Fishery Data Series No. 23-14

# Run Timing and Spawning Distribution of Copper River Chinook Salmon, 2019–2021

by

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and

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Alaska Department of Fish and Game

Divisions of Sport Fish and Commercial Fisheries

## Symbols and Abbreviations

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**Weights and measures (metric)**

| | |
|---|---|
| centimeter | cm |
| deciliter | dL |
| gram | g |
| hectare | ha |
| kilogram | kg |
| kilometer | km |
| liter | L |
| meter | m |
| milliliter | mL |
| millimeter | mm |

**Weights and measures (English)**

| | |
|---|---|
| cubic feet per second | $ft^3/s$ |
| foot | ft |
| gallon | gal |
| inch | in |
| mile | mi |
| nautical mile | nmi |
| ounce | oz |
| pound | lb |
| quart | qt |
| yard | yd |

**Time and temperature**

| | |
|---|---|
| day | d |
| degrees Celsius | °C |
| degrees Fahrenheit | °F |
| degrees kelvin | K |
| hour | h |
| minute | min |
| second | s |

**Physics and chemistry**

| | |
|---|---|
| all atomic symbols | |
| alternating current | AC |
| ampere | A |
| calorie | cal |
| direct current | DC |
| hertz | Hz |
| horsepower | hp |
| hydrogen ion activity (negative log of) | pH |
| parts per million | ppm |
| parts per thousand | ppt, ‰ |
| volts | V |
| watts | W |

**General**

| | |
|---|---|
| Alaska Administrative Code | AAC |
| all commonly accepted abbreviations | e.g., Mr., Mrs., AM, PM, etc. |
| all commonly accepted professional titles | e.g., Dr., Ph.D., R.N., etc. |
| at | @ |
| compass directions: | |
| east | E |
| north | N |
| south | S |
| west | W |
| copyright | © |
| corporate suffixes: | |
| Company | Co. |
| Corporation | Corp. |
| Incorporated | Inc. |
| Limited | Ltd. |
| District of Columbia | D.C. |
| et alii (and others) | et al. |
| et cetera (and so forth) | etc. |
| exempli gratia (for example) | e.g. |
| Federal Information Code | FIC |
| id est (that is) | i.e. |
| latitude or longitude | lat or long |
| monetary symbols (U.S.) | $, ¢ |
| months (tables and figures): first three letters | Jan,...,Dec |
| registered trademark | ® |
| trademark | ™ |
| United States (adjective) | U.S. |
| United States of America (noun) | USA |
| U.S.C. | United States Code |
| U.S. state | use two-letter abbreviations (e.g., AK, WA) |

**Mathematics, statistics**

| | |
|---|---|
| *all standard mathematical signs, symbols and abbreviations* | |
| alternate hypothesis | $H_A$ |
| base of natural logarithm | *e* |
| catch per unit effort | CPUE |
| coefficient of variation | CV |
| common test statistics | (F, t, $\chi^2$, etc.) |
| confidence interval | CI |
| correlation coefficient (multiple) | R |
| correlation coefficient (simple) | r |
| covariance | cov |
| degree (angular) | ° |
| degrees of freedom | df |
| expected value | *E* |
| greater than | > |
| greater than or equal to | ≥ |
| harvest per unit effort | HPUE |
| less than | < |
| less than or equal to | ≤ |
| logarithm (natural) | ln |
| logarithm (base 10) | log |
| logarithm (specify base) | $log_2$, etc. |
| minute (angular) | ′ |
| not significant | NS |
| null hypothesis | $H_O$ |
| percent | % |
| probability | P |
| probability of a type I error (rejection of the null hypothesis when true) | α |
| probability of a type II error (acceptance of the null hypothesis when false) | β |
| second (angular) | ″ |
| standard deviation | SD |
| standard error | SE |
| variance | |
| population | Var |
| sample | var |

# *FISHERY DATA SERIES NO. 23-14*

# RUN TIMING AND SPAWNING DISTRIBUTION OF COPPER RIVER CHINOOK SALMON, 2019–2021

by

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# ABSTRACT

A total of 1,975 radio tags were placed in migrating Chinook salmon *Oncorhynchus tshawytscha* in the Copper River from 2019 through 2021 to examine spawning distribution and run timing. Chinook salmon were captured with fish wheels in the Lower Copper River near Baird Canyon and tracked to upriver destinations with 10 fixed-tracking stations and a series of aerial surveys. Spawning distribution was estimated for 6 major spawning tributaries/areas each year using a weighting process. Estimated annual proportions of the escapement ranged from 0.19 to 0.24 for the Upper Copper River area, 0.19 to 0.27 for the Gulkana River, 0.01 to 0.05 for the Tazlina River, 0.10 to 0.19 for the Tonsina River, 0.19 to 0.28 for the Chitina River, and was 0.14 all 3 years for the Klutina River. Estimated annual abundances for the 6 major spawning tributaries/areas from 2019 through 2021 were 3,410–8,369 for the Upper Copper River area, 4,419–6,548 for the Gulkana River, 289–961 for the Tazlina River, 2,171–4,591 for the Tonsina River, 3,535–9,767 for the Chitina River, and 2,608–4,909 for the Klutina River. The annual estimated proportions of the total escapement that returned to 1 of the 9 original aerial index streams ranged from 0.39 to 0.47. The estimated annual proportion of the Gulkana River fish that spawned above the Alaska Department of Fish & Game (ADF&G) counting tower ranged from 0.58 to 0.68. Run timing patterns were similar during all 3 years with the Upper Copper River fish having the earliest run timings, followed by the Gulkana, Chitina, Tazlina, Tonsina, and Klutina Rivers.

A secondary analysis was performed weighting each radiotagged fish using adaptive resolution imaging sonar (ARIS) estimates of “large” fish, which were all presumed to be Chinook salmon. These results are presented in this report as Appendix A.

Keywords: Chinook salmon, *Oncorhynchus tshawytscha,* Copper River, radiotelemetry, run timing, abundance, escapement, Gulkana River counting tower, ARIS

# INTRODUCTION

The Copper River is a glacially dominated system located in southcentral Alaska and is the second largest river in Alaska in terms of discharge. The drainage is expansive, covering 61,440 $km^2$ and encompassing 3 mountain ranges: Alaska, Wrangell, and Chugach. The mainstem Copper River originates at the Copper Glacier and flows 530 km to the Gulf of Alaska, east of Prince William Sound. The Copper River supports spawning populations of anadromous Chinook salmon *Oncorhynchus tshawytscha*, sockeye salmon *O. nerka*, coho salmon *O. kisutch*, steelhead *O. mykiss*, and Dolly Varden *Salvelinus malma*, as well as various resident species.

Total numbers of Chinook salmon returning to the Copper River have been estimated annually since 1998. Returns of Chinook salmon to the Copper River have fluctuated but are currently about half of initial levels. The latest 5-year (2017–2021) mean estimate of the total Copper River Chinook salmon run was 48,557 (Table 1), which is substantially lower than initial abundance estimates, where the estimated mean total run was 86,694 fish from 1998 through 2007.

Chinook salmon in the Copper River support important commercial, subsistence, personal use, and sport fisheries. These fisheries are separated spatially along the course of the Copper River, with several subsistence fisheries being dually managed by the state and federal governments. A very brief description of the fisheries and the associated harvest is outlined below. Figure 1 demarcates the boundaries for all of the fisheries, and Table 1 summarizes Chinook salmon harvests from the prominent fisheries.

- The Copper River District (CRD) commercial fishery is a saltwater fishery located in the area of the confluence of the Copper River. It has the highest harvest rates of all the fisheries. The most recent 10-year mean annual harvest (2012–2021) of Chinook salmon was 12,359 (Figure 1, Table 1).

- The CRD subsistence fishery is a state-only fishery that occurs within the same boundaries as the commercial fishery mentioned previously. The most recent 10-year mean annual harvest (2012–2021) of Chinook salmon was 571 (Figure 1, Table 1).
- The Chitina subdistrict (Haley Creek upstream to the Chitina/McCarthy Bridge) is a state personal use dip net fishery and a federal subsistence fishery that allows fish wheels, dip nets, and hook and line as legal gear types. The most recent 10-year (2012–2021) mean harvest for this fishery was 1,221 Chinook salmon (Figure 1, Table 1).
- The Glennallen subdistrict fishery spans the area from the Chitina/McCarthy Bridge upstream to the Slana River. It is a dually managed subsistence fishery. The state subsistence fishery component allows for fish wheels and dip nets and the federal subsistence fishery component allows for fish wheels, dip nets, and rod and reel. The most recent 10-year (2012–2021) mean harvest of Chinook salmon for this fishery was 3,233, which is the most of any inriver fishery in the drainage (Table 1).
- The Batzulnetas subsistence fishery (Figure 1) is also dually managed and encompasses a small portion of the Upper Copper River below Tanada Creek. The participation in this fishery is minimal, and it is almost entirely a sockeye salmon fishery. Chinook salmon harvest is not allowed under the state permit but is allowed in the mainstem Copper River with the federal permit. Most years Chinook salmon are not harvested in this fishery.
- All sport fisheries in the Copper River are managed by the state. Most harvest comes from the Gulkana, Klutina, and Tonsina Rivers (Figure 1). The most recent 10-year (2012–2021) mean harvest of Chinook salmon was 905 for the Copper River drainage (Table 1).

Drainagewide escapement of Chinook salmon in the Copper River has been estimated annually by subtracting estimated inriver harvest from the inriver abundance estimate. Since 2003, Chinook salmon inriver abundance has been estimated by the Native Village of Eyak (NVE) using mark–recapture methodology in the lower river (Piche et al. 2022). Escapement numbers have not fluctuated as much as total run numbers due to harvest restrictions. From 2003–2021, the drainagewide sustainable escapement goal (SEG) was 24,000 Chinook salmon, and this goal was not met in 4 of the last 8 years (2014, 2016, 2020, and 2021; Table 1).

Spawning distribution and stock-specific run timing of Chinook salmon in the Copper River was last assessed from 2001 to 2004 (Savereide 2005). There were 3 major findings from these studies:

- Chinook salmon returning to the Copper River spawned in 6 major tributaries/areas of the drainage: the Chitina, Tonsina, Klutina, Tazlina, Gulkana, and Upper Copper Rivers (Table 2).
- Although there was considerable overlap in run timing among the different spawning stocks, a general pattern was observed where upriver spawning stocks had an earlier run timing than downriver stocks.
- The 9 aerial index streams (Little Tonsina River, Greyling Creek, St. Anne Creek, Manker Creek, Mendeltna Creek, Kaina Creek, Gulkana River, East Fork Chistochina River, and Indian Creek) surveyed by Alaska Department of Fish and Game (ADF&G) to evaluate Chinook salmon escapement accounted for 34–46% of the total spawning escapement in the Copper River.

Spawning distribution and stock-specific run timing of Chinook salmon in the Copper River has been integral to the management of the Copper River Chinook salmon fishery. The personal use and subsistence fisheries are all mixed-stock fisheries, meaning they harvest fish from multiple origins. The higher up a mixed-stock fishery is in the drainage, the fewer stocks that fishery relies on, and the more important the upriver stocks are to those fisheries. The upriver stocks typically endure more harvest pressure because they migrate through more fishery areas. Previous distribution and run timing studies have demonstrated that the upriver stocks generally have an earlier run timing than lower river stocks. Based on this information, important regulatory actions have taken place to allow for more upriver fish to reach upriver subsistence users. For example, commercial fishing openings are now limited during the early part of the run (5 AAC 24.361), and the Chitina subdistrict cannot open any sooner than June 7 (5 AAC 77.591). These changes in management, along with changes in oceanic and freshwater conditions, fisheries prosecution, and weather patterns, may have affected the distribution and run timing of the Copper River stocks, all of which warranted revisiting a drainagewide distribution study.

This project mimicked the distribution component of the Savereide (2005) study, with several notable exceptions. The 2005 study used approximately 500 radio tags per year and estimated spawning distribution and run timing in 6 major tributaries/areas of the Copper River, along with inriver abundance of Chinook salmon in the Copper River. In this study, the sample size was increased to 650 radio tags annually to expand the objectives to estimate not only spawning distribution and run timing in the same 6 major tributary/areas, but also abundance within these areas and the proportion of Gulkana River Chinook salmon that spawn above the ADF&G counting tower.

# OBJECTIVES

The objectives of this study during 2019–2021 were to do the following:

1) Estimate the proportions of spawning Chinook salmon in the Copper River in each major spawning tributary/area (Chitina, Tonsina, Klutina, Tazlina, Gulkana, and Upper Copper Rivers) such that all estimated proportions were within 6 percentage points of the true values 95% of the time.
2) Estimate the abundance of Chinook salmon spawning in each major spawning tributary/area (Chitina, Tonsina, Klutina, Tazlina, Gulkana, and Upper Copper Rivers) such that all estimates were within 35% of the true values 95% of the time.
3) Estimate the proportions of Chinook salmon spawning in the 9 tributaries historically assessed annually during aerial surveys (Little Tonsina River, Greyling Creek, St. Anne Creek, Manker Creek, Mendeltna Creek, Kaina Creek, Gulkana River, East Fork Chistochina River, and Indian Creek) such that all estimated proportions were within 6 percentage points of the true value 95% of the time.
4) Describe the stock-specific (Chitina, Tonsina, Klutina, Tazlina, Gulkana, and Upper Copper Rivers) run-timing patterns of Chinook salmon past Baird Canyon.
5) Estimate the proportions of spawning Chinook salmon above and below the counting tower on the Gulkana River such that all estimated proportions were within 15 percentage points of the true values 95% of the time.

Beyond the stated objectives, an additional task was to do the following:

1) Apportion length and age classes of radiotagged Chinook salmon to each of the 6 respective spawning tributary/areas.

# METHODS

## STUDY AREA

The radiotracking surveys in this study covered all previously documented adult Chinook salmon locations in the Copper River and additional areas were explored on a survey-by-survey basis. All tributaries large enough to support Chinook salmon were surveyed from Miles Lake up the Copper River to Tanada Lake, and up the Chitina River to a point about 25 river kilometers (RKM) above the Tana River. Parts of the mainstem Copper River were flown on every survey to monitor migration rates, and efforts were made to track the entire mainstem each year.

## STUDY DESIGN

### Overview

This study estimated the spawning distribution (in proportions), escapement abundances (in numbers of fish), and run timing patterns of Chinook salmon in 6 major drainage/areas of the Copper River (Chitina, Tonsina, Klutina, Tazlina, Gulkana, and Upper Copper Rivers). Chinook salmon were captured in fish wheels and implanted with radio tags over the course of the run in the mainstem Copper River near Baird Canyon. Migrations of radiotagged fish were monitored with a combination of 10 fixed-tracking stations positioned at various points throughout the Copper River drainage (Figure 2), as well as with aerial tracking surveys from a fixed-wing aircraft. Proportions of fish spawning in various tributaries were estimated as the ratio of weighted numbers of radiotagged fish migrating into a specific tributary to the total number of radio tags surviving and migrating into all spawning tributaries. Escapement numbers were estimated postseason after the drainagewide abundance estimate was calculated and released by NVE. Run timing patterns of various stocks at the capture site were identified from final locations and the date and time of initial capture. Additionally, the proportion of Gulkana River Chinook salmon spawning above an ADF&G counting tower on the Gulkana River was estimated.

### Fish Capture and Radiotagging

Chinook salmon were captured in 1 or 2 fish wheels operated by NVE in the Lower Copper River near Baird Canyon (Figure 2). The capture site was approximately 70 km upstream from the mouth of the Copper River. Fish wheels, one on each bank, were fished all day, every day from mid-May through mid-July, and each wheel was checked at least 3 times a day. The fish wheels had relatively large live wells to provide ample space and water flow. In addition, the live wells had adjustable slots (escapement panels) on the downstream end that allowed small sockeye salmon to escape, which decreased crowding.

A total of 650 Chinook salmon radio tags were allocated for each season, but the ultimate number of deployed tags varied by year depending on the number of radio tags never deployed (e.g., catch rates dropped at the end of the season) and the number of radio tags that were redeployed (i.e., when radiotagged fish were captured and the tags returned, we would try to redeploy the tags). Radio tags were F1845B pulse encoded transmitters made by Advanced Telemetry Systems (ATS). Each radio tag emitted a signal every 1.5 s and was distinguishable by its frequency and encoded pulse pattern. Tags were equipped with a motion sensor that emitted a unique code when a tagged fish was inactive (i.e., no detectable movement) for 24 hours. Eight frequencies with encoded pulse patterns were used each season.

For tagging, captured Chinook salmon were dipnetted one at a time from the live wells attached to the fish wheels, placed in a tagging cradle filled with water, and measured to the nearest mm mid eye to tail fork (METF). A ratio of the daily catch from the fish wheels was used to determine the number of fish to be radiotagged each day. Initially, 1 in 4 captured fish received a radio tag, but this ratio was adjusted periodically each season as the run progressed depending on run strength, run timing, and available tags. The goal was to distribute radio tags evenly throughout the entire length of the run, but this was difficult considering all of the associated dynamics such as changes in capture probability due to fluctuating water levels. Therefore, radio tags were weighted post season based on the estimated "true" tagging rates (tags released per abundance of fish passing) during various time periods throughout the run. The proportion and run timing estimates were then calculated using the weighted values (discussed in greater detail in the *Data Reduction and Analysis* section).

Radio tags were inserted through the esophagus and into the upper stomach using a 30 cm plastic tube with a diameter equal to that of the radio tags. A rubber band was double-to-triple wrapped around each radio tag to help minimize tag loss (Schwanke and Tyers 2018). The radio tags were pushed through the esophagus such that the antenna end of the radio tag was seated 0.5 cm beyond the posterior base of the pectoral fin. Implants were performed without the use of anesthesia. A sample of 3 scales were removed from the left side of each radiotagged fish approximately 2 rows above the lateral line along a diagonal line downward from the posterior insertion of the dorsal fin to the anterior insertion of the anal fin (Welander 1940). Scales were prepped for aging in early winter and ages were determined postseason from scale patterns as described by Mosher (1969). Each tagged fish also received a uniquely numbered Floy Tag before they were released at the capture site.

## Radiotracking Equipment and Radiotracking Procedures

Radiotagged Chinook salmon were tracked along the course of the Copper River using a network of 10 fixed-tracking stations (Figure 2). Stations were functional during all periods Chinook salmon were migrating, ranging from 15 May to 5 September. Each station included 2 deep-cycle batteries, a solar panel, an antenna switch box, a steel housing box, 2 Yagi antennas, and an ATS Model R4500C receiver. The receivers were programmed to scan through the frequencies at 2 s intervals and from both antennas simultaneously. When a signal of sufficient strength was encountered, the receiver paused for 12 seconds on each antenna, and then tag frequency, tag code, signal strength, date, time, and antenna number was recorded on the receiver. Cycling through all frequencies took ~5 minutes depending on the number of active tags in the reception range and level of background noise. The relatively short cycle period minimized the chance that a radiotagged fish would swim past the receiver site undetected. Recorded data were downloaded to a laptop computer every 5–21 days.

Tracking stations were placed at various locations in the mainstem Copper River and within select tributaries (Figure 2). Three tracking stations were placed in the mainstem Copper River. The first station was located about 3 RKM (2019) and 11 RKM (2020–2021) above the tagging site to detect fish that successfully moved upstream of the tagging area. The second station was placed upstream of the Chitina/McCarthy Bridge at a location about 2 RKM below the Tonsina River confluence.

The third station was placed about 2 RKM below the Gakona River and any fish passing this site was considered an "Upper Copper River" spawner. The lower reaches of each major tributary (Chitina, Tonsina, Klutina, Tazlina, and Gulkana Rivers) also had tracking stations. Any fish passing these stations were considered spawners for those tributaries. Lastly, 2 additional stations were placed in the Gulkana River to track fish movements relative to the ADF&G counting tower (Objective 5). The first station was at Sourdough Landing, which helped track fish movements up the river, and the second was at the ADF&G counting tower (Figure 2), which specifically estimated the proportion of the Gulkana River bound fish spawned above the counting tower.

The distribution of radiotagged Chinook salmon throughout the Copper River drainage was further examined by aerial tracking from a Piper Super Cub. The purpose of the aerial tracking flights was to locate tags in spawning tributaries other than those monitored by fixed-tracking stations, to locate fish that the tracking stations may have failed to record, and to validate that fish recorded past tracking stations did migrate into that particular stream. A minimum of 2 aerial-tracking surveys for each of the 6 major spawning tributary areas were performed each year. The Gulkana River was flown as many as 5 times in a given year to address Objective 5. Tracking flights were conducted with 1 aircraft and 1 person (in addition to the pilot) utilizing an R4500C receiver. All frequencies were programed into the receiver prior to each flight and the receiver scanned through the frequencies at 2 s intervals. The observer would pause the receiver when a fish was detected so it would decode the radio tag. Flight altitude ranged from 100 to 300 m above the ground. Two "H" antennas, 1 on each wing strut, were mounted such that the antennas received signals perpendicular to the direction of travel. Once a tag was identified, its frequency, code, and GPS location were automatically recorded to the receiver.

## DATA REDUCTION AND ANALYSIS

ATS R4500C receivers at fixed-tracking stations were downloaded every 5–21 days and receivers used for the aerial surveys were downloaded after each day's flights. Once the fixed-tracking stations were downloaded, the data files were sorted by frequency and code and left in chronological order. The date that fish passed a fixed-tracking station was recorded as the date of passage at that location (not the day they showed up on the receiver, but the day they passed it and left detection). For aerial surveys, the data files were sorted by frequency, code, and signal strength, and the data point with the strongest signal strength for each tag was recorded as that fish's location.

To facilitate data analysis, a master Excel file was constructed that contained all tagging, fixed-tracking station, aerial tracking information, and catch/harvest reports for each radiotagged fish. Tagging information included date, length, age (when it became available), radio tag frequency, and radio tag code. Then a series of columns were inserted, one for each fixed-tracking station, and dates fish passed each station were added. Information was synthesized on a fish-by-fish basis each year to determine a final fate for each radiotagged fish. The fate possibilities were *spawner*, *personal use harvest*, *subsistence harvest*, *sport fish harvest*, *censored*, and *failure* (Table 3). Censored fish were detected making positive movement up the river, but either disappeared (unreported harvest or radio tag quit working), experienced radio tag regurgitation, or died before reaching 1 of the 6 major spawning areas/tributaries. A subcategory was also created for spawners that designated which of the 6 major tributary/areas the fish went to, and another subcategory for Gulkana River spawners designated whether each fish spawned above or below the ADF&G counting tower. There has been no documentation of spawning in the mainstem Copper River so all fish that stalled out in the mainstem Copper River were categorized as censored, regardless of whether or not the radio tags emitted active or inactive codes (Evenson and Wuttig 2000; Wuttig and Evenson 2001; Savereide and Evenson 2002; Savereide 2005).

*Drainagewide Distribution of Spawners*

Among fish classified as "spawners" that migrated past the tracking stations located in the lower reaches of the 6 major spawning tributary/areas, the proportions of fish that have fate *j* were estimated as:

$$\hat{P}_j = \frac{\sum_i^{\text{days}} R_{ij}}{\sum_j^{\text{fates}} \sum_i^{\text{days}} R_{ij}} \quad (1)$$

where:

$R_{ij}$ = the number of fish tagged on day *i* having fate *j*.

The same procedure was used to determine the proportion of Chinook salmon migrating in the 9 aerial index streams: Little Tonsina River, Greyling Creek, St. Anne Creek, Manker Creek, Mendeltna Creek, Kaina Creek, Gulkana River, East Fork Chistochina River, and Indian Creek. A Chinook salmon was assigned to an aerial index stream if its radio tag was located there at least once during an aerial tracking flight.

Certain assumptions must be met to obtain unbiased estimates of the spawning distribution. The first is that radiotagging Chinook salmon did not affect their migratory behavior. There was no direct test for this, but Savereide (2005) determined that handling delay was negligible during the 2002–2004 study, which was mirrored in this study in terms of radio tag deployment. The second assumption was that captured Chinook salmon were radiotagged in proportion to the magnitude of the run. The tagging in this study was designed to distribute tags over time proportional to passage of salmon past the tagging site with the option of weighting the data if necessary. The weighting procedure compared the number of tags deployed versus estimated passage during temporal strata from an inriver abundance estimator. To facilitate Objectives 1–5 data analyses, ADF&G staff generated an independent inriver estimate using the methods of Darroch (1961) and the package *recapr* developed by Tyers (2021) for use in the R program, in which temporal strata were used to examine weighting procedures. When weighting was necessary, the results were applied to the NVE staff generated abundance estimate to ensure accurate estimates of abundances for Objective 2.

Variation in the ratio of tags deployed versus the corresponding Darroch-estimated passage for temporal strata were tested using a global Chi-squared test at a significance level of $\alpha = 0.05$. If there was sufficient evidence that the ratio varied, each radiotagged fish was given a numeric weight that took into account estimated differences in the probability that an individual fish was tagged over time. Weights for each day of tagging were computed and assigned, and weights for each day within a stratum were computed similarly:

$$w_{i \in k} = \frac{\hat{A}_k}{x_k} \quad (2)$$

where:

$\hat{A}_k$ = estimated abundance of salmon past the tagging site during a time period (temporal stratum) k, and

$x_k$ = the number of radio tags deployed during the time period (temporal stratum) k.

For each day that radio tags were deployed, the weighted number of fish tagged on day $i$ having fate $j$ was calculated as:

$$\tilde{R}_{ij} = R_{ij} * w_i \tag{3}$$

and $\tilde{R}_{ij}$ was substituted for $R_{ij}$ in equation (1).

Variance of $\hat{P}_j$ was estimated using a parametric bootstrap procedure (Efron and Tibshirani 1993). Within each bootstrap replicate, the number of fish $R_{ij}^*$ was resampled using a multinomial distribution with a probability vector equal to the observed proportions for each fate, and estimated abundance $\hat{A}_k^*$ for each temporal stratum was drawn from normal distributions with means and variances equal to the estimated means and variances for the temporal strata abundance. These were used to calculate sampling weights $w_{i \in k}^*$ for substitution into Equation 1.

*Distribution of Spawners in the Gulkana River*

All radiotagged fish located within the Gulkana River and designated as *spawners* were used to estimate the proportions of fish that spawn above and below the ADF&G counting tower. Although this is an estimate of a binomial proportion, the same approaches as described in Equations 1–3 were used for estimating the 2 proportions, but in this instance, fate $j$ represented fish spawning above, or below, the ADF&G counting tower. Unlike Objective 1 that used all fish that passed a tracking station in the lower portion of each of the 6 major spawning tributary/areas, Objective 5 needed to be treated slightly different. Because angler induced mortality and natural mortality existed in the tributaries, only fish deemed to have successfully spawned were used when determining what proportion of the Gulkana River escapement that spawned above/below the ADF&G counting tower. This was determined on a fish-by-fish basis; fish deemed not to have spawned were culled from the experiment (e.g., fish that stalled out before reaching a spawning area were excluded). Methods used to determine if a Gulkana River bound fish spawned were the same as those used in a previous Gulkana River Chinook salmon specific telemetry study (Schwanke and Tyers 2018).

*Escapement Estimation Within the 6 Tributary/Areas*

Escapement of fish spawning in the Chitina, Tonsina, Klutina, Tazlina, Gulkana, and Upper Copper Rivers were determined using the estimated proportions (weighted) of escapement from this study and the estimated inriver escapement (IR) information (NVE generated inriver abundance minus estimated inriver harvest):

$$\hat{E}_j = \widehat{IR} * \hat{P}_j \tag{4}$$

where:

$\hat{E}_j$ = estimated escapement of salmon in tributary $j$;

$\widehat{IR}$ = estimated inriver escapement; and

$\hat{P}_j$ = the proportion of radio tags found in tributary $j$.

The variance of the escapement by tributary was estimated as (Goodman 1960):

$$Var\ \widehat{E}_j = Var\ \widehat{P}_j * \widehat{IR} + Var\ \widehat{IR} * \ \widehat{P}_j - Var\ \widehat{P}_j * Var\widehat{IR}. \quad (5)$$

<u>*Stock-Specific Run Timing*</u>

Run-timing patterns were described as time-density functions, where the relative abundance of stock *j* that enters the fishery during time interval *t* was described by (Mundy 1979):

$$f_j(t) = \frac{R_{tj}}{\sum_i^{days} R_{ij}} \quad (6)$$

where:

$f_j(t)$ = the empirical temporal probability distribution over the total span of the run for fish spawning in a tributary (or portion thereof) *j*; and

$R_{tj}$ = the subset of radiotagged Chinook salmon bound for tributary *j* that were caught and tagged during day *t*.

For this purpose, stocks were defined as all Chinook salmon spawning in the Chitina, Tonsina, Klutina, Tazlina, Gulkana, and Upper Copper drainages (all waters upstream of the mainstem Copper River tracking station located about 2 RKM below the Gakona River confluence). Those fish assigned a fate of "spawner" were used to determine the time-density functions.

The mean date of passage ($\bar{t}_j$) past Baird Canyon for fish spawning in tributary j was estimated as:

$$\bar{t}_j = \sum_t t\, f_j(t), \quad (7)$$

The variance of the run timing distribution was estimated as:

$$Var\ (t_j) = \sum_t \left(t - \bar{t}_j\right)^2 f_j(t). \quad (8)$$

The same 2 assumptions mentioned above for the *Distribution of Spawners* data analyses were applied, with the same procedure for weighting the data (Equations 2 and 3).

<u>*Age and Length Information*</u>

Although not listed as an objective, age and length composition of radiotagged Chinook salmon bound for major tributaries was calculated. The proportion of fish at age or length category *k* was calculated as:

$$\hat{p}_k = \frac{y_k}{n} \quad (9)$$

where:

$\hat{p}_k$ = the estimated proportion of Chinook salmon that were age or length category *k*;

$Y_k$ = the number of Chinook salmon sampled that were age or length category *k*; and

*n* = the total number of Chinook salmon sampled.

The variance of this proportion was estimated as:

$$\hat{V}[\hat{p}_k] = \frac{\hat{p}_k(1-\hat{p}_k)}{n-1} \quad (10)$$

*Alternative Weighting Scenario Using Sonar Data*

An adaptive resolution imaging sonar (ARIS) located about 1 RKM below Miles Lake has been operated by ADF&G Division of Commercial Fisheries since 2019. This sonar is used to count and apportion small (≤772 mm fork length [FL]) and large (>772 mm FL) fish, with the premise that all "large" fish are Chinook salmon. Although this sonar operates in a slightly different timeframe as the NVE M–R study and does not account for small Chinook salmon, we applied this study's radiotelemetry data to the ARIS "large" fish counts. Although this data should not be compared directly to the Savereide (2005) data, it is presented in this report as Appendix A.

# RESULTS

## SUMMARY OF FISH CAPTURED

In 2019, 656 Chinook salmon were captured and radiotagged at Baird Canyon from 27 May to 1 July (Figures 3 and 4). A tagging ratio of 1 in 5 captured fish was used to start the season; however, this ratio was incrementally lowered when catches in the 2 fish wheels increased to unexpected numbers. Tagging ratios were adjusted down to 1:20 in mid-June, when catch rates remained unexpectedly high, and were 1:5 at the end of the season. Overall, the Baird Canyon fish wheels captured 4,685 unique fish and 14% were radiotagged.

In 2020, 586 Chinook salmon were radiotagged from 14 May to 11 July (Figures 3 and 4). Catch rates were lower in 2020 because only 1 fish wheel was operated that year, and because fewer fish entered the river (Table 1). The tagging rate started off at 1:5 and remained there until mid-June, when it was adjusted to 1:4 and then 1:3 as catch rates lowered. By the end of the season, catches dropped rapidly to very low levels and every fish was radiotagged. Despite this, almost 70 radio tags were never deployed and were saved for the following year. The total catch of unique fish was 2,337 for the season and 25% were radiotagged.

In 2021, 733 Chinook salmon were radiotagged from 20 May to 13 July (Figures 3 and 4). Only 1 fish wheel was operated most of the season, with the second wheel deployed on 21 June. Because of the supplemental tags from the previous year, the initial tagging rate at the beginning of the season was 1:3. Within a week it was adjusted to 1:2, then back to 1:3, and then it fluctuated between 1:3 and 1:4 for most of the run. The crew ran out of radio tags on 6 July but received a shipment of 30 returned tags the following day. The season ended with inconsistent daily tag rates, but of the 72 Chinook salmon captured after the crew ran out of radio tags, 30 were radiotagged, which was well within the seasons tagging ratio range. The total catch of unique fish was 1,961 and 37% were radiotagged.

## FATES, SPAWNING DISTRIBUTION, AND ABUNDANCE ESTIMATES

A total of 36 aerial surveys were flown from 2019 through 2021 (Table 4) and fixed-tracking stations were downloaded every 5–21 days depending on fish locations and passage rates. This information was used to assign fates (Table 3) for all radiotagged fish. Throughout all 3 years, 1,145 Chinook salmon were designated as spawners, 599 were censored, 53 were reported harvested in the PU fishery, 114 were reported harvested from the subsistence fishery, 20 were reported harvested from the sport fishery, and 63 were categorized as failures (Table 5).

Time strata used for the weighting of radio tags is presented in Table 6 and were similar to those used by NVE in their final inriver abundance estimates. The estimated spawning distribution of Chinook salmon was relatively similar across all 3 years (Figure 5 and Table 7). The rivers with the highest estimated proportion of spawners were the Chitina River in 2019 (0.28), and the Gulkana River in both 2020 (0.27) and 2021 (0.24). Most years, the Upper Copper, Gulkana, and Chitina River stocks had the highest estimated proportions of the escapement (Figure 5 and Table 7). The lone exception was in 2021, when the Tonsina River had the third highest estimated proportion of spawners (0.194), a fraction above the Chitina River (0.192). The Tazlina River consistently had the lowest estimated proportion of spawners.

Exact spawning locations were never determined, but aerial survey information provided a visual reference of general spawning distribution at the tributary scale, and for upper extent of spawning locations within a tributary. Figures 6–8 display the furthest upstream location of every fish located aerially, which reached 1 of the 6 spawning tributaries/areas with notable exceptions. Fish reported as harvested from sport fisheries were omitted since they had no chance of spawning. Also, fish detected at a spawning tributary/area fixed-tracking station and were never detected aerially outside the waters of the mainstem Copper and Chitina Rivers were omitted to avoid confusion because they in no way represented a possible spawning location.

Abundance estimates for the 6 major drainages were linearly related to the estimated proportions of the escapement going to each major drainage for that year. In 2019, the total drainagewide escapement was 35,145 fish, which was 13,588 more fish than estimated in 2020, and 16,714 more fish than in 2021 (Table 1). These differences in the overall escapement numbers are reflected in the estimated escapement numbers to each tributary (Table 8 and Figure 9). Each tributary had its highest escapement in 2019.

The cumulative proportion of radiotagged fish that spawned in the 9 traditional aerial survey index streams was 0.39 (SE = 0.03) in 2019, 0.47 in 2020 (SE = 0.04), and 0.43 (SE = 0.03) in 2021 (Table 9). As expected, the Gulkana River had the highest proportion of fish (0.19–0.27), followed by the East Fork Chistochina (0.06–0.08), and Indian Creek (0.04–0.06). Many of the smaller tributaries had 1% or less of the total estimated escapement returning to them.

The estimated proportion of Gulkana River spawners that spawned above the ADF&G counting tower was 0.63 (SE = 0.07) in 2019, 0.68 (SE = 0.07) in 2020, and 0.58 in 2021 (SE = 0.05; Table 10).

Lastly, several individual fish did something interesting: they entered 1 of the 6 major spawning tributaries/areas, only to turn around and go to a different one. In 2019, an individual fish (586 mm METF length radiotagged on 24 May) traveled to the East Fork Chistochina River, but then traveled back downstream 130 RKM to the Klutina River to spawn. This fish passed the Upper Copper River fixed-tracking station on 14 June, was detected 6 RKM up the East Fork Chistochina River during an aerial survey on 3 July, was detected coming back downriver by the Upper Copper River fixed-tracking station on 14 July, and then was detected entering the Klutina River on 15 July, where it was located twice about 15 RKM up the Klutina River during aerial surveys on 3 and 28 August. In 2021, 2 individual fish traveled up the Klutina River only to swim back downstream and spawn in the Tazlina River. The first of these fish (834 mm METF length radiotagged on 13 June) passed the Klutina River tracking station on 25 June, then came back downstream on 4 July, passed the Tazlina River fixed-tracking station on 6 July, then swam about 90 RKM upstream and spawned in Mendeltna Creek. The final fish (829 mm METF length radiotagged on 5 June) traveled up the Klutina River on 13 July, was located 5 RKM up the Klutina River during an aerial survey on 14 July, was detected coming back downstream on 19 July, was located between the Klutina and Tazlina Rivers on 20 July during another aerial survey, moved past the Tazlina River tracking station on 21 July, was detected about 15 RKM up the Tazlina during an aerial survey on 3 August, and finally, was detected with a mortality code in the Lower Tazlina River on 25 August.

## RUN TIMING

Run timing (from the capture site at Baird Canyon to spawning tributaries) was consistent among years in terms of order from earliest to latest. Fish that spawned higher in the Copper River drainage typically had earlier run timing. Cumulative run-timing curves consistently showed that Upper Copper River fish arrived first, followed by the Gulkana River (Figures 10–12). The Chitina River fish arrived next during all 3 years, then the Tazlina, Tonsina, and Klutina River fish. This trend was also true within individual drainages (i.e., Klutina and Tonsina), where fish traveling further up tributaries had earlier run timing than those spawning lower in the drainage within the mainstem (Table 11). Tributary spawning fish within the Klutina River had a mean date of passage that was 13, 17, and 12 days earlier than mainstem spawning fish in 2019, 2020, and 2021, respectively. Similarly, Tonsina River tributary fish arrived 21, 11, and 3 days sooner than mainstem fish during the same 3 respective years. In the Gulkana River, no real trend appeared between the run timing of fish that spawned above and below the counting tower (Table 11). This trend would be more distinct in the Gulkana River if the West Fork Gulkana confluence was above the counting tower. “Tributary” fish of the West Fork Gulkana River have earlier run timing but technically spawn below the counting tower (Schwanke and Tyers 2018).

## AGE AND LENGTH COMPOSITION

Results summarized in the previous sections were all estimated using the weighting procedures described in Equations 2 and 3. Apportionment of length and age information to each of the 6 major drainages was not weighted due to low sample sizes within individual age classes and length bins. The following results are meant to provide an overview of radiotagged fish and where they spawned.

Age-1.3 fish were the dominant age class across all locations during all years (Table 12). Age-1.4 fish were the next most frequent age class observed, with a higher proportion of them spawning in the Tonsina, Klutina, and Chitina Rivers. Our sampling indicated that age-1.4 fish composed a higher proportion of the spawning population in 2020 for all drainages in this study except the sample size limited Tazlina River (Table 12). The Upper Copper drainage had the lowest proportion of age-1.4 fish during all 3 years.

Length composition was summarized by apportioning spawning radiotagged fish into 3 length categories: 501–700 (small), 701–900 (medium), and 901–1,100 (large) mm METF. Other than the obvious trend of the medium length class dominating all drainages, few other trends appeared (Table 13). The Upper Copper River had no fish in the large category during any of the 3 years. All rivers had similar portions of fish in the smaller length class (501–700 mm METF), despite some rivers, such as the Chitina, Klutina, and Tonsina Rivers having a relatively high proportion of large fish.

# DISCUSSION

This study was designed to be directly compared to the distribution component of Savereide (2005). The 2 studies were nearly identical in how Chinook salmon were captured, where they were radiotagged, the types of radio tags used, how radio tags were inserted, the frequency of aerial surveys, and the locations of the 6 spawning tributary/areas fixed-tracking stations. Data analyses, including the weighting procedures, were also identical between studies, and consequently, this discussion begins with a comparison of results between the 2 studies.

Since the last comprehensive Chinook salmon distribution study concluded in 2002 through 2004 (Savereide 2005), several regulatory changes have occurred that could have likely affected spawning distribution and run timing of Copper River Chinook salmon. The management of the commercial fishery has been changed to a more conservative approach by allowing fewer early season commercial openings (e.g., May) and more "inside" closures (i.e., inside the Barrier Islands). Additionally, the personal use fishery now starts a week later. One intent of these regulatory changes was to allow more upriver fish (with an earlier run timing) to enter the river, which is the component of the run that is most important to subsistence users. If this strategy has been working, a higher percentage of "early" Chinook salmon destined for Upper Copper River stocks should be entering the river and possibly increasing their contribution to the escapement.

Despite these changes to the management of the fisheries, proportions of the total escapement returning to the 6 major spawning tributary/areas have not changed (Figure 13). No detectable changes occurred in the 2 most upriver stocks (Upper Copper or Gulkana Rivers). The Tazlina River had small sample sizes. The Chitina River had no trend between study periods, but 2021 was significantly different than 2003. The Klutina River proportion point estimates were higher in this study than all 3 years of the previous study, but the estimates were not significantly different. The Tonsina River had the most variability within years, but the proportion ranges for this study fell within the proportion ranges of the previous study (Figure 13). The within study variability for Tonsina River was interesting, because the 2 years with high proportions (2004 and 2021) were significantly different from the year with the lowest proportion (2002), but no clear trend existed between the study periods.

It appears Chinook salmon stocks of the Copper River are robust enough to maintain traditional spawning distributions despite changes in harvest strategies and environmental conditions. It should be noted, however, this does not mean harvest strategies have failed to allow more upriver fish to enter the subsistence fishery. Early season conservation measures in the commercial and personal use fisheries could be allowing more "early" fish to enter the subsistence fishery, but these fish may now be getting harvested at a higher rate. Additional studies designed to assess stock exploitation rates across fisheries could prove beneficial in guiding future management strategies. Also, knowing that most returning Chinook salmon are 4–6 years old (Table 12), maybe not enough time has elapsed for generational shifts in distribution occur.

It was difficult to compare finer scale proportion estimates for the 9 aerial index tributaries because too few radiotagged fish went to each tributary. Collectively, these 9 tributaries accounted for 0.34–0.46 of the total escapement from 2002 through 2004, and 0.39–0.47 from 2019 through 2021 (Table 9; Savereide 2005). Individually, all ranges of tributary escapement proportions overlapped between studies except for Indian Creek. From 2002 through 2005, 0.01–0.02 of the overall escapement went to Indian Creek, but 0.04–0.06 went there from 2019 through 2021. The East Fork Chistochina River also appeared to have higher proportions of fish returning during this study, but the proportions overlapped (0.05–0.06 from 2002 through 2004, and 0.06–0.08 from 2019 through 2021). Regardless of sample size, this evidence suggests that smaller stocks within the major spawning tributaries are also withstanding harvest strategy changes and environmental fluctuations. Additionally, the increased proportions of radiotagged fish in 2 of the important spawning tributaries of the Upper Copper River could be a result of the management measures implemented to reduce fishing pressure on early-run Chinook salmon.

Run timing at Baird Canyon did not appear to change between studies. Mean date of passage and duration of passage at Baird Canyon for the 6 major tributary areas exhibited no discernable trends (Figure 14). This was not unexpected considering the myriad of annual variables (e.g., ice out and water discharge rates) that affect run timing, and the relatively short duration of this study. However, it is interesting that the run timing at the Gulkana River ADF&G counting tower (defined as date of 50% passage) followed the same trend as arrival of these fish at Baird Canyon. Fifty percent passage at the ADF&G counting tower was early in 2019 (26 June), average in 2020 (9 July), and late in 2021 (19 July; Hansen and Ocaña 2022). Although this study partially defined run timing as mean date of passage, the same trend was evident at Baird Canyon with Gulkana River bound fish arriving progressively later all 3 years (Table 11 and Figure 14). Even though the run timing similarities were expected, it reflects what we know about Chinook salmon life history and the limited window of time available to successfully spawn, as it relates to incubation and emergence (Murray and McPhail 1988; Shanley and Albert 2014).

The proportion of Gulkana River fish that spawned above the counting tower fell within the ranges of previous studies. From 2002 through 2004, 0.50–0.86 of the Gulkana River run was estimated to have spawned above the ADF&G counting tower (unpublished data in Savereide 2005). Then, from 2013 through 2015, 0.45–0.54 of the Gulkana River run was estimated to have spawned above the ADF&G counting tower (Schwanke and Tyers 2018). They felt their tagging locations may have biased the results high for fish estimated to spawn below the ADF&G counting tower, and suggested future studies addressing Gulkana River specific spawning locations use the NVE Baird Canyon capture locations as the tagging site. This study followed those recommendations, and resulting estimated proportions were 0.58–0.68 for fish spawning above the ADF&G counting tower (Table 10), which was greater than the range observed during the 2013–2015 study. This comparison provides further evidence that the results from Schwanke and Tyers (2018) were biased, likely because fish were radiotagged too late in their migration and in much warmer water. It should also be noted that the 2013–2015 study design did not allow for the weighting of radiotagged fish, and any inconsistencies in tag rates would have also biased the results.

The run timing in the Gulkana River was similar for fish spawning above and below the ADF&G counting tower (Table 11). Fish that spawn in the mainstem Gulkana River below the counting tower have the latest run timing in the Gulkana River drainage (Schwanke and Tyers 2018). However, West Fork Gulkana River fish have some of the earliest run timing in the Gulkana River, and those fish are also classified as spawning below the ADF&G counting tower. When combined, the West Fork Gulkana fish likely offset the mainstem Gulkana River fish and resulted in similar run timings for fish spawning above and below the ADF&G counting tower (Table 11).

Measuring migratory success of Copper River Chinook salmon was not an objective of this study, however, each tagged fish was assigned a fate (Tables 3 and 5), and results are worth discussing because of the extended periods of low inriver abundance (Piche et al. 2022) and low total runs that occurred prior to this study (Somerville and Hansen 2021). This, in conjunction with Savereide

(2005), gave the opportunity to provide a direct comparison of the proportion of radiotagged fish that successfully made it to 1 of the 6 major spawning tributary/areas during 2 different abundance regimes. When combining all 3 years from each study, the proportion of radiotagged Chinook salmon that reached 1 of the 6 major spawning tributaries/area was 0.62 in the Savereide (2005) study and 0.58 for this study, which is 7% lower (Table 5). While these results are statistically similar (chi-square value = 1.66; $p$-value = 0.20), the differences could be biologically meaningful and worth discussing.

Savereide (2005) concluded that properly radiotagging Chinook salmon did not adversely affect survival. In contrast, Bromaghin et al. (2007) determined residual effects from radiotagging chum salmon using fish wheels negatively affected their ability to migrate for a significant amount of time. Although different crew members radiotagged Chinook salmon during our study and the Savereide (2005) study, the same methods were used, and we assumed tagging effects, or lack thereof, remained similar between the 2 studies. Although the validity of this assumption could not be tested, it should be noted that there were differences in the methodology to determine the fates of non-spawning and non-harvested fish that did not make it to spawning tributary/areas between the studies. For example, Savereide (2005) had tracking stations immediately above and below the Chitina subdistrict fishery boundaries (Figure 1) because the mark–recapture component of that study necessitated them. In that study, those 2 tracking stations helped define the fish classified as tag failures and upstream migrants. This study did not require either of those fixed-tracking stations, and consequently, different definitions and nomenclature were used to describe fish that did not make it to spawning area and were not harvested (i.e., tag failure and censored).

A total of 3.2% of radiotagged fish were classified as failures (Table 5), meaning they were never detected following the tagging event. This occurred either due to tag failure, radiotagged fish going back downriver, or somehow fish evaded detection during migration. Although there was no way to differentiate between these potential causes, of the approximately 150 radio tags returned from harvested fish throughout this study, only 1 malfunctioned. This tag was never detected and was not emitting a signal when returned to the office.

Radio tag loss is assumed to have been similar between studies considering the nearly identical capture and tagging methods. Radio tags can be regurgitated naturally or expelled when fish are caught and released. Documented radio tag regurgitation rates in Chinook salmon range from 0.4–10.9% ($n$ = 7,712; Keefer et al. 2004). Applying this range of regurgitation rates to our study resulted in a very wide range for potentially expelled tags (8–215), and was of little use when deciphering results. A total of 5 radio tags were documented as regurgitated during this study. Two radio tags were found in holding tanks at the Canyon Creek fish wheels, a location approximately 91 RKM upstream of the tagging site, and 3 radio tags were found in holding tanks at the Baird Canyon tagging site fish wheels. The tags found at the Baird Canyon tagging site were presumably regurgitated upon recapture following initial tagging release, and it is our assumption that these tags were expelled due to the stress incurred during capture and holding. Limited data exists on the impacts of fishery capture and handling on radio tag retention, but capture and release in the personal use and sport fisheries is common due to annual harvest limits, and this practice may have encouraged tag regurgitation. Chinook salmon are also periodically released from subsistence fish wheels and dip nets due to voluntary conservation measures or the preference of sockeye salmon, which could have also encouraged tag regurgitation.

A substantial portion (30%) of radiotagged fish were censored from this study (Table 5). Fish received a fate of "censored" due to the following suspected causes: (1) unreported harvest;

(2) radio tag regurgitation following initial detection on a mainstem or aerial telemetry receiver, but prior to being detected on a spawning area/tributary receiver; (3) en route mortality; (4) tag malfunction following initial detection on a mainstem or aerial telemetry receiver but prior to being detected on a tributary receiver; or (5) tributary/spawning area receiver malfunction. Interpretation of data suggests that causes 1–3 probably contributed the most to the group of censored fish (discussed below), and that 4 and 5 probably occurred at a much lower rate. No returned radio tags shut off prematurely, and only 3 fish were found during aerial tracking flights in a tributary/area where they had not been previously detected by their respective fixed-tracking station (2 on the Klutina River and 1 on the Chitina River).

Unreported harvest surely occurred during this study. Radiotracking stations near the road system often detected radio tags at high signal strengths and for short periods of time, indicating that some tags were being transported in a highway vehicle. Savereide (2005) put more effort into identifying and categorizing harvested fish because that information was paramount to the mark–recapture component of that study. Harvest rates and locations were not important for the objectives of this study, and consequently, only fish reported as harvested were classified as such. This discrepancy undoubtedly contributed to the much lower documented harvest rate in this study compared to the previous study, and contributed to the high proportion of radiotagged fish that were censored.

In the absence of comparable harvest rates of radiotagged fish, we examined overall harvest of the estimated inriver abundance during the 3-year periods of each study. The estimated proportion of the inriver estimate that was harvested from the personal use and subsistence fisheries was 0.19 in 2002, 0.11 in 2003, and 0.16 in 2004 (calculated from data in Table 1). During this study, estimated inriver harvest rates were similar: 0.16 in 2019, 0.14 in 2020, and 0.14 in 2021. Averaging these estimated annual rates for each study's 3-year period revealed a similar proportion of 0.15, suggesting inriver harvest rates were similar between studies and did not contribute to the higher proportion of fish that did not spawn in 1 of the 6 major spawning tributary/areas during this study.

En route mortality of migrating adult Chinook salmon has not been studied on the Copper River, but documented causes elsewhere include consumption by predators, injury, unsuccessful straying, the cumulative stress effects from harmful pathogens, insufficient energy reserves, disrupted physiological processes, natural and anthropogenic barriers to passage, and environmental variables such as discharge and water temperature (Cooke et al. 2004; Rand et al. 2006; Cooke et al. 2006; Keefer et al. 2008; Hinch and Martins 2011; Hinch et al. 2012; Strange 2012; Carey et al. 2019). In addition, capture and handling effects from fisheries or research studies like this one may increase migratory stress and have negative effects on survival. The inability to differentiate between these causes within this study are unfortunate, but further investigation into the more likely candidates causing en route mortality could be beneficial for Copper River Chinook salmon management and useful when assessing current and future threats to sustainability. Changes in these variables over time (e.g., increased stress and mortality) could help explain the differences in the proportion of radiotagged fish reaching 1 of the 6 spawning tributary/areas between studies.

Changing climate and warming waters have been recent topics of discussion in salmon management. Studies have shown large scale climate drivers, hatchery enhancement, food web changes, and marine factors can influence Chinook salmon production (Hunt et al. 2011; Mantua et al. 2015; Cunningham et al. 2018). In addition, water temperature impacts migratory rates and migratory success of adult salmon (McCullough 1999; McCullough et al. 2001; Ricthter and Kolmes 2005; Rand et al. 2006; Strange 2010; Carey et al. 2019; Keefer et al. 2019). Specific to Alaska Chinook salmon, Jones (2020) linked warm water to lower productivity in Alexander Creek and the Deshka River in Southcentral Alaska but documented no loss of productivity in nearby cooler water streams such as the Kenai and Chulitna Rivers. Von Biela et al. (2020) documented heat stress in over half the Chinook salmon sampled on the Yukon River in 2016 and 2017 and speculated en route mortality was linked. Widespread mortality of pre-spawn Pacific salmon was documented throughout Alaska during the record-breaking warm summer of 2019, although only 18% of the collected specimens were from glacial rivers (Von Biela et al. 2022). Very little information exists on water temperature profiles in the Copper River drainage or how water temperature and discharge impacts migration timing, rates of migration, and migratory success of salmon. Climate and glacier modelling suggest precipitation and melt water are anticipated to increase in the Copper River watershed by 48% through 2099 (Valentin et al. 2018). The relationship between migratory speed, discharge, water temperature, and salmon bioenergetics would be beneficial for understanding future management challenges for Copper River salmon. Additional data on migratory stressors and their impact on spawning success for Copper River salmon would also be valuable. A deeper look into migratory rates of passage between telemetry sites in this study, Savereide (2005), and the 20 years of NVE migratory data between mark and recapture sites would probably provide additional insight into these relationships.

The foundation of Alaska's salmon *Oncorhynchus* spp. management is based on escapement goal policies. In general, Alaska's salmon fisheries are currently managed by monitoring the number of adult spawners (escapement) and modeling the relationship between escapements and subsequent returns (recruitment), typically in a density-dependent framework (Ricker 1975). Modeling salmon recruitment is often constrained by the amount and quality of data, and even the best models contain high degrees of variability in recruitment rates attributable to both freshwater and oceanic conditions (Peterman et al. 1998; Needle 2002; Joy et al. 2021). Furthermore, age-structured production models that are widely used to understand a stock's dynamics require information about processes like recruitment and mortality. Currently, these models rely on accurate and precise measurements of escapement that do not factor in the effect of en route and pre-spawn mortality. Identifying the mechanisms, like the ones described previously, that significantly improve the fit of spawner-recruit models may allow managers to better manage and forecast salmon runs in the future.

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# TABLES AND FIGURES

Table 1.–Summary of Chinook salmon harvests and upriver escapement in the Copper River, 1998–2021.

| Year | Commercial harvest[a] | CRD Subsistence harvest[b] | Sport harvest[c] | Glennallen Subdistrict harvest[d] | Chitina Subdistrict harvest[d] | Total harvest | Upriver return estimate[e] | Estimated total return | Spawning escapement | Estimate source |
|---|---|---|---|---|---|---|---|---|---|---|
| 1998 | 70,238 | 295 | 8,245 | 1,842 | 6,723 | 87,343 | 46,403 | 116,936 | ND | ND |
| 1999 | 63,508 | 353 | 6,742 | 3,278 | 5,913 | 79,794 | 32,090 | 95,951 | 16,157 | ADF&G |
| 2000 | 32,018 | 689 | 5,531 | 4,856 | 3,168 | 46,262 | 38,047 | 70,754 | 24,492 | ADF&G |
| 2001 | 40,551 | 826 | 4,904 | 3,553 | 3,113 | 52,947 | 39,778 | 81,155 | 28,208 | ADF&G |
| 2002 | 39,552 | 549 | 5,098 | 4,217 | 2,056 | 51,472 | 32,873 | 72,974 | 21,502 | ADF&G |
| 2003 | 49,031 | 710 | 5,717 | 3,092 | 1,921 | 60,471 | 44,764 | 94,505 | 34,034 | NVE |
| 2004 | 38,889 | 1,106 | 3,435 | 3,982 | 2,502 | 49,914 | 40,564 | 80,559 | 30,645 | NVE |
| 2005 | 35,764 | 260 | 4,093 | 2,618 | 2,094 | 44,829 | 30,333 | 66,357 | 21,528 | NVE |
| 2006 | 31,309 | 779 | 3,425 | 3,229 | 2,681 | 41,423 | 67,789 | 99,877 | 58,454 | NVE |
| 2007 | 40,276 | 1,145 | 5,113 | 3,939 | 2,722 | 53,195 | 46,349 | 87,770 | 34,575 | NVE |
| 2008 | 12,067 | 470 | 3,616 | 3,218 | 2,022 | 21,393 | 41,343 | 53,880 | 32,487 | NVE |
| 2009 | 10,394 | 212 | 1,355 | 3,036 | 223 | 15,220 | 32,401 | 43,007 | 27,787 | NVE |
| 2010 | 10,582 | 276 | 2,416 | 2,425 | 718 | 16,417 | 22,323 | 33,181 | 16,764 | NVE |
| 2011 | 19,788 | 212 | 1,753 | 3,062 | 1,080 | 25,895 | 33,889 | 53,889 | 27,994 | NVE |
| 2012 | 12,623 | 237 | 535 | 2,510 | 572 | 16,477 | 31,452 | 44,312 | 27,835 | NVE |
| 2013 | 9,445 | 854 | 285 | 2,522 | 762 | 13,868 | 32,581 | 42,880 | 29,012 | NVE |
| 2014 | 11,011 | 153 | 931 | 1,785 | 733 | 14,613 | 24,158 | 35,322 | 20,709 | NVE |
| 2015 | 23,701 | 167 | 1,343 | 2,614 | 1,585 | 29,410 | 32,306 | 56,174 | 26,764 | NVE |
| 2016 | 13,161 | 73 | 327 | 2,471 | 726 | 16,758 | 16,009 | 29,243 | 12,485 | NVE |
| 2017 | 14,628 | 778 | 1,731 | 3,366 | 1,973 | 22,476 | 40,725 | 56,131 | 33,655 | NVE |
| 2018 | 7,303 | 1,356 | 1,280 | 7,668 | 1,374 | 18,981 | 52,524 | 61,183 | 42,202 | NVE |
| 2019 | 18,605 | 808 | 1,565 | 4,315 | 2,689 | 27,982 | 43,714 | 63,127 | 35,145 | NVE |
| 2020 | 6,119 | 657 | 967 | 2,892 | 847 | 11,482 | 26,293 | 33,069 | 21,587 | NVE |
| 2021 | 6,995 | 624 | 90 | 2,190 | 945 | 10,844 | 21,656 | 29,275 | 18,431 | NVE |
| Average 2017–2021 | 10,730 | 845 | 1,127 | 4,086 | 1,566 | 18,353 | 36,982 | 48,557 | 30,204 | |
| Average 2012–2021 | 12,359 | 571 | 905 | 3,233 | 1,221 | 18,289 | 32,142 | 45,072 | 26,783 | |

*Note*: ND = no data; NVE = Native Village of Eyak.

[a] Includes commercial harvest plus homepack, donated, and educational harvests.

[b] Includes State and Federal subsistence harvests in the Copper River District.

[c] Includes sport harvest in the Copper River Delta and the Upper Copper River upstream of Haley Creek.

[d] These data are expanded to reflect unreported state harvest and include reported federal harvest (2002–2004) and expanded federal harvest beginning in 2005.

[e] Prior to 1999 upriver returns were calculated by applying the percentage of Chinook salmon in the Glennallen and Chitina subdistrict fisheries to the sonar count. Starting in 1999, upriver Chinook salmon returns are estimated through a mark–recapture method.

Table 2.–Spawning distribution of Copper River Chinook salmon by major drainage, 2002–2004.

| | 2002 | | 2003 | | 2004 | |
|---|---|---|---|---|---|---|
| Spawning tributary | Proportion | SE | Proportion | SE | Proportion | SE |
| Upper Copper | 0.22 | 0.03 | 0.22 | 0.04 | 0.25 | 0.04 |
| Gulkana | 0.27 | 0.04 | 0.17 | 0.03 | 0.20 | 0.03 |
| Tazlina | 0.04 | 0.02 | 0.05 | 0.02 | 0.02 | 0.01 |
| Klutina | 0.10 | 0.03 | 0.11 | 0.03 | 0.12 | 0.03 |
| Tonsina | 0.08 | 0.02 | 0.10 | 0.04 | 0.19 | 0.03 |
| Chitina | 0.29 | 0.03 | 0.34 | 0.03 | 0.22 | 0.03 |

Table 3.–List of possible fates for all radiotagged Chinook salmon, 2019–2021.

| Fate | Description |
|---|---|
| Spawner | A fish that migrated into 1 of the 6 major spawning tributary/areas (Upper Copper, Gulkana, Chitina, Tazlina, Klutina, and Tonsina Rivers), based on tracking station and aerial survey data. For the Gulkana River, spawning fish were subcategorized even further as fish that spawned above the counting tower (AT) and below the counting tower (BT). |
| Personal Use (PU) harvest | A fish that was reported as harvested from the Chitina subdistrict. |
| Subsistence (SUB) harvest | A fish that was reported as harvested from the Glennallen subdistrict. |
| Sport Fish (SF) harvest | A fish that was reported as harvested while sport fishing |
| Censored | Fish that made detectable upstream progress from the tagging site, but never made it to 1 of the 6 major spawning areas/tributaries nor was reported as harvested. |
| Failure | A fish that was never recorded at a tracking station or found aerially. |

Table 4.–Aerial tracking dates for Chinook salmon in the 6 major spawning tributaries/areas in the Copper River drainage, 2019–2021.

| | | Locations Flown[a] | | | | | |
|---|---|---|---|---|---|---|---|
| Survey number | Survey date | Gulkana River | Upper Copper River | Chitina River | Tazlina River | Klutina River | Tonsina River |
| 1 | 6/27/2019 | X | | | | | |
| 2 | 7/3/2019 | | X | | | | |
| 3 | 7/5/2019 | | | X | | | |
| 4 | 7/6/2019 | X | | | | | |
| 5 | 7/10/2019 | | | | X | X | X |
| 6 | 7/15/2019 | X | | | | | |
| 7 | 7/25/2019 | X | | | | | |
| 8 | 8/1/2019 | | X | | | | |
| 9 | 8/2/2019 | | | X | | | |
| 10 | 8/3/2019 | | | | X | X | X |
| 11 | 8/9/2019 | X | | | | | |
| 12 | 8/27/2019 | | | X | | | |
| 13 | 8/28/2019 | X | | | X | X | X |
| 14 | 7/6/2020 | X | | | | | |
| 15 | 7/8/2020 | | | X | | | |
| 16 | 7/26/2020 | X | | | | | |
| 17 | 7/27/2020 | | X | | | | |
| 18 | 7/30/2020 | | | | X | X | X |
| 19 | 8/4/2020 | | | X | | | |
| 20 | 8/7/2020 | X | | | | | |
| 21 | 8/12/2020 | | X | | | | |
| 22 | 8/18/2020 | X | | | | | |
| 23 | 9/1/2020 | | | | X | X | X |
| 24 | 9/17/2020 | X | | | | | |
| 25 | 7/9/2021 | X | | | | | |
| 26 | 7/12/2021 | | | X | | | |
| 27 | 7/13/2021 | | X | | | | |
| 28 | 7/14/2021 | | | | X | X | X |
| 29 | 7/23/2021 | X | | | | | |
| 30 | 8/2/2021 | | X | | | | |
| 31 | 8/3/2021 | | | | X | X | X |
| 32 | 8/5/2021 | X | | | | | |
| 33 | 8/18/2021 | X | | | | | |
| 34 | 8/19/2021 | | | X | | | |
| 35 | 8/26/2021 | | | | X | X | X |
| 36 | 9/1/2021 | X | | | | | |

[a] Parts of the mainstem Copper River were flown over almost every survey to track upstream progress and identify fish that did not make it to a tributary (censored).

Table 5.–General fates of all radiotagged Chinook salmon, 2019–2021.

| | Number of radio tags | | | |
|---|---|---|---|---|
| Fate[a] | 2019 | 2020 | 2021 | Total |
| Total deployed | 656 | 586 | 733 | 1,975 |
| Spawner | 385 | 322 | 438 | 1,145 |
| Personal Use harvest (PU)[b] | 27 | 12 | 14 | 53 |
| Subsistence harvest (SUB)[b] | 39 | 44 | 31 | 114 |
| Sport Fish harvest (SF)[b] | 7 | 12 | 1 | 20 |
| Censored | 192 | 186 | 221 | 599 |
| Failure | 13 | 22 | 28 | 63 |

[a] Fates are defined in Table 3.

[b] Only includes fish reported as harvested.

Table 6.–Strata information used to weight the radio tags (spawning fish only) using the Darroch estimator, 2019–2021.

| | 2019 | | | 2020 | | | 2021 | | |
|---|---|---|---|---|---|---|---|---|---|
| Strata # | Strata dates | # Tags[a] | Fish passage[b] | Strata Dates | # Tags[a] | Fish passage[b] | Strata Dates | # Tags[a] | Fish passage[b] |
| 1 | 5/10–5/31 | 264 | 23,352 | 5/14–5/31 | 101 | 15,976 | 5/18–6/08 | 241 | 13,105 |
| 2 | 6/01–6/11 | 75 | 8,825 | 6/01–6/07 | 60 | 4,189 | 6/09–7/13 | 197 | 10,700 |
| 3 | 6/12–7/1 | 46 | 16,219 | 6/08–6/14 | 49 | 3,945 | | | |
| 4 | | | | 6/15–7/11 | 112 | 5,081 | | | |
| Totals | | 385 | 48,396 | | 322 | 29,191 | | 438 | 23,805 |

[a] Only includes fish that made it to 1 of the 6 spawning tributary/areas

[b] Number is an independent ADF&G Darroch estimate minus inriver harvest (personal use, subsistence, and sport). This estimate was just used to develop strata used for the weighting process. Once the radio tags were properly weighted, they were applied to the Native Village of Eyak (NVE) inriver estimate.

Table 7.–Spawning distribution of Copper River Chinook salmon by major drainage, 2019–2021.

| | 2019 | | 2020 | | 2021 | |
|---|---|---|---|---|---|---|
| Fate | Proportion | SE | Proportion | SE | Proportion | SE |
| Upper Copper | 0.24 | 0.02 | 0.22 | 0.03 | 0.19 | 0.02 |
| Gulkana | 0.19 | 0.02 | 0.27 | 0.03 | 0.24 | 0.02 |
| Tazlina | 0.03 | 0.01 | 0.01 | 0.01 | 0.05 | 0.01 |
| Klutina | 0.14 | 0.03 | 0.14 | 0.02 | 0.14 | 0.02 |
| Tonsina | 0.13 | 0.03 | 0.10 | 0.03 | 0.19 | 0.02 |
| Chitina | 0.28 | 0.03 | 0.26 | 0.03 | 0.19 | 0.02 |

Table 8.–Abundance estimates of Copper River Chinook salmon by major drainage, 2019–2021.

| | 2019 | | 2020 | | 2021 | |
|---|---|---|---|---|---|---|
| Fate | Abundance | SE | Abundance | SE | Abundance | SE |
| Upper Copper | 8,369 | 1,151 | 4,708 | 856 | 3,410 | 480 |
| Gulkana | 6,548 | 960 | 5,805 | 982 | 4,419 | 591 |
| Tazlina | 961 | 411 | 289 | 123 | 884 | 208 |
| Klutina | 4,909 | 1,113 | 3,112 | 543 | 2,608 | 400 |
| Tonsina | 4,591 | 1,027 | 2,171 | 447 | 3,575 | 494 |
| Chitina | 9,767 | 1,320 | 5,502 | 856 | 3,535 | 503 |

Table 9.–Proportions of Chinook salmon located in nine aerial survey index streams in the Copper River drainage, 2019–2021.

| | 2019 | | 2020 | | 2021 | |
|---|---|---|---|---|---|---|
| Fate | Proportion | SE | Proportion | SE | Proportion | SE |
| Gulkana River | 0.19 | 0.02 | 0.27 | 0.03 | 0.24 | 0.02 |
| East Fork Chistochina River | 0.07 | 0.01 | 0.08 | 0.02 | 0.06 | 0.01 |
| Manker Creek | 0.02 | 0.01 | 0.03 | 0.01 | 0.02 | 0.01 |
| St. Anne Creek | 0.01 | <0.01 | 0.01 | 0.01 | 0.01 | <0.01 |
| Little Tonsina River | 0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| Greyling Creek | 0.01 | 0.01 | 0.03 | 0.01 | 0.01 | 0.01 |
| Indian Creek | 0.06 | 0.01 | 0.04 | 0.01 | 0.04 | 0.01 |
| Kaina Creek | 0.01 | 0.01 | 0.01 | <0.01 | 0.01 | 0.01 |
| Mendeltna Creek | 0.02 | 0.01 | 0.01 | <0.01 | 0.03 | 0.01 |
| Total in Index Streams | 0.39 | 0.03 | 0.47 | 0.04 | 0.43 | 0.03 |

Table 10.–Proportions of spawning Gulkana River Chinook salmon in relation to the Gulkana River counting tower, 2019–2021.

| | 2019 | | 2020 | | 2021 | |
|---|---|---|---|---|---|---|
| Fate | Proportion | SE | Proportion | SE | Proportion | SE |
| Above tower | 0.63 | 0.07 | 0.68 | 0.07 | 0.58 | 0.05 |
| Below tower | 0.37 | 0.07 | 0.32 | 0.07 | 0.42 | 0.05 |

Table 11.–Statistics regarding the run timing past the capture site in Baird Canyon of the major Chinook salmon spawning stocks in the Copper River, 2019–2021.

| | 2019 | | | 2020 | | | 2021 | | |
|---|---|---|---|---|---|---|---|---|---|
| Spawning location | Dates spanned | Mean date of tagging ($\bar{t}$) | SE $\bar{t}$ | Dates spanned | Mean date of tagging ($\bar{t}$) | SE $\bar{t}$ | Dates spanned | Mean date of tagging ($\bar{t}$) | SE $\bar{t}$ |
| Upper Copper | 5/15–6/13 | 5/26 | 6.0 | 5/18–6/26 | 5/28 | 6.5 | 5/23–6/14 | 6/2 | 4.9 |
| Gulkana | 5/16–6/15 | 5/28 | 7.3 | 5/17–6/28 | 5/30 | 7.7 | 5/20–7/1 | 6/4 | 6.2 |
| Above tower | 5/16–6/15 | 5/28 | 6.9 | 5/19–6/28 | 5/31 | 7.9 | 5/20–7/1 | 6/4 | 6.4 |
| Below tower | 5/19–6/14 | 5/28 | 7.9 | 5/19–6/15 | 5/30 | 7.1 | 5/25–6/14 | 6/4 | 5.3 |
| Tazlina | 5/25–6/22 | 6/12 | 10.5 | 6/1–6/23 | 6/11 | 7.7 | 5/27–6/23 | 6/9 | 6.2 |
| Klutina | 5/21–6/29 | 6/18 | 9.5 | 5/28–7/11 | 6/17 | 11.8 | 5/27–7/11 | 6/20 | 13.3 |
| Mainstem | 5/24–6/29 | 6/21 | 7.0 | 6/3–7/11 | 6/23 | 9.7 | 6/3–7/11 | 6/26 | 10.8 |
| Tributaries | 5/21–6/21 | 6/8 | 10.2 | 5/28–7/9 | 6/6 | 9.2 | 5/27–6/26 | 6/8 | 6.8 |
| Tonsina | 5/19–6/26 | 6/14 | 11.2 | 5/22–7/9 | 6/14 | 12.2 | 5/31–7/9 | 6/17 | 9.2 |
| Mainstem | 5/19–6/26 | 6/17 | 8.6 | 5/22–7/9 | 6/18 | 12.4 | 5/31–7/9 | 6/17 | 8.8 |
| Tributaries | 5/20–6/7 | 5/27 | 6.7 | 5/28–6/23 | 6/7 | 8.8 | 5/31–7/4 | 6/14 | 10.3 |
| Chitina | 5/15–6/25 | 6/4 | 9.9 | 5/14–7/1 | 6/3 | 11.2 | 5/22–7/12 | 6/8 | 10.4 |

Table 12.–Estimated proportion of radiotagged fish in each age class.

| | Upper Copper | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 2019 | | | 2020 | | | 2021 | | |
| Age | n | prop | SE prop | n | prop | SE prop | n | prop | SE prop |
| 1.2 | 2 | 0.02 | 0.02 | 2 | 0.08 | 0.06 | 4 | 0.09 | 0.04 |
| 1.3 | 81 | 0.90 | 0.03 | 15 | 0.60 | 0.10 | 39 | 0.83 | 0.06 |
| 1.4 | 2 | 0.02 | 0.02 | 4 | 0.16 | 0.07 | 2 | 0.04 | 0.03 |
| 2.2 | 0 | 0.00 | 0.00 | 1 | 0.04 | 0.04 | 0 | 0.00 | 0.00 |
| 2.3 | 5 | 0.06 | 0.02 | 3 | 0.12 | 0.07 | 2 | 0.04 | 0.03 |

| | Gulkana River | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 2019 | | | 2020 | | | 2021 | | |
| Age | n | prop | SE prop | n | prop | SE prop | n | prop | SE prop |
| 1.2 | 0 | 0.00 | 0.00 | 5 | 0.13 | 0.05 | 4 | 0.06 | 0.03 |
| 1.3 | 64 | 0.94 | 0.03 | 20 | 0.50 | 0.08 | 61 | 0.90 | 0.04 |
| 1.4 | 4 | 0.06 | 0.03 | 12 | 0.30 | 0.07 | 2 | 0.03 | 0.02 |
| 2.2 | 0 | 0.00 | 0.00 | 1 | 0.03 | 0.03 | 0 | 0.00 | 0.00 |
| 2.3 | 0 | 0.00 | 0.00 | 1 | 0.03 | 0.03 | 1 | 0.01 | 0.01 |
| 2.4 | 0 | 0.00 | 0.00 | 1 | 0.03 | 0.03 | 0 | 0.00 | 0.00 |

| | Chitina River | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 2019 | | | 2020 | | | 2021 | | |
| Age | n | prop | SE prop | n | prop | SE prop | n | prop | SE prop |
| 1.2 | 1 | 0.01 | 0.01 | 3 | 0.13 | 0.05 | 2 | 0.04 | 0.03 |
| 1.3 | 83 | 0.94 | 0.02 | 37 | 0.55 | 0.06 | 41 | 0.73 | 0.06 |
| 1.4 | 3 | 0.03 | 0.02 | 26 | 0.39 | 0.06 | 9 | 0.16 | 0.05 |
| 1.5 | 0 | 0.00 | 0.00 | 1 | 0.01 | 0.01 | 1 | 0.02 | 0.02 |
| 2.3 | 1 | 0.01 | 0.01 | 0 | 0.00 | 0.00 | 3 | 0.05 | 0.03 |

| | Tazlina River | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 2019 | | | 2020 | | | 2021 | | |
| Age | n | prop | SE prop | n | prop | SE prop | n | prop | SE prop |
| 1.2 | 0 | 0.00 | 0.00 | 0 | 0.00 | 0.00 | 1 | 0.09 | 0.09 |
| 1.3 | 4 | 0.80 | 0.20 | 1 | 0.50 | 0.50 | 10 | 0.91 | 0.09 |
| 1.4 | 1 | 0.20 | 0.20 | 0 | 0.00 | 0.00 | 0 | 0.00 | 0.00 |
| 1.5 | 0 | 0.00 | 0.00 | 1 | 0.50 | 0.50 | 0 | 0.00 | 0.00 |

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Table 12.–Page 2 of 2.

| | Klutina River | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 2019 | | | 2020 | | | 2021 | | |
| Age | n | prop | SE prop | n | prop | SE prop | n | prop | SE prop |
| 1.2 | 1 | 0.06 | 0.06 | 8 | 0.22 | 0.07 | 5 | 0.16 | 0.07 |
| 1.3 | 15 | 0.88 | 0.08 | 16 | 0.43 | 0.08 | 23 | 0.72 | 0.08 |
| 1.4 | 1 | 0.06 | 0.06 | 13 | 0.35 | 0.08 | 4 | 0.13 | 0.06 |
| 2.3 | 0 | 0.00 | 0.00 | 0 | 0 | 0.00 | 0 | 0.00 | 0.00 |

| | Tonsina River | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 2019 | | | 2020 | | | 2021 | | |
| Age | n | prop | SE prop | n | prop | SE prop | n | prop | SE prop |
| 1.2 | 0 | 0.00 | 0.00 | 5 | 0.17 | 0.07 | 9 | 0.16 | 0.05 |
| 1.3 | 12 | 0.67 | 0.11 | 15 | 0.52 | 0.09 | 39 | 0.68 | 0.06 |
| 1.4 | 5 | 0.28 | 0.11 | 6 | 0.21 | 0.08 | 9 | 0.16 | 0.05 |
| 1.5 | 0 | 0.00 | 0.00 | 1 | 0.03 | 0.03 | 0 | 0.00 | 0.00 |
| 2.3 | 1 | 0.06 | 0.06 | 2 | 0.07 | 0.05 | 0 | 0.00 | 0.00 |

Table 13.–Estimated proportion of radiotagged fish in various length categories.

| Upper Copper | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 2019 | | | 2020 | | | 2021 | | |
| Length bin (METF) | n | prop | SE prop | n | prop | SE prop | n | prop | SE prop |
| 501–700 | 14 | 0.11 | 0.03 | 10 | 0.20 | 0.06 | 11 | 0.14 | 0.04 |
| | 10 | | | | | | | | |
| 701–900 | 8 | 0.89 | 0.03 | 39 | 0.80 | 0.06 | 69 | 0.86 | 0.04 |
| 901–1100 | 0 | 0.00 | 0.00 | 0 | 0.00 | 0.00 | 0 | 0.00 | 0.00 |

| Gulkana River | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 2019 | | | 2020 | | | 2021 | | |
| Length bin (METF) | n | prop | SE prop | n | prop | SE prop | n | prop | SE prop |
| 501–700 | 8 | 0.09 | 0.03 | 8 | 0.12 | 0.04 | 12 | 0.11 | 0.03 |
| 701–900 | 81 | 0.90 | 0.03 | 56 | 0.82 | 0.05 | 91 | 0.87 | 0.03 |
| 901–1100 | 1 | 0.01 | 0.01 | 4 | 0.06 | 0.03 | 2 | 0.02 | 0.01 |

| Chitina River | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 2019 | | | 2020 | | | 2021 | | |
| Length bin (METF) | n | prop | SE prop | n | prop | SE prop | n | prop | SE prop |
| 501–700 | 3 | 0.03 | 0.02 | 6 | 0.08 | 0.03 | 3 | 0.04 | 0.02 |
| 701–900 | 99 | 0.93 | 0.02 | 68 | 0.85 | 0.04 | 76 | 0.90 | 0.03 |
| 901–1100 | 4 | 0.04 | 0.02 | 6 | 0.08 | 0.03 | 5 | 0.06 | 0.03 |

| Tazlina River | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 2019 | | | 2020 | | | 2021 | | |
| Length bin (METF) | n | prop | SE prop | n | prop | SE prop | n | prop | SE prop |
| 501–700 | 1 | 0.13 | 0.13 | 0 | 0.00 | 0.00 | 3 | 0.14 | 0.08 |
| 701–900 | 7 | 0.88 | 0.13 | 6 | 1.00 | 0.00 | 17 | 0.81 | 0.09 |
| 901–1100 | 0 | 0.00 | 0.00 | 0 | 0.00 | 0.00 | 1 | 0.05 | 0.05 |

| Klutina River | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 2019 | | | 2020 | | | 2021 | | |
| Length bin (METF) | n | prop | SE prop | n | prop | SE prop | n | prop | SE prop |
| 501–700 | 1 | 0.04 | 0.04 | 14 | 0.19 | 0.05 | 9 | 0.15 | 0.05 |
| 701–900 | 22 | 0.81 | 0.08 | 49 | 0.68 | 0.06 | 50 | 0.81 | 0.05 |
| 901–1100 | 4 | 0.15 | 0.07 | 9 | 0.13 | 0.04 | 3 | 0.05 | 0.03 |

| Tonsina River | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 2019 | | | 2020 | | | 2021 | | |
| Length bin (METF) | n | prop | SE prop | n | prop | SE prop | n | prop | SE prop |
| 501–700 | 1 | 0.03 | 0.03 | 7 | 0.16 | 0.05 | 13 | 0.15 | 0.04 |
| 701–900 | 25 | 0.81 | 0.07 | 33 | 0.73 | 0.07 | 71 | 0.84 | 0.04 |
| 901–1100 | 5 | 0.16 | 0.07 | 5 | 0.11 | 0.05 | 1 | 0.01 | 0.01 |

*Note*: METF = mid eye to tail fork length (mm).

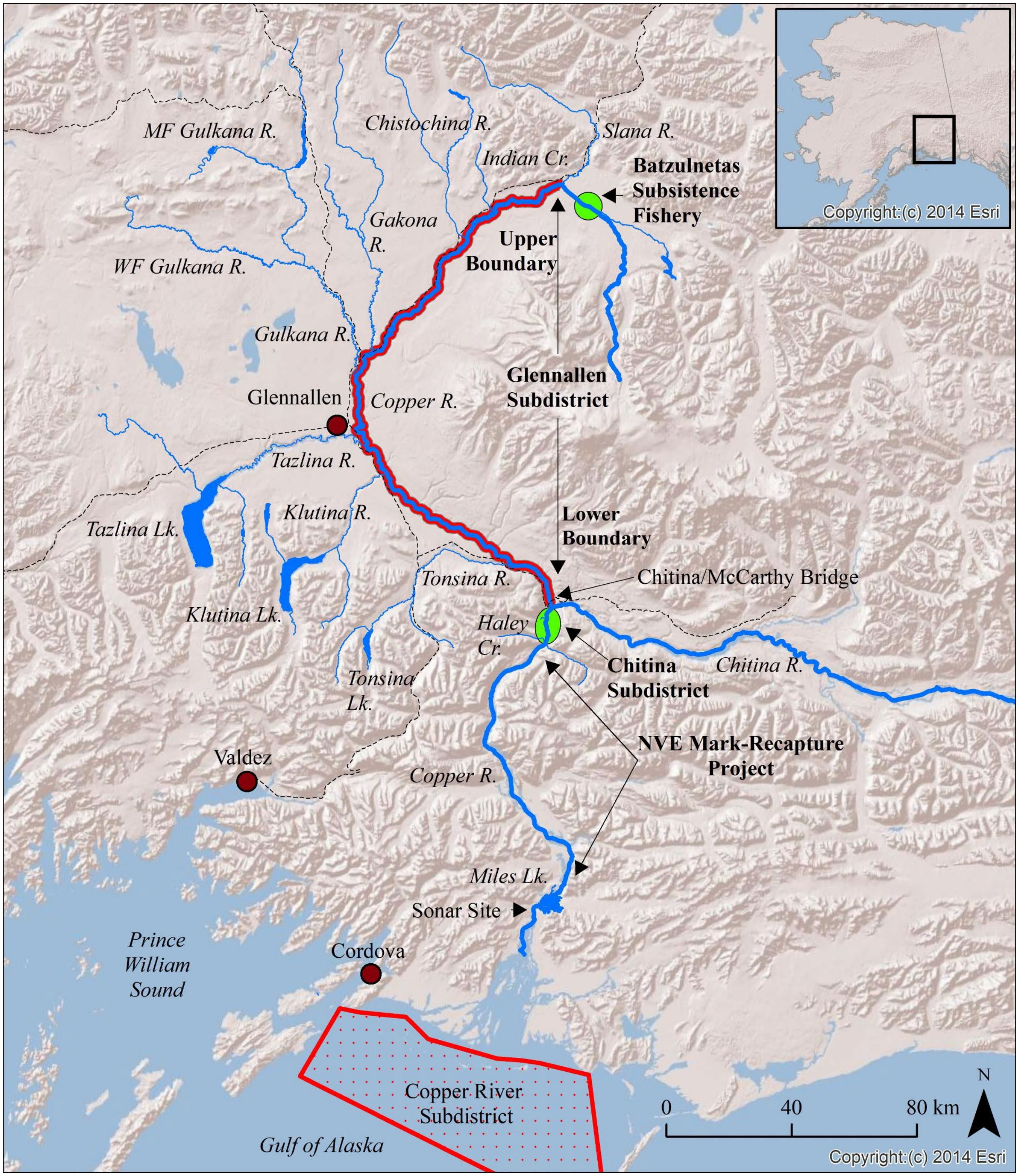


Figure 1–Map of the Upper Copper River drainage demarcating the personal-use and subsistence fisheries, the major spawning tributaries, aerial index streams, and Native Village of Evak (NVE) mark–recapture project location.


Figure 2.–Map of the Copper River drainage with demarcations for the tagging area and fixed-tracking stations.

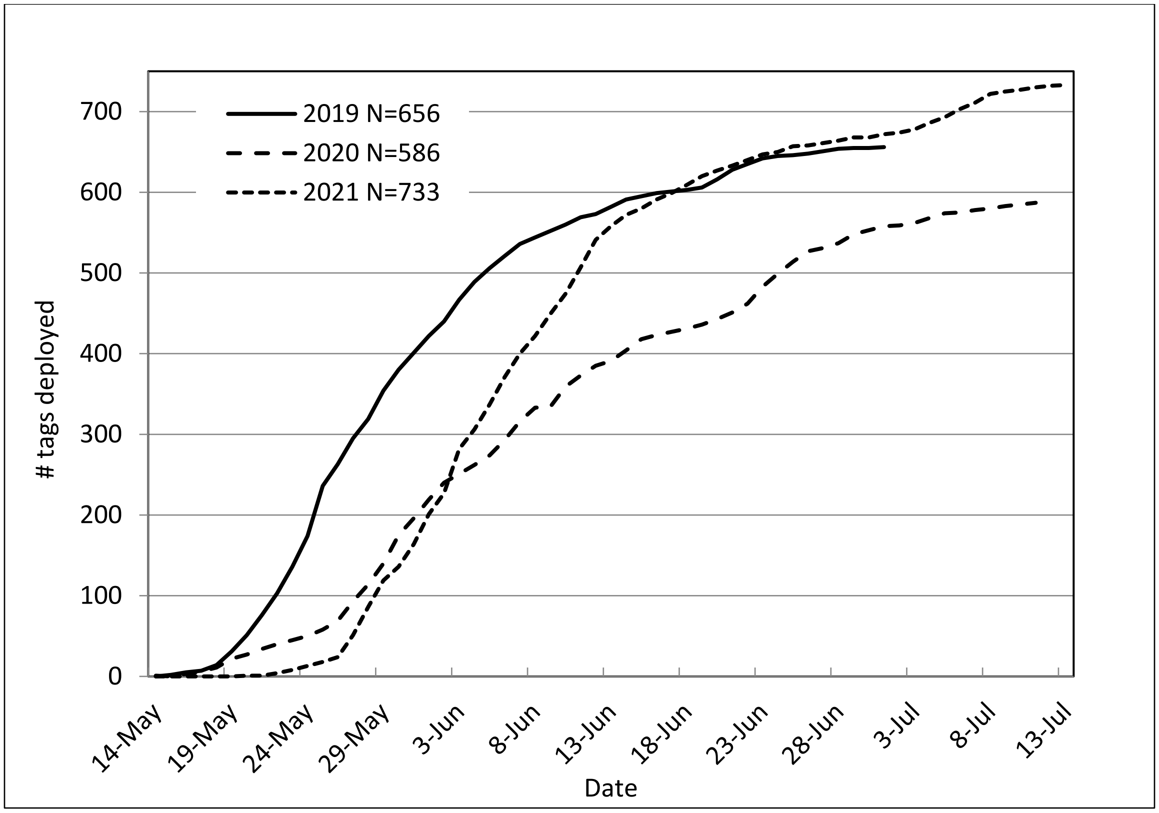


Figure 3.–Cumulative radio tag deployment, 2019–2021.

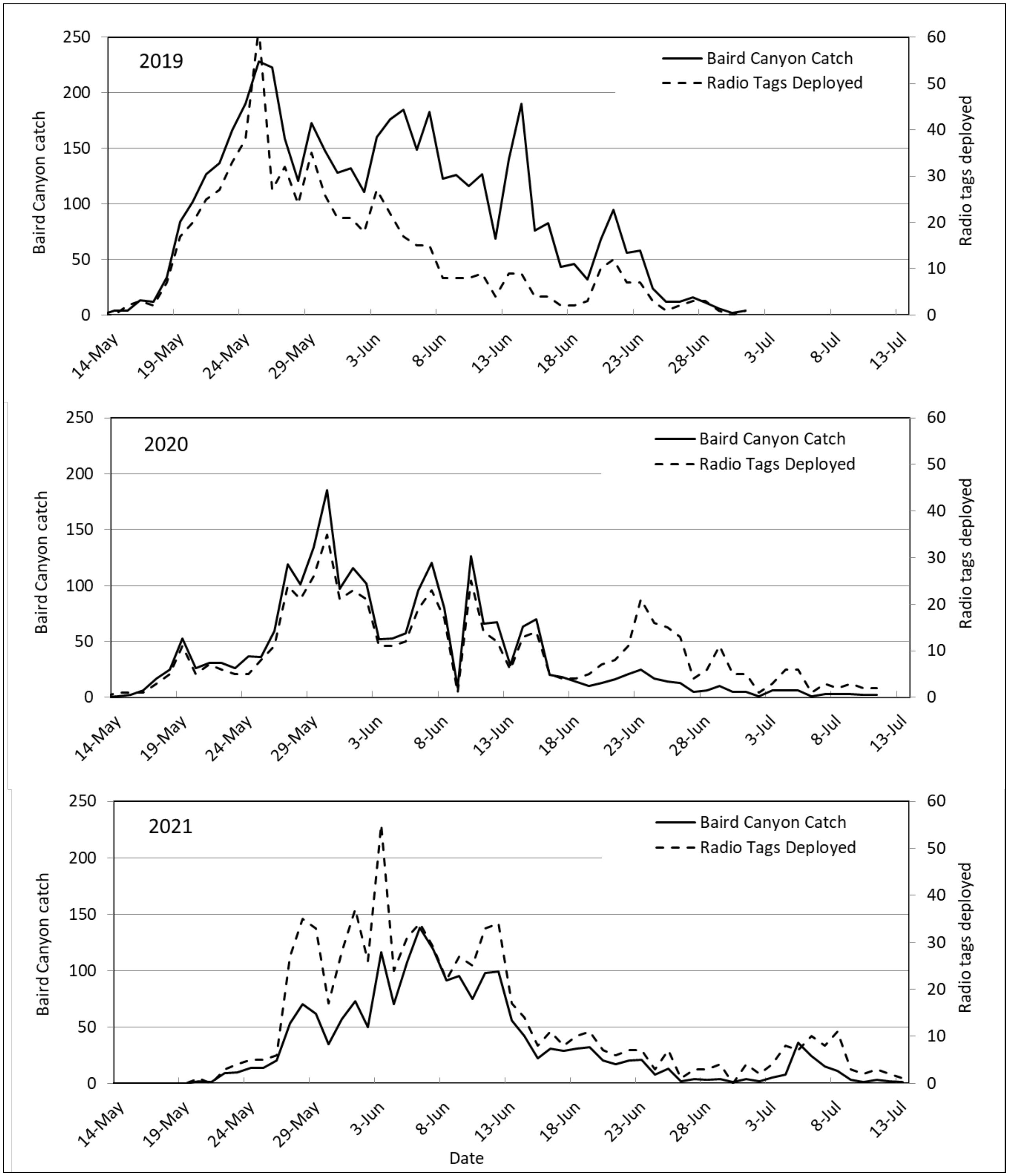


Figure 4.–Daily catch and number of radio tags deployed at the Baird Canyon fish wheels, 2019–2021.

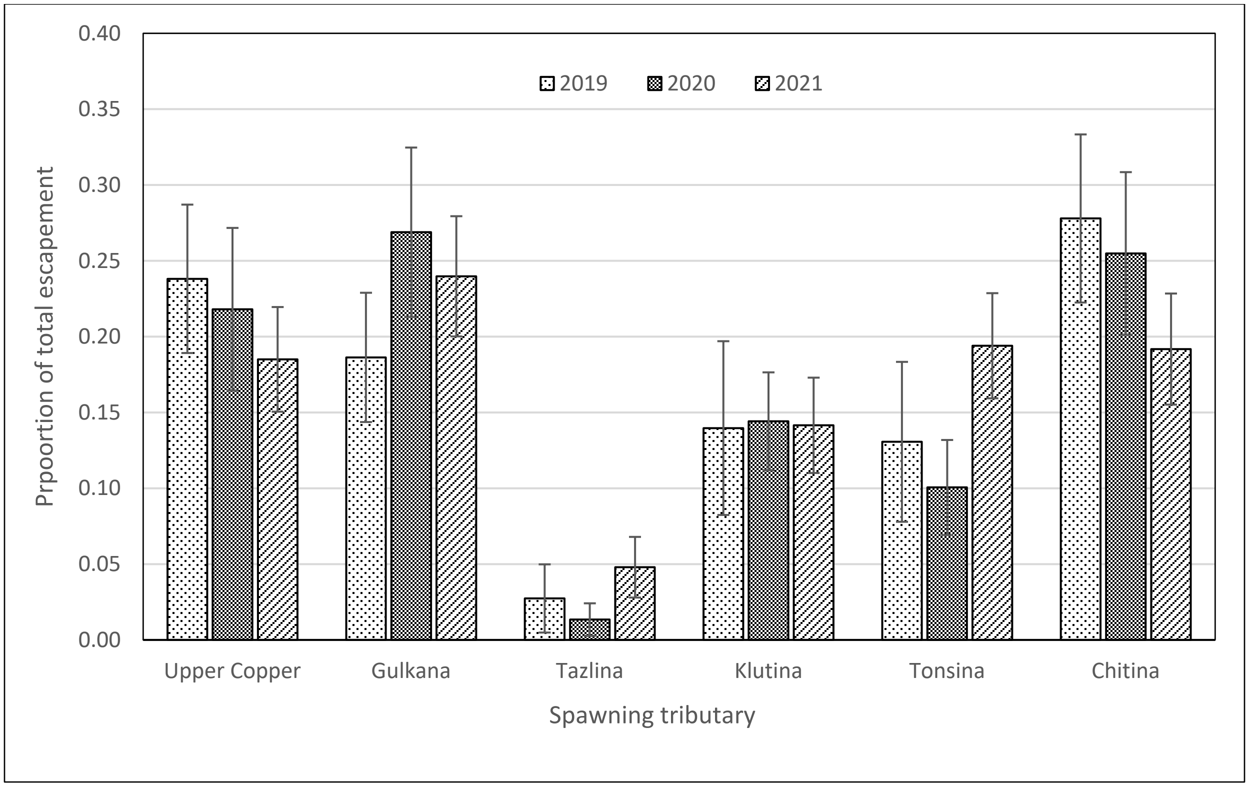


Figure 5.–Spawning distribution and 95% confidence intervals of Copper River Chinook salmon by major drainage, 2019–2021.

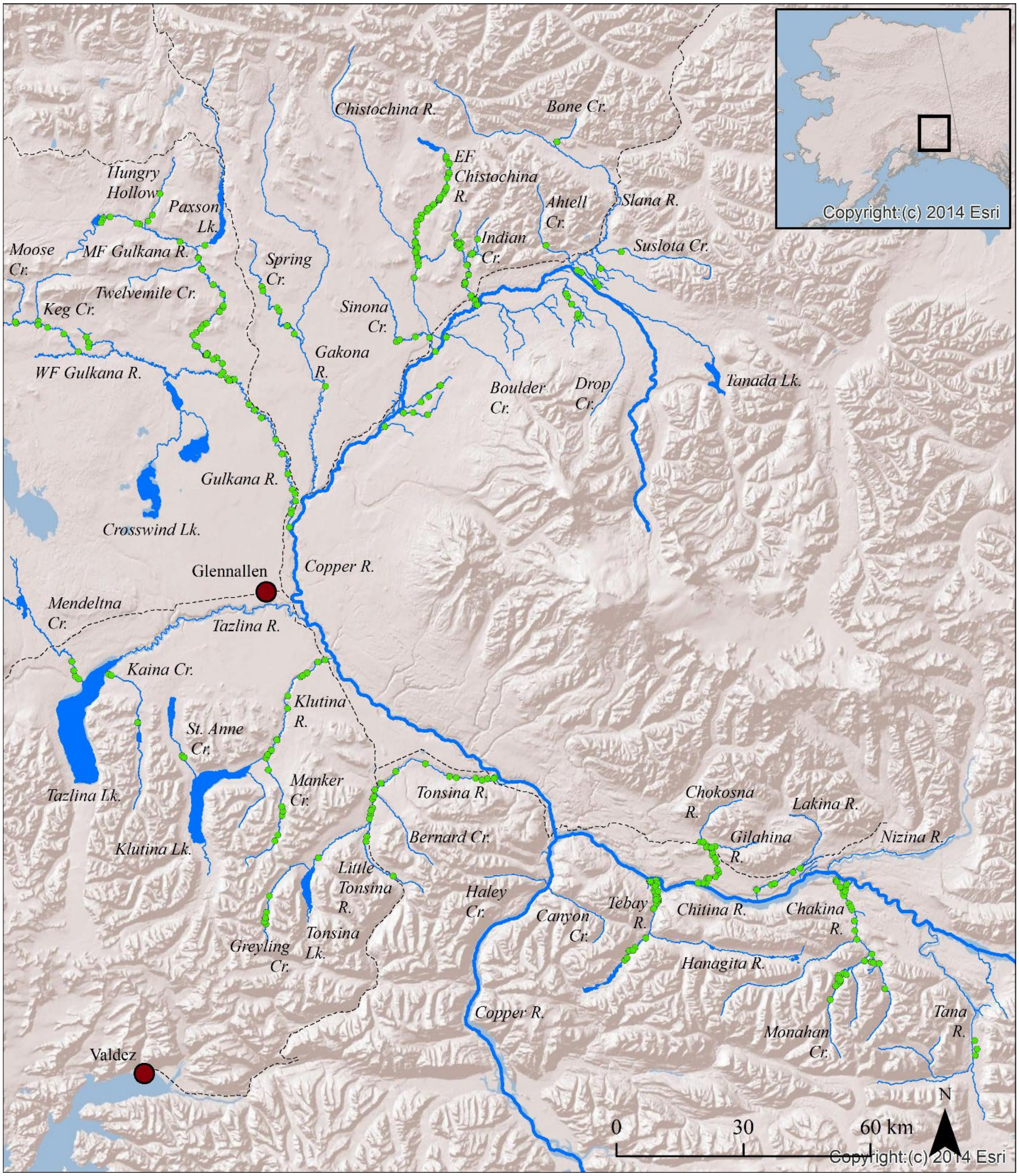


Figure 6.–Distribution of radiotagged Chinook salmon located aerially within 1 of the 6 major spawning tributaries/areas. Each dot represents the furthest upstream location of individual fish during 2019.


Figure 7.–Distribution of radiotagged Chinook salmon located aerially within 1 of the 6 major spawning tributaries/areas. Each dot represents the furthest upstream location of individual fish during 2020.


Figure 8.–Distribution of radiotagged Chinook salmon located aerially within 1 of the 6 major spawning tributaries/areas. Each dot represents the furthest upstream location of individual fish during 2021.

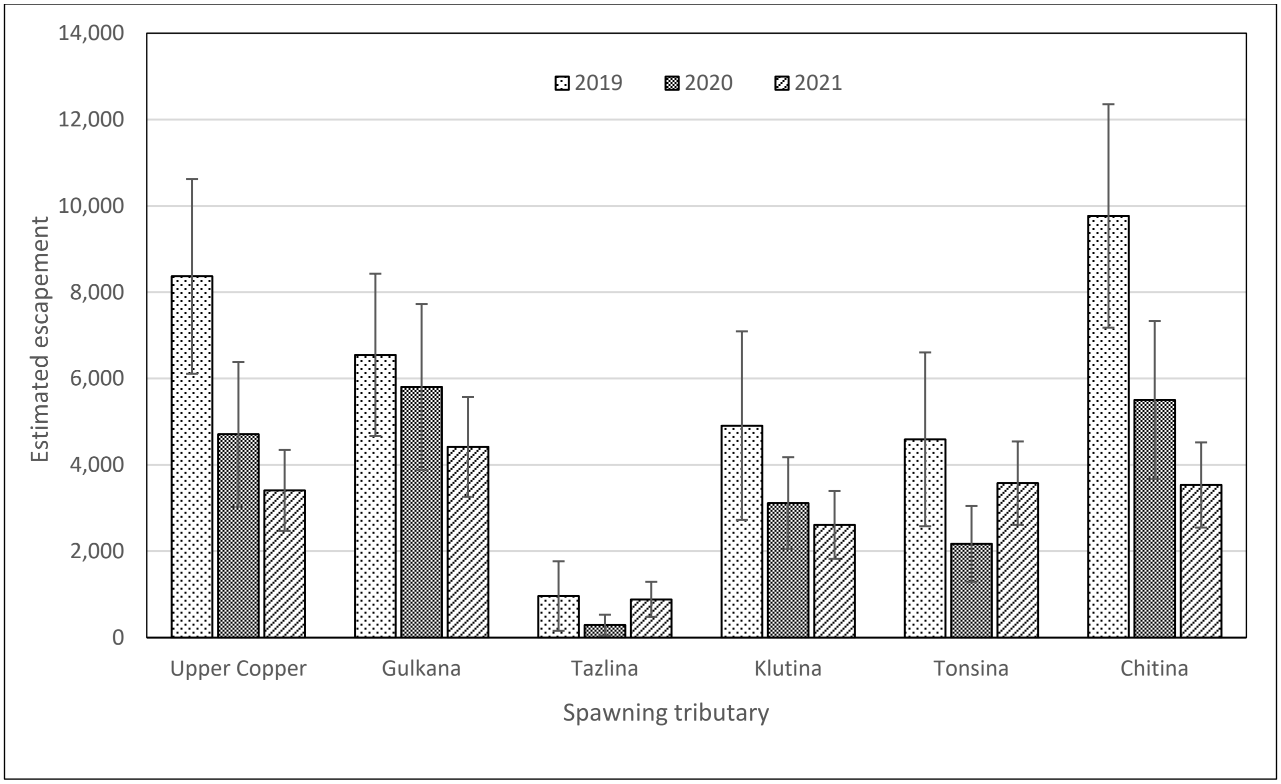


Figure 9.–Estimated escapement and 95% confidence intervals of Copper River Chinook salmon by major drainage, 2019–2021.

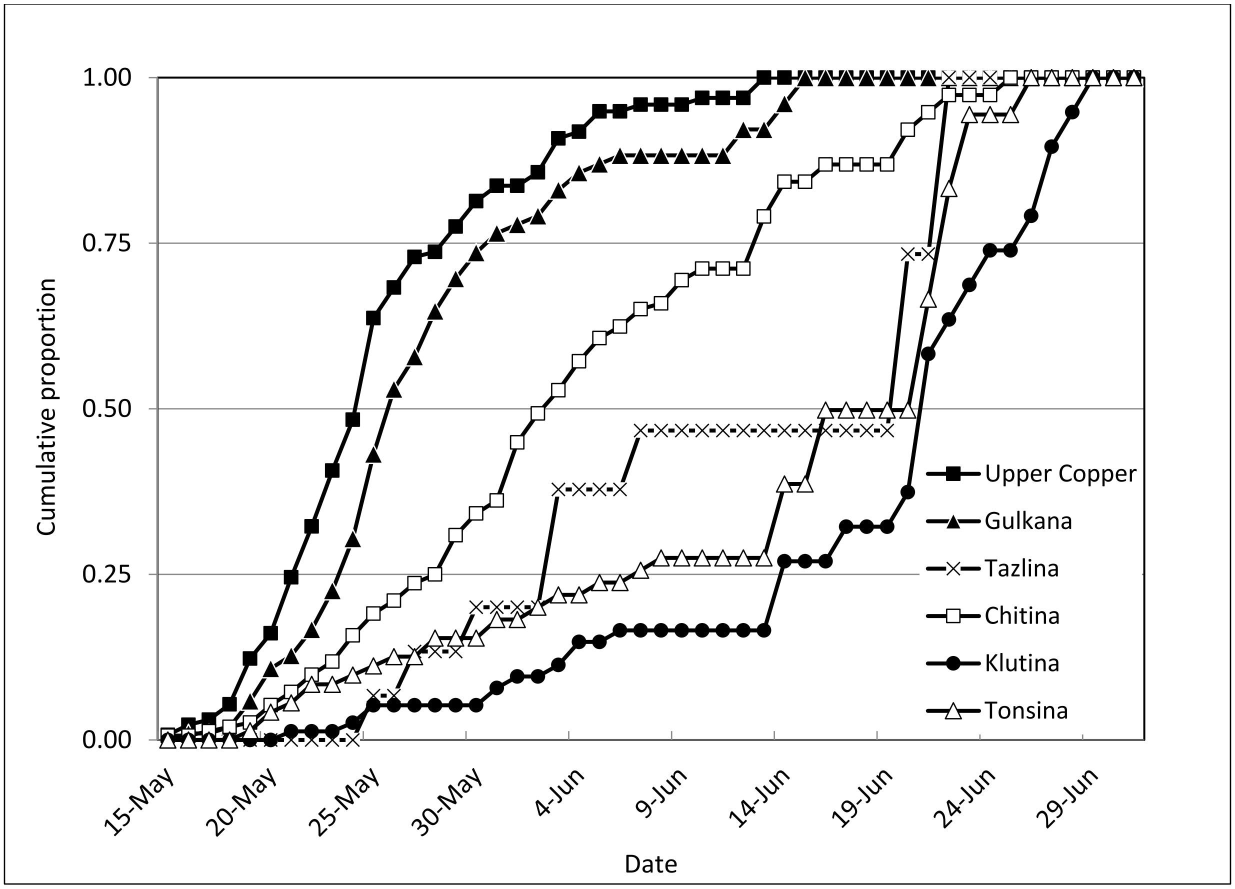


Figure 10.–Cumulative run timing of Chinook salmon at the capture site for the major stocks in the Copper River, 2019.

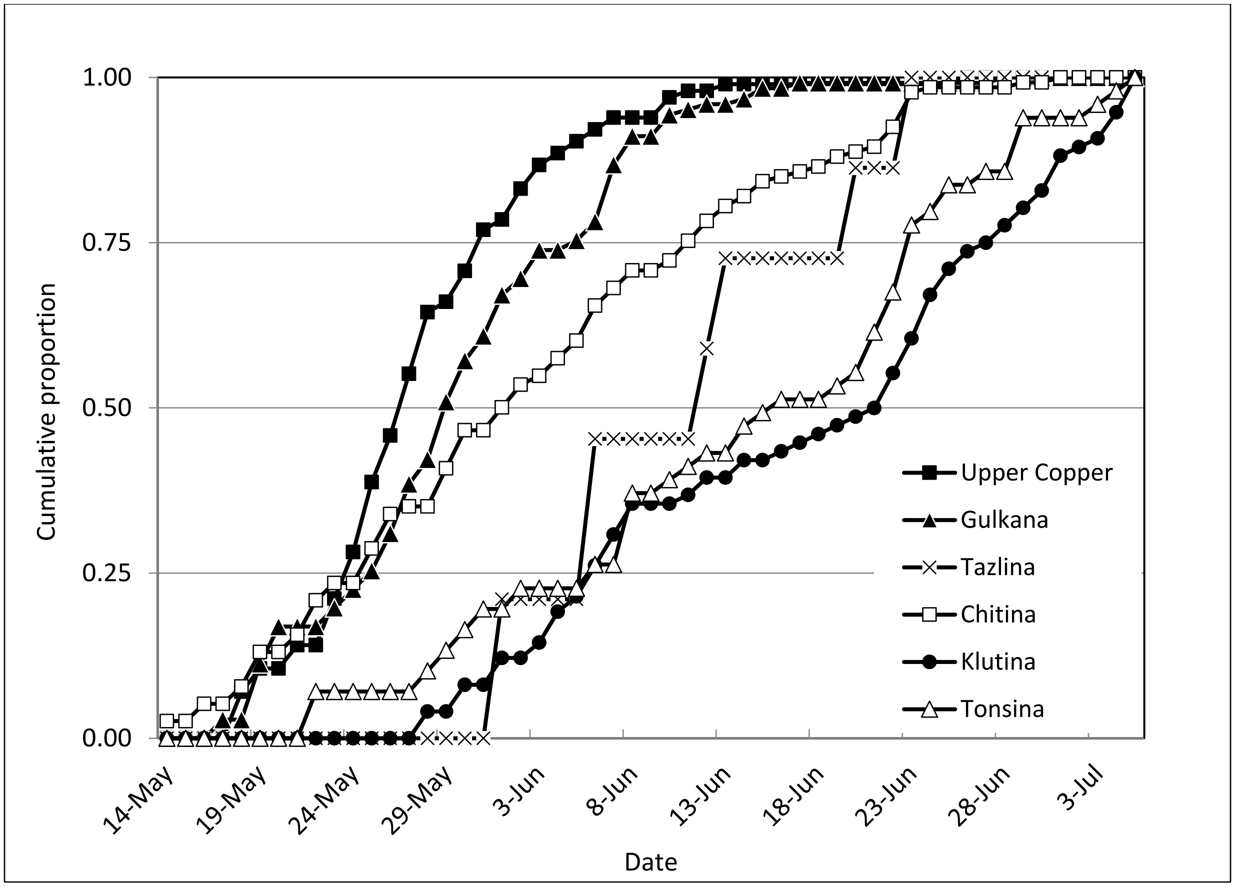


Figure 11.–Cumulative run timing of Chinook salmon at the capture site for the major stocks in the Copper River, 2020.

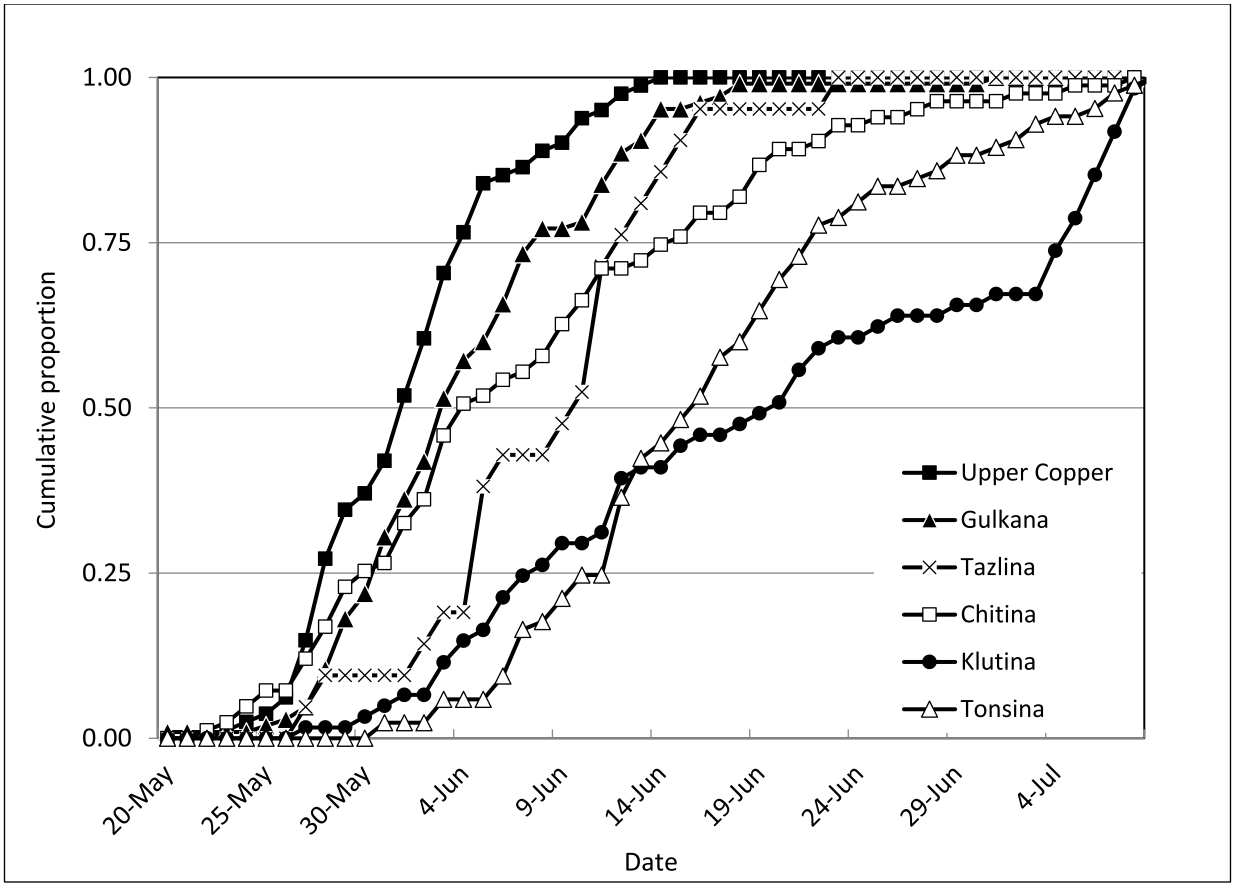


Figure 12.–Cumulative run timing of Chinook salmon at the capture site for the major stocks in the Copper River, 2021.

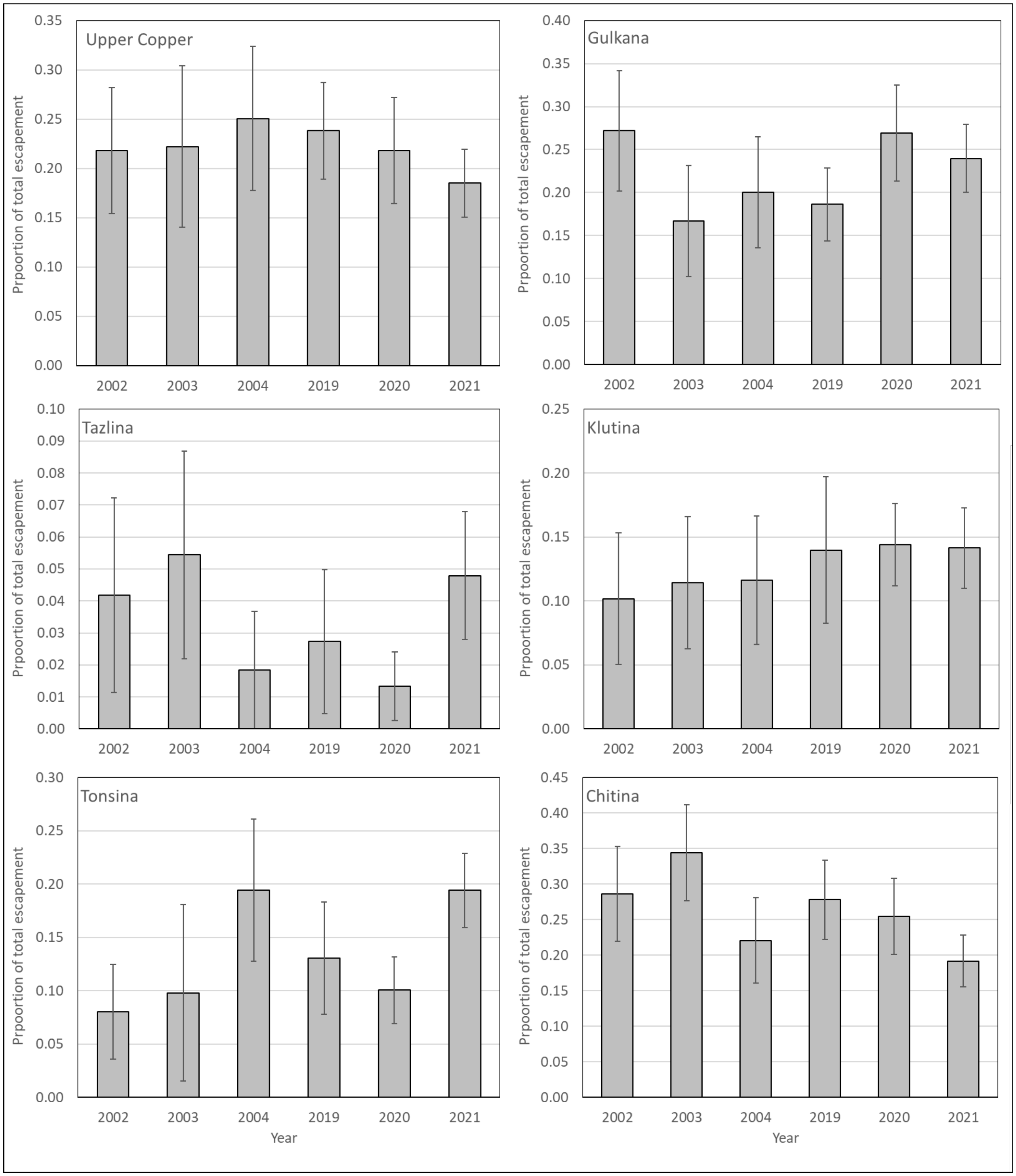


Figure 13.–Spawning distribution and 95% confidence intervals of Copper River Chinook salmon by major drainage, 2002–2004 and 2019–2021.

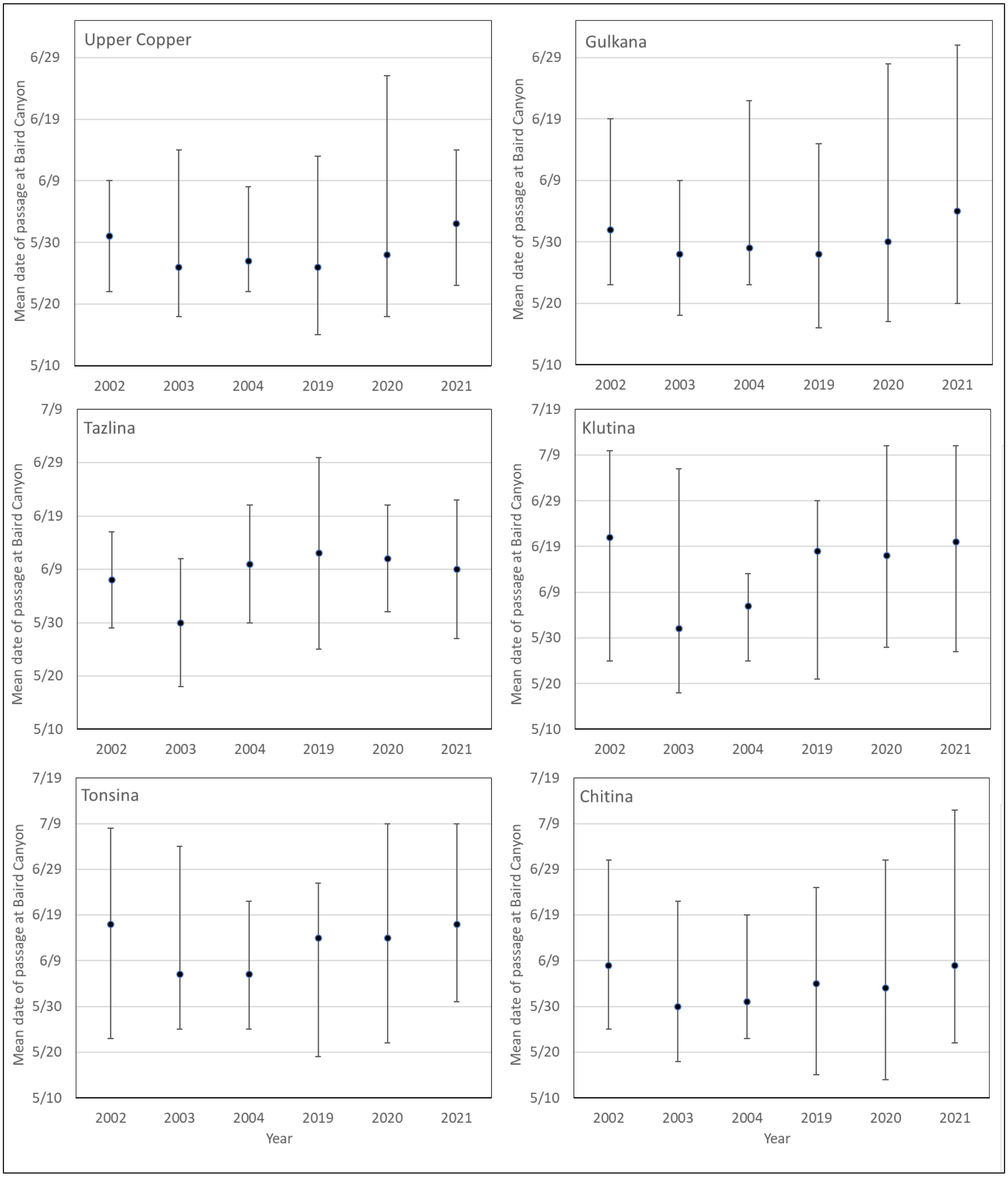


Figure 14.–Mean date of passage at Baird Canyon with the spanned dates of passage, 2002–2004 and 2019–2021.

# APPENDIX A:
# APPORTIONING THE ARIS INRIVER ESTIMATE OF LARGE FISH TO THE TELEMETRY DATA

Appendix A1.–Apportioning the ARIS inriver estimate of large fish to the telemetry data Introduction and Methods.

# INTRODUCTION AND METHODS

An ARIS has been operated on the Copper River by the ADF&G Division of Commercial Fisheries since 2018. This sonar is located about 21 RKM below the Baird Canyon fish capture location used during this telemetry study. The sonar project apportions its counts by small (≤772 mm fork length [FL]) and large (>772 mm FL) fish, with the premise that all "large" fish are Chinook salmon. Although this sonar operates longer than the Native Village of Eyak (NVE) mark–recapture (M–R) study and does not account for small Chinook salmon, we applied the sonar "large" fish counts to this study's radiotelemetry data to weight the individually tagged fish for a secondary round of data analyses (Equations 1–10). It should be noted that the sonar estimates used for this report were up-to-date at the time of this publication. There is a possibility that data interpretation could change over time and numbers could be slightly different in subsequent reports by ADF&G Division of Commercial Fisheries.

Sonar counts are a timeline of continuous counts with no temporal strata to evaluate tag rates. In order to find optimal date stratum breaks for the weighting of radio tags using sonar passage, an algorithm was constructed that inserted stratum breaks at the value that maximized a chi-squared test statistic. First, 2 days were added to the sonar counts to account for the delay it takes fish to get from the sonar site to the Baird Canyon fish wheel locations. Visually, these cumulative passage numbers (by date) were then plotted with the cumulative tag deployment dates. Stratum breaks were iteratively inserted, given a minimum allowable bin width in days (e.g., 5 days), and minimum allowable bin size in number of radiotagged fish (e.g., 13 radio tags). Plots of resulting chi-squared test statistic vs. number of bins were inspected to determine a stratification scheme that resulted in a relatively large test statistic value and relatively small number of bins. Multiple iterations of stratification schemes with high chi-squared test statistics were examined with the 2019 data, and they all ended up being similar, indicating that the technique worked well for distinguishing periods with changes in capture/radiotagging probabilities. Equations 1–10 were used to address objectives 1–5 using the sonar passage to "weight" the tags to estimate proportions, and the final sonar counts for "large" salmon were then used for abundance estimation.

# RESULTS AND DISCUSSION

Objective 1–5 results are displayed below as Appendices A2–A18 in nearly identical formats as those reported previously that used the NVE-Darroch as the weighting estimator. Although the results should not be compared directly to Savereide (2005), they are presented in this report for a visual comparison between the 2 weighting processes (NVE-Darroch technique vs. ARIS technique) for 2019–2021.

Adjusted sonar counts (2 days were added to adjust for swim time to the radiotagging site), radio tag deployment, and temporal strata used for weighting are presented in Appendices A2 and A8. When using the sonar passage of large fish (>772 mm FL) to weight the radiotagged fish in this study, proportions and run timing visually changed with obvious patterns. The proportions of early run fish (i.e., Upper Copper and Gulkana Rivers) were generally reduced and the proportions of the later run stocks generally increased (i.e., Tonsina and Klutina Rivers; Table 7, Figure 5, Appendices A3, A9, A14–A16). Tributary proportions were reduced as well because tributary fish

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typically have earlier run timing (Table 9 and Appendix A5). Estimated abundances in the 6 major spawning tributary/areas followed no real trend as the proportion estimates were applied to different estimates of escapement (Table 8, Figure 9, Appendices A4 and A10). Run timing also changed across the board, with later estimated run timing occurring when sonar passage was used to weight radiotagged fish (Table 11 and Appendix A6). The proportion of Gulkana River fish that spawned above the ADF&G counting tower changed little (Table 10 and Appendix A6), probably because of the mixed component of tributary and mainstem fish spawning above and below the ADFG&G counting tower. Despite this overwhelming trend of late run fish increasing in proportions, and a nearly across the board shift to a later run timing when sonar passage was used as the weighting mechanism, only 3 single data points were significantly different at the 95% confidence interval. In 2020 and 2021, the 95% confidence intervals for the proportion of spawners returning to the Upper Copper area missed overlapping by fractions of a percentage point (Appendices A15 and A16). In 2020, the Klutina River had an NVE-Darroch weighted proportion of 0.14 (95% CI = 0.11–0.18) and the sonar weighted proportion was 0.26 (95% = CI 0.21-0.30; Appendix 15). The greatest changes in proportions occurred for the stocks with the earliest and latest run timing, which was likely due to the inherent differences of the estimators (Darroch vs. sonar) used to weight the radio tags.

First, the different start and end times of the NVE mark–recapture project and sonar project likely had the biggest effect on the weighting process. Generally, the NVE fish wheel project started enumerating fish earlier than the sonar, and the sonar project counted later than the NVE fish wheels. The differences in daily fish wheel catches vs. sonar counts and cumulative fish wheel counts vs. sonar counts are presented as Appendices A17 and A18 and are discussed in greater detail below.

The sonar project remained in operation longer than the NVE mark–recapture project all 3 years. NVE ceased tagging operations on 2 July in 2019, 13 July in 2020 and 17 July in 2021. The sonar ceased operations on 27 July in 2019, 28 July in 2020 and 28 July in 2021. This was 25, 15, and 11 days later during those respective years, and during those time periods the sonar enumerated an additional 3,821, 438, and 2,017 “large” fish. Although these additional fish do not represent a significant portion of the overall sonar passage, they were all added to the final stratum in the weighting process, which added more weight to the fish radiotagged at the end of the project. Simply put, the longer periods of enumeration at the sonar site increased the weighting value of fish tagged later in the runs. Appendix A2 illustrates that the ratios of the radio tags deployed vs. sonar passage were very low in the final stratum all 3 years. Low ratios of radiotagged fish translates to more weight for each radiotagged fish in that stratum.

Conversely, different starting times affected the weighting in the first stratum. The fish wheels and sonars commenced operation at different times all 3 years. Start dates were similar in 2019 and 2021. However, in 2020 there was a disparity between the 2 studies. The sonar did not start counting fish until 19 May, and assuming a 2-day swim speed delay, those fish would not reach Baird Canyon until 21 May. The NVE fish wheel project started on 10 May and started capturing and radiotagging Chinook salmon on 14 May. By 21 May, the NVE fish wheels had already caught 161 Chinook salmon and radiotagged 34 of them. Of those 34 radiotagged fish, a total of 16 (5.0% of all radiotagged spawning fish in 2020) later made it to a spawning area and were used to estimate

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proportions, abundances, and run timing (Appendix A2). However, these fish have little weight due to the sonar not counting fish for most of that period. Those radiotagged fish were weighted to a minuscule amount of the overall sonar passage (just 97 fish out of a cumulative total of 22,072). Obviously, the sonar missed fish in the beginning of 2020, which substantially reduced the weight of the early radiotagged fish.

In addition to differences in project duration, there was also a difference in the estimated population of inference between the 2 projects. The sonar estimated "large" fish >772 mm FL, which corresponded to a MEF length of about 700 mm. The NVE mark–recapture estimated all Chinook salmon 500 mm FL (approximately ≥450 mm MEF). This deviation between studies likely contributed to the deviations in the results. For example, early run fish such as the Upper Copper River stock are generally smaller than Klutina River fish, and through the weighting process would be underrepresented if the sonar did not count all of these smaller sized fish. For example, if 20% of the passage at the capture site during temporal stratum X were <700 mm MEF, and the radio tags were applied at that same proportion (i.e., 20% of the radio tags were deployed in fish <700 mm MEF), those radiotagged fish would be weighted by a sonar passage estimate that did not include them. Theoretically, the lower sonar passage for that temporal stratum would reduce the weight of radiotagged fish early in the run, hence reducing the proportion of fish bound for upriver reaches.

Lasty, the sonar passage is a continuous count and the NVE mark–recapture experiment is an estimation. Estimation techniques can have temporal disparities in accuracy as sample sizes are reduced due to various covariates such as changes in water flow or temperature. Changing water levels likely affect the NVE based Darroch estimator more than the sonar counts. Typically, NVE fish wheel catches are compromised when the water is high, due to decreases in catch and tag rates at each site. Sometimes the fish wheels are even shut off during periods of high water, causing negative bias in the estimate. The sonar is typically more robust in high water conditions and can continue to accurately assess passage. As with most glacial rivers, the Copper River generally increases in flow throughout the summer, often times negatively affecting fish wheel catch rates as summer progresses. This seasonal trend of increasing water discharge could lead to less accurate, or less precise, estimates of passage in later strata. If these estimates later in the season are lower than the sonar passage estimates, that would help explain the shift favoring later run fish in each of the 3 years when using the sonar passage to weight the radiotagged fish. As stated earlier, all 3 years heavily weighted the radiotagged fish at the end of the study when sonar data was used.

In summary, the sonar estimates fish passage differently, not only in technique, but also in duration and size of fish being estimated. Both estimating techniques are influenced differently with changing water conditions throughout the year. The differences in estimated proportions and run timing between the 2 weighting techniques are influenced by all of these factors.

Appendix A2.–Strata information used to weight the radio tags (spawning fish only) using the sonar passage, 2019–2021.

| | 2019 | | | 2020 | | | 2021 | | |
|---|---|---|---|---|---|---|---|---|---|
| Strata # | Strata dates | # Tags | Fish passage | Strata dates | # Tags | Fish passage | Strata dates | # Tags | Fish passage |
| 1 | 5/10–5/18 | 12 | 224 | 5/14–5/21 | 16 | 97 | 5/18–6/28 | 50 | 328 |
| 2 | 5/19–5/21 | 49 | 157 | 5/22–6/06 | 134 | 7,240 | 5/29–5/31 | 45 | 1,720 |
| 3 | 5/22–5/26 | 128 | 5,298 | 6/07–6/18 | 74 | 8,543 | 6/01–6/03 | 70 | 3,806 |
| 4 | 5/27–6/03 | 112 | 7,919 | 6/19–7/21 | 13 | 568 | 6/04–6/11 | 114 | 9,230 |
| 5 | 6/04–7/30 | 84 | 35,699 | 6/22–6/23 | 28 | 473 | 6/12–6/23 | 108 | 5,149 |
| 6 | | | | 6/24–7/30 | 57 | 5,151 | 6/24–7/07 | 41 | 3,470 |
| 7 | | | | | | | 7/08–7/30 | 10 | 4,662 |
| Totals | | 385 | 49,297 | | 322 | 22,072 | | 438 | 28,365 |

Appendix A3.–Spawning distribution of Copper River Chinook salmon by major drainage, weighted by sonar passage, 2019–2021.

| | 2019 | | 2020 | | 2021 | |
|---|---|---|---|---|---|---|
| Fate | Proportion | SE | Proportion | SE | Proportion | SE |
| Upper Copper | 0.15 | 0.02 | 0.13 | 0.02 | 0.12 | 0.02 |
| Gulkana | 0.14 | 0.02 | 0.21 | 0.02 | 0.21 | 0.02 |
| Tazlina | 0.03 | 0.01 | 0.02 | 0.01 | 0.05 | 0.01 |
| Klutina | 0.17 | 0.03 | 0.26 | 0.02 | 0.20 | 0.02 |
| Tonsina | 0.15 | 0.03 | 0.15 | 0.02 | 0.23 | 0.02 |
| Chitina | 0.36 | 0.04 | 0.24 | 0.03 | 0.18 | 0.02 |

Appendix A4.–Abundance estimates of Copper River Chinook salmon by major drainage, weighted by sonar passage, 2019–2021.

| | 2019 | | 2020 | | 2021 | |
|---|---|---|---|---|---|---|
| Fate | Abundance | SE | Abundance | SE | Abundance | SE |
| Upper Copper | 6,158 | 947 | 2,251 | 311 | 3,131 | 380 |
| Gulkana | 5,614 | 951 | 3,611 | 415 | 5,358 | 508 |
| Tazlina | 1,321 | 603 | 314 | 144 | 1,308 | 298 |
| Klutina | 7,010 | 1,349 | 4,441 | 416 | 4,907 | 579 |
| Tonsina | 6,150 | 1,283 | 2,551 | 376 | 5,897 | 549 |
| Chitina | 14,475 | 1,595 | 4,199 | 445 | 4,539 | 585 |

Appendix A5.–Proportions of Chinook salmon located in nine aerial survey index streams in the Copper River drainage, weighted by sonar passage, 2019–2021.

| | 2019 | | 2020 | | 2021 | |
|---|---|---|---|---|---|---|
| Fate | Proportion | SE | Proportion | SE | Proportion | SE |
| Gulkana River | 0.14 | 0.02 | 0.21 | 0.02 | 0.21 | 0.02 |
| East Fork Chistochina River | 0.06 | 0.02 | 0.05 | 0.01 | 0.05 | 0.01 |
| Manker Creek | 0.03 | 0.01 | 0.03 | 0.01 | 0.02 | 0.01 |
| St. Anne Creek | 0.01 | <0.01 | 0.01 | 0.01 | 0.01 | 0.01 |
| Little Tonsina River | <0.01 | <0.01 | 0.01 | 0.01 | 0.01 | <0.01 |
| Greyling Creek | 0.02 | 0.01 | 0.02 | 0.01 | 0.01 | 0.01 |
| Indian Creek | 0.02 | <0.01 | 0.02 | 0.01 | 0.02 | 0.01 |
| Kaina Creek | 0.02 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 |
| Mendeltna Creek | 0.01 | 0.01 | 0.01 | 0.01 | 0.03 | 0.01 |
| Total in Index Streams | 0.31 | 0.04 | 0.43 | 0.04 | 0.35 | 0.03 |

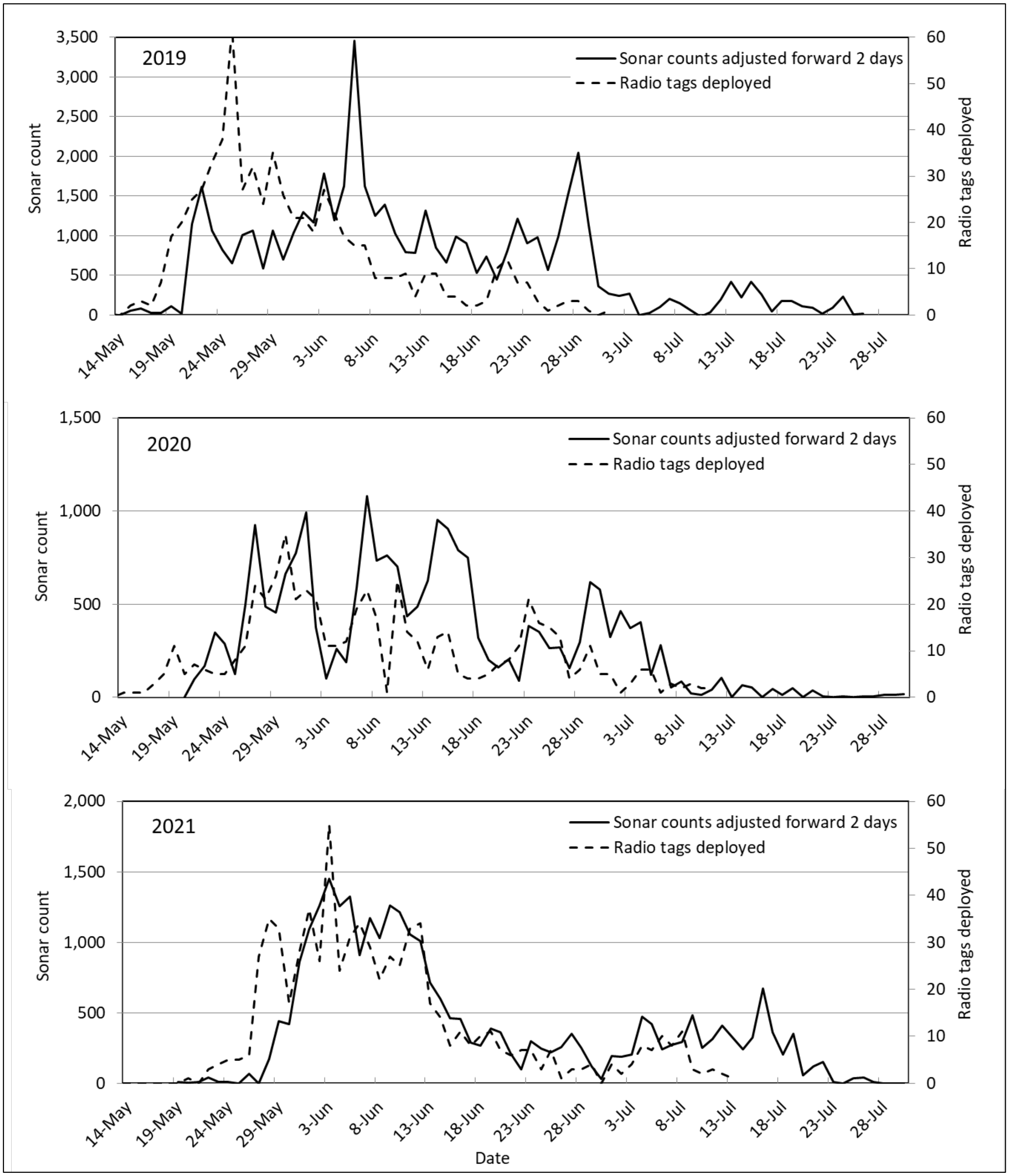
Appendix A6.–Statistics regarding the run timing past the capture site in Baird Canyon of the major Chinook salmon spawning stocks in the Copper River, weighted by sonar passage, 2019–2021.

| | 2019 | | | 2020 | | | 2021 | | |
|---|---|---|---|---|---|---|---|---|---|
| Spawning location | Dates spanned | Mean date of tagging ($\bar{t}$) | SE $\bar{t}$ | Dates spanned | Mean date of tagging ($\bar{t}$) | SE $\bar{t}$ | Dates spanned | Mean date of tagging ($\bar{t}$) | SE $\bar{t}$ |
| Upper Copper | 5/15–6/13 | 5/31 | 6.7 | 5/18–6/26 | 6/1 | 7.6 | 5/23–6/14 | 6/2 | 4.2 |
| Gulkana | 5/16–6/15 | 6/1 | 7.3 | 5/17–6/28 | 6/3 | 7.4 | 5/20–7/1 | 6/5 | 5.8 |
| Above tower | 5/16–6/15 | 6/1 | 7.3 | 5/19–6/28 | 6/3 | 7.9 | 5/20–7/1 | 6/4 | 6.2 |
| Below tower | 5/19–6/14 | 6/2 | 8.2 | 5/19–6/15 | 6/2 | 6.2 | 5/25–6/14 | 6/5 | 4.6 |
| Tazlina | 5/25–6/22 | 6/13 | 9.2 | 6/1–6/23 | 6/13 | 6.8 | 5/27–6/23 | 6/8 | 6.2 |
| Klutina | 5/21–6/29 | 6/18 | 8.7 | 5/28–7/11 | 6/22 | 12.0 | 5/27–7/11 | 7/1 | 11.5 |
| Mainstem | 5/24–6/29 | 6/19 | 7.7 | 6/3–7/11 | 6/27 | 10.1 | 6/3–7/11 | 7/4 | 7.9 |
| Tributaries | 5/21–6/21 | 6/10 | 8.5 | 5/28–7/9 | 6/12 | 11.9 | 5/27–6/26 | 6/8 | 7.1 |
| Tonsina | 5/19–6/26 | 6/16 | 8.3 | 5/22–7/9 | 6/20 | 11.4 | 5/31–7/9 | 6/17 | 9.2 |
| Mainstem | 5/19–6/26 | 6/18 | 6.9 | 5/22–7/9 | 6/23 | 10.5 | 5/31–7/9 | 6/23 | 12.1 |
| Tributaries | 5/20–6/7 | 6/3 | 5.2 | 5/28–6/23 | 6/10 | 8.6 | 5/31–7/4 | 6/16 | 11.0 |
| Chitina | 5/15–6/25 | 6/7 | 7.5 | 5/14–7/1 | 6/9 | 10.0 | 5/22–7/12 | 6/15 | 15.1 |

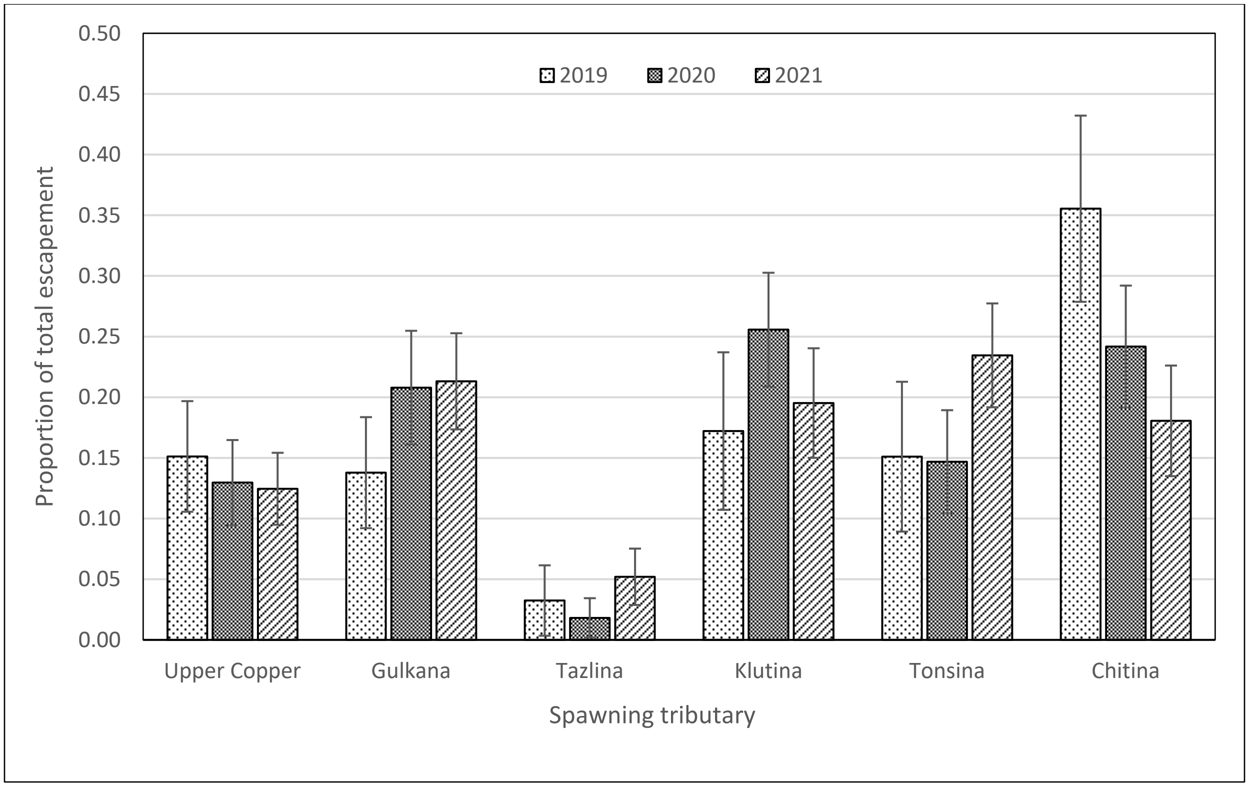
Appendix A7.–Spawning distribution of Gulkana River Chinook salmon in relation to the Gulkana River counting tower, weighted by sonar passage, 2019–2021.

| | 2019 | | 2020 | | 2021 | |
|---|---|---|---|---|---|---|
| Fate | Proportion | SE | Proportion | SE | Proportion | SE |
| Above tower | 0.64 | 0.10 | 0.71 | 0.07 | 0.55 | 0.06 |
| Below tower | 0.36 | 0.10 | 0.29 | 0.07 | 0.45 | 0.06 |

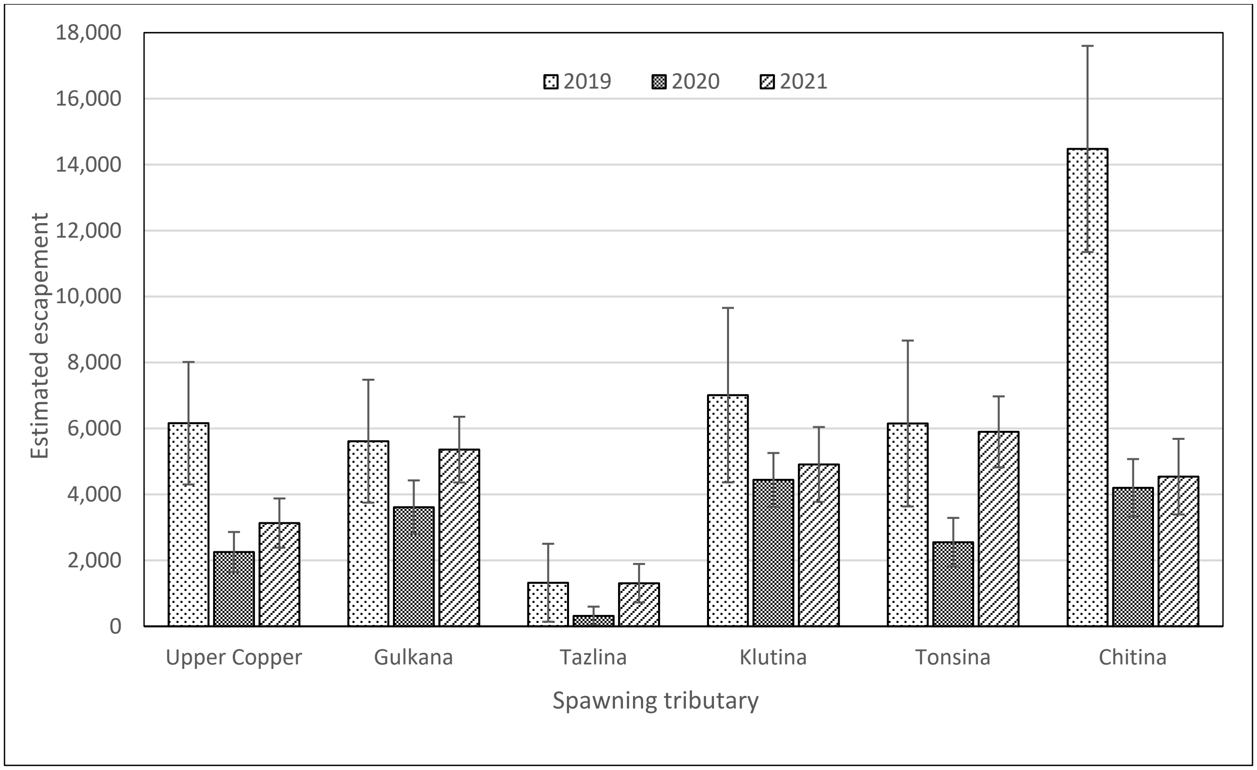
Appendix A8.–Daily sonar counts and number of radio tags deployed at the Baird Canyon fish wheels, 2019–2021.



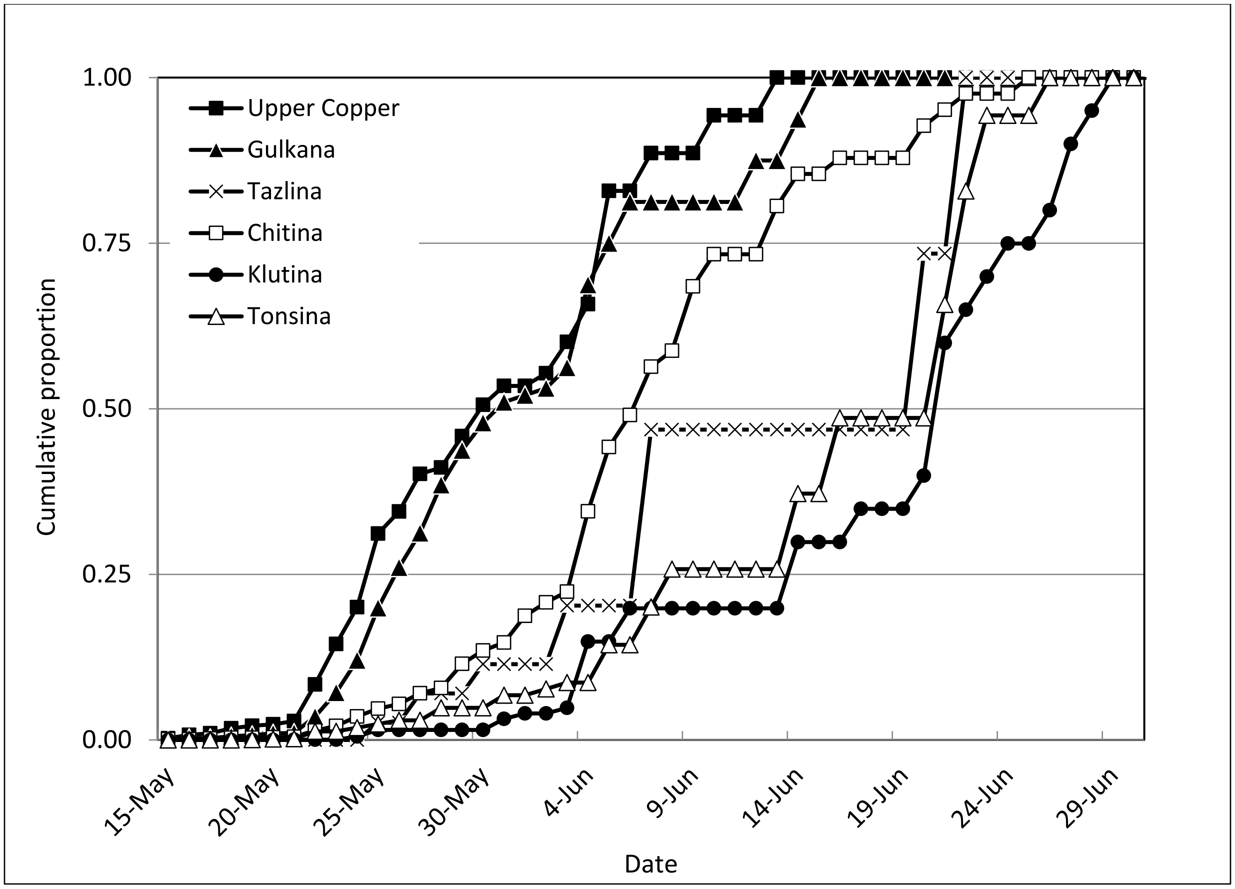
Appendix A9.–Spawning distribution and 95% confidence intervals of Copper River Chinook salmon by major drainage, weighted by sonar passage, 2019–2021.



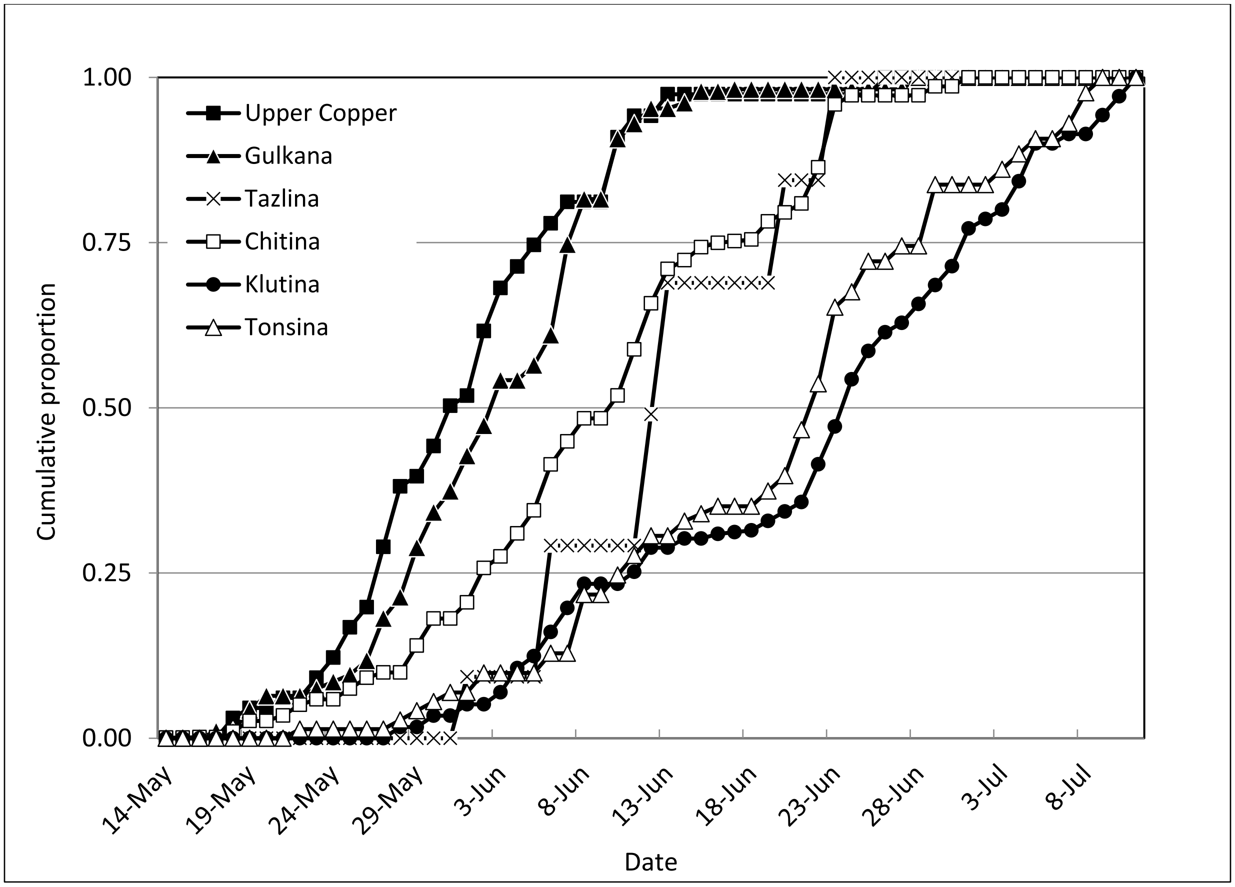
Appendix A10.–Estimated escapement and 95% confidence intervals of Copper River Chinook salmon by major drainage, weighted by sonar passage, 2019–2021.



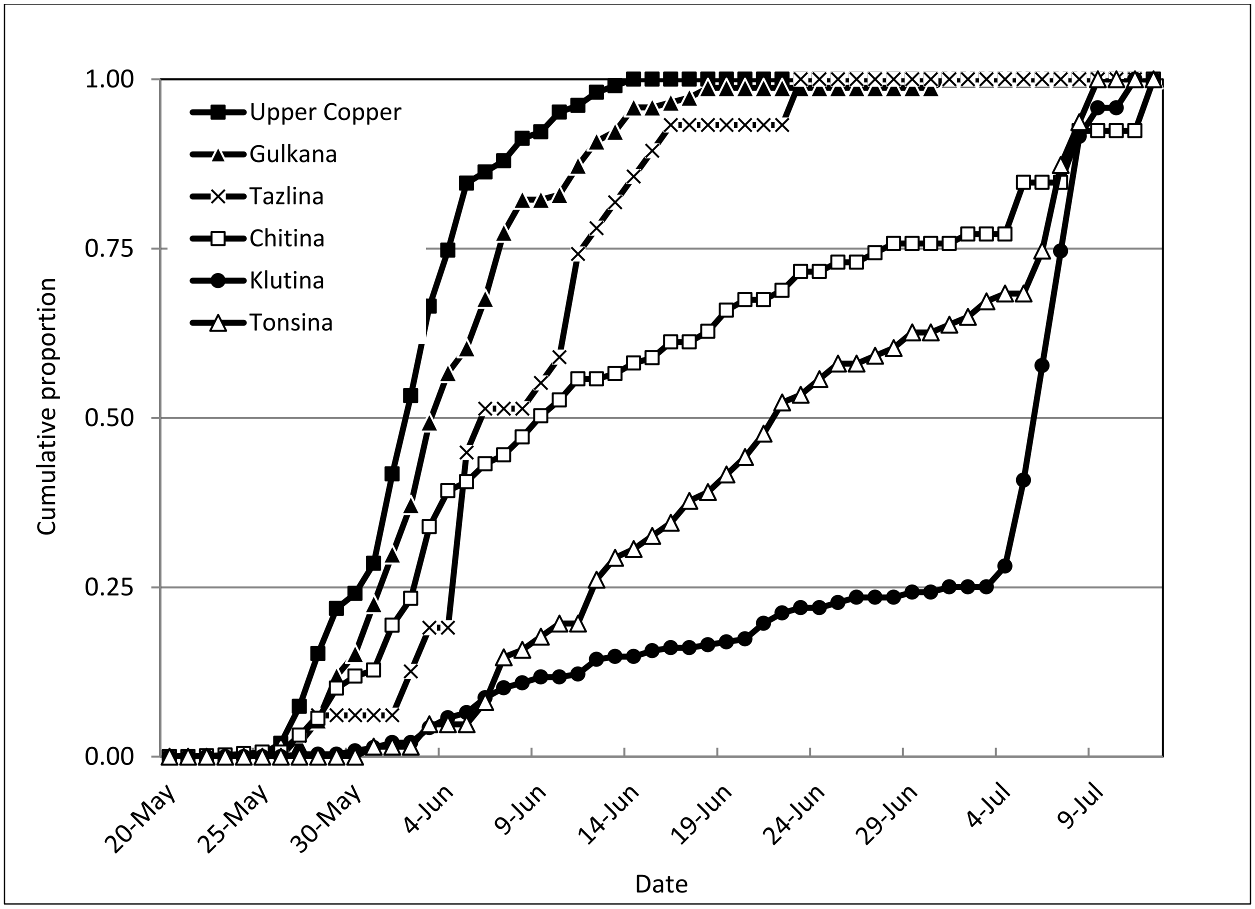
Appendix A11.–Cumulative run timing of Chinook salmon at the capture site for the major stocks in the Copper River, weighted by sonar passage, 2019.



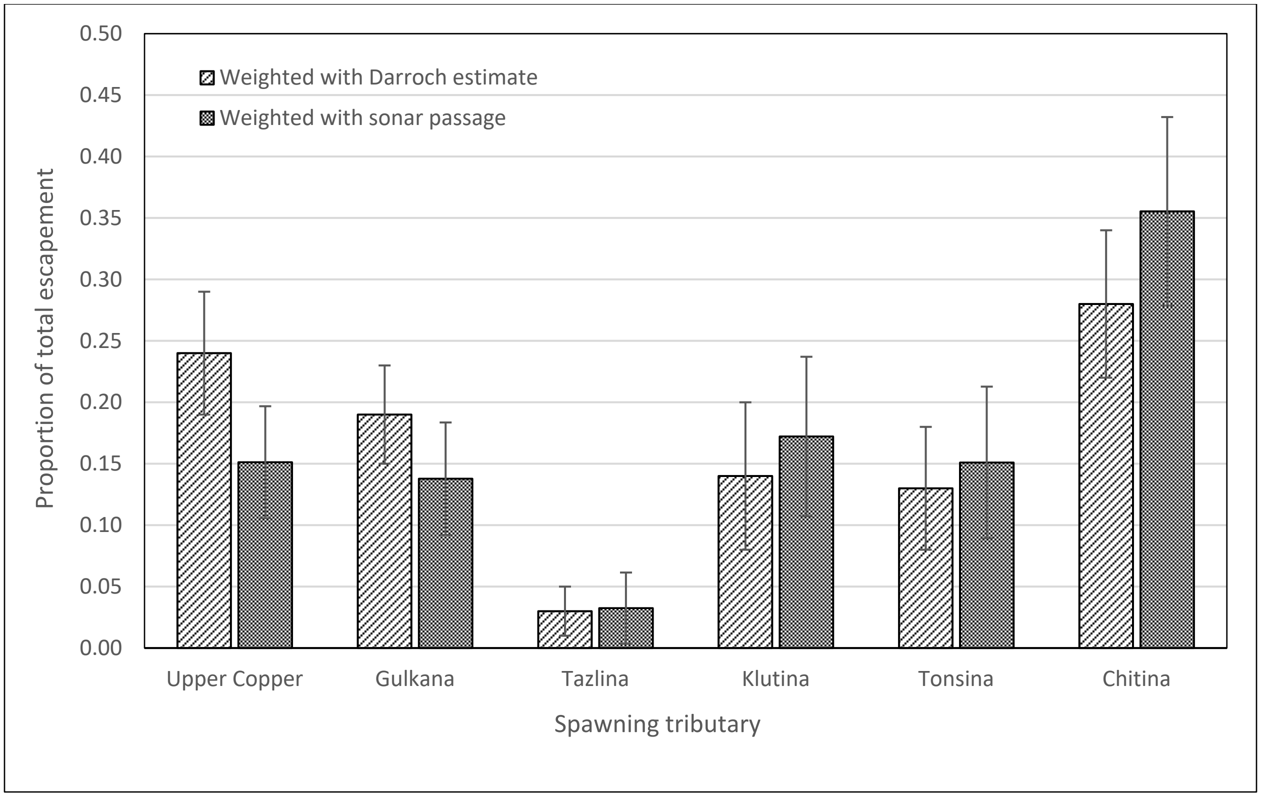
Appendix A12.–Cumulative run timing of Chinook salmon at the capture site for the major stocks in the Copper River, weighted by sonar passage, 2020.



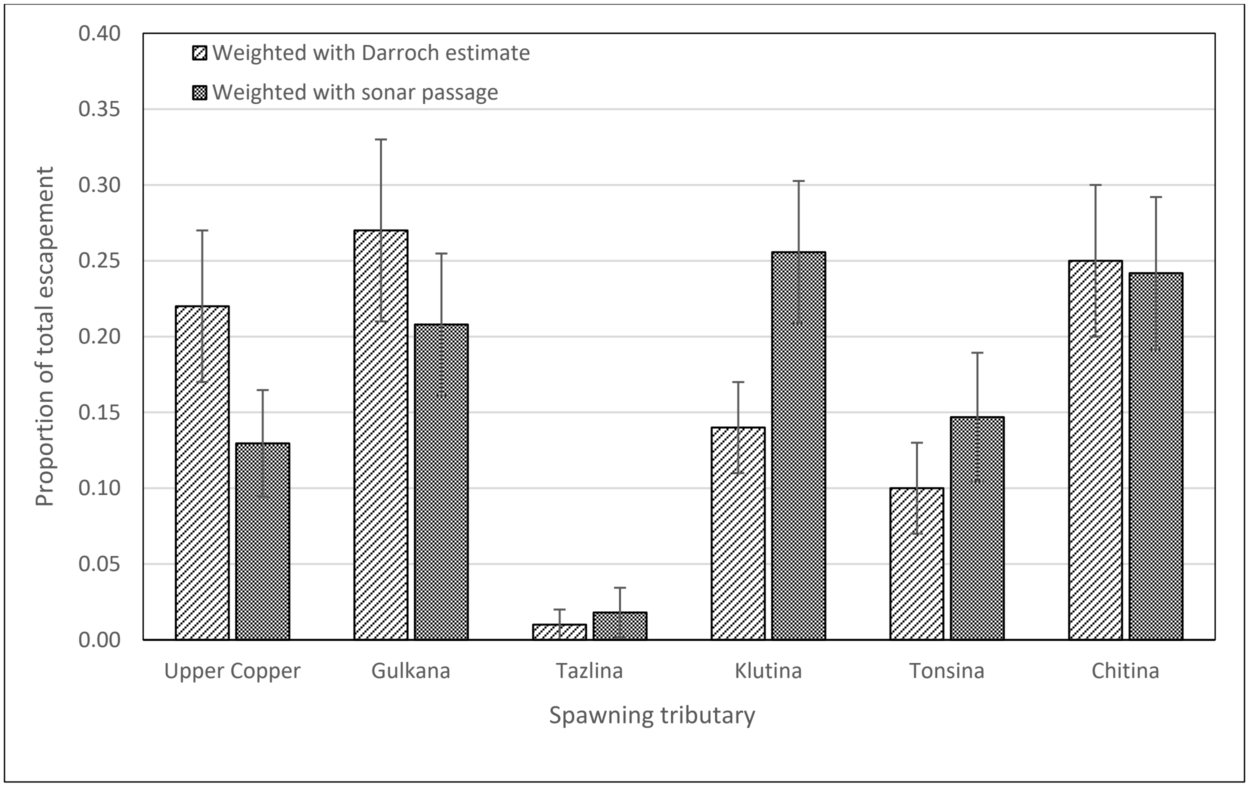
Appendix A13.–Cumulative run timing of Chinook salmon at the capture site for the major stocks in the Copper River, weighted by sonar passage, 2021.



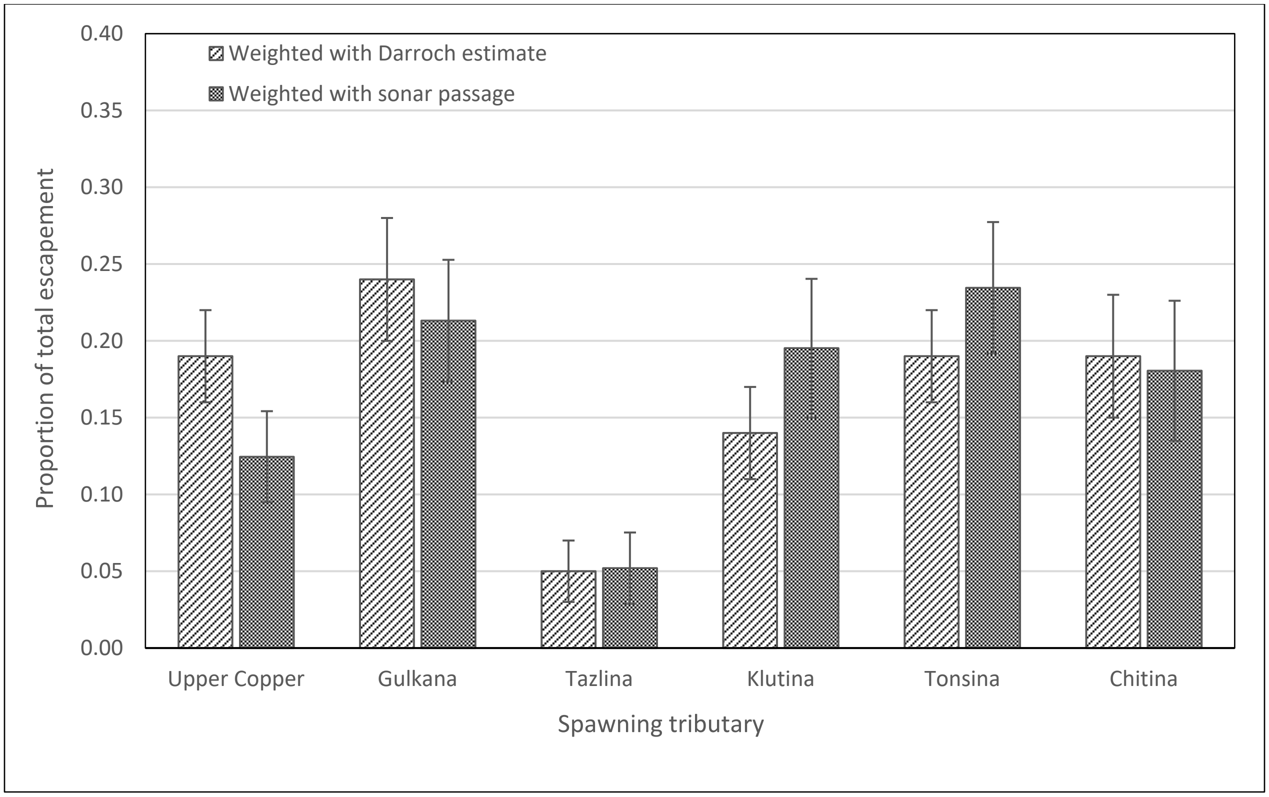
Appendix A14.–Spawning distribution and 95% confidence intervals of Copper River Chinook salmon by major drainage, weighted by the NVE-Darroch estimator and the sonar passage, 2019.



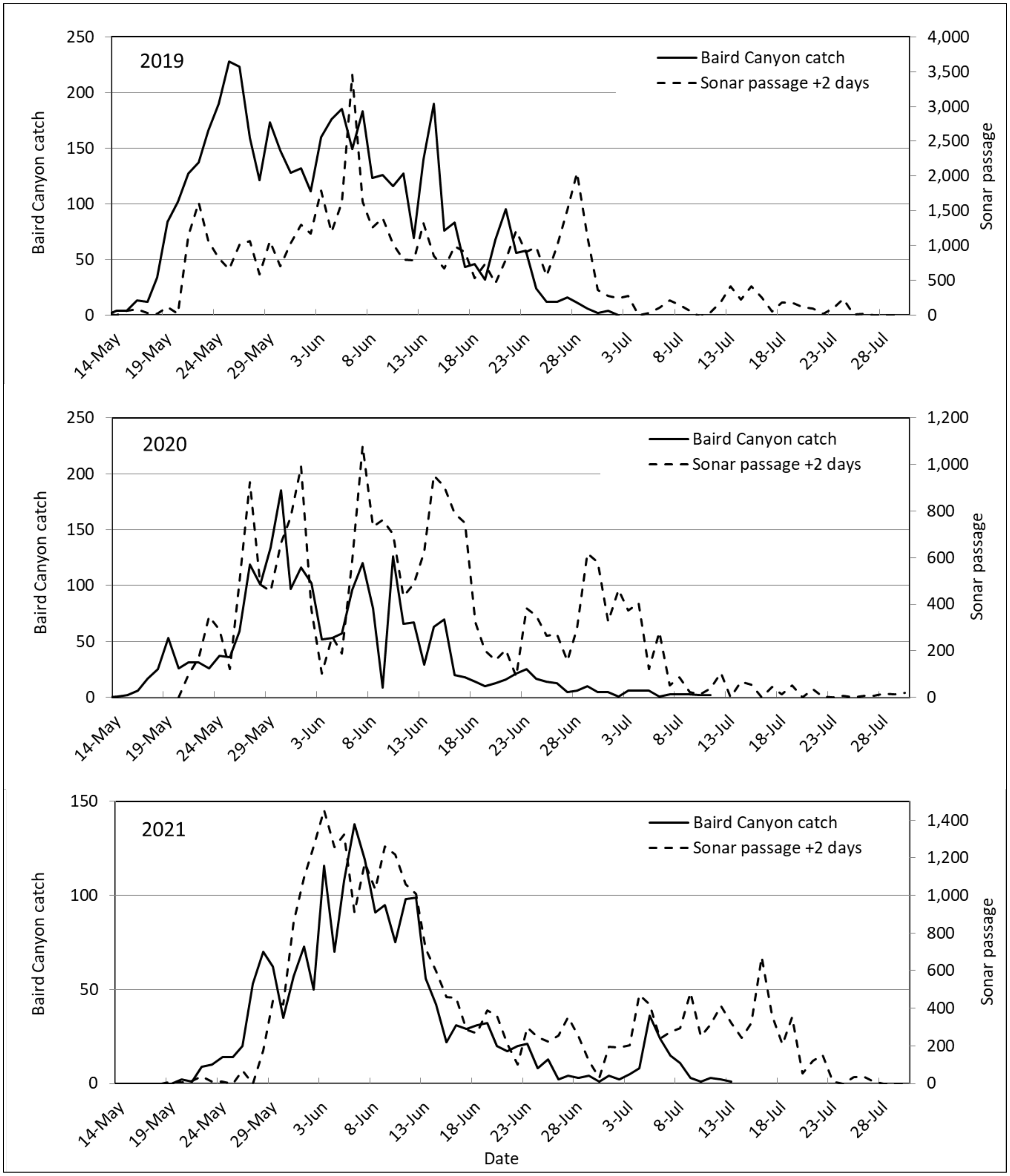
Appendix A15.–Spawning distribution and 95% confidence intervals of Copper River Chinook salmon by major drainage, weighted by the NVE-Darroch estimator and the sonar passage, 2020.



Appendix A16.–Spawning distribution and 95% confidence intervals of Copper River Chinook salmon by major drainage, weighted by the NVE-Darroch estimator and the sonar passage, 2021.



Appendix A17.–Daily catch rates of Chinook salmon from the Native Village of Eyak fish wheels and sonar estimates of large fish (>772 mm fork length [FL]).



Appendix A18.–Cumulative proportion of Chinook salmon catch from the Native Village of Eyak fish wheels and sonar estimates of large fish (>772 mm fork length [FL]).