative Count | Marked Daily Count | Marked Cumulative Count |
|---|---|---|---|---|---|
| 11-Aug | B | 0 | 0 | 0 | 0 |
| 12-Aug | A | 1 | 1 | 0 | 0 |
| 17-Aug | B | 1 | 2 | 0 | 0 |
| 17-Aug | C | 2 | 4 | 0 | 0 |
| 17-Aug | Nayororun | 1 | 5 | 0 | 0 |
| 18-Aug | A | 1 | 6 | 0 | 0 |
| 21-Aug | A | 3 | 9 | 0 | 0 |
| 21-Aug | Nayororun | 1 | 10 | 0 | 0 |
| 22-Aug | E | 1 | 11 | 0 | 0 |
| 23-Aug | B | 2 | 13 | 0 | 0 |
| 23-Aug | C | 4 | 17 | 0 | 0 |
| 23-Aug | D | 5 | 22 | 0 | 0 |
| 23-Aug | Nayororun | 1 | 23 | 0 | 0 |
| 24-Aug | A | 1 | 24 | 0 | 0 |
| 25-Aug | B | 13 | 37 | 0 | 0 |
| 25-Aug | C | 8 | 45 | 0 | 0 |
| 26-Aug | A | 8 | 53 | 0 | 0 |
| 26-Aug | B | 8 | 61 | 0 | 0 |
| 26-Aug | C | 1 | 62 | 0 | 0 |
| 26-Aug | E | 1 | 63 | 0 | 0 |
| 27-Aug | B | 13 | 76 | 1 | 1 |
| 28-Aug | A | 0 | 76 | 0 | 1 |
| 28-Aug | B | 4 | 80 | 1 | 2 |
| 28-Aug | C | 4 | 84 | 0 | 2 |
| 28-Aug | D | 3 | 87 | 0 | 2 |
| 29-Aug | A | 8 | 95 | 0 | 2 |
| 29-Aug | B | 5 | 100 | 0 | 2 |
| 31-Aug | A | 2 | 102 | 0 | 2 |
| 31-Aug | B | 4 | 106 | 0 | 2 |
| 31-Aug | C | 14 | 120 | 0 | 2 |
| 31-Aug | D | 2 | 122 | 0 | 2 |
| 1-Sep | C | 3 | 125 | 0 | 2 |
| 1-Sep | D | 2 | 127 | 0 | 2 |
| 1-Sep | E | 5 | 132 | 0 | 2 |
| 1-Sep | Ongivinuk | 1 | 133 | 0 | 2 |
| 2-Sep | B | 2 | 135 | 0 | 2 |
| 2-Sep | C | 7 | 142 | 0 | 2 |
| 2-Sep | D | 3 | 145 | 0 | 2 |

**Appendix 3. Summary of biological data and tracking history for radio-tagged Chinook salmon in the Togiak River, 2012. Lengths are from mid-eye to fork in the tail.**

| Tagging Stratum | Date Tagged | Fish ID | Age | Sex | Length (mm) | Fate[a] |
|---|---|---|---|---|---|---|
| 1 | 21-Jun | 1 | - | F | 831 | Ongivinuk |
| 1 | 24-Jun | 2 | 1.3 | M | 646 | Ongivinuk |
| 1 | 25-Jun | 3 | 1.3 | F | 720 | Nayorurun |
| 1 | 26-Jun | 4 | 1.3 | M | 837 | Unknown† |
| 1 | 27-Jun | 5 | 1.3 | U | 709 | Unknown |
| 1 | 27-Jun | 6 | 1.4 | F | 850 | Harvested |
| 1 | 29-Jun | 7 | 1.3 | U | 812 | Harvested |
| 1 | 29-Jun | 8 | - | U | 805 | F |
| 1 | 29-Jun | 9 | 1.3 | F | 762 | Harvested |
| 1 | 30-Jun | 10 | 1.2 | U | 592 | A |
| 1 | 30-Jun | 11 | 1.3 | F | 831 | Ongivinuk |
| 1 | 30-Jun | 12 | 1.3 | U | 734 | Nayorurun |
| 2 | 2-Jul | 13 | 1.3 | M | 740 | Regurgitared |
| 2 | 2-Jul | 14 | 1.3 | F | 863 | A |
| 2 | 2-Jul | 15 | 1.3 | F | 843 | Nayorurun |
| 2 | 2-Jul | 16 | 1.3 | M | 729 | Unknown† |
| 2 | 2-Jul | 17 | - | U | 752 | B |
| 2 | 2-Jul | 18 | 1.2 | F | 726 | Harvested |
| 2 | 2-Jul | 19 | 1.4 | F | 862 | Harvested |
| 2 | 2-Jul | 20 | 1.4 | F | 864 | C |
| 2 | 2-Jul | 21 | 1.4 | F | 835 | Harvested |
| 2 | 2-Jul | 22 | - | M | 833 | Harvested |
| 2 | 2-Jul | 23 | 1.3 | F | 813 | C |
| 2 | 3-Jul | 24 | 1.3 | M | 743 | B |
| 2 | 3-Jul | 25 | 1.3 | M | 726 | Gechiak |
| 2 | 3-Jul | 26 | 2.3 | F | 769 | Nayorurun |
| 2 | 4-Jul | 27 | 1.4 | M | 776 | C |
| 2 | 4-Jul | 28 | - | M | 793 | E |
| 2 | 4-Jul | 29 | 1.4 | F | 846 | Unknown |
| 2 | 4-Jul | 30 | 1.3 | M | 753 | C |
| 2 | 4-Jul | 31 | 1.3 | M | 713 | Nayorurun |
| 2 | 5-Jul | 32 | 1.3 | F | 798 | D |
| 2 | 5-Jul | 33 | 1.3 | F | 829 | Harvested |
| 2 | 5-Jul | 34 | 1.4 | F | 900 | A |
| 2 | 6-Jul | 35 | 1.3 | F | 777 | B |
| 2 | 6-Jul | 36 | 1.4 | U | 958 | F |
| 2 | 7-Jul | 37 | 1.3 | F | 810 | D |
| 2 | 7-Jul | 38 | - | M | 718 | B |
| 2 | 8-Jul | 39 | 2.3 | F | 715 | C |
| 2 | 8-Jul | 40 | 1.4 | M | 843 | B |

**Appendix 3. Continued.**

| Tagging Stratum | Date Tagged | Fish ID | Age | Sex | Length (mm) | Fate[a] |
|---|---|---|---|---|---|---|
| 2 | 8-Jul | 41 | 1.2 | M | 542 | Dead/Regurgitated |
| 2 | 8-Jul | 42 | 1.4 | F | 902 | D |
| 2 | 8-Jul | 43 | 1.3 | F | 758 | Nayorurun |
| 2 | 8-Jul | 44 | - | F | 862 | B |
| 2 | 8-Jul | 45 | 1.3 | F | 779 | Kemuk |
| 2 | 8-Jul | 46 | 1.3 | M | 758 | Unknown† |
| 2 | 8-Jul | 47 | 1.3 | F | 833 | B |
| 2 | 9-Jul | 48 | 1.3 | F | 775 | Nayorurun |
| 2 | 9-Jul | 49 | 1.3 | F | 843 | Ongivinuk |
| 2 | 9-Jul | 50 | 1.3 | U | 882 | Harvested |
| 2 | 9-Jul | 51 | 1.3 | F | 802 | F |
| 2 | 9-Jul | 52 | 1.3 | M | 766 | D |
| 2 | 9-Jul | 53 | 1.3 | M | 739 | C |
| 2 | 9-Jul | 54 | 2.3 | F | 834 | Unknown |
| 2 | 9-Jul | 55 | 1.3 | M | 837 | E |
| 2 | 9-Jul | 56 | - | F | 865 | Dead/Regurgitated |
| 2 | 10-Jul | 57 | 1.4 | F | 835 | Pungokepuk |
| 2 | 10-Jul | 58 | 1.3 | U | 797 | Harvested |
| 2 | 10-Jul | 59 | 1.3 | U | 730 | F |
| 2 | 10-Jul | 60 | 1.3 | U | 675 | D |
| 2 | 10-Jul | 61 | 1.4 | F | 835 | C |
| 2 | 10-Jul | 62 | 2.3 | F | 905 | Unknown† |
| 2 | 10-Jul | 63 | 1.3 | U | 735 | A |
| 2 | 10-Jul | 64 | 1.3 | M | 760 | D |
| 3 | 11-Jul | 65 | 1.3 | F | 797 | Dead/Regurgitated |
| 3 | 11-Jul | 66 | 1.3 | M | 802 | A |
| 3 | 11-Jul | 67 | 1.3 | F | 745 | Dead/Regurgitated |
| 3 | 11-Jul | 68 | 1.5 | F | 905 | A |
| 3 | 11-Jul | 69 | 1.3 | M | 746 | C |
| 3 | 12-Jul | 70 | - | F | 777 | D |
| 3 | 12-Jul | 71 | - | M | 729 | B |
| 3 | 12-Jul | 72 | 1.3 | M | 788 | D |
| 3 | 12-Jul | 73 | - | U | 765 | D |
| 3 | 12-Jul | 74 | 2.3 | F | 856 | Harvested |
| 3 | 13-Jul | 75 | 1.3 | F | 855 | E |
| 3 | 13-Jul | 76 | 1.3 | F | 790 | Dead/Regurgitated |
| 3 | 13-Jul | 77 | 1.4 | F | 895 | B |
| 3 | 13-Jul | 78 | 1.3 | M | 737 | C |
| 3 | 14-Jul | 79 | 1.4 | M | 996 | C |
| 3 | 14-Jul | 80 | 1.4 | M | 899 | C |

**Appendix 3. Continued.**

| Tagging Stratum | Date Tagged | Fish ID | Age | Sex | Length (mm) | Fate[a] |
|---|---|---|---|---|---|---|
| 3 | 15-Jul | 81 | 1.3 | M | 835 | D |
| 3 | 16-Jul | 82 | 1.3 | F | 887 | Unknown† |
| 3 | 16-Jul | 83 | 1.4 | F | 834 | Dead/Regurgitated |
| 3 | 17-Jul | 84 | - | F | 872 | Ongivinuk |
| 3 | 17-Jul | 85 | 1.3 | M | 752 | E |
| 3 | 18-Jul | 86 | 2.3 | M | 766 | C |
| 3 | 18-Jul | 87 | 2.3 | F | 764 | Gechiak |
| 3 | 18-Jul | 88 | 1.3 | F | 987 | A |
| 3 | 18-Jul | 89 | 1.3 | F | 909 | C |
| 3 | 18-Jul | 90 | 1.4 | F | 852 | Harvested |
| 3 | 19-Jul | 91 | 1.3 | F | 858 | Unknown |
| 3 | 19-Jul | 92 | 1.3 | F | 840 | A |
| 3 | 19-Jul | 93 | 1.3 | M | 875 | Harvested |
| 4 | 21-Jul | 94 | 1.4 | F | 777 | Unknown |
| 4 | 21-Jul | 95 | 2.3 | U | 778 | Unknown |
| 4 | 21-Jul | 96 | 1.4 | F | 822 | Harvested |
| 4 | 22-Jul | 97 | 1.3 | U | 845 | Kemuk |
| 4 | 22-Jul | 98 | 1.3 | M | 820 | Kemuk |
| 4 | 22-Jul | 99 | 1.3 | F | 762 | A |
| 4 | 22-Jul | 100 | 1.3 | F | 785 | F |
| 4 | 22-Jul | 101 | - | F | 843 | A |
| 4 | 22-Jul | 102 | 2.2 | F | 675 | Dead/Regurgitated |
| 4 | 22-Jul | 103 | - | F | 865 | Unknown |
| 4 | 22-Jul | 104 | 2.3 | F | 794 | A |
| 4 | 23-Jul | 105 | 1.3 | M | 772 | Harvested |
| 4 | 23-Jul | 106 | 2.3 | M | 875 | B |
| 4 | 23-Jul | 107 | 1.3 | M | 677 | B |
| 4 | 23-Jul | 108 | 1.3 | F | 799 | E |
| 4 | 23-Jul | 109 | 1.2 | M | 604 | Kemuk |
| 4 | 23-Jul | 110 | 1.3 | F | 879 | E |
| 4 | 23-Jul | 111 | 1.3 | M | 742 | Kemuk |
| 4 | 23-Jul | 112 | 1.3 | M | 846 | Pungokepuk |
| 4 | 23-Jul | 113 | 2.3 | M | 911 | Harvested |
| 4 | 24-Jul | 114 | 1.3 | F | 848 | E |
| 4 | 24-Jul | 115 | 1.3 | M | 665 | Harvested |
| 4 | 24-Jul | 116 | 1.3 | M | 728 | C |
| 4 | 25-Jul | 117 | 1.3 | F | 847 | F |
| 4 | 25-Jul | 118 | 2.3 | M | 751 | C |
| 4 | 25-Jul | 119 | 1.4 | F | 902 | C |
| 4 | 26-Jul | 120 | 2.3 | U | 856 | D |

**Appendix 3. Continued.**

| Tagging Stratum | Date Tagged | Fish ID | Age | Sex | Length (mm) | Fate[a] |
|---|---|---|---|---|---|---|
| 4 | 26-Jul | 121 | 1.3 | F | 839 | C |
| 4 | 26-Jul | 122 | 1.3 | M | 681 | Harvested |
| 4 | 26-Jul | 123 | 2.2 | F | 734 | C |
| 4 | 26-Jul | 124 | 2.3 | M | 703 | C |
| 4 | 26-Jul | 125 | 1.3 | F | 857 | Unknown |
| 4 | 27-Jul | 126 | 2.3 | U | 808 | D |
| 4 | 27-Jul | 127 | 1.4 | F | 849 | C |
| 4 | 27-Jul | 128 | 2.4 | F | 810 | Unknown |
| 4 | 27-Jul | 129 | 2.3 | M | 851 | B |
| 4 | 28-Jul | 130 | 1.3 | F | 865 | Nayororun |
| 4 | 28-Jul | 131 | 1.4 | F | 823 | Unknown† |
| 4 | 29-Jul | 132 | - | F | 912 | B |
| 4 | 29-Jul | 133 | 1.3 | U | 752 | F |
| 5 | 31-Jul | 134 | 1.4 | M | 922 | B |
| 5 | 31-Jul | 135 | 1.4 | M | 856 | C |
| 5 | 31-Jul | 136 | 2.3 | M | 852 | C |
| 5 | 31-Jul | 137 | 1.4 | M | 764 | C |
| 5 | 1-Aug | 138 | - | M | 933 | B |
| 5 | 1-Aug | 139 | 2.3 | F | 821 | B |
| 5 | 4-Aug | 140 | 1.2 | F | 828 | C |
| 5 | 5-Aug | 141 | 1.3 | F | 769 | C |
| 5 | 6-Aug | 142 | - | F | 774 | B |
| 5 | 7-Aug | 143 | - | M | 685 | A |
| 5 | 8-Aug | 144 | 1.3 | U | 814 | B |
| 5 | 8-Aug | 145 | - | M | 683 | A |
| 5 | 8-Aug | 146 | 2.3 | F | 843 | B |
| 6 | 12-Aug | 147 | 1.4 | F | 758 | C |

†Denotes fish whose fate is unknown but are suspected to have been harvested.
[a]Mainstem spawning fates are as follows:

A = From the first fixed telemetry station to Gechiak Creek
B = Gechiak Creek to Pungokepuk Creek
C = Pungokepuk Creek to Nayororun (Kashaiak) River
D = Nayororun River to Kemuk River
E = Kemuk River to Ongivinuk River
F = Ongivinuk River to Togiak Lake