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Estimation of Chinook Salmon Escapement, Distribution and Run Timing in the Togiak River Watershed Using Radio Telemetry, Togiak National Wildlife Refuge, Alaska, 2011

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Estimation of Chinook Salmon Escapement, Distribution and Run Timing in the Togiak River Watershed Using Radio Telemetry, Togiak National Wildlife Refuge, Alaska, 2011

Theresa L. Tanner and Suresh A. Sethi

Abstract

Radio telemetry 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 2011, radio transmitters were implanted into 171 Chinook salmon and another 119 fish were marked with spaghetti tags in the lower 5 km of the Togiak River for the marking event. A total of 113 fish (66%) were successfully tracked to spawning locations. Forty-three (25%) had an indeterminate fate, 9 (5%) were known harvests, and six (4%) were assigned a fate of dead/regurgitated. Eighty-eight percent (n = 99) of the tracked fish selected spawning locations in the mainstem of the Togiak River, and 12% (n = 14) selected spawning locations in the tributaries, primarily in Ongivinuk River (5%, n = 6) and Gechiak Creek (4%, n = 4). A resistance-board weir was installed in Gechiak Creek to serve as the recapture event for the mark-recapture effort. A total of 232 unmarked and 9 marked Chinook salmon were counted through the weir from 23 June through 3 September. Eight age classes were identified from scales collected in 2011, with the majority of the samples consisting of age 1.4 fish (71% of marked fish and 49% of fish sampled through the weir). Females comprised 70% of the marked fish and 55% of the fish sampled through the weir. Chinook salmon lengths ranged from 155 mm to 1050 mm for marked fish and from 340 mm to 1021 mm for fish sampled through the weir. The spawning population estimate for Chinook salmon that entered the Togiak River is 7,041 fish (95% CI = {4,160 ; 14,143}). 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.

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 (ADFG) 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. The harvest includes 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 is estimated by expanding visual counts with assumed correction factors. The accuracy of aerial survey counts is greatly affected by stream life,

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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 flown and calculated since 2005 (Salomone et al. 2009). The Office of Subsistence Management, through its strategic planning process, has 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 ADFG. 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 second year of a three-year radio telemetry 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; and
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 2011. ADFG staff obtained only a partial aerial count, and an abundance estimate from aerial survey data was 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 km^2, comprises nine major lakes and five major tributaries, and is bounded 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).

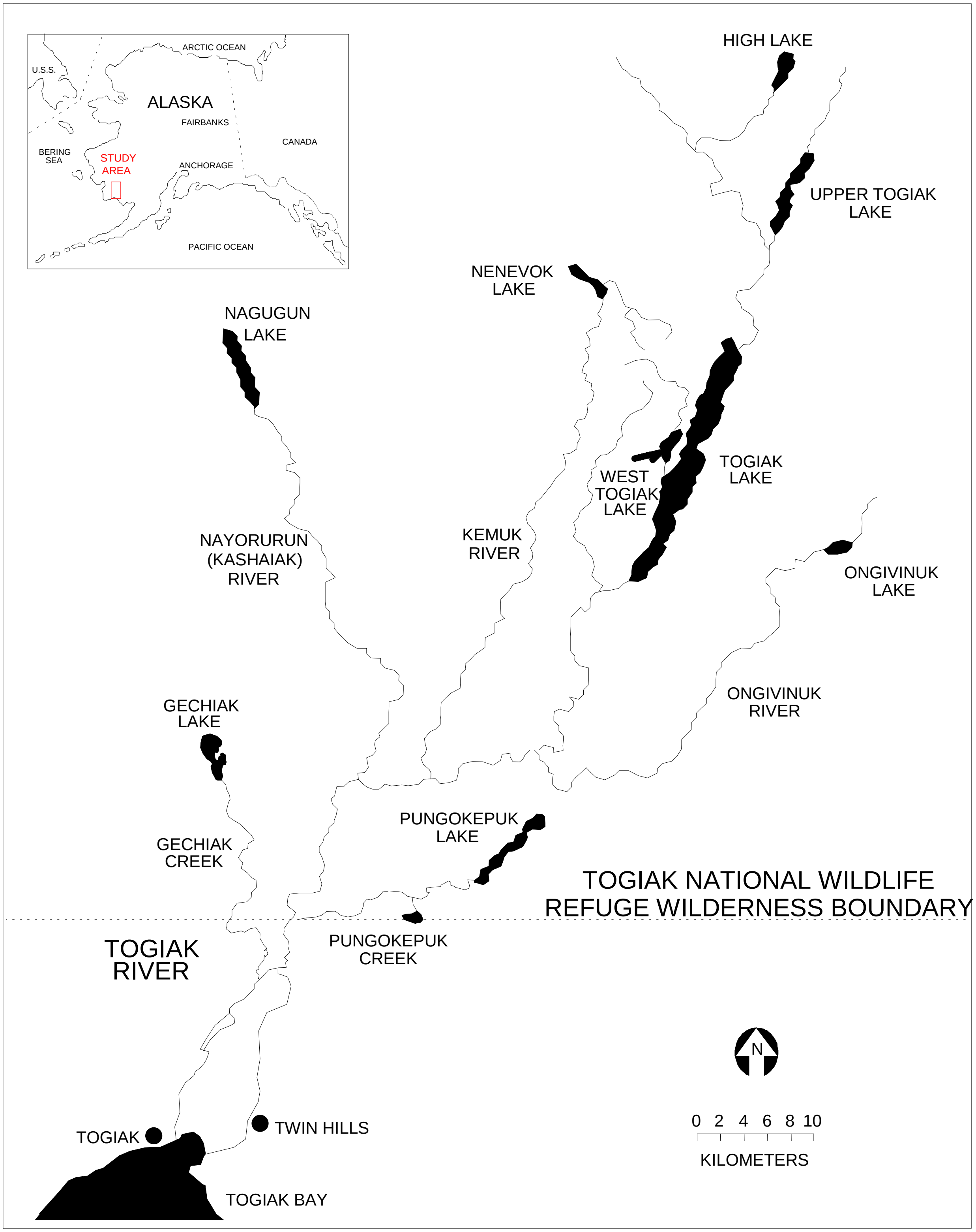

Figure 1. Map of the Togiak River watershed in Southwest Alaska.

Methods

A radio telemetry 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 gillnet (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 gillnet 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 2011). Gill net 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, 2011.

Strata	Dates	Radio Transmitter Allocation	Spaghetti Tag Color
1	19 June – 2 July	45	Fluorescent Pink
2	3 – 9 July	45	White
3	10 – 16 July	45	Fluorescent Green
4	17 – 23 July	45	Fluorescent Yellow
5	24 July – 6 August	20	International Orange
	Total:	*200*	

Chinook salmon longer than 450 mm (mid-eye to tail fork) 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.

Efforts were made to minimize stress to Chinook salmon during capture and handling. Captured fish were removed from gillnets 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 about two minutes or less.

Recapture event---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 positioned in the thalweg of the creek allowed for boat passage. The boat passage panels were marked with orange buoys on either side, and were not maintained with their resistance boards deployed.

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 to 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. For the hours the weir went unmanned, the live trap was closed to passage. The weir was cleaned of debris and inspected daily for integrity. Repairs were made as needed.

Figure 2. The resistance-board weir installed in Gechiak Creek, 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 aged using the standards and guidelines of Mosher (1968). 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 goal 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 above 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

Radio telemetry 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 in to 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 up 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. Names and locations (decimal degrees) of fixed telemetry stations in the Togiak River watershed, 2011.

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

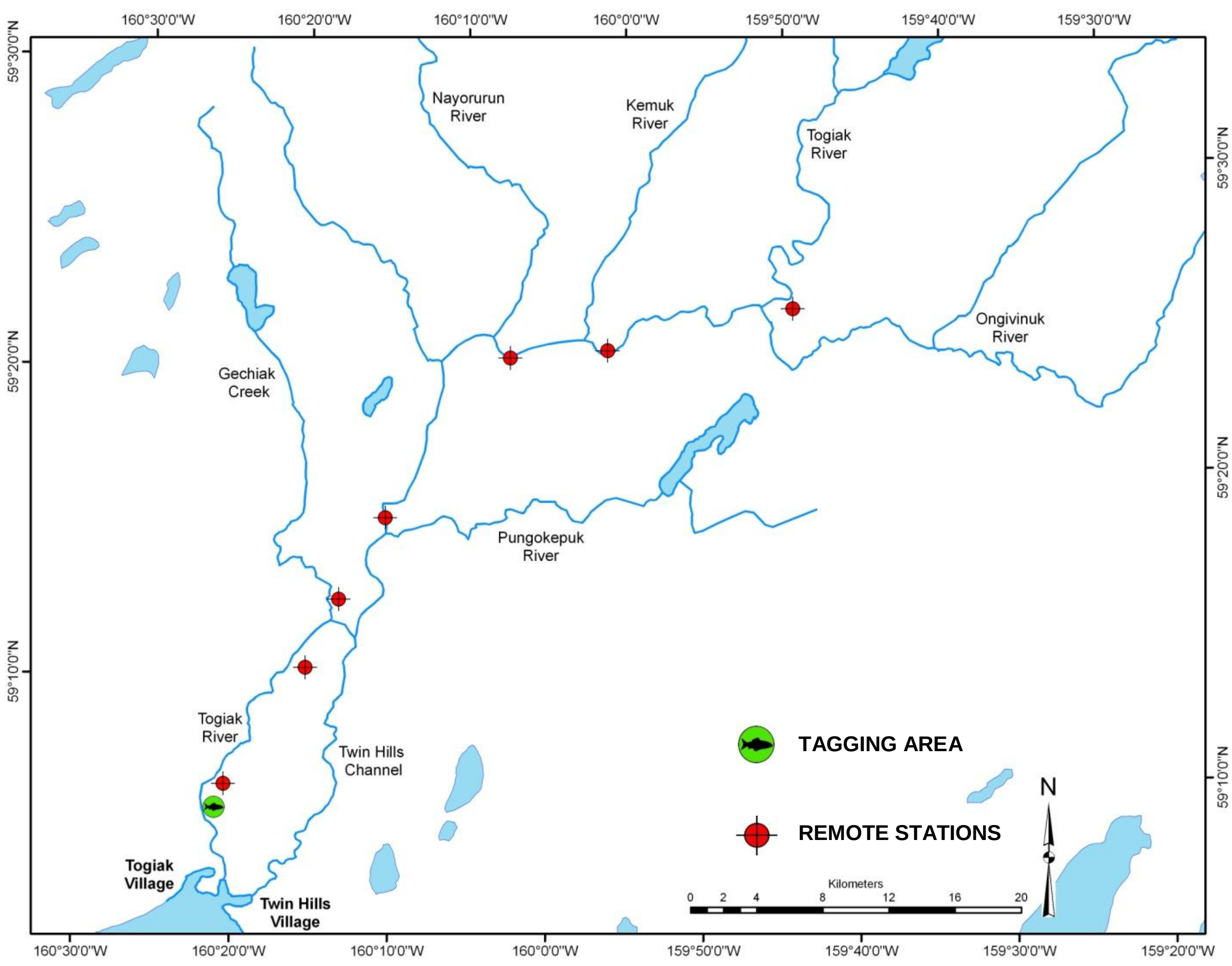

Figure 3. Remote data logging receiver station locations and tagging area in the Togiak River, 2011.

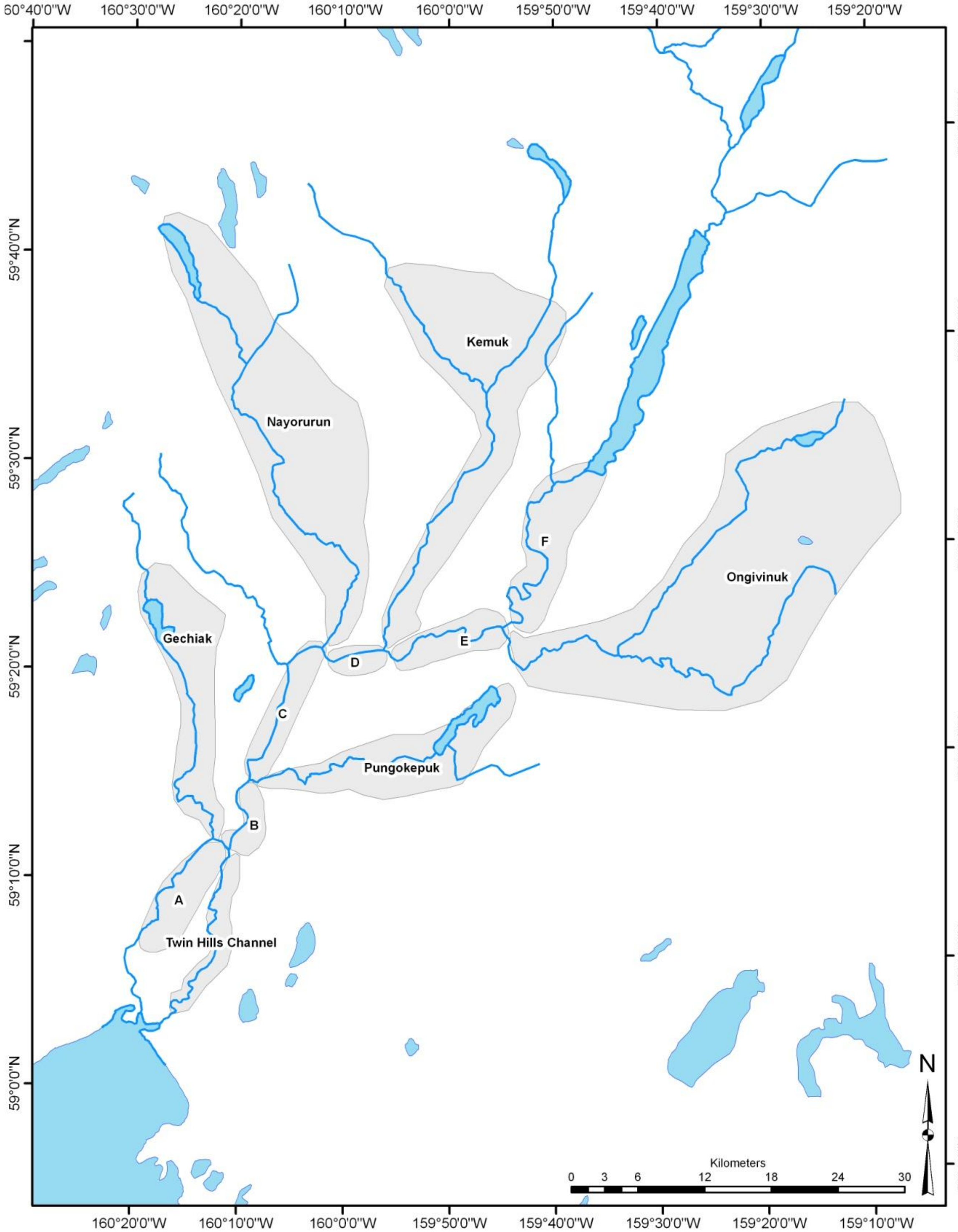

Figure 4. Mainstem river sections corresponding to ADFG aerial survey delineations and tributary fates assigned to radio tagged Chinook salmon in the Togiak River, 2011. The exception is the Twin Hills Channel, which was designated as a possible spawning fate for the first time in 2010.

Radio telemetry 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 ADFG (Brookover et al. 1996). Tributary spawners were assigned to one of six tributaries. In addition to the tributary survey areas designated by ADFG, 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) were calculated and a two-sample t-test assuming unequal variances was conducted 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, 2011.

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 and extends methods outlined in Tanner and Sethi (2011). 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). 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. The assumptions of Lincoln-Petersen closed-population mark recapture estimators are as follows (e.g. Pollock et al. 1990):

1. the population is closed (no additions or deletions);
2. marks are not lost or misidentified;
3. all animals are equally likely to be captured at each sampling occasion.

Recruitment, i.e. additions, to the population was nonexistent as fish entering the river system had to pass the tagging site. The Lincoln-Petersen estimator still provides valid estimates of run size at the marking site if post-tagging mortality occurs but is randomly distributed throughout the population (Krebs 1999). Because Floy spaghetti tags are relatively non-invasive to large fish such as salmon, and radio tags were only released into large and healthy fish, we assume tagging-related mortality was low or nonexistent, and any tagging-related mortality events were randomly distributed throughout the population. Similarly, we assumed any other mortality events that occurred between the tagging and recovery site, for example due to sport harvest or natural mortality, were expected to be randomly distributed throughout the population. Therefore we believe that Assumption 1 of population closure is upheld insofar that any mortality events that occurred would not bias the Lincoln-Petersen estimator.

Assumption 2 is defensible because we found no evidence in the field of tag shedding, and tags were easily identified at the weir.

Assumption 3 is of greatest concern for this study because the second sampling occasion was a systematic subsample of the broader population. This concern was discussed in length in Tanner and Sethi (2011). Previous simulation efforts (Tanner and Sethi 2011) demonstrated that to achieve an unbiased estimate of total escapement, tagging effort needed to be in proportion to abundance at the tagging site such that all substocks received equivalent tagging rates (tags in substock/substock abundance). In this manner, the systematic recapture subsample at the Gechiak weir behaves as random sample from the broader population. To accomplish this, we modified the tagging protocol in 2011 to administer equal tagging effort in each tagging strata. We assumed the standard relationship that catch (*C*, i.e. Chinook marked and released) is directly proportional to effort (*E*) and abundance (*N*) through a catchability coefficient (*q*), with $C = NEq$. Through rearrangement of this simple catch equation, it can be seen that if effort and catchability remain constant throughout tagging strata (denote this by E and q, respectively), then a constant tagging rate, *k*, would be applied to all populations passing the tagging site: $C/N = k = Eq$. Finally, to improve sample sizes, we increased the number of tags released by deploying both radio tags and Floy tags.

Following recommendations in Seber (1982) when analyzing sparse data for small population sizes, we used the Chapman variant of the Lincoln-Peterson estimator to assess Chinook spawning stock abundance. The Chapman estimate of total abundance, N_C is:

$$N_C = \frac{(n_1+1)(n_2+1)}{(m_2+1)} - 1 \qquad 1$$

where n_1 is the number of Chinook salmon tagged and released at the tagging site over all time strata, n_2 is the number of Chinook salmon counted passing the Gechiak Creek weir (the recapture event), and m_2 is the number of marked Chinook salmon captured at the weir. The

Chapman estimator is derived under a classical maximum likelihood framework where the random variable for the number of marks captured in second sampling session, m_2, is a hypergeometric distribution. Confidence intervals for N_C were constructed using a parametric bootstrap routine in R (R Development Core Team 2010) by generating 100,000 bootstrap samples of m_2 from a hypergeometric distribution with parameters equal to those under the point estimate of the Champan estimator. Simulated m_2 values were used to create a distribution of N_C's and subsequent quantiles of the bootstrapped estimates provided confidence intervals.

In addition to the Chapman estimator, we implemented a Bayesian version of the classic Lincoln-Petersen estimator, N_B. In this formulation, we modeled both tags and unmarked salmon captured in the second sample session as binomial processes:

$$m_2 | n_1, p \sim Binomial(n_1, p) \quad (2)$$

$$u | U, p \sim Binomial(U, p) \quad (3)$$

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:

$$\log U \sim Uniform(0,14) \quad (4)$$

$$p \sim Beta(1,1) \quad (5)$$

Finally, total abundance, N_B, was included as a derived parameter in the model as $m_2 + U$. We chose to conduct the Bayesian implementation of the Lincoln-Petersen estimator for two reasons. First, the posterior distribution for N_B contains all uncertainty from priors and estimation of both *U* and *p* in an exact fashion, versus asymptotic approximations under likelihood-based methods, e.g. see Kery and Schaub 2012. Second, under a Bayesian estimate, we can make probability statements for derived parameters such as total population size and for two other quantities of interest: the probability that run size in 2011 was smaller than the point estimate of run size in 2010 ($N_{C,2010}$; 10,096) and the probability that the 2011 run size was smaller than the point estimate of run size in 2010 which has been inflated by 20% ($N_{1.2C+,2010}$) as an ad hoc method to adjust for suspected downward bias due to unequal tagging rates across the Gechiak subpopulation and the rest-of-river run in 2010 (Tanner and Sethi 2011). 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 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 separated groups. Synchronous run timing curves for subpopulations provides evidence of the former, whereas staggered run timing curves is suggestive of the latter. Escapement data were unavailable for Togiak Chinook, other than data from the Gechiak weir. In light of this, we used tag release timings at the marking site of successfully fated fish, where fated spawning location indicates subpopulation membership, e.g. Gechiak, Ongivinuk, or Mainstem A spawner assignments.

We examined the following questions associated with run timing of Chinook subpopulations in the Togiak River during the 2011 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 construction of either a Chi-square statistics or through use of the Fisher exact text implemented in R.

Results

Marking event---Gillnet sampling for Chinook salmon was conducted over a total of 43 hours between 22 June and 7 August, and a total of 339 Chinook salmon were captured between 22 June and 5 August (Figure 5). The highest total catches occurred on 10 and 27 July when 23 and 21, respectively, Chinook salmon were caught. Of the 339 Chinook salmon captured, 171 received radio tags with a secondary spaghetti tag and 117 Chinook were tagged with only a spaghetti tag, for a total of 288 fish marked in the gill net fishing (Table 4). Of the additional 51 fish captured in gill nets, 28 were recaptured marked fish, 19 fish escaped the net or the cradle before they could be marked, and 4 other Chinook salmon received mortal gill damage. Other species captured included chum *O. keta* (n = 114) and sockeye *O. nerka* (n = 169) salmon, rainbow trout (n = 4), and char *Salvelinus* spp. (n = 11).

Low, clear water conditions early in the season for the mainstem sampling effort caused concerns about net avoidance behaviors. On 13 July, we incorporated hook and line sampling to complement our gill net fishing efforts. All of the spinners had the barbs pinched down to minimize injury. Hook and line sampling efforts entailed biological technicians letting out line until the weight and spinner ‘tapped’ along the substrate while the boat driver maintain a slow downstream troll. Fishing effort was timed and standardized to one hour of total line soak time. A total of 24 hours soak time from 13 July – 5 August only resulted in two Chinook salmon being captured, one of which received spaghetti tags and the other which escaped from the cradle before being marked. Other species captured included char spp. (n = 11) and a rainbow smelt (n = 1).

All fishing efforts resulted in a total of 290 marked fish, 171 Chinook salmon with both a radio tag and a Floy tag and another 119 fish with only a spaghetti tag (Table 4).

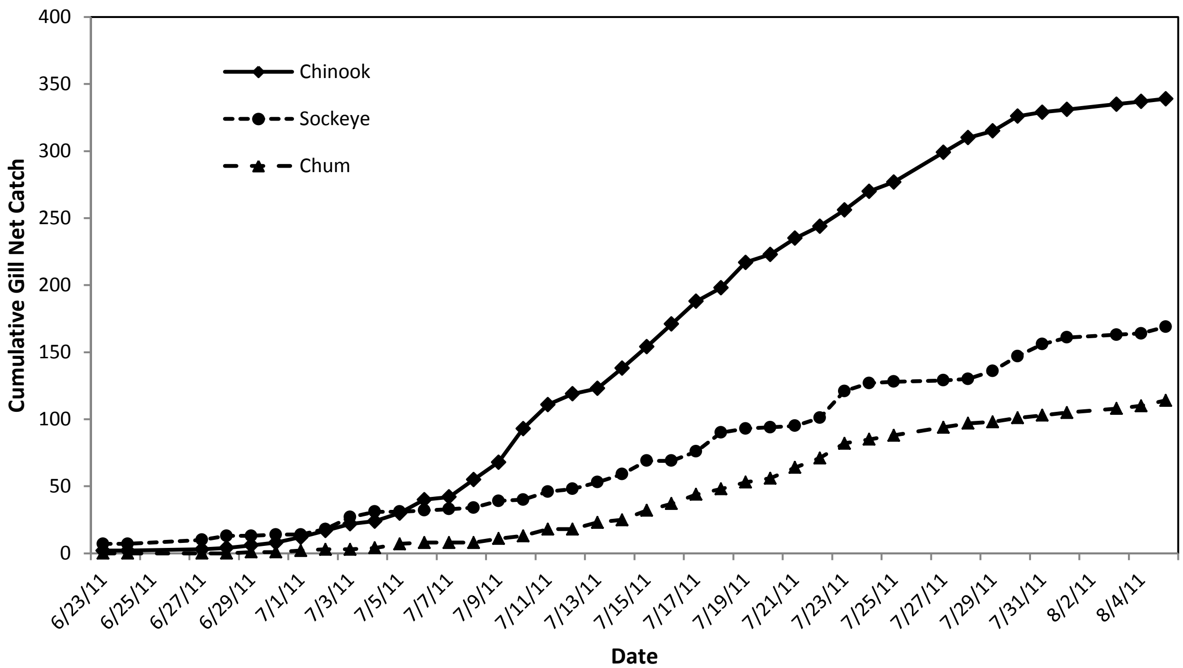

Figure 5. Cumulative total catch of Chinook (*n* = 339), sockeye (*n* = 169), and chum (*n* = 114) salmon caught by gillnet in the lower Togiak River, 2011.

Table 4. Radio transmitter and spaghetti tag deployment numbers for determining spawning distribution and population estimate of Chinook salmon. In total, 290 Chinook salmon were marked in the lower Togiak River, 2011.

Stratum	Week(s)	Radio Transmitters Deployed	Spaghetti Tags Deployed
1	June 19 – 25 June 26 – July 2	9	3
2	July 3 – 9	34	10
3	July 10 – 16	59	34
4	July 17 – 23	40	33
5	July 24 – 30 July 31 – August 6	29	38
Total:		*171*	*119*

Eight age classes of Chinook salmon were expected to occur in the Togiak River run (1.2, 1.3, 1.4, 1.5, 2.1, 2.2, and 2.3), although only two of these (1.3 and 1.4) were expected to comprise the majority of the run.

From the marking event in the lower Togiak River, age data were obtained from 289 Chinook salmon, of which 38 fish could not be aged because of illegible or regenerated scales. Eight age classes were present in 2011, with age 1.3 (16%), and 1.4 (71%) comprising 87% of the sample (Table 5). Sex was determined for 283 Chinook salmon, with an additional 6 fish sampled who could not be sexed using secondary sexual characteristics. Females comprised 70% of Chinook salmon sampled (Table 6; Figure 6). Lengths were measured from 284 Chinook salmon, and ranged from 655 mm to 1,020 mm for females and 415 mm to 1,050 mm for males (Table 7).

Table 5. Age composition of Chinook salmon marked in the lower Togiak River, 2011.

Age	*n*	%	SE(%)
1.1	1	0	0.4
1.2	11	4	1.3
1.3	41	16	2.3
1.4	178	71	2.9
1.5	3	1	0.7
2.2	3	1	0.7
2.3	9	4	1.2
2.4	5	2	0.9
Total[a]	*187*	*100*	

[a]Total number sampled does not include fish whose age could not be determined (*n*=38).

Table 6. Sex composition of Chinook salmon radio tagged in the lower Togiak River, 2011.

Sex	*n*	%	SE(%)
Female	199	70	2.7
Male	84	30	2.7
Total[a]	*283*	*100*	

[a]Total number sampled does not include fish whose sex could not be determined (*n*=6).

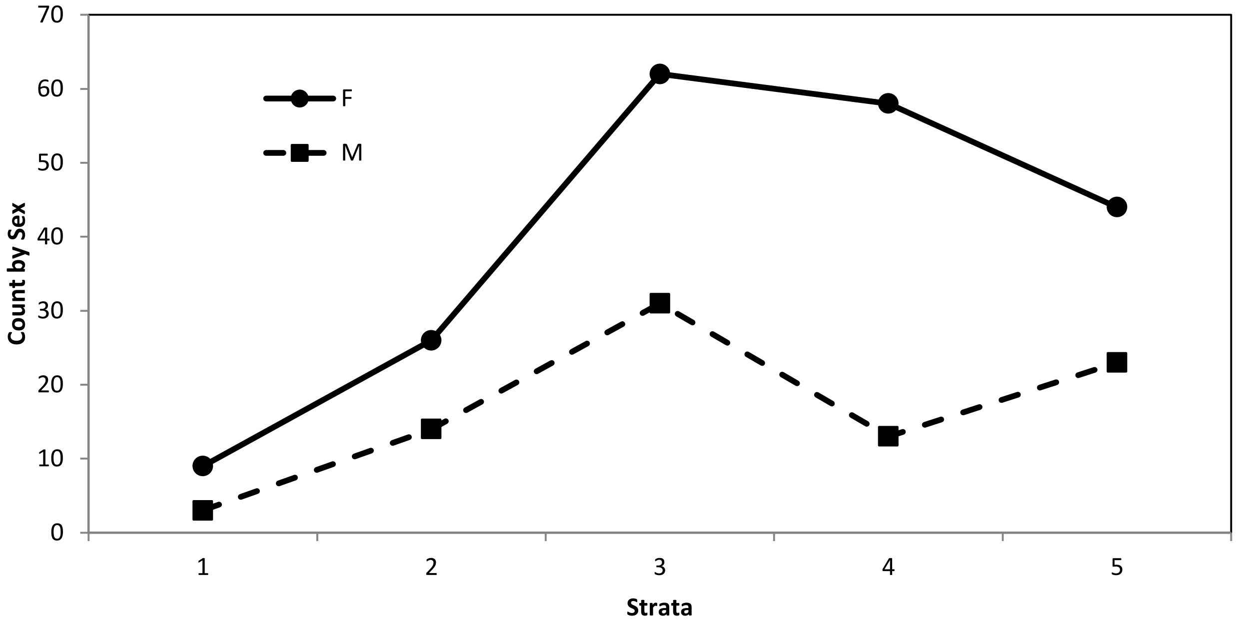

Figure 6. Sex composition of Chinook salmon radio tagged in the lower Togiak River, 2011, by strata. Total: Female *n*=199; Male *n*=84; Unknown Sex *n*=6.

Table 7. Mean length (mm), SE, range, and sample size by age of Chinook salmon radio tagged in the lower Togiak River, 2011.

Length	Age Class							
	1.1	1.2	1.3	1.4	1.5	2.2	2.3	2.4
n[a]	1	11	41	178	3	3	9	5
Mean	415	619	813	886	839	797	863	892
SE	-	6	4	3	5	5	4	5
Minimum	415	520	692	738	780	717	772	775
Maximum	415	893	1015	1050	930	885	966	985

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

Recapture event---The resistance-board weir was installed in Gechiak Creek on 22 June. Daily operations began at 0600 hours on 23 June. Weir operation was disrupted due to high water 12 – 15 July, with a partial count on 11 July. On 18 July, erosion was discovered under approximately 3 m of the river right base rail. A small accumulation of woody debris above the weir scoured out fine substrate behind the debris and under the fencing and base rail. Once detected, the debris was removed, and sand bags were used to fill in around the base of the weir. Though the weir remained operational, it cannot be considered fish tight; therefore, data collected for 16 – 19 July are considered partial counts. The weir was operated until noon on 3 September, at which time it was dismantled and removed from the river.

In total, 241 Chinook salmon were counted through the weir, with the highest daily count occurring on 29 July (Appendix 2). Of the 241 Chinook salmon enumerated, 232 were unmarked and 9 were marked with spaghetti tags. Other species captured included Coho *O. kisutch* (*n* = 2,259), chum (*n* = 20,024), and sockeye (*n* = 5,465) salmon (Figure 7), rainbow trout (*n* = 1,073), char (*n* = 70), whitefish (*n* = 2), and Arctic grayling (*n* = 2). An additional 33 fish that were counted through the weir could not be identified to species. The whitefish counted through the weir were not all identified to species; however, one of the whitefish counted was identified as a round whitefish *Prosopium cylindraceum*.

From the recapture event in Gechiak Creek, age data were obtained from 157 unmarked Chinook salmon sampled from the weir, of which 14 fish could not be aged because of illegible or regenerated scales. Eight age classes were present in 2011, with ages 1.3 (27%) and 1.4 (49%) comprising 76% of the sample (Table 8). Sex was determined for 155 Chinook salmon, with 2 additional fish who could not be sexed using secondary sexual characteristics. Females comprised 55% of Chinook salmon sampled (Table 9; Figure 8). Lengths were measured from 92 Chinook salmon, and lengths ranged from 739 mm to 1,021 mm for females and 340 mm to 1,021 mm for males (Table 10).

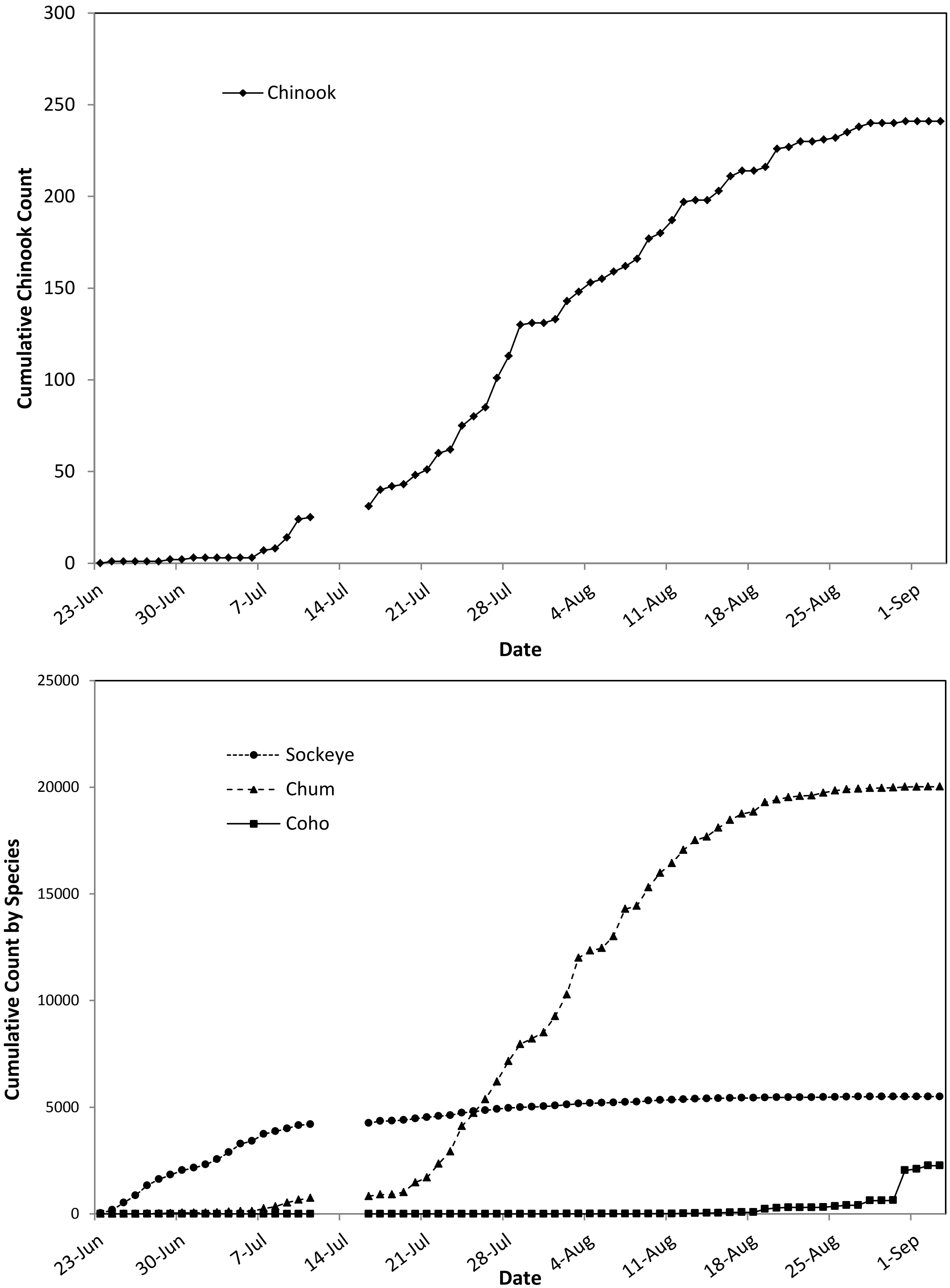

Figure 7. Cumulative count of Chinook salmon (*n*=241) counted through the Gechiak Creek weir (top) and cumulative count of sockeye (*n*=5,495), chum (*n*=20,025), and coho (*n*=2,259) salmon counted through the Gechiak Creek weir by species (bottom), 2011. Breaks in data series indicate dates the weir was inoperable due to high water.

Table 8. Age composition of unmarked Chinook salmon sampled through the Gechiak Creek weir, 2011.

Age	*n*	%	SE (%)
1.1	4	3	1.4
1.2	21	15	3.0
1.3	38	27	3.7
1.4	70	49	4.2
2.1	2	1	1.0
2.2	1	1	0.7
2.3	5	3	1.5
2.4	2	1	1.0
Total[a]	*143*	*100*	

[a]Total number sampled does not include fish whose age could not be determined (*n*=14).

Table 9. Sex composition of unmarked Chinook salmon sampled through the Gechiak Creek weir, 2011.

Sex	*n*	%	SE(%)
Female	86	55	4.0
Male	69	45	4.0
Total[a]	*155*	*100*	

[a]Total number sampled does not include fish whose sex could not be determined (*n*=2).

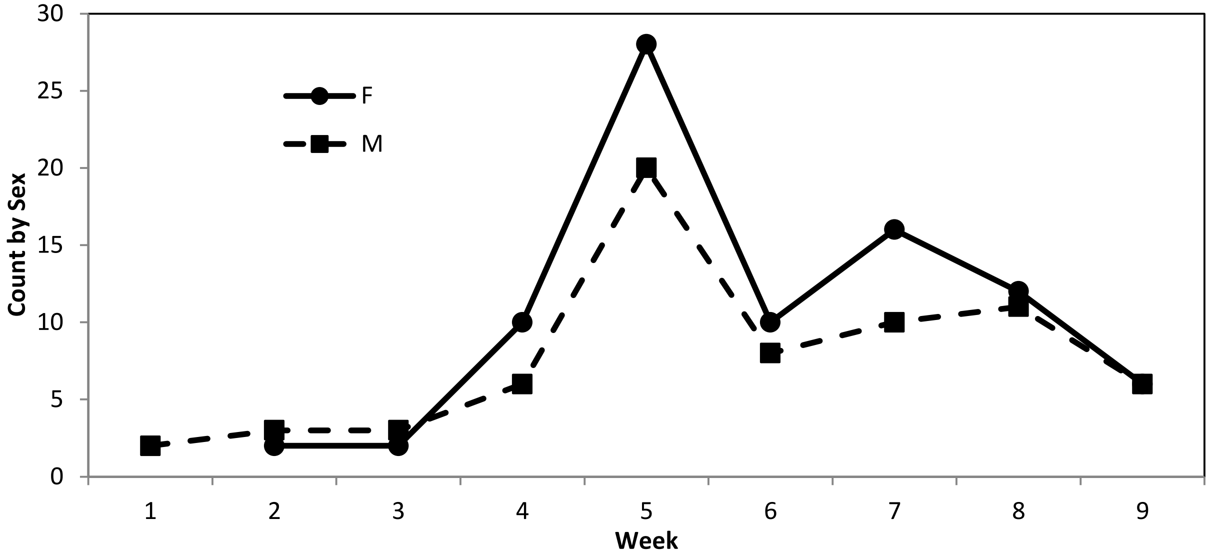

Figure 8. Weekly sex composition of unmarked Chinook salmon sampled through the Gechiak Creek weir, 2011. Total: Female *n*=86; Male *n*=69; Unknown Sex *n*=2. Sampling occurred 24 June – 31 August in 2011.

Table 10. Mean length (mm), SE, range, and sample size by age of unmarked Chinook salmon sampled through the Gechiak Creek weir, 2011.

Length	Age Class							
	1.1	1.2	1.3	1.4	2.1	2.2	2.3	2.4
n[a]	4	21	38	70	2	1	5	2
Mean	395	546	750	886	531	563	793	941
SE	3	3	5	6	3	4	5	6
Minimum	340	445	492	739	526	563	678	900
Maximum	485	651	910	1021	536	563	840	981

[a]Number sampled does not include fish whose age could not be determined (*n*=14).

Radio telemetry---All seven fixed telemetry stations were operational in time to capture upstream movement by radio tagged Chinook salmon. The Entry, Second, and Gechiak stations were installed on 22 June, one day before the first radio tag was deployed in the lower river. The Ranger, Kemuk, and Nayorurun fixed stations were installed on 26 June, with the first radio tagged fish recorded at Ranger station on 13 July. The last station located furthest upriver, Ongivinuk, was not installed until 15 July; however, the first radio tagged fish did not pass the Ongivinuk station until 21 July. We believe all fixed stations were installed and operational in time to capture fish movement. Two stations experienced temporary failures in 2011. Ranger station was not properly reset to scan after a routine download, resulting in no movement data recorded at that site for 25 – 31 August. Kemuk station was damaged by a bear on two occasions, and it failed to detect radio tags 27 – 31 July and on 9 August.

Six aerial searches were conducted between 19 July and 7 September, with the flights occurring at weekly intervals beginning 9 August. Forty-two boat searches were conducted from 30 June to 2 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 171 Chinook salmon between 23 June and 5 August. Of the 171 tagged Chinook salmon, a total of 113 fish (66%) were successfully tracked to spawning areas, 43 (25%) were not successfully tracked to a spawning location, 9 (5%) were harvested, and six (4%) were assigned a fate of dead/regurgitated (Table 11, Appendix 3).

Table 11. Fate of Chinook salmon radio-tagged in the Togiak River, 2011.

Fate	Number	Percentage
Spawning Location:		
Mainstem (1 of 6 river sections)	99	55
Tributary (1 of 6 tributaries)	14	8
Total	*113*	*66*
Unknown Fate:		
Undetermined/insufficient location information	11	6
Undetermined/suspected harvest	32	19
Total	*43*	*25*
Removed From Study:		
Harvested	9	5
Dead/Regurgitated	6	4
Total	*15*	*9*
Total Tagged:	171	100

Eighty-eight percent (*n* = 99) of the fated spawners selected spawning locations in mainstem areas of the Togiak River, with 19% (*n* = 22) in the lower mainstem below Gechiak Creek. Twelve percent (*n* = 14) selected spawning locations in tributaries, with 4% (*n* = 4) selecting locations in Gechiak Creek (Table 12). The importance of the lower mainstem spawning sections is again confirmed. Of the tributaries, Gechiak Creek again proved to be an important spawning tributary. However, in 2011, more radio tagged fish spawned in the Ongivinuk River than any other tributary, including the Gechiak.

Table 12. Distribution of Chinook salmon within ADFG spawning survey river sections in the Togiak River drainage based on radio tracking in 2008, 2009, 2010, and 2011; and ADFG average aerial survey estimates during 1987 to 2005.

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

[a]ADFG 1987-2005 average aerial survey estimates from Westing et al. (2007).
[b]Twin Hills Channel not included in surveys prior to 2010.
"-" is no data.

Results from a two-sample t-test assuming unequal variances provide evidence of a difference in the average number of days spent holding in the lower river between mainstem and tributary spawners ($t_{0.05\ 2\ ,25} = 2.060$, *p* value = 0.049). Mainstem spawners spent an average of 16 days (minimum = 2, maximum = 37) in the lower river after tagging, and tributary spawning fish held low in the system for an average of 12 days (minimum = 3, maximum = 21) in the lower river post-tagging. Most of the radio tagged Chinook salmon were first detected within their spawning area, i.e. Mainstem A – F or tributary, by mid-August, primarily between 9 and 16 August, but as early as 30 July or as late as 22 August. Spawning behavior appears to be most active during the latter half of August.

Spawning abundance---The Chapman point estimate of Chinook run size in the Togiak river that escaped past the commercial fishery in Togiak Bay is $N_C = 7{,}041$ with a 95% bootstrap confidence interval of {4,160; 14,143}. Unfortunately, little gain in precision of the abundance estimate was achieved in the 2011 season as compared to the 2010 Chapman estimate with 95% bootstrapped confidence intervals, although we believe the 2011 estimate to be less biased: in 2010, the 95% bootstrapped confidence interval width was 158% of the Chapman point estimate, whereas in 2011 the 95% bootstrap confidence interval was 142% of the Chapman point estimate.

The Bayesian implementation of the pooled Lincoln-Petersen estimator successfully reached convergence (Figure 9), with Gelman-Brooks-Rubin statistic of all tracked parameters < 1.005. The abundance estimate was similar to the Chapman point estimate, with a posterior median estimate of total run size of $N_B = 7{,}160$ with a 95% credibility interval of {4,233; 14,225} (Figure 9). The estimated probability of detection was quite low with a posterior median of 0.034 and a 95% credibility interval of {0.017, 0.058} (Figure 9).

The 2011 run size was approximately 3,000 fish smaller than the 2010 run (as compared to the 2010 Chapman point estimate: -2,936 using the 2011 Bayesian estimate and -3,055 when using the 2011 Chapman estimate). From the Bayesian analysis and conditional on the pooled Lincoln-Petersen model and the data, we can state that there is an 84% chance that the 2011 run was smaller than the 2010 Chapman point estimate and a 94% chance the 2011 run was smaller than the 20%-inflated 2010 Chapman point estimate (an ad-hoc bias adjustment of the 2010 estimate; see above).

Run timing---Tag release data were sparse, resulting in a problem of observing very few or zero tag releases in many strata for a number of subpopulations. As a result, tests of independence likely have low power to detect differences in run timing. Similar to the 2010 season, results indicate a significant difference in run timing between the pooled group of mainstem spawning fish versus tributary spawning populations ($\chi^2_{d.f.=4} = 9.35$, *p* value = 0.053; Fisher exact test, *p* value = 0.025). While both groups had the highest tag release in stratum 3 (Table 4), only one of the successfully fated radio tagged Chinook salmon released after stratum 3 spawned in a tributary location, whereas 45 tags (~45% of successfully fated tags) spawned in the mainstem river post-stratum 3 (Table 13), indicating that tributary fish likely entered the river earlier than mainstem spawning animals (Figure 10). No other significant differences in run timing were found amongst tributary populations, mainstem populations, or in a test between the Gechiak and rest-of-river run, although we again caution that these tests likely have low power.

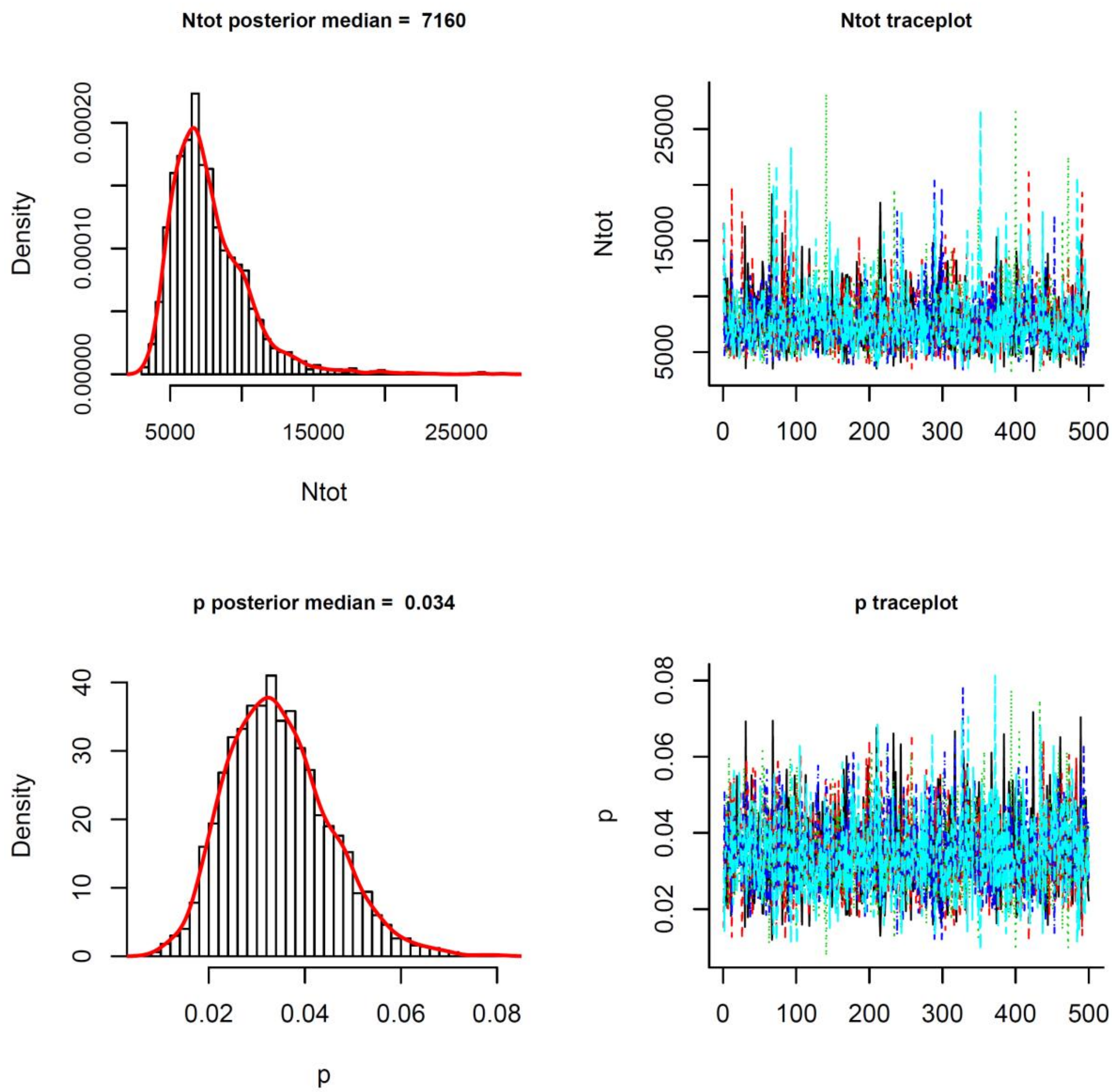

Figure 9. Marginal posterior distributions (left panels) and traceplots (right panels) for a Bayesian implementation of the pooled Lincoln-Petersen estimator of total Togiak River Chinook salmon abundance in 2011 that escaped past the commercial fishery in Togiak Bay. Distributions are based upon 2,500 posterior draws; red lines represent a kernel smoothed density estimate. Traceplots (right panels) display five MCMC chains overlaid on each plot.

Table 13. Number of radio-tagged Chinook salmon tracked by strata to ADFG spawning survey river sections in the Togiak River drainage (*n*=113), 2011.

	River Section											
	Mainstem						*Tributary*					
Strata	A	B	C	D	E	F	Gechiak	Pungokepuk	Nayorurun	Kemuk	Ongivinuk	Twin Hills Channel
1	0	0	1	1	0	0	0	0	0	0	1	0
2	2	4	4	0	1	4	2	0	0	0	1	0
3	6	9	8	9	5	0	3	0	3	1	4	0
4	5	6	6	2	7	1	0	0	0	0	0	0
5	9	1	4	1	0	3	0	1	0	0	0	0
Total	*22*	*20*	*23*	*13*	*13*	*8*	*5*	*1*	*3*	*1*	*6*	*0*

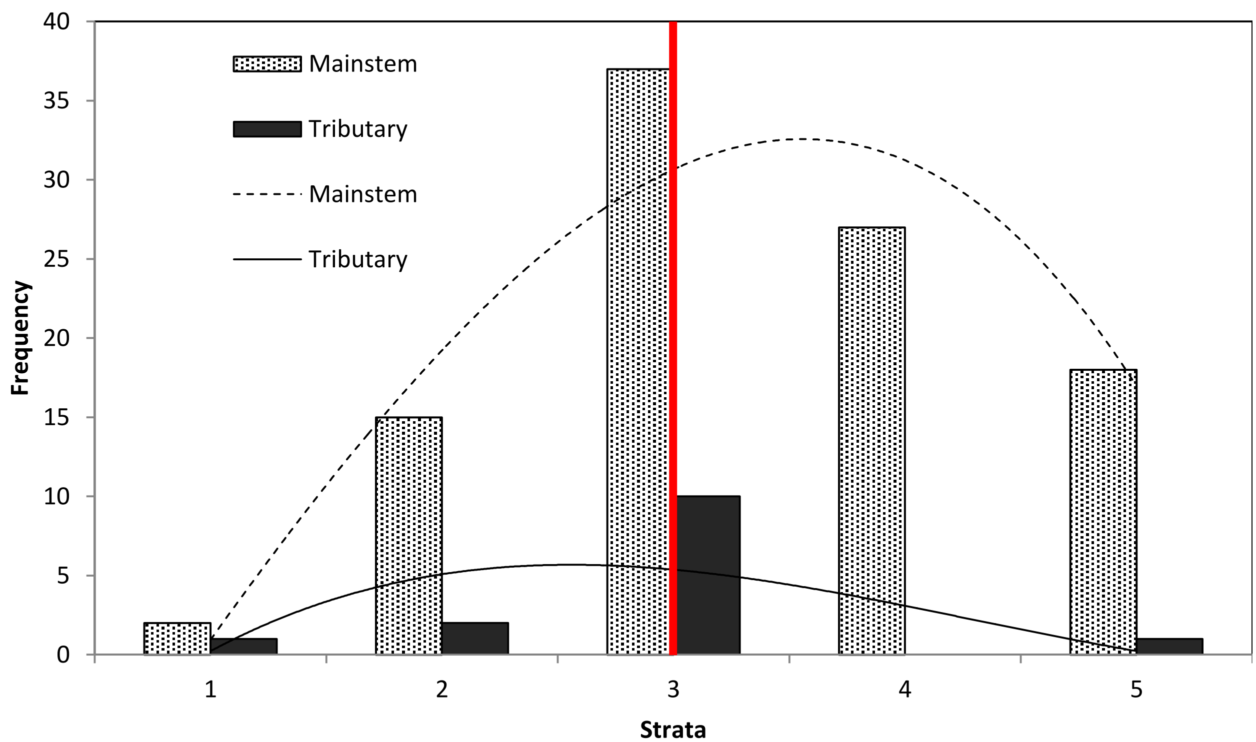

Figure 10. The frequency of radio tagged fish spawning in either mainstem (light bars and dashed line) or tributaries (dark bars and solid line), by strata, in the Togiak drainage, 2011. The red line (center of sampling strata) highlights the slight skew represented by the different run timing into the lower river for mainstem and tributary spawners.

Discussion

Based on prior experience, we began fishing to capture Chinook salmon for tagging on 23 June 2011 and only captured one Chinook salmon on that date. In contrast, we began fishing on 20 June in 2008 and did not capture a Chinook salmon until 26 June (Anderson 2009), on 25 June in 2009 and only captured and tagged two Chinook salmon (Anderson 2010), but captured eight fish when we started fishing on 22 June 2010 (Tanner & Sethi 2011). In 1988 and 1990, results of a sonar project stationed on the Pungokepuk River estimated the Chinook salmon run start date to be approximately 25 June (Irving et. al 1995). This leads us to believe that we captured most, if not all of the early run in the Togiak River.

From 2008 through 2011, 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 (Tanner and Sethi 2011), and 70% in 2011. This finding was consistent with the selectivity of the gill net mesh size used, since it favored capture of larger-bodied Chinook salmon that tend to be female. In 2010, most Chinook salmon sampled at the weir were males (55%), while the sex ratio of all tagged fish that spawned in Gechiak Creek in 2010 was roughly equal (4 males, 4 females, and 1 unknown). In 2011, females comprised more than half (55%) of the fish sampled at the weir, and of the five radio tagged fish that spawned in Gechiak Creek, three were female.

In all years of this study, the dominate age classes have been ages 1.3 and 1.4. The dominate age class in 2010 was age 1.3 (74% of marked fish and 55% of fish sampled through the weir), which was consistent with the 2008 study (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, with 71% and 49% of the fish sampled from gill nets and the weir, respectively.

Anderson (2010) and Tanner and Sethi (2011) reported that Chinook salmon appear to hold within the lower river in large concentrations until late July, which we confirmed in 2011. Tributary spawning fish not only exhibit earlier run timing than mainstem spawners, but the tributary fish spend less time holding in the lower reaches of the Togiak River. However, all radio tagged fish spent an average of 11 to 14 days within or below Mainstem A after they were tagged, and 47 out of 91 radio tagged fish that spawned in Mainstem B – F or a tributary held lower in the river for two weeks or longer.

Lengthy holding times in the lower river can be consequential to the population, as these areas are typically the most heavily fished in the sport and subsistence fisheries. This holding behavior increases the likelihood of tagged fish being harvested by either sport or subsistence fishermen. Of our 171 radio tagged fish, 32 were successfully tracked to different locations over a period of 2 – 4 weeks before they seemingly disappeared from the system, resulting in a fate assignment of unknown (Table 11). Though these 32 Chinook salmon were not reported to have been harvested, we suspect that they may have been captured and removed from the system in one of the fisheries. If we include these 32 Chinook salmon with the 9 fish that were reported harvested, then 24% rather than 5% of all radio tagged Chinook salmon were harvested. However, we must note that the same movement and disappearance characteristics of what we defined as a Suspected Harvest may in fact be a mid-season radio tag failure, though we deemed a tag failure to be unlikely.

Recommendations

We recommend that paired abundance estimates from the mark-recapture experiment and aerial counts be used to develop a more precise aerial survey program as an appropriate and affordable management tool. 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 to use for long-term annual monitoring.

In some respects, the precision of the spawning abundance estimate from the study design employed here is limited by the number of Chinook salmon spawning in the Gechiak tributary, a relatively small component of the total run. For example, in 2010 and 2011, only 381 and 241 Chinook salmon, respectively, passed the Gechiak weir, with only 8 and 9 tags, respectively, recovered in the systematic Gechiak weir recapture sample. In order to improve the precision of the abundance estimate, we recommend adding carcass surveys as an additional recapture event in 2012. Because our tagging design attempts to ensure that all subpopulations receive equal tagging rates by standardizing the marking effort, opportunistic carcass sampling throughout the Togiak drainage provides valid recapture effort so long as tagged and untagged fish have equal chances of becoming spawned out carcasses available to be detected in carcass surveys. A Lincoln-Petersen abundance estimate can be calculated using the pooled number of recaptured unmarked fish (both the untagged Chinook salmon passing the Gechiak weir and the untagged carcasses) and recaptured marked fish (both the tagged Chinook salmon passing the Gechiak weir and the tagged carcasses). Opportunistic ground surveys should be conducted through the spawning period, with the following data 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 including numbers of each of the five marks (color coded spaghetti tags), 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 there is any uncertainty about whether a fish has been marked, it should be excluded from both counts and noted as “unknown”. Once a carcass has been sampled, it should be mutilated by cutting off the caudal fin to avoid double-counting in future surveys.

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Appendix 1. R code to run the pooled Lincoln Petersen model in WinBUGS .

```
# Bayesian implementation of Togiak abundance estimate for the 2011 season
# NOTE: this R code implements a classical Lincoln Petersen estimator based upon a binomial
distribution likelihood
# for the tags and for the unmark recaptures.  This requires the user to have WinBUGS installed
on their machine
# and package "R2WinBUGS" in their R library.

# Suresh A. Sethi, v. 2.9.12

# set directories, load packages
    library(R2WinBUGS)
    setwd("YourLocation")
    bd <- "YourBUGSLocation" # need to use bugs.directory = bd in all bugs() calls

# Observed data
        T <- 290 # all tags released (288 from gillnetting, 2 from hook and line)
        C <- 241-9 # unmarks recaptured, 241 total Chinook over weir, 9 had tags
        R <- 9 # marks recaptured at weir

# write and fit the model using R2WinBUGS
# step 1) write model
    sink("PoolPetersen.2.9.12.txt")
    cat("
    model {
        # Data###
            #T = number marks released; C = number of unmarked recaps; R = number marked
recaps
        # Parameters fit in the model ###
            # p = catchability
            # logU = total unmarked population on log scale
        # Calculated and derived parameters ###
            # Ntot total population which is sum of U and total marks released
        # priors
            p ~ dbeta(1,1) # can also try p ~ dunif(0,1)
            logU~dunif(0,14)
            levelU<-(exp(logU))
            U<-round(levelU)
            # Alternatively, use U ~ dflat(), but this runs slower and the inits() function below
need be modified

        # likelihood: Pr (data|estimated parameters)
            R ~ dbin(p,T) # recovery of marked fish|catchability and # tags released
            C ~ dbin(p,U)  # capture of newly unmarked fish|catchability and unmark pop. size

        # derived quantities
            Ntot <- U + T
```

Appendix 1. Continued.

```
            } # end WinBUGS model code
    ",fill=T)
    sink()

    # step 2) package the data for WinBUGS
        win.data <- list(T=T,C=C,R=R.)
    # step 3) specify 'inits' function
    # initial value for U must be at least at great as C
        inits <- function(){list( p=runif(1), logU=log(C)+runif(1,1,2) )}
    # step 4) specify parameters to track during the MCMC implementation
        params <- c("p","U","Ntot")
    # step 5) MCMC settings
        nc = 5; ni = 1000000; nb = 950000; nt = 100
    # step 6) run Gibbs sampler to implement MCMC estimation of the model under Bayesian
specification
        out <- bugs(data=win.data,inits=inits, parameters=params, model =
"PoolPetersen.2.9.12.txt", n.thin=nt, n.chains=nc,
            n.burnin=nb, n.iter=ni, debug=T,bugs.directory=bd, working.directory=getwd() )

    # Validate model
    # Check whether chains for tracked parameters have converged by checking for Gelman-
Brooks-Rubin Rhat
    # statistics of less than 1.1 across parallel chains (Brooks and Gelman 1998).
        out$sum[out$sum[,"Rhat"]<1.1,];rownames(out$sum)[out$sum[,"Rhat"]<1.1] #
parameters with Rhat <1.1

    # diagnostics plot, marginal posterior distributions of Ntot and p, traceplots
    par(mfrow=c(2,2))
    hist(out$sims.list$Ntot,nclass=50,freq=F,main=paste("Ntot posterior median =
",round(median(as.numeric(out$sims.list$Ntot)),0)),
        cex.main=.8,xlab="Ntot",cex.axis=.9)
    lines(density(out$sims.list$Ntot,adjust=1),lty=1,lwd=2,col="red")
    matplot(out$sims.array[,1:nc,"Ntot"],type="l",main="Ntot
traceplot",bty="l",cex.main=.8,ylab="Ntot") # population.mean trace

    hist(out$sims.list$p,nclass=50,freq=F,main=paste("p posterior median =
",round(median(as.numeric(out$sims.list$p)),3)),
        cex.main=.8,xlab="p")
    lines(density(out$sims.list$p,adjust=1),lty=1,lwd=2,col="red")
    matplot(out$sims.array[,1:nc,"p"],type="l",main="p
traceplot",bty="l",cex.main=.8,ylab="p") # population.mean trace

    # post-processing of WinBUGS posterior draws in R to calculate probability N_2011 <
N_2010 or < 1.2*N_2010
    P1 <- sum(out$sims.list$N < 10096)/length(out$sims.list$N); P1 # P(Nhat2011 < Nhat2010)
    P2 <- sum(out$sims.list$N < 1.2*10096)/length(out$sims.list$N); P2 # P(Nhat2011 <
Nhat2010_20%Inflated)
```

Appendix 2. Count of Chinook salmon marked with spaghetti tags and unmarked Chinook salmon through the Gechiak Creek weir, 2011.

Date	No. Untagged Counted	No. Tagged Counted	Total Daily Count	Cumulative Total Count
23-Jun	0	0	0	0
24-Jun	1	0	1	1
25-Jun	0	0	0	1
26-Jun	0	0	0	1
27-Jun	0	0	0	1
28-Jun	0	0	0	1
29-Jun	1	0	1	2
30-Jun	0	0	0	2
1-Jul	1	0	1	3
2-Jul	0	0	0	3
3-Jul	0	0	0	3
4-Jul	0	0	0	3
5-Jul	0	0	0	3
6-Jul	0	0	0	3
7-Jul	4	0	4	7
8-Jul	1	0	1	8
9-Jul	6	0	6	14
10-Jul	10	0	10	24
11-Jul*	1	0	1	25
12-Jul	-	-	-	-
13-Jul	-	-	-	-
14-Jul	-	-	-	-
15-Jul	-	-	-	-
16-Jul*	6	0	6	31
17-Jul*	8	1	9	40
18-Jul*	2	0	2	42
19-Jul*	1	0	1	43
20-Jul	5	0	5	48
21-Jul	3	0	3	51
22-Jul	9	0	9	60
23-Jul	2	0	2	62
24-Jul	13	0	13	75
25-Jul	4	1	5	80
26-Jul	5	0	5	85
27-Jul	16	0	16	101
28-Jul	12	0	12	113
29-Jul	16	1	17	130
30-Jul	1	0	1	131
31-Jul	0	0	0	131
1-Aug	2	0	2	133
2-Aug	10	0	10	143
3-Aug	5	0	5	148
4-Aug	5	0	5	153
5-Aug	2	0	2	155
6-Aug	3	1	4	159

Appendix 2. Continued.

Date	No. Untagged Counted	No. Tagged Counted	Total Daily Count	Cumulative Total Count
7-Aug	3	0	3	162
8-Aug	4	0	4	166
9-Aug	10	1	11	177
10-Aug	3	0	3	180
11-Aug	5	2	7	187
12-Aug	8	2	10	197
13-Aug	1	0	1	198
14-Aug	0	0	0	198
15-Aug	5	0	5	203
16-Aug	8	0	8	211
17-Aug	3	0	3	214
18-Aug	0	0	0	214
19-Aug	2	0	2	216
20-Aug	10	0	10	226
21-Aug	1	0	1	227
22-Aug	3	0	3	230
23-Aug	0	0	0	230
24-Aug	1	0	1	231
25-Aug	1	0	1	232
26-Aug	3	0	3	235
27-Aug	3	0	3	238
28-Aug	2	0	2	240
29-Aug	0	0	0	240
30-Aug	0	0	0	240
31-Aug	1	0	1	241
1-Sep	0	0	0	241
2-Sep	0	0	0	241
3-Sep[†]	0	0	0	241
Total	232	9	241	

"-" 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.
"†" denotes a partial count on the day the weir was closed, then disassembled and removed from the river.

Appendix 3. Summary of biological data and tracking history for radio tagged Chinook salmon in the Togiak River, 2011.

Tagging Stratum	Date Tagged	Fish ID	Age	Sex	Length (mm)	Fate[a]	Number of Detections
1	23-Jun	144	1.3	M	698	D	44
1	28-Jun	44	1.4	F	990	Harvested	10
1	30-Jun	70	1.4	F	880	Unknown	3
1	1-Jul	27	1.4	F	983	Harvested	7
1	1-Jul	156	1.3	F	796	C	22
1	2-Jul	1	1.4	F	939	Unknown	42
1	2-Jul	60	1.3	M	692	Ongivinuk	22
1	2-Jul	82	--	F	895	Unknown†	7
1	2-Jul	148	1.4	F	760	Unknown†	28
2	3-Jul	20	1.4	M	840	Unknown†	3
2	3-Jul	30	1.4	F	891	Unknown†	7
2	3-Jul	96	--	F	843	B	20
2	3-Jul	108	2.3	F	922	F	18
2	3-Jul	149	2.4	F	927	Unknown†	15
2	4-Jul	56	1.3	U	836	Unknown†	6
2	4-Jul	122	1.4	F	840	B	23
2	5-Jul	23	1.4	F	895	Gechiak	49
2	5-Jul	78	1.4	F	890	Harvested	6
2	5-Jul	137	1.4	F	809	Unknown	2
2	6-Jul	5	1.4	F	820	F	33
2	6-Jul	13	--	F	870	Unknown	13
2	6-Jul	37	--	F	810	Unknown†	9
2	6-Jul	48	1.4	F	970	Unknown†	12
2	6-Jul	110	1.4	F	875	F	23
2	6-Jul	132	1.3	F	820	Unknown	27
2	7-Jul	126	1.2	M	610	C	22
2	7-Jul	133	--	F	825	Unknown†	5
2	8-Jul	41	1.4	F	981	Harvested	8
2	8-Jul	52	2.3	M	824	A	41
2	8-Jul	64	1.4	M	932	A	29
2	8-Jul	74	1.4	M	869	Ongivinuk	17
2	8-Jul	88	2.3	F	772	C	20
2	8-Jul	92	1.4	M	867	Unknown†	9
2	8-Jul	99	1.4	M	963	B	17
2	8-Jul	114	1.4	F	780	C	27
2	8-Jul	141	1.4	F	888	Unknown†	19
2	8-Jul	164	1.4	F	864	Unknown†	6
2	9-Jul	31	2.2	F	885	B	15
2	9-Jul	34	--	F	847	E	37
2	9-Jul	57	1.4	M	892	C	27

Appendix 3. Continued.

Tagging Stratum	Date Tagged	Fish ID	Age	Sex	Length (mm)	Fate[a]	Number of Detections
2	9-Jul	103	1.4	F	859	Unknown†	13
2	9-Jul	128	1.4	F	738	Unknown†	25
2	9-Jul	168	1.3	M	760	F	39
3	10-Jul	6	1.4	F	774	Harvested	16
3	10-Jul	9	--	F	892	Unknown†	6
3	10-Jul	16	1.2	M	633	Unknown†	5
3	10-Jul	42	--	F	-	Unknown†	7
3	10-Jul	53	1.4	F	951	Unknown†	63
3	10-Jul	66	1.4	F	950	Nayorurun	11
3	10-Jul	79	1.4	M	890	Nayorurun	26
3	10-Jul	104	--	M	-	D	22
3	10-Jul	111	1.4	M	961	B	16
3	10-Jul	118	1.3	F	823	C	20
3	10-Jul	127	1.4	F	967	C	49
3	10-Jul	157	--	F	910	Dead/Regurgitated	16
3	10-Jul	160	--	M	920	B	9
3	11-Jul	17	1.4	F	892	E	45
3	11-Jul	24	1.4	U	850	A	29
3	11-Jul	38	1.4	F	975	D	25
3	11-Jul	71	1.4	F	870	Ongivinuk	14
3	11-Jul	75	1.4	M	1001	A	13
3	11-Jul	97	1.4	F	865	B	27
3	11-Jul	119	1.4	F	939	B	30
3	11-Jul	134	1.4	F	935	Unknown†	14
3	11-Jul	142	1.4	M	913	Ongivinuk	22
3	12-Jul	10	1.4	F	932	B	38
3	12-Jul	28	1.2	F	655	Kemuk	20
3	12-Jul	49	1.4	M	908	C	30
3	12-Jul	83	1.4	M	857	Ongivinuk	21
3	12-Jul	100	1.3	F	841	A	18
3	12-Jul	109	1.2	M	628	Gechiak	21
3	12-Jul	123	1.4	F	916	D	23
3	12-Jul	153	1.4	F	863	E	20
3	13-Jul	35	1.4	M	942	D	38
3	13-Jul	61	1.4	M	980	D	37
3	13-Jul	145	1.3	M	866	B	21
3	13-Jul	169	1.4	F	856	C	20
3	14-Jul	2	1.3	M	823	D	35
3	14-Jul	21	--	F	1020	Unknown	24
3	14-Jul	45	1.3	F	796	Gechiak	25

Appendix 3. Continued.

Tagging Stratum	Date Tagged	Fish ID	Age	Sex	Length (mm)	Fate[a]	Number of Detections
3	14-Jul	65	--	F	890	Unknown†	19
3	14-Jul	67	1.4	F	873	D	25
3	14-Jul	138	1.4	M	904	E	35
3	14-Jul	161	1.4	F	847	E	24
3	14-Jul	165	1.4	M	918	D	40
3	15-Jul	14	1.4	F	933	Ongivinuk	17
3	15-Jul	89	1.4	F	869	Gechiak	18
3	15-Jul	93	2.4	F	847	Unknown	59
3	15-Jul	101	1.4	F	879	C	15
3	15-Jul	115	1.4	F	799	C	28
3	15-Jul	150	1.4	F	845	B	14
3	16-Jul	3	1.4	F	899	A	33
3	16-Jul	36	2.2	F	788	E	23
3	16-Jul	46	1.4	F	872	A	24
3	16-Jul	50	1.4	F	839	Dead/Regurgitated	7
3	16-Jul	58	1.4	F	918	Unknown†	10
3	16-Jul	68	2.3	F	966	C	20
3	16-Jul	80	2.2	M	717	B	21
3	16-Jul	112	1.4	F	857	C	18
3	16-Jul	116	1.3	F	789	D	21
3	16-Jul	124	1.4	M	749	B	20
3	16-Jul	139	1.4	F	805	A	17
4	17-Jul	22	--	F	980	Harvested	6
4	17-Jul	39	1.4	F	963	Unknown†	8
4	17-Jul	72	1.4	M	1000	B	17
4	17-Jul	84	1.2	M	660	E	41
4	17-Jul	87	1.4	F	800	A	19
4	17-Jul	90	1.4	F	815	Unknown†	12
4	17-Jul	98	1.4	F	950	A	31
4	17-Jul	135	1.4	F	950	B	38
4	17-Jul	158	--	--	--	Harvested	7
4	17-Jul	166	2.4	F	985	C	27
4	18-Jul	25	1.4	F	911	B	28
4	18-Jul	32	1.4	F	844	C	16
4	18-Jul	129	2.3	F	910	C	31
4	18-Jul	143	1.4	F	939	Unknown†	16
4	18-Jul	162	1.4	M	909	B	15
4	19-Jul	11	--	M	805	Unknown†	17
4	19-Jul	18	1.4	F	839	Unknown†	10
4	19-Jul	76	1.4	F	900	D	49

Appendix 3. Continued.

Tagging Stratum	Date Tagged	Fish ID	Age	Sex	Length (mm)	Fate[a]	Number of Detections
4	19-Jul	105	1.4	F	930	C	27
4	19-Jul	106	1.4	F	830	Unknown†	21
4	19-Jul	151	1.4	F	895	E	23
4	19-Jul	154	1.4	F	925	Dead/Regurgitated	14
4	20-Jul	54	1.3	F	792	C	17
4	20-Jul	120	1.2	M	562	C	19
4	21-Jul	7	1.4	F	750	Dead/Regurgitated	15
4	21-Jul	43	1.4	M	880	B	23
4	21-Jul	94	1.4	F	872	Dead/Regurgitated	11
4	21-Jul	130	1.2	F	893	Unknown	42
4	21-Jul	146	1.2	M	560	A	39
4	21-Jul	170	1.4	F	855	E	17
4	21-Jul	171	2.4	F	926	E	19
4	22-Jul	29	--	F	895	B	20
4	22-Jul	62	1.4	F	938	A	42
4	22-Jul	63	1.4	F	860	E	36
4	22-Jul	163	1.4	F	825	E	19
4	23-Jul	8	1.4	F	860	Dead/Regurgitated	13
4	23-Jul	33	--	F	891	E	36
4	23-Jul	69	1.4	F	923	A	42
4	23-Jul	102	1.4	F	919	F	21
4	23-Jul	152	1.3	M	817	D	20
5	24-Jul	19	1.4	F	941	Harvested	4
5	24-Jul	26	1.4	F	864	Unknown†	15
5	24-Jul	47	--	F	922	Unknown	24
5	24-Jul	121	1.4	F	821	A	27
5	25-Jul	117	1.4	M	825	Unknown†	7
5	25-Jul	131	1.4	F	895	D	42
5	27-Jul	15	1.4	F	927	A	24
5	27-Jul	55	1.3	M	733	A	25
5	27-Jul	73	1.4	F	875	Unknown†	13
5	27-Jul	81	1.4	F	830	Unknown	10
5	27-Jul	95	1.4	M	970	C	18
5	27-Jul	107	--	F	926	A	28
5	27-Jul	125	1.4	F	890	A	18
5	27-Jul	136	1.3	F	870	F	26
5	28-Jul	4	1.3	F	732	F	42
5	28-Jul	40	1.4	F	885	B	18
5	28-Jul	59	1.3	M	712	A	27
5	28-Jul	91	1.4	F	808	A	37
5	28-Jul	167	1.3	F	895	C	21

Appendix 3. Continued.

Tagging Stratum	Date Tagged	Fish ID	Age	Sex	Length (mm)	Fate[a]	Number of Detections
5	29-Jul	77	1.4	F	900	A	40
5	29-Jul	113	1.4	F	828	A	17
5	30-Jul	51	--	M	--	C	21
5	30-Jul	147	1.4	F	775	Harvested	15
5	30-Jul	155	1.4	F	874	Pungokepuk	21
5	30-Jul	159	2.3	M	809	F	14
5	31-Jul	140	1.5	M	807	Unknown	6
5	1-Aug	85	1.3	M	756	C	17
5	3-Aug	86	1.5	F	930	Unknown†	48
5	5-Aug	12	1.4	F	899	Unknown†	10

†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 Nayorurun (Kashaiak) River
D = Nayorurun River to Kemuk River
E = Kemuk River to Ongivinuk River
F = Ongivinuk River to Togiak Lake