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Inriver Abundance, Spawning Distribution, and Run Timing of Copper River Chinook Salmon in 2002

Annual Report for Study 02-015
USFWS Office of Subsistence Management
Fishery Information Service Division

by
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Alaska Department of Fish and Game **Division of Sport Fish**

Symbols and Abbreviations

The following symbols and abbreviations, and others approved for the Système International d'Unités (SI), are used in Division of Sport Fish Fishery Manuscripts, Fishery Data Series Reports, Fishery Management Reports, and Special Publications without definition.

Weights and measures (metric)

centimeter	cm
deciliter	dL
gram	g
hectare	ha
kilogram	kg
kilometer	km
liter	L
meter	m
metric ton	mt
milliliter	ml
millimeter	mm

Weights and measures (English)

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

Time and temperature

day	d
degrees Celsius	°C
degrees Fahrenheit	°F
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	pH
parts per million	ppm
parts per thousand	ppt, ‰
volts	V
watts	W

General

All commonly accepted abbreviations.	e.g., Mr., Mrs., a.m., p.m., etc.
All commonly accepted professional titles.	e.g., Dr., Ph.D., R.N., etc.
and	&
at	@
Compass directions:	
east	E
north	N
south	S
west	W
Copyright	©
Corporate suffixes:	
Company	Co.
Corporation	Corp.
Incorporated	Inc.
Limited	Ltd.
et alii (and other people)	et al.
et cetera (and so forth)	etc.
exempli gratia (for example)	e.g.,
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
number (before a number)	# (e.g., #10)
pounds (after a number)	# (e.g., 10#)
registered trademark	®
trademark	™
United States (adjective)	U.S.
United States of America (noun)	USA
U.S. state and District of Columbia abbreviations	use two-letter abbreviations (e.g., AK, DC)

Mathematics, statistics, fisheries

alternate hypothesis	H_A
base of natural logarithm	e
catch per unit effort	CPUE
coefficient of variation	CV
common test statistics	F, t, χ^2, etc.
confidence interval	C.I.
correlation coefficient	R (multiple)
correlation coefficient	r (simple)
covariance	cov
degree (angular or temperature)	°
degrees of freedom	df
divided by	÷ or / (in equations)
equals	=
expected value	E
fork length	FL
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.
mideye-to-fork	MEF
minute (angular)	'
multiplied by	x
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
standard length	SL
total length	TL
variance	Var

FISHERY DATA SERIES 03-21

INRIVER ABUNDANCE, SPAWNING DISTRIBUTION, AND RUN TIMING OF COPPER RIVER CHINOOK SALMON IN 2002

by

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ABSTRACT

In 2002, radiotelemetry methods were used to estimate inriver abundance, spawning distribution, and run timing of chinook salmon *Oncorhynchus tshawytscha* in the Copper River, Alaska. Two-sample mark-recapture techniques were used to estimate inriver abundance at the lower boundary of the Chitina subdistrict dipnet fishery. Total abundance was estimated to be 32,873 (SE=8,863) chinook salmon ≥ 620 mm MEF for the period 22 May-14 September. The estimated spawning proportions by major drainage were, 0.25 for the Klutina River, 0.20 for the Tonsina River, 0.16 for the Gulkana River, 0.25 for the Chitina River, 0.03 for the Tazlina River, and 0.03 for the East Fork Chistochina River. Run-timing patterns at the capture site varied among the major spawning stocks. The mean date of passage at the capture site varied from 1 June for chinook bound for the upper Copper River to 24 June for the Klutina River mainstem spawners. In addition, the run-timing of chinook salmon bound for the tributaries of the Tonsina and Klutina rivers was earlier than their mainstem counterparts.

Key words: chinook salmon, *Oncorhynchus tshawytscha*, Copper River, East Fork Chistochina River, Gulkana River, Tazlina River, Klutina River, Tonsina River, Chitina River, inriver abundance, mark-recapture, radiotelemetry, spawning distribution, aerial index, run-timing patterns.

INTRODUCTION

The Copper River chinook salmon population supports a large commercial gillnet fishery near the mouth of the river plus inriver subsistence and recreational fisheries. The average annual chinook salmon harvest from 1999-2002 was 43,131 fish for the commercial fishery, 3,424 fish for the Glennallen subdistrict subsistence (GSS) fishery, 2,023 fish for the Chitina subdistrict dipnet (CSDN) fishery[1], and 5,919 fish (preliminary) for the recreational fishery. In the GSS fishery, the majority of fishers use fish wheels to harvest salmon but dip nets are also allowed. In contrast, the CSDN fishery is strictly a dip net fishery. Recreational fishers in the Klutina, Tonsina, and Gulkana rivers use rod and reel gear.

The Copper River chinook salmon return was managed under an escapement objective of 28,000-56,000 chinook salmon from 2000-2002[2]. In order to attain this goal, fishery managers with the Alaska Department of Fish and Game (ADF&G) base decisions on the Miles Lake in-season sonar counts, weekly commercial fishery harvest reports, and harvest estimates from the inriver fisheries.

In 2001, the Office of Subsistence Management (OSM) Fisheries Resource Monitoring Program (FRMP) funded a multi-year study titled *Feasibility of Using Fishwheels for Long-Term Monitoring of Chinook Salmon Escapement on the Copper River* (FIS01-020). This was a priority for funding in the 2001 FRMP, as the ADFG, Division of Sport Fish project to estimate inriver abundance was scheduled for completion after 2001. After a successful feasibility study (Smith and Link 2003) the FRMP decided to fund a multi-year study to estimate *Inriver Abundance, Spawning Distribution, and Run Timing of Copper River Salmon* (FIS02-015) to supplement study FIS01-020. Estimates were determined by radio-tagging a sub sample of

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[1] Prior to 2000, the fishery in the Chitina subdistrict was classified as a personal use fishery, and dip nets were the legal gear. From 2000-2002, the Alaska Board of Fisheries designated the dip net fishery a subsistence fishery. In 2003, the board repealed it's subsistence designation and reverted the fishery back to a personal use designation. This study was conducted when the fishery was classified as a subsistence fishery, but it currently is designated a personal use fishery. To avoid confusion, the fishery is referred to as the Chitina subdistrict dip net (CSDN) throughout the report.

[2] In 2003 the Alaska Board of Fisheries repealed the Copper River chinook salmon management plan and implemented a sustainable escapement goal (SEG) of 24,000 chinook salmon.

chinook salmon captured for study FIS01-020. The primary emphasis of study FIS02-015 was to estimate spawning distribution and run timing, but the study design also provided for estimation of inriver abundance.

An accurate method for estimating the inriver abundance of Copper River chinook salmon is required to determine if the escapement goal was met. Escapement is calculated post-season by subtracting estimates of inriver harvest from the inriver abundance estimate acquired in this study. Estimates of spawning distribution determines the proportion of the total abundance of chinook salmon found in the six major tributaries. Run-timing patterns are used to establish transit times between fisheries and spawning tributaries, as well as chinook salmon recreational fishing seasons. Inseason measures of chinook salmon escapement are not comprehensive and include aerial counts of nine out of forty identified spawning streams, sonar counts at the Miles Lake station that does not apportion the count between sockeye salmon *O. nerka* and chinook salmon, and counts of chinook salmon at a counting tower station on the Gulkana River. This report is a summary of the first year of a three-year (2002-2004) study that will annually assess the Copper River chinook salmon inriver abundance, spawning distribution, and run timing.

OBJECTIVES

The objectives of this study were to:

1. Estimate the inriver abundance of chinook salmon in the Copper River at the CSDN fishery;
2. Estimate the proportions of spawning chinook salmon in the Copper River in each major spawning tributary (Chitina, Tonsina, Klutina, Tazlina, Gulkana, and Chistochina rivers) such that all estimates are within 6 percentage points of the true values 95% of the time;
3. Estimate the proportion of chinook salmon spawning in the nine tributaries assessed annually during aerial surveys (Little Tonsina River, Grayling Creek, St. Anne Creek, Manker Creek, Mendeltna Creek, Kiana Creek, Gulkana River, East Fork Chistochina River, and Indian Creek) such that the estimate is within 6 percentage points of the true value 95% of the time; and,
4. Describe the stock-specific run-timing patterns at the point of capture in Baird Canyon where stocks are defined as all chinook salmon spawning in the Chitina, Tonsina, Klutina, Tazlina, Gulkana, and Chistochina rivers.

METHODS

STUDY DESIGN

Inriver abundance of Copper River chinook salmon was estimated with a combination of radiotelemetry and two-event mark-recapture methods. The first event involved marking chinook salmon with radio tags at Baird Canyon in the mainstem Copper River upstream of the sonar station at Miles Lake. The second event consisted of chinook salmon harvested in the CSDN fishery from 8 June to 14 September and chinook salmon sampled from subsistence fish wheel catches located just upstream of the CSDN fishery. Marked fish in the second event were returned by CSDN fishers, or were inferred as harvested in the CSDN fishery by data collected at five automated radio tracking stations located within and on the boundaries of the CSDN fishery.

Spawning distributions and stock-specific run-timing patterns were determined from four tracking stations outside of the CSDN fishery area and aerial tracking surveys. The distribution of chinook salmon in the various spawning streams was estimated as the ratio of radio-tagged salmon migrating into a specific tributary to the total number of radio-tagged salmon surviving and migrating into all spawning tributaries. Stock-specific run timing at Baird Canyon was determined from the date and time of initial capture to the date and time of passage by one of the major spawning tributaries.

CAPTURE AND TAGGING

Chinook salmon were captured and radio-tagged from two aluminum fish wheels on the east bank of the Copper River in Baird Canyon from 22 May to 12 July (Figure 1). Each fish wheel had large live tanks (4.3 m long x 1.5 m deep x 0.6 m wide) on both sides and 6.1 m (20 foot) diameter baskets that fished in a minimum of 3.05 m (10 feet) of water, as described in Smith and Link (2003). Both fish wheels fished 24 hours a day seven days a week from 22 May to 12 July. Fish wheels were checked at least three times a day to ensure chinook salmon spent a minimal amount of time in the live tanks.

Each time the fish wheel was checked the captured chinook salmon were:

1) removed from the live tank and placed in a sampling trough;

2) measured to the nearest 5 mm total length (snout to fork); and,

3) sexed based on external characteristics.

The objective of the study was to distribute 500 radio tags proportional to run strength and timing. To accomplish this we used the run-timing patterns from the previous three years of the study (Evenson and Wuttig 2000, Wuttig and Evenson 2001, Savereide and Evenson 2002) to define average run-timing and subsequently use this average pattern to determine the number of radio tags to deploy each day (Figure 2).

Radio tags were inserted through the esophagus and into the upper stomach of chinook salmon with an implant device. The device was a 45-cm piece of polyvinyl chloride (PVC) tubing with a slit on one end to seat the radio transmitter into the device. Another section of PVC that fit through the center of the first tube acted as a plunger to position the radio tag. To ensure proper radio transmitter placement the distance between a point 1-cm posterior from the base of the pectoral fin to the tip of the snout was used to determine how far to insert the implant device into the fish.

All radio-tagged chinook salmon also received a uniquely numbered gray spaghetti tag constructed of a 5-cm section of tubing shrunk onto a 38-cm piece of 80-lb monofilament fishing line (Pahlke and Etherton 1999). The spaghetti tag was sewn through the musculature of the fish 1-2 cm ventral to the insertion of the dorsal fin between the third and fourth fin rays of the dorsal fin. The entire handling process required approximately two to three minutes per fish.

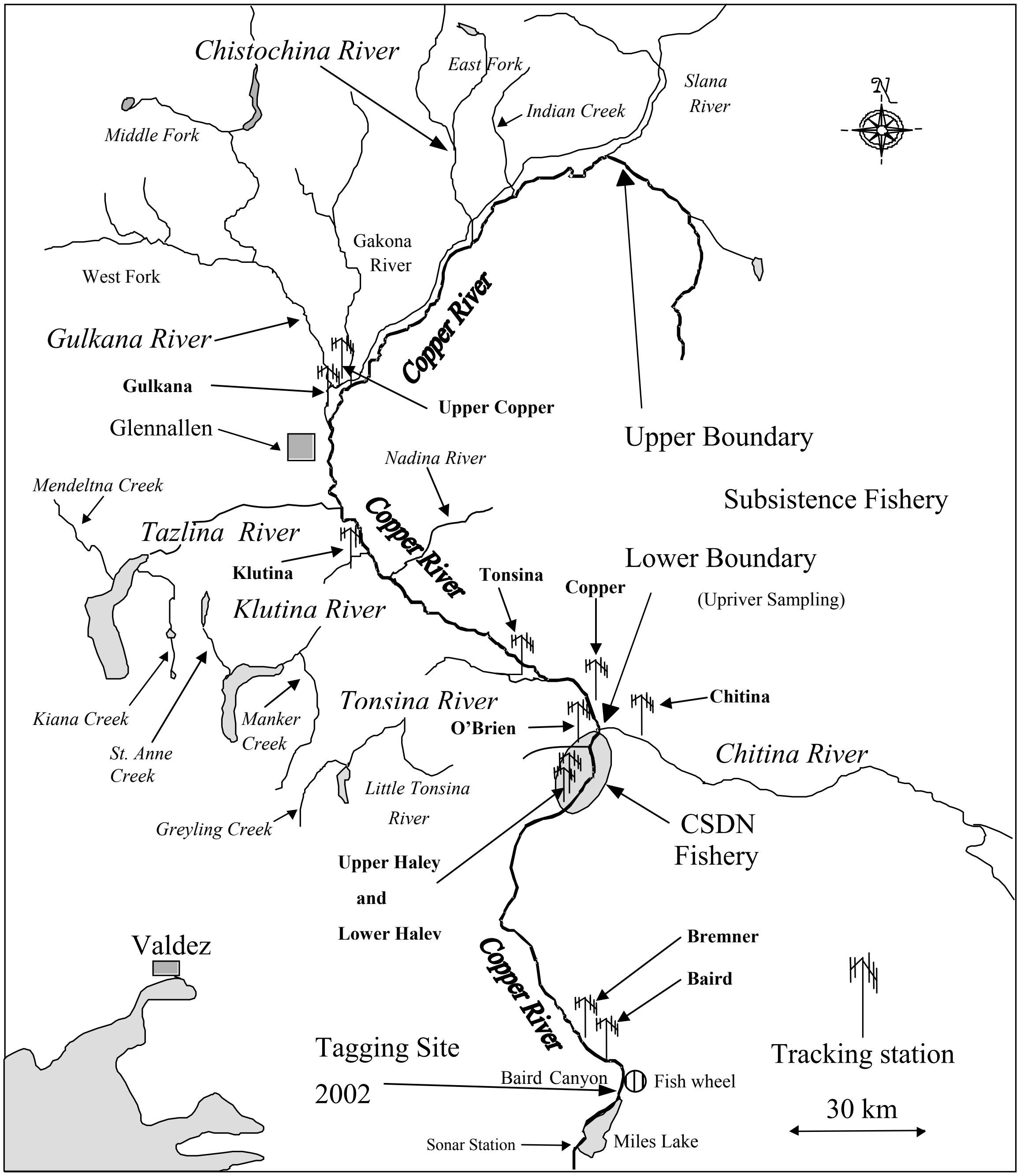

Figure 1.–Map of the Copper River drainage demarcating the tagging site, boundaries of the CSDN and subsistence fisheries, and location of eleven radio tracking stations, 2002.

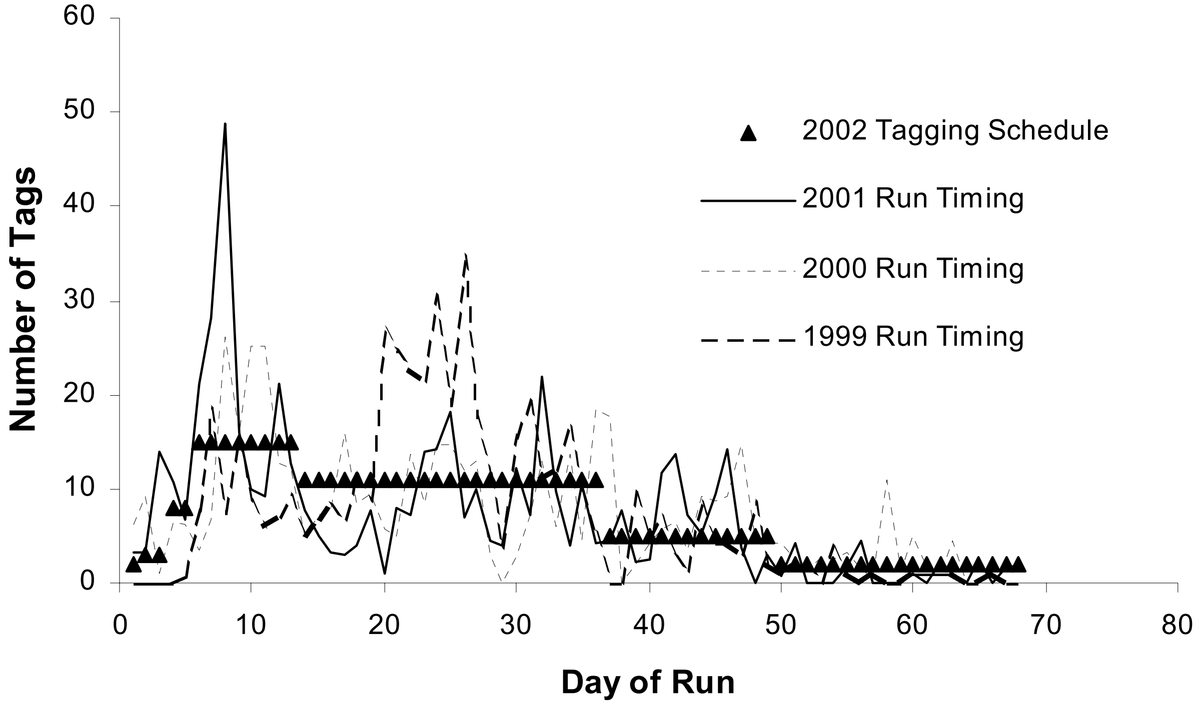

Figure 2.–Run timing at Haley Creek 1999-2001 and number of radio tags to be deployed by day of the run in 2002.

RADIO-TRACKING EQUIPMENT AND TRACKING PROCEDURES

Radio tags were Model Five pulse encoded transmitters made by ATS[3]. Each radio tag was distinguishable by its frequency and encoded pulse pattern. Thirty-four frequencies spaced approximately 20 kHz apart in the 149-150 MHz range with up to 15 encoded pulse patterns per frequency were used for a total of 500 uniquely identifiable tags.

Stationary radio-tracking stations were used to record migrating radio-tagged chinook salmon. Each station included two 12 V deep cycle batteries, a solar array, an ATS model 5041 Data Collection Computer (DCC II), an ATS model 4000 receiver, an antenna switching box, a water-proof metal housing box, and a pair of four-element yagi antennas (one aimed upstream and the other downstream). The receiver and data collection computer were programmed to scan through the frequencies at four-second intervals and both antennas received signals simultaneously. When a radio signal was encountered, the receiver paused for seven seconds, and the date, time, tag frequency, tag code, and signal strength for each antenna were recorded by the data logger. Depending on the number of active tags in reception range, a full cycle through all 34 frequencies required 5-10 minutes. Data were downloaded onto a laptop computer every 7-10 days.

A total of eleven stationary radio-tracking stations were used to track radio-tagged chinook salmon throughout the entire Copper River drainage (Figure 1). The first two stations enumerated all radio-tagged fish that successfully migrated from the capture site and were located approximately 5 km upstream from Baird Canyon.

Five radio-tracking stations were used to identify all radio-tagged chinook salmon entering and exiting the CSDN fishery. Two stations were placed on the west bank of the Copper River at the lower boundary of the CSDN fishery, one directly above the boundary marker, and one approximately 500 m downstream. A third station was placed within the CSDN fishery on a west-side bluff overlooking the Copper River at O'Brien Creek. A fourth station was placed on the north bank of the Chitina River approximately 5 km upstream from its confluence with the Copper River. A fifth station was placed on a west-side bluff overlooking the Copper River immediately upstream from the upper boundary of the CSDN fishery.

The four remaining stations coupled with the station on the Chitina River were used to enumerate the total number of radio-tagged chinook salmon in all major spawning tributaries. Radio-tagged fish entering the Tonsina, Klutina, and Gulkana rivers were recorded by stations placed 1-5 km upstream from the mouths of the rivers. The last station was placed on the mainstem Copper River approximately 2 km downstream from the mouth of the Gakona River. This station enumerated all radio-tagged fish bound for spawning streams upstream of the Gulkana River, collectively referred to as the Upper Copper River.

Aerial radio-tracking surveys were used to establish the distribution of radio-tagged chinook salmon throughout the entire Copper River drainage to a point just downstream of the sonar station (Figure 1). Aerial surveys were conducted to locate radio-tagged chinook salmon in tributaries not monitored by the tracking stations, to locate fish that the tracking stations failed to record, and to validate that fish recorded on the data loggers migrated into that particular tributary. Aerial surveys were conducted on 24-27 June, 23-26 July, and 20-27 August.

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[3] Advanced Telemetry Systems, Isanti, Minnesota. Use of this company name does not constitute endorsement, but is included for scientific completeness.

FATES OF RADIO-TAGGED CHINOOK SALMON

Data from the tracking stations, aerial surveys, and tag return information were used to determine the final fate assigned to each radio tag (Table 1).

Table 1.–List of possible fates of radio-tagged chinook salmon in the Copper River, 2002.

Fate	Description
Radio Failure	A fish that was never recorded swimming upstream into the CSDN fishery.
CSDN Recapture[a]	A fish harvested in the CSDN fishery.
Subsistence Fishery Mortality	A fish harvested in the Glennallen subdistrict subsistence fishery upstream of the McCarthy Road bridge.
Sport Fishery Mortality	A fish harvested in one of the sport fisheries.
Spawner[b]	A fish that migrated through the CSDN fishery and entered a spawning tributary of the Copper River.
Upstream migrant	A fish that migrated upstream of the CSDN fishery, was never reported as being harvested, and was either located only in the mainstem Copper River, or was never located anywhere after passing through the fishery.

[a] These radio-tagged fish constituted the marked fish in the second sample of the mark-recapture experiment.

[b] These radio-tagged fish were used to estimate spawning distribution and stock-specific run-timing.

ESTIMATION OF INRIVER ABUNDANCE

Two-sample mark-recapture techniques were used to estimate the inriver abundance of chinook salmon at the point of entry into the CSDN fishery. Radio-tagged fish entering the CSDN fishery represented marked fish for the first event. The reported harvest from the CSDN fishery coupled with upriver sampling activities comprised the second event. The marked component of the second event consisted of radio-tagged fish harvested in the CSDN fishery and radio-tagged fish observed during upriver sampling.

Second Event: CSDN Fishery Harvest and Upriver Sampling

Upriver sampling consisted of sampling subsistence catches from fish wheels located near the lower boundary of the subsistence fishery (Figure 1). Upriver sampling was initiated to supplement the number of chinook salmon examined in the second event because the regulatory bag limit of chinook salmon was reduced from four to one fish beginning in 2000. Subsistence fish wheels were sampled from Thursday to Monday every week from 1 June to 2 August. Attempts were made to sample the majority of the subsistence harvest in the sampling area using one crew member working split-shifts to cover the greater part of the day. Scales were collected from chinook salmon sampled at the fish wheels to supplement the samples taken from the CSDN fishery.

Length and sex data from the CSDN harvest and upriver sampling were collected as a means to test for selective sampling. CSDN fishers returning tags were queried for information regarding date and location of capture. CSDN harvest was estimated from returned permits that required the fisher to record the total number of chinook salmon and the date they were harvested. CSDN fishers were required to return or mail in their permits to an ADF&G office at the end of the season. Harvest of chinook salmon by those CSDN fishers who were issued, but did not return a permit, was estimated by modeling the trend in harvest of those fishers who returned permits after each of four reminder mailings. Because the return rate of permits was large (84%), this estimate from non-returned permits constituted only a small portion of the total harvest.

Conditions for a Consistent Abundance Estimator

Certain conditions must be met to get an accurate estimate of abundance from a mark-recapture experiment (Seber 1982). Those assumptions expressed in terms of the conditions of this study, and the respective design considerations and testing procedures are described below.

1 Radio-tagging and handling did not make the fish more or less vulnerable to recapture than unhandled fish.

To reduce the affects of handling, holding time of all captured fish was minimized. Injured fish and fish that appeared to be affected by handling were not tagged. The time required for radio-tagged fish to move from the capture site into the CSDN fishery as well as transit times through the CSDN fishery were recorded by the tracking stations.

There was no explicit test for this assumption because the behavior of unhandled fish could not be observed. However, we compared recapture and migration rates between groups of fish affected differently by handling, as reflected in the time required to recover from handling and reach the tracking station at the lower boundary of the CSDN fishery. Groups were defined as those that took less than 11 days, 11-19 days, and greater than 19 days to migrate from the release site into the fishery. Similarity in recapture and migration rates among the groups was considered evidence that this assumption was met.

2 There was no selection for or against radio-tagged fish in the CSDN fishery.

Selection for radio-tagged chinook salmon would result in an abundance estimate that was biased low, and selection against radio-tagged fish would produce an estimate that was biased high.

There were no explicit tests for tag selection. However, to minimize the chances of violating the assumption, no reward was offered for returned radio tags. In addition, gray spaghetti tags were used to reduce the likelihood of a fisher easily identifying a tagged fish and selecting it for harvest. Gray tags were less identifiable at time of capture but identifiable while processing the fish.

3 All radio-tagged fish harvested in the CSDN fishery were accurately reported.

To ensure accurate reporting, tag recoveries were obtained through on-site creel sampling and by voluntary tag returns. Tag recovery forms and instructions were sent to ADF&G offices in Fairbanks, Delta Junction, Glennallen, Cordova, Palmer, and Anchorage. Informational bulletins were posted at all ADF&G offices and at strategic positions in and around the CSDN fishery. Informational cards were distributed with CSDN permits issued at ADF&G offices encouraging tag returns. Drop boxes with envelopes requesting information regarding time and location of capture were posted at the primary access point to the CSDN fishery (O'Brien Creek). All radio tags were labeled with information to encourage reporting of harvested tags. If either the radio tag or spaghetti tag from a reportedly harvested fish were not returned, the CSDN fisher was contacted and queried to ensure that the fish was harvested (in past cases some tags have been removed by anglers and the fish released) and that both tags were attached. Tags that were harvested in the CSDN fishery and not reported were identified using the tracking stations located at O'Brien and Haley creeks. Radio tags removed from the water have a pronounced and unquestionable increase in signal strength. Criteria for an unreported harvested fish were: 1) a pronounced and prolonged recording of a signal by a data logger at O'Brien and/or Haley Creek; 2) the radio tag was never recorded upstream of the CSDN fishery; and 3) no downstream movement of the radio tag was detected after the radio-tagged fish had entered the CSDN fishery.

4 Radio-tagged fish did not lose their tags, and there was no mortality of radio-tagged fish between the tagging site and the CSDN fishery.

Any tagged fish that was not identified as entering the CSDN fishery by tracking stations and aerial surveys was designated as a "failure" and was removed from the analysis. All fish were double marked with radio tags and individually numbered spaghetti tags. Both tags were requested from CSDN fishers recovering tagged chinook salmon. When only a spaghetti tag was returned, and the tracking stations at the lower boundary of the fishery did not record the fish moving into the fishery, a follow up telephone call was made to find out if the radio tag had been present.

5 Marked fish mixed completely with unmarked fish between the capture site and the CSDN fishery.

Because sampling with fish wheels and fishing in the CSDN fishery was bank-oriented, fish swimming up only the center of the river may not have been included in the estimate. In 1999-2001, approximately equal cross-over rates (interpreted as mixing) from bank of tagging to bank of recapture were observed. It was not known if there was a segment of the population that only migrated up the center of the river but it was assumed that if fish crossed-over, then there was likely not a center-only segment. In this study, there was no explicit test for this assumption because all tagged fish were released from the east bank. However, it was assumed that because equal mixing was observed in three consecutive years, and the tagging site in this study was farther downstream that the equal mixing assumption was met. However, if there was no cross-over between sampling events, and there was a center-only segment, the estimate would be biased low and would not include the unknown fraction of the population that migrated up the center of the river.

6 Fish had equal probabilities of being marked or equal probabilities of being captured regardless of size or sex.

Fish wheels were used as a capture device during the first sampling event. Sex and length were recorded for all radio-tagged fish. For the second sampling event, sex and length data were collected from a sample of fish harvested from the CSDN fishery. Sex-selective sampling was tested using contingency table analysis to compare ratios of recaptured and non recaptured fish of each gender. If this test indicated a significant bias, the following tests on the length distributions were performed for males and females separately. If there was no significant bias, males and females were combined and Kolmogorov-Smirnov (K-S) tests for equal capture probabilities on the cumulative length distributions were performed for: Test A) all fish radio-tagged during the first event and radio-tagged fish captured in the second event (CSDN fishery); and Test B) all fish radio-tagged during the first sampling event and all fish sampled in the second event (CSDN fishery sampling).

7 *Fish had equal probabilities of being marked regardless of time of capture.*

Equal fishing effort was expended at all times during the first event. Radio tags were deployed in a manner proportional to run strength. Date and capture time of all fish were recorded. Marked to unmarked ratios in the second event were compared among weeks to evaluate if this condition was met. Testing of this assumption required temporal harvest data from the CSDN fishery, which was available from most returned CSDN fishery permits. The estimated harvest from unreported permits and reported permits without date of capture information was assigned to temporal strata in proportion to the distribution of the actual reported harvest.

8 *Marked fish had equal probabilities of being recaptured regardless of when they entered the fishery.*

Recaptured to not recaptured ratios in the second event were compared among weeks to evaluate if this condition was met.

Estimator

Chapman's modified Peterson two-event mark-recapture model was used to estimate inriver abundance (Seber 1982). The estimate was germane to the point of entry into the CSDN fishery (prior to any inriver harvest of chinook salmon). Because some chinook salmon were tagged and migrated through the CSDN fishery prior to its opening, the estimate only pertained to the period 8 June – 14 September.

The estimated variance of $\hat{N}$ was approximate because $\hat{C}$ was estimated from returned CSDN permits. Because the estimate of CSDN harvest was very precise (CV < 0.1%), the sampling error in $\hat{C}$ was considered negligible.

To estimate the total inriver chinook salmon run, including those portions of the run that passed through the CSDN fishery before the recovery event began (8 June), $\hat{N}$ was multiplied by the inverse of the estimated proportion of the run $\hat{P}$ that passed by the capture sites between 8 June and 14 September:

$$\hat{N}' = \hat{N}\hat{P}^{-1} \tag{1}$$

$$\hat{\text{var}}(\hat{N}') = \hat{N}^2\, \hat{\text{var}}(\hat{P}^{-1}) + (\hat{P}^{-1})^2\, \hat{\text{var}}(\hat{N}) - \hat{\text{var}}(\hat{P}^{-1})\, \hat{\text{var}}(\hat{N})\,. \tag{2}$$

The method for estimating $\hat{P}^{-1}$ and its variance used weekly estimates of abundance in the CSDN fishery from a Darroch (1961) capture-recapture model with weekly cumulative CPUE data for the weeks of the fishery to model the uncertainty with which CPUE predicted salmon abundance during the fishery. Markov-chain Monte Carlo (MCMC) methods were used to perform a Bayesian analysis (Carlin and Louis, 2000) of the relationship between weekly abundance and CPUE, which was used, in turn, to estimate fish abundance for weeks of the run outside the fishery. The estimate $\hat{P}^{-1}$ and its variance were calculated from the 500,000 MCMC samples drawn from its posterior distribution:

$$\hat{P}^{-1} = \frac{\sum_{i=1}^{S} \tilde{P}_i^{-1}}{S} \quad \text{and} \quad \hat{\text{var}}(\hat{P}^{-1}) = \frac{\sum_{i=1}^{S} \left(\tilde{P}_i^{-1} - \hat{P}^{-1}\right)^2}{S} \tag{3}$$

where:

S = the number of Monte Carlo draws; and,

$\tilde{P}_i^{-1}$ is the value of the expansion factor for the *i*th draw. Each $\tilde{P}_i^{-1}$ was calculated:

$$\tilde{P}_i^{-1} = \frac{\sum_{j \in B} \tilde{N}_{ij} + \sum_{j \in D} N_j^* + \sum_{j \in A} \tilde{N}_{ij}}{\sum_{j \in D} N_j^*} \tag{4}$$

where:

N_j^* are weekly estimates of numbers of salmon in the recovery area using a time stratified Darroch (1961) estimation procedure with the capture-recapture data;

$\tilde{N}_{ij}$ is the projected number of salmon in the recovery area during week j in the ith simulation; and,

B, D, and A are the weeks before, during, and after the second (recovery) event.

To calculate the $\tilde{N}_{ij}$ the WINBUGS software package (Spiegelhalter et al. 1996) was used to simulate the posterior distribution of the parameters in the following model, given the data $\boldsymbol{j} \in \boldsymbol{D}$,

$$N_j^* = \beta * \text{CPUE}_j + \varepsilon_j \text{ where } \varepsilon_j \sim N(0, \boldsymbol{D}\,\sigma^2) \tag{5}$$

where ***D*** is a diagonal matrix representing any heteroskedasticity in the variance structure. The MCMC posterior distribution for $\hat{\beta}$ was used to generate the necessary projections:

$$\tilde{N}_{ij} = \hat{\beta}_i * \text{CPUE}_j. \tag{6}$$

DISTRIBUTION OF SPAWNERS

All radio-tagged fish located and designated as "spawners" (Table 1) were assigned sub-fates corresponding to the tributary they were spawning in (e.g., "Gulkana River spawner"). Hours of fishing effort remained constant because the fishwheels ran continuously. Among fish that migrated past the lower two tracking stations, the proportion of fish that have fate j were estimated by:

$$\hat{P}_j = \frac{\sum_{i}^{\text{days}} R_{ij}}{\sum_{j}^{\text{fates}} \sum_{i}^{\text{days}} R_{ij}} \tag{7}$$

where R_{ij} is the number of fish tagged on day i having fate j. Variance was estimated using bootstrap resampling techniques (Efron and Tibshirani 1993). Each bootstrap replicate draws a random sample from the total number of radio tag fates and their corresponding weights. From each replicate the proportion of spawners with spawning fate j ($\hat{P}^*{}_j$) was calculated for a total of 1,000 bootstrap data sets. The percentile method was used to estimate confidence intervals.

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

Conditions for a Consistent Spawning Distribution Estimator

Certain assumptions must be met to obtain unbiased estimates of the spawning distribution:

1. *Radio-tagging chinook salmon did not affect their migratory behavior (final spawning destination).*

There was no explicit test for this assumption because the behavior of unhandled fish was unknown. However, we compared transit times through the CSDN fishery between groups of fish affected differently by handling as described under assumption 1 for the abundance estimator.

2. *Captured chinook salmon were radio-tagged in proportion to the magnitude of the run.*

The tagging protocol described was designed to distribute tags over time proportional to passage of salmon past the tagging site. Marked to unmarked ratios in the second event were compared among weeks to evaluate if this condition was met. Testing of this assumption required temporal harvest data from the CSDN fishery. The estimated harvest from unreported permits and reported permits without date of capture information were assigned to temporal strata in proportion to the distribution of the actual reported harvest.

STOCK-SPECIFIC RUN TIMING

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

$$f_j(t) = \frac{m_{jt}}{m_j} \tag{10}$$

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;

m_{jt} = the subset of m_j radio-tagged chinook salmon bound for tributary *j* that were caught and tagged during day *t*; and,

m_j = the total number of radio-tagged chinook salmon that ended up in tributary *j*.

For this purpose, stocks were defined as all chinook salmon spawning in the Chitina, Tonsina, Klutina, Tazlina, Gulkana and the Upper Copper (all waters upstream from the Gulkana River) drainages. Those fish assigned a fate of "spawner" (Table 1) were used to determine the time-density functions.

The mean date of passage ($\bar{t}_j$) by the point on the river of tagging for fish spawning in tributary j will be estimated as:

$$\bar{t}_j = \sum_t t\, f_j(t) \tag{11}$$

the variance of the run timing distribution estimated as:

$$Var\ (t_j) = \sum_t (t - \bar{t}_j)^2 f_j(t). \tag{12}$$

Conditions for a Consistent Run Timing Estimator

Certain assumptions must be met to obtain unbiased estimates of stock-specific run timing:

1 Radio-tagging chinook salmon did not affect their migratory behavior (final spawning destination).

There was no explicit test for this assumption because the behavior of unhandled fish was not known. However, as with estimates of spawning distribution, a comparison of transit times through the CSDN fishery between groups of fish affected differently by handling was conducted to evaluate this assumption.

2 Captured chinook salmon were radio-tagged in proportion to stock-specific abundance.

The tagging protocol described was designed to distribute tags over time proportional to passage of salmon past the tagging site. Marked to unmarked ratios in the second event were compared among weeks to evaluate if this condition was met.

RESULTS

CAPTURE AND TAGGING

From 22 May to 12 July, 1,518 chinook salmon were captured in the Baird Canyon fish wheels. Of these chinook salmon 462 were radio-tagged and released. The daily catch of chinook salmon ranged from zero fish on 6 July to 98 fish on 5 June. The daily radio-tagging rate varied from 11%-100% of all captured chinook salmon (Figure 3).

RADIO-TRACKING EQUIPMENT AND TRACKING PROCEDURES

In previous radiotelemetry studies (Evenson and Wuttig 2000; Wuttig and Evenson 2001; Savereide and Evenson2002) on the Copper River, there were no problems detecting the number of radio-tagged fish that migrated past the stationary tracking stations. In 2002, a number of the tracking stations failed to consistently record passing chinook salmon because of a problem in the latest version of the tracking software (Table 2). A total of 36 radio-tagged chinook salmon

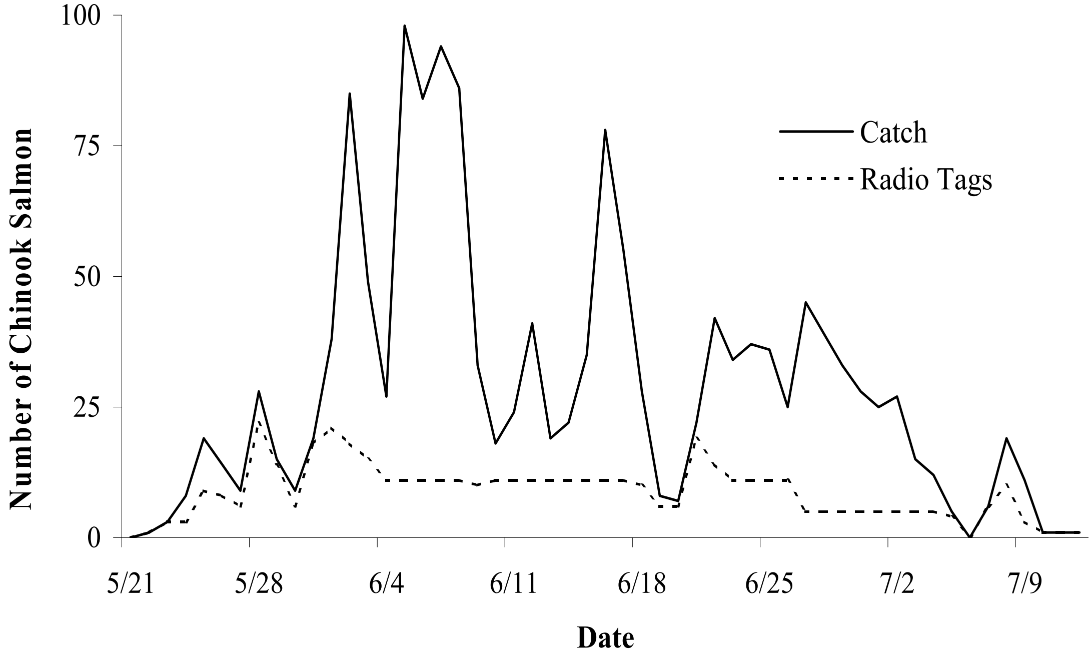


Figure 3.–Number of radio tags deployed each day and total daily catch of chinook salmon in the Copper River, 2002.

Table 2.–Efficiency of tracking stations in detecting passing radio-tagged chinook salmon in the Copper River drainage, 2002.

Station [a]	Total tags known to pass site [b]	Number located during aerial surveys	Number logged by tracking station	Aerial tracking efficiency [c]	Station efficiency
Chitina	76	74	56	97.4%	73.7%
Klutina	75	52	71	69.3%	94.7%
Gulkana	49	48	44	98.0%	89.8%
Tonsina	60	50	57	83.3%	95.0%
Upper Copper	37	37	15	100.0%	40.5%
Baird	442		21		4.8%
Bremner	442		249		56.3%
Copper	343		134		39.1%
O'Brien	395		217		54.9%
Upper Haley	426		184		43.2%
Lower Haley	426		104		24.4%
Haley Combined	426		259		60.8%

[a] The locations of all tracking stations are shown in bold in Figure 1.

[b] Includes all fish logged by stations, located from aerial surveys, and captured in the fisheries.

[c] Efficiency of aerial tracking was only evaluated for the spawning tributaries.

were never detected in the CSDN fishery, and 18 of these fish were never recorded by any tracking station or aerial survey and were considered tag failures.

FATES OF RADIO-TAGGED CHINOOK SALMON

Each radio-tagged chinook salmon was determined to have one of nine possible fates. Of the 462 total radio-tagged chinook salmon 426 fish entered the CSDN fishery (Table 3). Twenty-six tags were harvested in the CSDN fishery. Four hundred radio-tagged chinook salmon migrated through the CSDN fishery. Forty-one of these fish were never reported as harvested or located in a spawning tributary, 53 fish were known to be harvested in subsistence fish wheels, 23 fish were known to be harvested in sport fisheries, and 306 fish were located in spawning areas (Table 3).

Table 3.–Fates of radio-tagged chinook salmon in the Copper River, 2002.

Fate[a]	Number of Tags
Total Deployed	462
Radio Failure	36
Total Entering CSDN Fishery	426
CSDN Fishery Recapture	26
Total Fish Passing Through CSDN fishery	400
Upstream Migrant[b]	41
Subsistence Fishery Mortality	53
Spawner	306
Sport Fishery Mortality	23

[a] Refer to Table 1 for definition of fates.

[b] Includes 14 tags that passed through the CSDN fishery and drifted back downstream and 27 fish that were found in the mainstem of the Copper River upstream of the CSDN fishery.

ESTIMATION OF INRIVER ABUNDANCE

Second Event: CSDN Fishery Harvest and Upriver Sampling

Total estimated harvest in 2002 in the CSDN fishery was 2,023 chinook salmon (SE=18), and 26 radio-tagged chinook salmon were harvested. Sampling efforts upriver of the CSDN fishery allowed for inspection of an additional 241 chinook salmon and recovery of eight additional radio-tagged fish. However, these fish were not used in the mark-recapture experiment because the actual marked to unmarked ratio of chinook salmon in the sampled harvest was altered by fishers that retained radio-tagged chinook salmon in their live wells until the technician was available to sample their harvest resulting in a non random sample.

Conditions for a Consistent Abundance Estimator

The probability of capture for chinook salmon in the CSDN fishery did not appear to be altered by tagging or handling techniques. Transit times through the CSDN fishery were similar between fish that displayed minimal (less than 11 d), moderate (11-19 d), and substantial (greater than 19 d) delays between time of capture and entry into the CSDN fishery (Figure 4). The majority of radio-tagged fish entering the CSDN fishery migrated through the fishery in less than

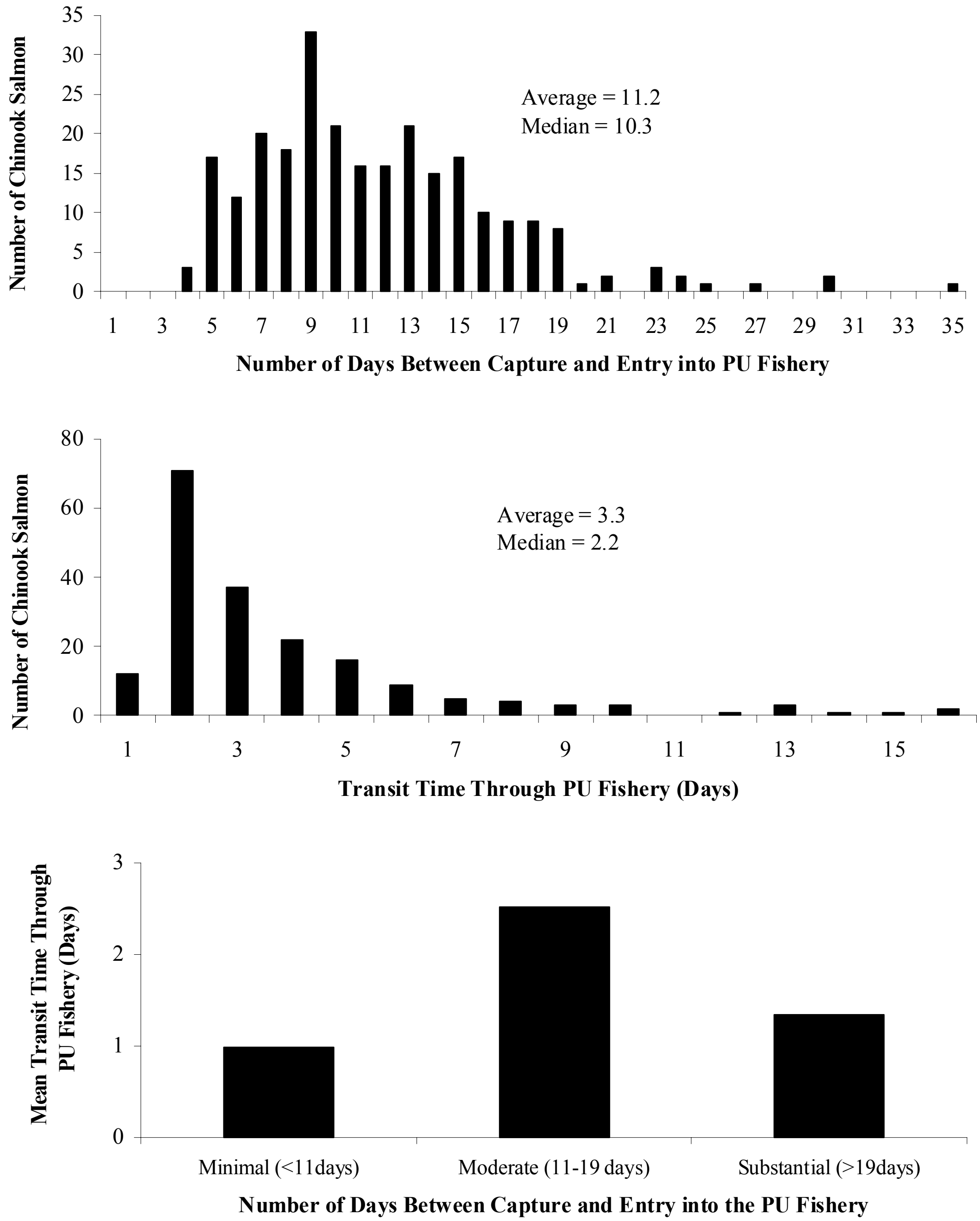


Figure 4.–Delay after handling (top panel), transit times through the CSDN fishery (middle panel), and a comparison of mean transit times through the CSDN fishery of fish that exhibited minimal, moderate, and substantial delays (bottom panel) for radio-tagged chinook salmon in the Copper River, 2002.

five days (Figure 4). The tracking stations located at the lower end of the CSDN fishery detected nearly 50% of the radio-tagged fish within 11 days of capture and less than 5% required 19 days or more (Figure 4). Furthermore, recapture rates were independent of the amount of time fish were delayed in migrating upstream (χ^2=2.71; df=2, P=0.26; Table 4).

Table 4.–Recapture rates for chinook salmon exhibiting minimal (<11 d), moderate (11-19 d), and substantial (>19 d) delays after handling, 2002.

	Delay After Handling			
	< 11 days	11-19 days	> 19 days	Total
Recaptured	**33**	**8**	**3**	44
Not Recaptured	**311**	**96**	**11**	418
Total	344	104	14	462
Recapture Rate[a]	0.11	0.08	0.27	0.11

[a] Chi-square test for heterogeneity in recapture rates was performed for cells with bold numbers (χ^2=2.71; df=2; P=0.26).

Twenty-six of the 27 radio tags harvested by CSDN fishers were voluntarily returned. The one radio tag not reported was assumed to have been harvested based on strong signal strength recordings at the O'Brien Creek tracking station.

There was no tag loss or natural mortality between the first and second samples. Thirty-six of 462 radio-tagged chinook salmon were removed from the analysis because they never entered the CSDN fishery. The remaining 426 radio-tagged fish either successfully migrated through, or were harvested in the CSDN fishery.

Movements of radio-tagged fish between banks indicated that marked fish mixed with unmarked fish between sampling events. Because chinook salmon were radio-tagged and released only from the east bank, contingency tests comparing recapture rates and movements between the east and west banks could not be performed. However, of the 27 fish released on the east bank and recaptured in the CSDN fishery, 14 were recaptured on the west bank. In addition, the migration of radio-tagged chinook salmon not recaptured provided further evidence of mixing between banks because 75% of the fish that were tagged on the east bank migrated to tributaries on the west side of the Copper River.

The probability of a chinook salmon being recaptured was not influenced by its gender. Recapture rates of males (0.09) and females (0.05) were not significantly different (χ^2 =0.81; df=2; P=0.37). In contrast, size-selective sampling was detected for the first sample. Cumulative length frequency distributions of fish marked during the first event and fish recaptured during the second event were not significantly different (DN=0.16; P=0.29; Figure 5). However, cumulative length frequency distributions of marked fish during the first event and sampled fish during the second event were significantly different (DN=0.13; P<0.01; Figure 5). Results of these tests indicated that an unstratified estimate of abundance was appropriate, but only length, age, and sex data from the second event would be used to estimate composition proportions.

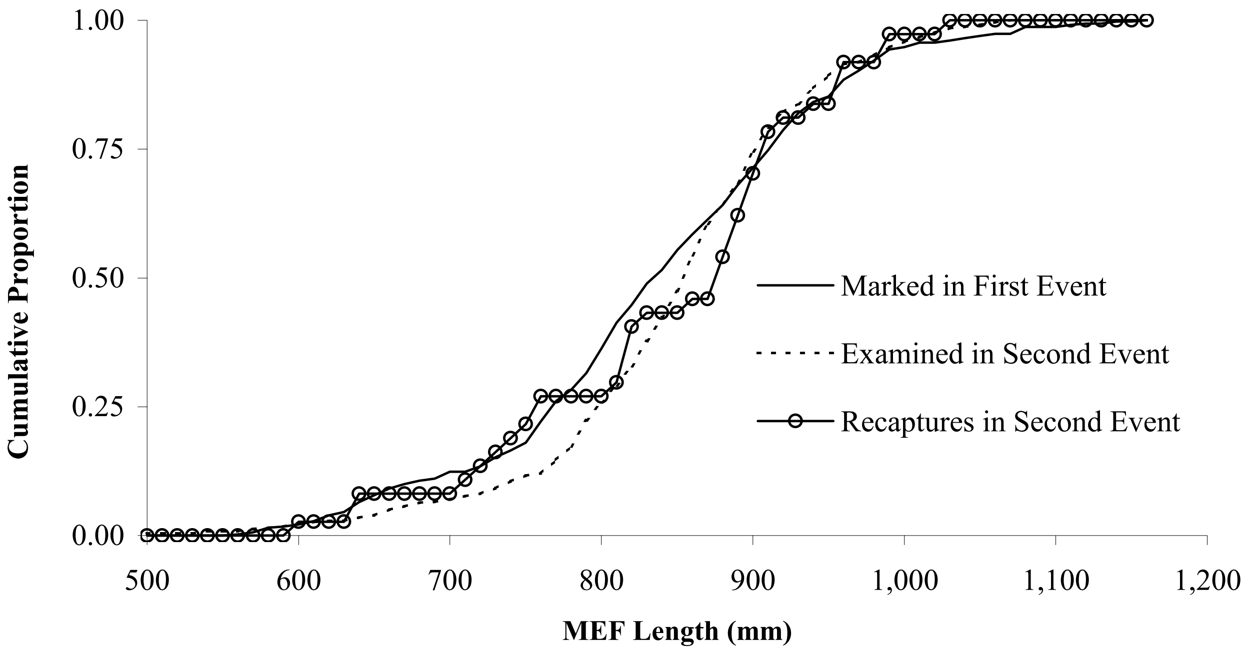


Figure 5.-Cumulative length frequency distributions of all fish marked with radio tags during the first event, all fish examined in the second event, and all radio-tagged fish recaptured during the second event, 2002.

The probability of a chinook salmon being marked was independent of time of capture. Weekly marked to unmarked ratios were not significantly different (χ^2 =6.70; df=7; P=0.46; Table 5). The probability of a chinook salmon being recaptured was also independent of their entry time into the CSDN fishery. Weekly recapture rates were not significantly different (χ^2 =5.82; df=5; P=0.32; Table 5).

Estimator

Chapman's modified Petersen two-sample model (Seber 1982) was used to estimate inriver abundance of chinook salmon because the tests of consistency indicated that the model conditions were met. The 2002 estimated inriver abundance was 30,809 (SE=5,590) chinook salmon ≥ 620 mm MEF for the period 8 June-14 September. To account for the proportion of the run that passed prior to the opening of the CSDN fishery on 8 June the estimate was expanded using the relationship between weekly abundance and CPUE during the first sample (Figure 6). The estimated proportion of the total run that migrated through the fishery from 8 June to 14 September was 0.94 (SE=0.05). Therefore, total estimated abundance entering the CSDN fishery from 22 May to 14 September was 32,873 (SE=8,863) chinook salmon ≥ 620 mm MEF.

DISTRIBUTION OF SPAWNERS

Conditions for a Consistent Spawning Distribution Estimator

There was evidence that both conditions necessary for unbiased estimates of spawning distribution were met. The probability of a chinook salmon being marked was independent of time of capture (χ^2 =6.23; df=7; P=0.51). Transit times through the CSDN fishery were similar between fish that displayed minimal (less than 11 d), moderate (11-19 d), and substantial (greater than 19 d) delays between time of capture and entry into the CSDN fishery (Figure 4).

Estimator

Equation 7 was used to estimate the spawning distribution because all model conditions were met. Radio-tagged chinook salmon were located in all six major drainages of the Copper River (Table 6) including 35 tributary streams (Table 7). The smallest proportion of spawners returned to the Tazlina River (0.03) and the largest proportion returned to the Klutina and Chitina rivers (0.25; Figure 7). The proportion of chinook salmon detected in the nine aerial index streams accounted for 0.32 of chinook salmon in all spawning tributaries.

The Gulkana River accounted for the largest proportion of spawners in the nine index streams (Table 8). Mainstem spawners accounted for 0.77 of all chinook salmon in the Tonsina River and 0.75 of those in the Klutina River, which combined represented a substantial proportion (0.33) of the total escapement (Table 9).

RUN TIMING

The same conditions required for unbiased estimates of the spawning distribution were satisfied for the estimates of run timing.

Estimator

Run-timing patterns at the capture site varied among the individual spawning stocks (Figure 8). The mean date of passage at the Baird Canyon fish wheels for all chinook salmon captured in 2002 was 8 June and ranged from 1 June for the upper Copper River drainage stock to 20 June for the Klutina River mainstem stock (Table 10). The mean date of passage varied for all stocks

Table 5.–Contingency table analyses comparing weekly marked:unmarked and recaptured:not recaptured ratios for radio-tagged chinook salmon, 2002.

Test for Equal Proportions in the Second Event

Period[a]	June 8- June 14	June 15- June 21	June 22- June28	June 29- July 5	July 6- July 12	July 13- July 19	July 20- July 26	July 27- Sept. 14
Marked	5	8	2	2	1	4	3	1
Unmarked	370	351	268	248	228	267	120	145
Marked:Unmarked	0.01	0.02	0.01	0.01	0.00	0.01	0.03	0.01
	χ^2 =6.70; df=7; P=0.46							

Test for Complete Mixing between the First and Second Events

Period[b]	May 29- June 4	June 5- June 11	June 12- June 18	June 19- June 25	June 26- July 2	July 3- July 12
Recaptured	7	4	6	3	1	5
Not Recaptured	96	72	70	75	40	31
Recapture Rate	0.07	0.06	0.09	0.04	0.03	0.16
	χ^2 =5.82; df=5; P=0.32					

[a] Weekly periods correspond with the opening of the CSDN fishery.

[b] Weekly periods began with the date the first recaptured fish was radio-tagged.

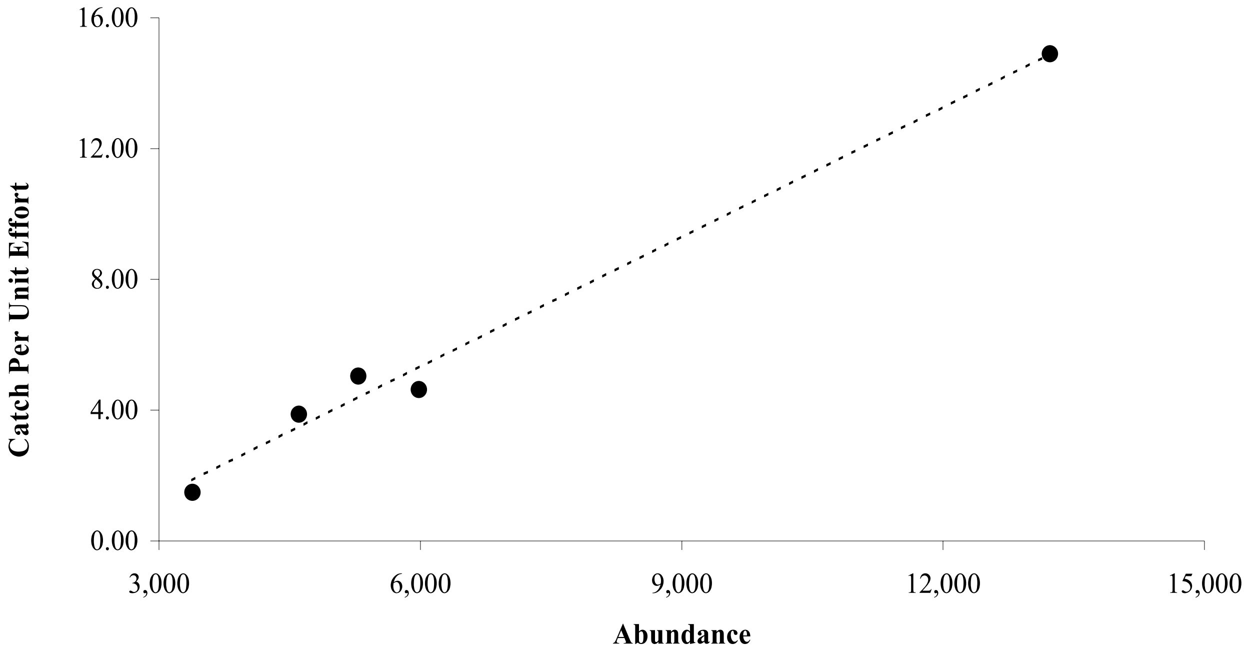


Figure 6.–Periodic estimates of abundance of chinook salmon and cumulative periodic CPUE, 2002. Periodic refers to a single week or pooled weeks. Dashed line is a linear trendline.

Table 6.–Distribution of radio-tagged chinook salmon in major spawning drainages in the Copper River, 1999-2002.

Spawning Stream	Proportion of All Spawners			2002	
	1999	2000	2001	Proportion of All Spawners	Percentile Limits (2.5^{th},97.5^{th})
Chitina River	0.22	0.13	0.14	0.25	(0.20, 0.30)
Gulkana River	0.12	0.25	0.18	0.16	(0.12, 0.20)
Klutina River	0.27	0.27	0.26	0.25	(0.20, 0.30)
Tazlina River	0.03	0.03	0.05	0.03	(0.01, 0.05)
Tonsina River	0.24	0.20	0.21	0.20	(0.15, 0.24)
Upper Copper Drainage	0.11	0.12	0.15	0.12	(0.09, 0.16)

Table 7.–Numbers of radio-tagged chinook salmon located in tributaries of the Copper River during aerial tracking surveys, 1999-2002.

Tributary	1999	2000	2001	2002
Upper Copper River Drainage				
Mainstem Copper River	0	6	4	2
Ahtell River	2	0	1	0
Bone Creek	1	3	4	3
Chistochina River (mainstem)	2	4	5	4
E. Fork Chistochina River	6	7	12	9
No Name (south of E. Fork Chistochina River)	2	1	0	0
Sinona Creek	2	2	1	1
Gakona River (mainstem)	4	0	4	2
Spring Creek	2	4	5	2
No Name (Opposite Spring Creek)	2	1	1	1
Indian River	2	3	3	4
Drop Creek	3	1	2	1
Tulsona Creek	0	0	1	0
No Name (east side parallel to Drop Creek)	0	1	1	1
No Name (east side opposite Indian River)	2	2	1	1
No Name (east side opposite Sinona Creek)	1	1	0	2
No Name (east side upstream of Yokneda Lakes)	1	1	1	2
Gulkana River Drainage				
Gulkana River (mainstem)	14	58	29	34
Middle Fork Gulkana River	3	1	5	4
West Fork Gulkana River	3	1	5	6
Hungry Hollow Creek	1	0	1	2
Paxson Lake Outlet	1	3	1	2
No Name (west side upstream of West Fork)	0	3	0	1

-continued-

Table 7.–Page 2 of 2.

Tributary	1999	2000	2001	2002
Tazlina River Drainage				
Kiana Creek	5	7	6	5
Mendeltna Creek	4	2	5	3
Klutina River Drainage				
Klutina River (mainstem)	46	58	57	57
Manker Creek	13	11	10	16
St. Anne Creek	3	5	8	3
Mahlo Creek	0	1	1	0
Tonsina River Drainage				
Tonsina River (mainstem)	51	45	56	49
Greyling Creek	8	8	4	3
Little Tonsina River	7	1	3	5
Dust Creek	1	1	1	1
Bernard Creek	1	0	0	2
Chitina River Drainage				
Chitina River (Mainstem)	0	5	0	
Chakina River	12	8	6	4
Gilahina River	3	9	9	12
Lakina River	3	1	1	8
Monahan Creek	2	2	6	2
Tana River	6	1	2	7
Tebay River	35	11	18	15

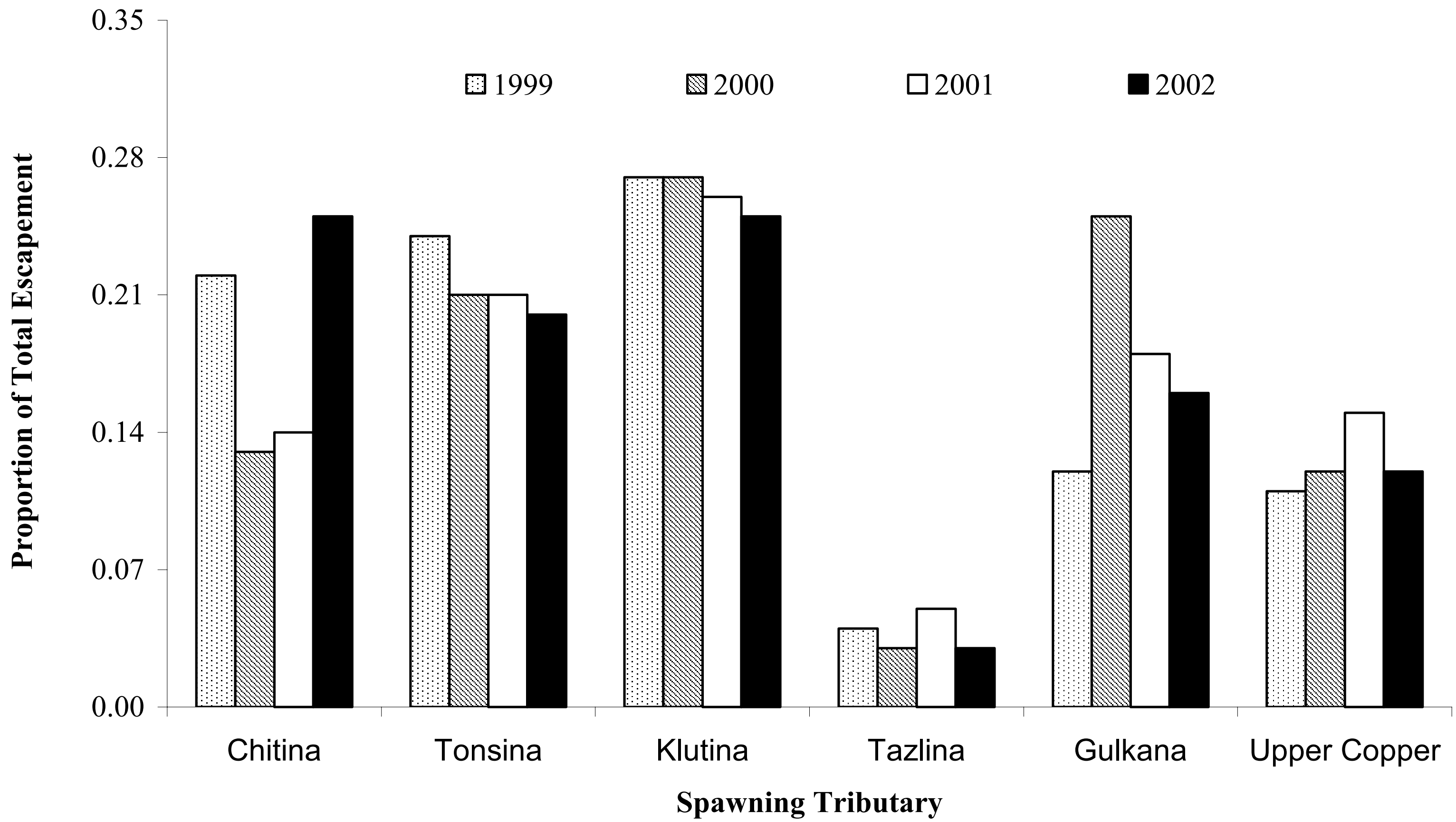


Figure 7.–Spawning distribution of Copper River chinook salmon by major drainage, 1999-2002.

Table 8.–Proportions of radio-tagged chinook salmon located in nine aerial survey index streams in the Copper River drainage, 1999-2002.

	Proportion of All Spawners			2002	
Spawning Stream	1999	2000	2001	Proportion of All Spawners	Percentile Limits (2.5^{th},97.5^{th})
Gulkana River	0.12	0.25	0.18	0.16	(0.12, 0.20)
E. Fork Chistochina River	0.02	0.02	0.05	0.03	(0.01, 0.05)
Manker Creek	0.04	0.04	0.03	0.05	(0.03, 0.08)
St. Anne Creek	0.01	0.02	0.03	0.01	(0.00, 0.02)
Little Tonsina River	0.02	<0.01	0.01	0.02	(0.00, 0.03)
Greyling Creek	0.02	0.02	0.01	0.01	(0.00, 0.02)
Indian Creek	<0.01	0.01	0.01	0.01	(0.00, 0.03)
Kiana Creek	0.01	0.03	0.02	0.02	(0.00, 0.03)
Mendeltna Creek	0.01	0.01	0.02	0.01	(0.00, 0.02)
Proportion of Total in Index Streams	0.26	0.40	0.37	0.32	(0.27, 0.37)

Table 9.–Proportions of chinook salmon spawning in the mainstem and tributaries of the Tonsina and Klutina rivers, 2002.

River	Number of Radio Tags	Proportion of Spawners	Percentile Limits (2.5^{th}, 97.5^{th})
Tonsina River			
Mainstem	46	0.77	(0.57, 1.00)
Greyling Creek	3	0.05	(0.00, 0.12)
L. Tonsina River	5	0.08	(0.02, 0.17)
Bernard Creek	2	0.03	(0.00, 0.08)
Dust Creek	1	0.02	(0.00, 0.05)
Quartz Creek	3	0.05	(0.00, 0.12)
All Tributaries	14	0.23	(0.12, 0.35)
Klutina River			
Mainstem	56	0.75	(0.57, 0.93)
Manker Creek	16	0.21	(0.12, 0.32)
St. Anne Creek	3	0.04	(0.00, 0.09)
Mahlo Creek	0	0.00	(0.00, 0.00)
All Tributaries	19	0.25	(0.15, 0.37)

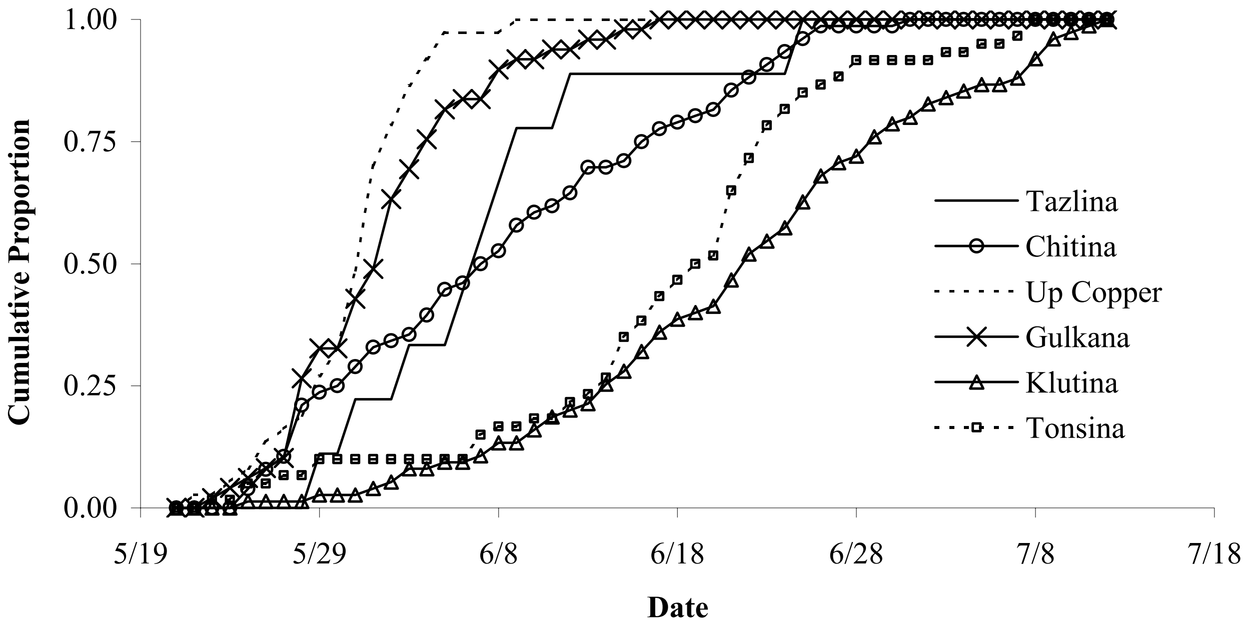


Figure 8.–Run-timing patterns of chinook salmon at the capture site for the major stocks in the Copper River, 2002.

Table 10.–Statistics regarding the migratory timing past the capture site in Baird Canyon of the major chinook salmon spawning stocks in the Copper River, 2002.

Spawning Stock	Duration (No. of Days)	Mean Date of Passage ($\bar{t}$)	SE ($\bar{t}$)
Upper Copper River	5/22-6/9 (18)	5/31	3.5
Gulkana River	5/23-6/17 (25)	6/1	5.4
Chitina River	5/25-7/1 (37)	6/8	10.0
Tazlina River	5/29-6/25 (27)	6/7	7.4
Tonsina River (All)	5/23-7/8 (46)	6/17	10.2
Mainstem	5/23-7/8 (46)	6/18	9.9
Tributaries	5/25-6/27 (33)	6/14	10.8
Klutina River (All)	5/25-7/10 (46)	6/21	11.1
Mainstem	6/2-7/12 (40)	6/25	9.4
Tributaries	5/25-6/26 (32)	6/11	8.3

in all four years of the study, but individual stocks displayed similar patterns between years (Figure 9). In general, migratory timing of chinook salmon bound for tributaries of the Tonsina and Klutina rivers was earlier than their mainstem spawning counterparts (Figure 10).

In a related study, Smith and Link (2003) found no significant difference between mean travel times of spaghetti-tagged and radio-tagged chinook salmon. A comparison between tagged fish and fish not tagged is not possible; however, these results suggest that regardless of the tagging procedure chinook salmon will exhibit similar run timing patterns.

DISCUSSION

This was the fourth consecutive year of an ongoing study to estimate annual inriver abundance, spawning distribution, and run timing of chinook salmon in the Copper River drainage. An unstratified two-event mark-recapture model was used to estimate the abundance of chinook salmon at the point of entry into the CSDN fishery. Experimental assumptions such as tag loss, emigration, and mortality were explicitly tested because the fates of all radio-tagged fish were known. However, potential bias from factors such as unreported harvest, illegal harvest, selection for tagged fish, inability to detect radio-tagged fish that were harvested, and removal of tags could not be explicitly tested.

Unreported harvest in the CSDN fishery, defined as harvest by permitted CSDN fishers who did not return their permit, would bias the abundance estimate low because these fish were not accounted for in the total harvest estimate. The number of chinook salmon harvested by CSDN fishers who did not return their permits was estimated based on harvest rate trends from CSDN fishers that returned their permits after multiple reminder letters. The high return rate of permits (84%), coupled with observations that persons who did not return permits tended to harvest fewer fish than persons who did return permits suggested that the unreported harvest was negligible.

Illegal harvest in the CSDN fishery, defined as harvest without a permit, would also bias the abundance estimate low because radio-tagged fish that were harvested were used in the estimation whether they were reported or not, whereas unmarked fish that were harvested and not reported were not. For this reason, the estimate of chinook salmon abundance is only affected if a radio-tagged chinook salmon was illegally harvested. In this study there was little evidence to suggest that radio-tagged chinook salmon were illegally harvested. Twenty-five of the 26 radio-tagged fish harvested in the CSDN fishery were returned by fishers holding a permit. The remaining one fish was harvested when the fishery was open, but it is not known whether it was harvested by a permit holder.

Failure to detect radio-tagged chinook salmon harvested in the CSDN fishery would have biased the estimate of chinook salmon abundance high. The probability that this situation occurred was low because tracking stations located at the upper and lower boundaries of the CSDN fishery and O'Brien Creek were able to detect all but 18 out of 426 of the radio-tagged fish that entered and exited the fishery. Further, nearly all radios from tagged fish captured by CSDN fishers (25 of 26) were voluntarily returned. One tagged fish was assumed harvested based on high signal strength recordings at the O'Brien Creek tracking station.

CSDN fishers that select for radio-tagged chinook salmon or remove and return radio tags from chinook salmon that were not harvested would bias the abundance estimate low because the marked (radio-tagged) to unmarked (not radio-tagged) ratio of captured chinook salmon would

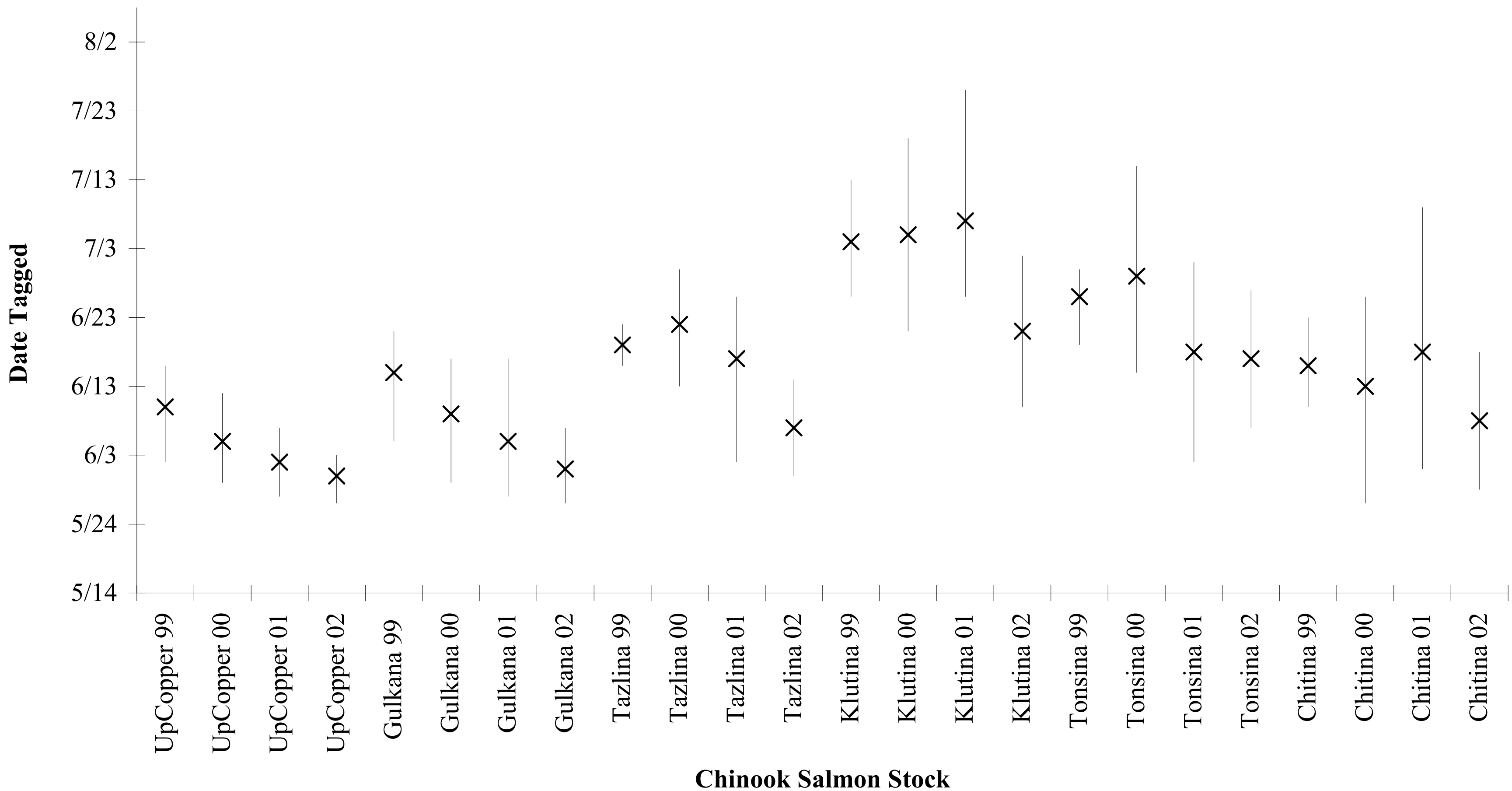
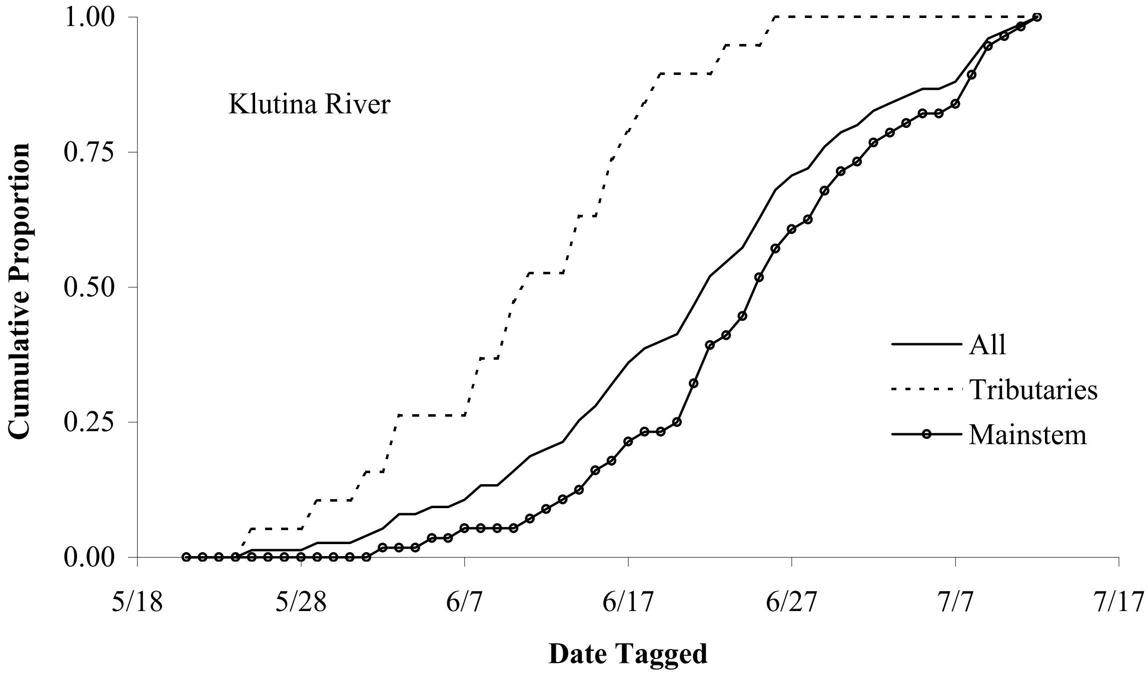


Figure 9.–Mean passage date (symbol) and 80% range (vertical lines) of Copper River chinook salmon stocks at the capture site in 1999-2002.



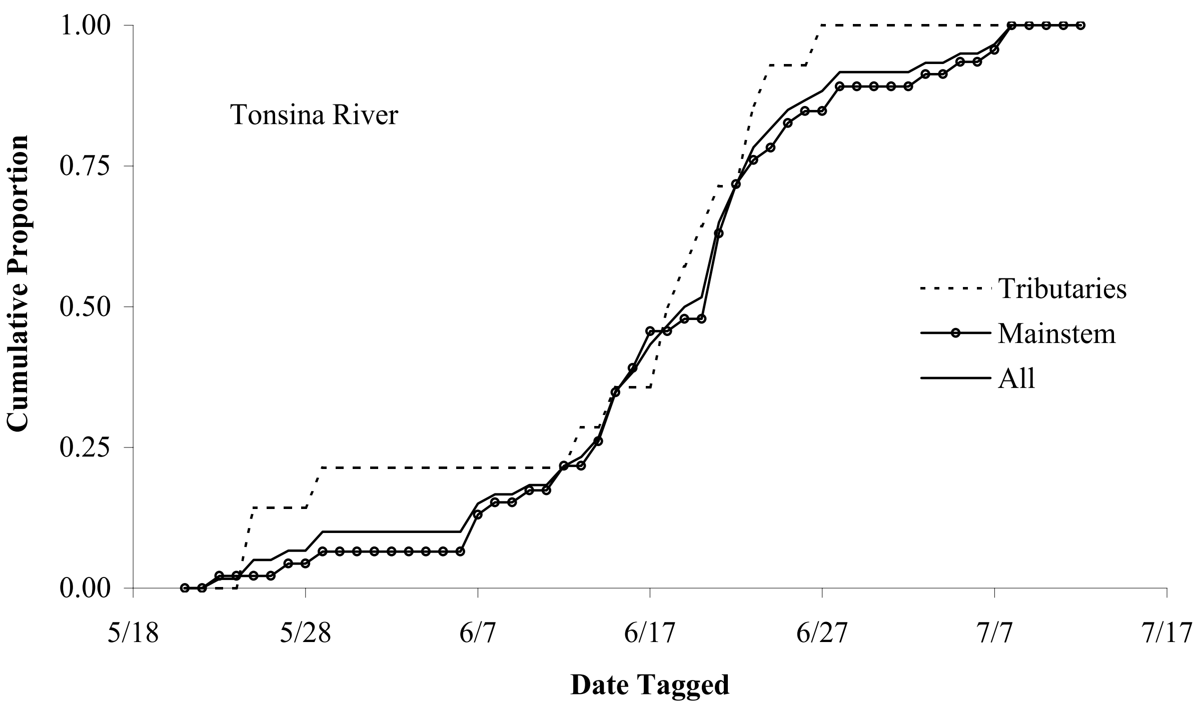


Figure 10.–Run-timing patterns of chinook salmon in the Klutina and Tonsina rivers for tributary and mainstem spawners, 2002.

be inflated or larger than expected. Selection for radio-tagged chinook salmon was assumed negligible because there was no reward offered for returned tags and gray-colored spaghetti tags that were difficult to detect while dip-netting fish were used. In fact, several CSDN fishers stated they did not notice the spaghetti or radio tag until they had processed their fish. When possible, fishers who returned tags were asked whether the tagged fish was harvested or released. None of the CSDN fishers that were queried indicated that they had removed a tag and released a fish.

In addition to the potential sources of bias previously discussed, the results of two other studies suggest that this study's inriver abundance estimate could be biased low. Smith and Link (2003) reported an inriver abundance estimate of 38,893, this was approximately 6,000 fish greater than the abundance estimate generated in this report. However, Smith and Link report that the estimate was relatively imprecise and probably biased due to limited numbers of recaptures. The Gulkana River counting tower project reported an escapement estimate of 6,078 (Sarafin *In prep.*). If one were to apply the estimated spawning distribution to the total inriver abundance estimate from this study, the escapement estimate for the Gulkana River would be considerably smaller than what was estimated at the tower. However, it is not recommended that the estimated spawning distribution expanded by the Gulkana River tower count be used to develop inriver abundance estimates for the Copper River tributaries because of the imprecision associated with this method of estimation.

The design of the mark-recapture experiment incorporated the harvest of chinook salmon in the CSDN fishery for the second event. The advantages of this were that a relatively large number of fish were examined for marks, the additional cost to the experiment was minimal, and relatively few fish needed to be handled and marked. However, frequent and prolonged fishery openings were required to estimate chinook salmon abundance, especially in June when a large portion of the run was passing through the study area. Even with early fishery openings (by regulation the fishery cannot open before 1 June), a portion of the early run had already migrated through the study area.

In 2002, the CSDN fishery opened on 8 June and there were relatively few closures thereafter. Therefore the CSDN harvest was used to estimate abundance for 94% of the run. Prior to the opening of the fishery on 8 June, marked fish from the first event passed through the fishery area, but their probability of capture was zero. Therefore, to estimate abundance for the period prior to 8 June the mark-recapture estimate of abundance for the period during the fishery was expanded by the proportion of the total run it represented. The relationship between periodic estimates of CPUE in the marking event and their corresponding estimate of abundance was determined for periods when the fishery was open and applied to the estimate of abundance when the fishery was closed to model uncertainty in the estimate.

The estimated proportion of the run accounted for by the mark-recapture study incorporated two sources of uncertainty because the variation in the relationship between cumulative weekly CPUE (process error) and weekly abundance estimates (measurement error) is characteristic of the uncertainty in estimating total abundance (Figure 6). The variation associated with this method of estimation was greater than the variation associated with the mark-recapture model. Therefore, active sampling in late May and early June, prior to the opening of the fishery would be preferable to the expansion technique. It is suggested that future studies incorporate sampling of subsistence fish wheel catches of federally qualified users prior to the opening of the CSDN fishery. There are numerous fish wheels that operate in the area of the McCarthy Road Bridge.

and catches are generally high early in the season. Federally-qualified users can begin fishing on 15 May.

The affects of inserting radio tags into chinook salmon are not fully understood. The proportion of radio-tagged chinook salmon that failed to migrate upstream varied between 4% (n=14) in 1999, 10% (n=56) in 2000, 9% (n=43) in 2001, and 8% (n=36) in 2002 (Evenson and Wuttig 2000; Wuttig and Evenson 2001; Savereide and Evenson 2002). Comparable studies on chinook salmon in the Stikine and Taku rivers in Southeast Alaska have observed similar failure or retreat rates (Pahlke and Bernard 1996; Bernard et al. 1999). Even though the failure rates observed in this study are not uncommon, the central question of whether handling affects the probability of capture in the second event still remains. One measure of this handling effect was the delay in migration after the fish had been tagged. The assumption was that any delay in their migration was a relative measure of stress, and stressed fish may have migrated upstream in nearshore waters with lower velocities. A radio-tagged chinook salmon exhibiting these characteristics would be more vulnerable to capture by shore-positioned dipnetters. Similar recapture rates between fish that exhibited minimal, moderate, and substantial delays coupled with comparable transit times through the CSDN fishery suggested that any handling-induced changes did not affect the probability of capture.

Previous studies have provided varying theories on the effects of radio tags on salmon migration. Monan and Liscom (1975) suggested that spring and fall run chinook salmon can successfully migrate to their spawning grounds when fitted with internal radio tags. In contrast, Gray and Haynes (1979) found that the proportion of chinook salmon fitted with internal radio tags that returned to their spawning grounds was significantly less than fish tagged with only spaghetti tags. The latter study concluded that the majority of unsuccessful migrations were caused by placing the radio tag well into the stomach instead of just behind the esophageal sphincter or anterior stomach. In this study radio tags were placed in the anterior stomach of chinook salmon and 77% of the radio-tagged fish that migrated through the CSDN fishery were located in a spawning tributary. These results imply that correctly placed internal radio tags will not influence the migration of spawning chinook salmon.

The distribution of spawning chinook salmon was relatively consistent from 1999-2002 (Figure 7). The Tazlina River consistently exhibited a small proportion of the total escapement because there are only two relatively small spawning streams used by chinook salmon in this drainage. The Upper Copper drainage was also consistent across years and exhibited a larger proportion of the total escapement because the area is fairly large and numerous spawning streams are available. The Tonsina and Klutina rivers, which exhibit early and late runs of chinook salmon, were consistently over 20% of the total escapement with very little annual variation. In contrast, the Gulkana and Chitina rivers both exhibit relatively large changes in the annual distribution of chinook salmon. The pronounced differences in run timing of the various stocks and the probability that exploitation of stocks in the commercial and inriver fisheries varies annually is a likely explanation for some of the variability noted in the spawning distribution.

Failing to allocate radio tags among stocks in proportion to their relative stock abundance could be a significant source of bias in estimating spawning distribution. In 2002, an ADF&G counting tower on the Middle Fork Gulkana River estimated total chinook salmon passage. In addition, a radio tracking station located at the counting tower enumerated radio-tagged chinook salmon passing the counting tower. A comparison between the marked (radio-tagged) to unmarked (not radio-tagged) ratios of chinook salmon at the counting tower and in the CSDN harvest could provide a means to evaluate whether radio tags for that stock were distributed in proportion to stock abundance. However, despite this comparison, expanding the total count from the Gulkana River counting tower for the purpose of estimating the total escapement of chinook salmon in the Copper River drainage would yield spurious system-wide projections because the potential for bias is substantial and the presence or absence of bias can not be detected or corrected.

The spawning distribution of chinook salmon in the Copper River drainage from 1999-2002 indicated that the nine spawning streams that are aerial surveyed annually for an index of escapement represent a small and variable proportion of the total drainage-wide escapement. Chinook salmon located in the nine index streams only accounted for 26% (1999), 40% (2000), 37% (2001), and 31% (2002) of all spawning fish in the Copper River drainage. The largest contributor to the total escapement count was the Gulkana River, which accounted for 47% of the escapement in the index streams in 1999, 63% in 2000 and 2001, and 51% in 2002. However, escapement in the Gulkana River represented only 12%, 25%, 18%, and 16% respectively, of the total drainage-wide escapement. The interannual variation in the proportion of the total escapement represented by these nine streams and the fact that a majority of these streams support stocks with early run-timing patterns suggest that the aerial escapement index that has been conducted since the late 1960s to assess chinook spawning abundance during peak spawning is neither a consistent nor reliable measure of total escapement.

In 1999-2002 the run timing of chinook salmon at the Baird Canyon capture site revealed that upriver stocks, such as the Upper Copper River and Gulkana River stocks, were the first to enter the CSDN fishery and downriver stocks, such as the Klutina River and Tonsina River stocks, were the last. This type of run-timing pattern where upriver salmon stocks enter first inriver and downriver stocks enter last has been observed in other large river systems (Koski et al. 1994; Pahlke and Bernard 1996). If this run timing holds true at the mouth of the Copper River, where fish are vulnerable to the commercial fishery, then it is probable that individual stocks are subject to varying levels of exploitation.

As in previous years of the study, the majority of radio-tagged fish located within the Klutina and Tonsina rivers were located in the mainstem portions of the rivers. In 1999, mainstem spawners in these two rivers represented 33% of all spawning chinook salmon. This number increased to 40% in 2000 and was similar in 2001 at 39%. In 2002, mainstem spawners accounted for 36% of all spawning chinook salmon in the Klutina and Tonsina rivers. These mainstem spawners are the largest component of the spawning population and have never been directly assessed because both rivers are large, fast-flowing, and glacially occluded, which makes aerial surveys and other assessment techniques difficult to perform. Radiotelemetry studies are an effective means of assessing escapements under these conditions.

Another characteristic shared by the chinook salmon stocks in the Tonsina and Klutina rivers was the run timing of the mainstem and tributary spawners. In 2002, as in previous years, tributary spawners were the first to arrive inriver and mainstem spawners arrived a measurable time later (Figure 10). These behavioral differences are analogous to the early and late-run stocks of the Kenai River. Burger et al. (1985) suggested that Kenai and Skilak lakes increase the fall and winter temperatures of downstream waters in the Kenai River, enabling successful reproduction for late-run mainstem spawners. Both the Klutina and Tonsina rivers have large lakes at their headwaters that may produce the warmer water temperatures needed for late-run spawners.

CONSULTATIONS AND CAPACITY DEVELOPMENT

This was a cooperative project involving Tribal (NVE), State (ADF&G), Federal (USFWS), and private (LGL) organizations. The involvement and cooperation of these various groups ensured that subsistence, recreational and commercial fishers understood and supported the project. Fishery technicians involved were local hires from the Copper River area and were trained in the collection of biological data and tagging and handling large fish from research fish wheels. In addition, technicians observed the radio tracking and data collection processes involved with radiotelemetry. A public presentation on the results of the study was given in Cordova in November, 2002.

CONCLUSIONS

The radiotelemetry study on chinook salmon in the Copper River provides:

1. an estimate of the total inriver abundance downstream from all inriver fisheries;
2. estimates of the spawning distribution throughout the Copper River drainage;
3. estimates of the stock-specific run-timing of the six major spawning stocks;
4. a cooperative working environment between multiple groups and users; and,
5. necessary data to assess current management practices.

RECOMMENDATIONS

It is recommended that the Federal Office of Subsistence Management and ADF&G support:

1. continued efforts to estimate the inriver abundance or total escapement of chinook salmon;
2. studies that estimate the exploitation rates of the major spawning stocks; and,
3. cooperative studies that provide important information for the management of the Copper River chinook salmon fisheries.

ACKNOWLEDGEMENTS

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