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Inriver Abundance, Spawning Distribution and Run Timing of Copper River Chinook Salmon, 2002–2004

Final 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 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)

Measures (fisheries)

fork length	FL
mideye-to-fork	MEF
mideye-to-tail-fork	METF
standard length	SL
total length	TL

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, χ^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. 05-50

INRIVER ABUNDANCE, SPAWNING DISTRIBUTION, AND RUN TIMING OF COPPER RIVER CHINOOK SALMON, 2002–2004

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ABSTRACT

From 2002–2004, radiotelemetry methods were used to estimate spawning distribution, run timing, and inriver abundance of Chinook salmon *Oncorhynchus tshawytscha* in the Copper River, Alaska. Chinook salmon were captured in fish wheels in the lower Copper River near Baird Canyon, and approximately 500 fish each year were fitted with radio transmitters. Radio-tagged fish were tracked to upriver destinations using a combination of ground-based receiving stations and aerial tracking techniques. Chinook salmon in the Copper River spawned in six major tributaries, and their spawning distribution varied considerably during the study for the Gulkana, Tonsina, and Chitina stocks, while the Klutina, Tazlina, and East Fork Chistochina stocks remained relatively constant. The estimated spawning proportions by major tributary were 0.10 (2002), 0.11 (2003) and 0.12 (2004) for the Klutina River; 0.08, 0.10 and 0.19 for the Tonsina River; 0.27, 0.17 and 0.20 for the Gulkana River; 0.29, 0.34 and 0.22 for the Chitina River; 0.04, 0.05 and 0.02 for the Tazlina River; and, 0.05, 0.05 and 0.06 for the East Fork Chistochina River. The estimated proportions of Chinook salmon located in the nine aerial index streams accounted for 0.46 (2002), 0.34 (2003), and 0.35 (2004) of Chinook salmon total escapement.

Run-timing patterns varied among the major spawning stocks but the same general pattern existed over time, where upriver stocks migrated past the capture site earlier than downriver stocks. The mean date of passage ranged from as early as 26 May for Chinook salmon bound for the upper Copper River in 2003 to as late as 24 June for the 2002 Klutina River mainstem spawners. In addition, over all 3 years of the study, the run timing of Chinook salmon bound for the tributaries of the Tonsina and Klutina rivers was earlier than their mainstem counterparts.

Two-event mark-recapture techniques were used to estimate inriver abundance at the lower boundary of the Chitina subdistrict dip net (CSDN) fishery. In the first event, Chinook salmon were radio-tagged downriver of the CSDN fishery. The total estimated harvest in the CSDN fishery comprised all fish examined for marks in the second event, and those fish harvested with radio tags comprised recaptured fish from the first event. Total abundance was estimated to be 32,873 (SE=8,863) in 2002, 33,488 (SE=8,389) in 2003, and 33,793 (SE=11,038) in 2004 for Chinook salmon $\geq$ 620 mm mideye-to-fork (MEF). However, based on information regarding catchability of Chinook salmon during the early portion of the run from a concurrent spaghetti tagging mark-recapture study that utilized fish wheels and not the CSDN fishery as the recapture event, the estimates of abundance from this study which expand the mark-recapture estimate to account for the early portion of the run not sampled are likely biased low.

Key words: Chinook salmon (*Oncorhynchus tshawytscha*), Chitina River, Copper River, East Fork Chistochina River, Gulkana River, Klutina River, mark-recapture, radiotelemetry, run-timing patterns, spawning distribution, Tazlina River, Tonsina River.

INTRODUCTION

The Copper River is a glacially dominated system located in Southcentral Alaska and is the second largest river in Alaska in terms of average discharge. It flows south from the Alaska Range and Wrangell and Chugach Mountains and empties into the Gulf of Alaska, slightly east of Prince William Sound (Figure 1). The Copper River drainage (61,440 km^2) supports spawning populations of Chinook salmon *Oncorhynchus tshawytscha*, sockeye salmon *O. nerka*, and coho salmon *O. kisutch* as well as various resident fish species.

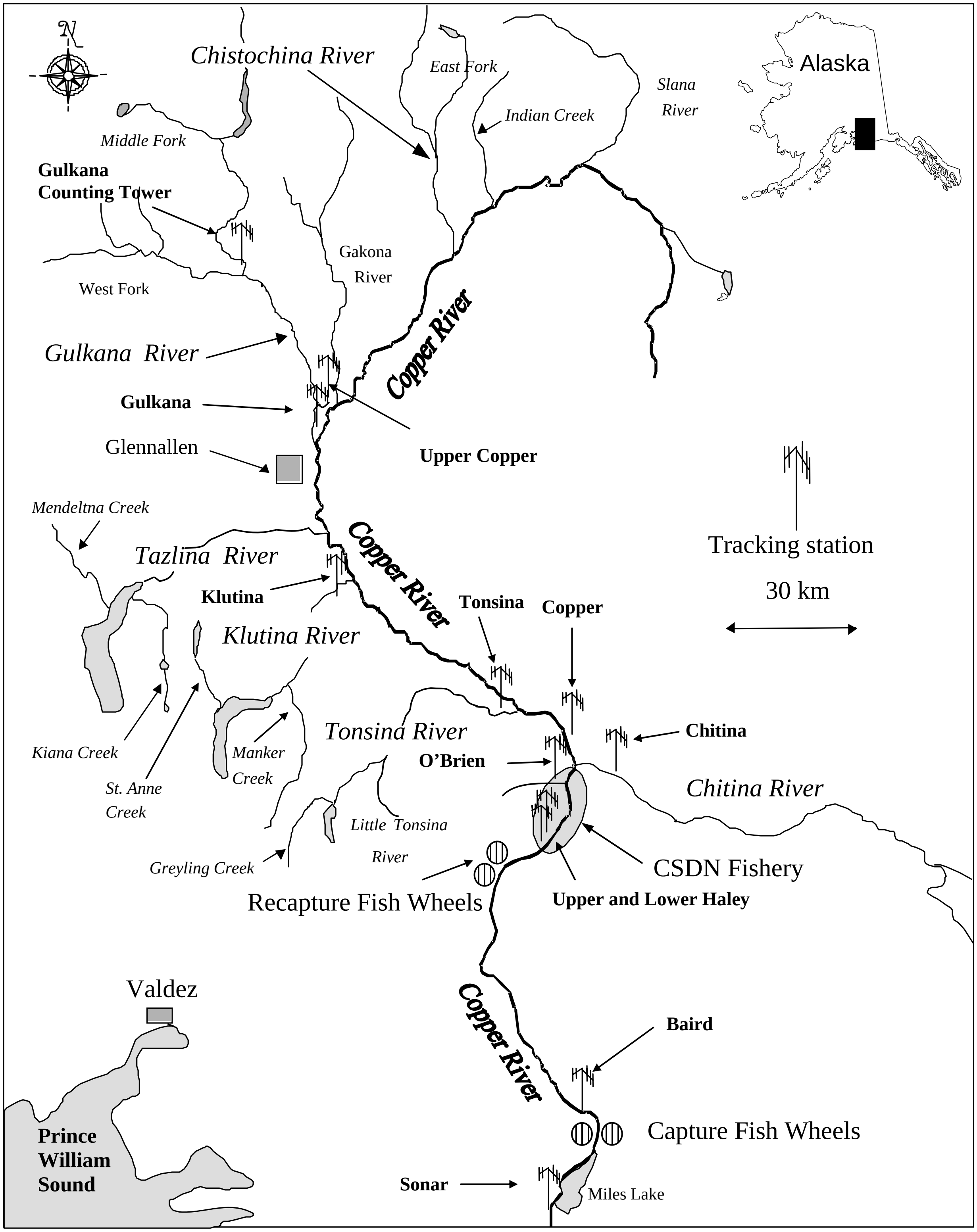

Figure 1.–Map of the Copper River drainage demarcating the capture and recapture fish wheels, boundaries of the CSDN fishery, location of 12 radio tracking stations, and nine aerial index streams, 2003.

The Copper River Chinook salmon population supports a commercial gillnet fishery near the mouth of the river plus inriver subsistence, personal use (PU), and sport fisheries. The average annual Chinook salmon harvest from 20002004 was 39,240 fish in the commercial fishery, 3,700 fish in the Glennallen subdistrict subsistence (GSS) fishery, 2,544 fish in the Chitina subdistrict dip net (CSDN) personal use fishery, and approximately 5,499 fish in the sport fishery. The GSS fishery runs from 1 June to 30 September from the north side of the Chitina-McCarthy Bridge to the village of Slana, and the majority of fishers use fish wheels to harvest salmon but dip nets and rod and reel are also allowed. Federally qualified subsistence fishers can use fish wheels within the CSDN fishery and the season runs from 15 May to 30 September. However, the state-managed CSDN fishery (which accounts for nearly all of the total harvest in the subdistrict) is strictly a dip net fishery and typically runs from early June to the end of September. The total number of CSDN permits issued since 1984, when the fishery was declared personal use, has ranged from 10,006 in 1998 to 4,031 in 1986. Sport fishing occurs mainly in the Klutina, Tonsina, and Gulkana rivers and anglers are limited to rod and reel gear.

An accurate method for estimating the inriver abundance of Copper River Chinook salmon is required to determine if the sustainable escapement goal (SEG) of 24,000 Chinook salmon is met annually. In 2001, the Office of Subsistence Management (OSM) Fisheries Resource Monitoring Program (FRMP) funded a multi-year mark-recapture study conducted by the Native Village of Eyak (NVE) titled *Feasibility of Using Fish Wheels for Long-Term Monitoring of Chinook Salmon Escapement on the Copper River* (FIS01-020). The main objective of that study was to estimate Chinook salmon inriver abundance using large fish wheels and two-event mark-recapture methodology. After a successful feasibility study (Smith et al. 2003), the FRMP decided to fund a multi-year study entitled *Migratory Timing and Spawning Distribution of Chinook Salmon in the Copper River* (this study; FIS02-015) to supplement the mark-recapture study. Estimates of run timing and distribution were determined by radio-tagging a sub-sample of Chinook salmon captured in the fish wheels during the mark-recapture project. The primary emphasis of study FIS02-015 was to estimate spawning distribution and run timing, but the study design and additional Federal Aid in Fish Restoration funding also provided for an independent estimate of inriver abundance.

Copper River Chinook salmon escapement is calculated postseason by subtracting estimates of inriver harvest from an inriver abundance estimate. Inseason measures of Chinook salmon escapement are not comprehensive and include aerial counts of 9 out of 40 identified spawning streams, and enumeration of Chinook salmon at a counting tower on the Gulkana River. Estimates of the proportion of Chinook salmon spawning in the 9 aerial index streams are used to determine the proportion of the total escapement that is assessed during aerial surveys.

Estimates of Chinook salmon spawning distribution are used to determine the proportion of the total abundance of fish in the 6 major Copper River tributaries. Run-timing patterns are used to determine passage of spawning stocks through the inriver fisheries and into the spawning tributaries, and are used to aid in determining the Chinook salmon sport fishing seasons. This work represents the culmination of a 6 year study that annually assessed spawning distribution, run timing and inriver abundance of Copper River Chinook salmon. Studies from 19992001 were conducted using different capture techniques and locations, and those results are summarized in Evenson and Wuttig (2000), Wuttig and Evenson (2001), and Savereide and Evenson (2002). This report is a summary of the final 3 years of the study (2002–2004) that was funded by OSM-FRMP.

OBJECTIVES

The objectives of this study from 2002–2004 were to:

1. Estimate the proportions of spawning Chinook salmon in the Copper River in each major spawning tributary (Chitina, Tonsina, Klutina, Tazlina, Gulkana, and East Fork Chistochina rivers);
2. Estimate the proportion of Chinook salmon spawning in the nine tributaries assessed annually during aerial surveys (Little Tonsina River, Greyling Creek, St. Anne Creek, Manker Creek, Mendeltna Creek, Kiana Creek, Gulkana River, East Fork Chistochina River, and Indian Creek);
3. 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 Upper Copper rivers; and,
4. Estimate the inriver abundance of Chinook salmon in the Copper River at the CSDN fishery.

METHODS

CAPTURE AND TAGGING

Chinook salmon were captured using two aluminum fish wheels located on the east and west banks of the Copper River in Baird Canyon (Figure 1). The fish wheels were deployed soon after break-up in mid-May and fished until the run was over in early-July. 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 et al. (2003). Both fish wheels were designed to fish 24 hours a day and 7 days per week, however there were instances where changes in water level or floating debris caused the wheel to stop fishing. Fish wheels were checked at least 3 times a day to ensure Chinook salmon spent a minimal amount of time in the live tanks.

Each time the fish wheels were checked all 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 tail fork); and,
3) Sexed based on external characteristics.

A systematic approach was taken to attempt to radio-tag Chinook salmon in proportion to run strength and timing where fishing was conducted every day and a portion of the daily catch was radio-tagged. Initially, 1 out of every 3 Chinook salmon captured was radio-tagged. The tagging rate was adjusted according to total daily catches and the number of radio tags remaining.

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.

Radio-Tracking Equipment and Tracking Procedures

Radio tags were Model F1845 pulse encoded transmitters made by ATS[1]. Each radio tag was distinguishable by its frequency and encoded pulse pattern. There were 20 frequencies spaced approximately 20 kHz apart in the 149-150 MHz range with 25 encoded pulse patterns per frequency that were used for a total of 500 uniquely identifiable tags. Radio-tagged Chinook salmon were tracked along the course of the Copper River using a network of 12 ground-based tracking stations (Figure 1). Each station included a receiver and data logger that were powered by two 12 V batteries charged with a solar array. Two, five-element Yagi antennas were mounted on a mast such that one antenna pointed upstream and the other downstream to detect directional movement. The receiver and data logger were programmed to scan through the frequencies at 3-s intervals, and receive 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 were recorded on the data logger. The relatively short cycle period minimized the chance that a radio-tagged fish swam past the receiver site without being detected. Cycling through all frequencies required 57 minutes depending on the number of active tags in the reception range and level of background noise. Recorded data were periodically downloaded to a laptop computer.

The first tracking station was placed at the Alaska Department of Fish and Game (ADF&G) Miles Lake sonar site (Figure 1), approximately 20 km below the capture site. This station was used to assist with identifying any radio-tagged fish that dropped out of the system. This station was removed in 2004 because radio-tagged fish that dropped out of the system was less than five in 2002 and 2003 and all were located from the air or returned by commercial fishermen. The second station was placed at the NVE Baird Canyon camp, approximately 2 km upstream from the capture site. Two stations were placed on the west bank of the Copper River downstream of the CSDN fishery (below Haley Creek) to determine the total number of radio-tagged Chinook salmon that entered the fishery. One station was placed on a bluff overlooking both O'Brien Creek (a popular fish cleaning area) and the Copper River to monitor radio-tagged fish harvested in the CSDN fishery but not reported. The sixth station was placed on the north bank of the Chitina River approximately 6 km upstream from its confluence with the Copper River. The seventh station was placed on a west-side bluff of the Copper River immediately upstream from the upper boundary of CSDN fishery. The latter five stations, in combination, were used to identify all radio-tagged Chinook salmon entering and exiting the CSDN fishery. Tagged fish entering the Tonsina, Klutina, and Gulkana rivers were recorded from stations placed near the mouths of these rivers. In addition, a second station was placed on the Gulkana River at the site of the ADF&G salmon counting tower to evaluate the proportion of Gulkana River Chinook salmon that migrate past the counting tower. The twelfth station was placed on the mainstem

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

Copper River approximately 2 km downstream from the mouth of the Gakona River. This station was used to enumerate all fish with radio tags entering the Upper Copper River drainage upstream of the Gulkana River.

The distribution of radio-tagged Chinook salmon throughout the Copper River drainage was further determined by aerial tracking from small aircraft. Three aerial-tracking surveys of the entire drainage including the mainstem Copper River were conducted at the beginning, middle, and end of the run. Tracking flights were conducted with one R4500 receiver. All frequencies were loaded into the receiver prior to each flight. Dwell time on each frequency was 2 s. Flight altitude ranged from 100 to 300 m above ground. Two antennas, one on each wing strut, were mounted such that the antennas received peak signals perpendicular to the direction of travel. Once a tag was identified, its frequency, code, and location coordinates were recorded. After the information was recorded, the plane circled back to the point where the signal was first heard and tracking resumed. The purpose of the aerial tracking was to locate tags in spawning tributaries other than those monitored by remote tracking stations, to locate fish that the tracking stations failed to record, and to validate that fish recorded on one of the data loggers did migrate into that particular tributary.

STUDY DESIGN

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-tagged fish (Table 1).

Table 1.–List of possible fates of radio-tagged Chinook salmon in the Copper River, 2003.

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.

Spawning Distribution

A total of 12 stationary radio-tracking stations were used to determine the proportion of total escapement and stock-specific run-timing patterns for the Chitina, Tonsina, Klutina, Tazlina, Gulkana, and Upper Copper (all waters upstream from the Gulkana River) drainages (Figure 1).

Among fish that migrated past the lower two tracking stations, the proportion of fish that had fate *j* was estimated as:

$$\hat{P}_j = \frac{\sum_{i}^{\text{days}} R_{ij}}{\sum_{j}^{\text{fates}} \sum_{i}^{\text{days}} R_{ij}} \tag{1}$$

where R_{ij} was 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 drew 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 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 migrating into all spawning tributaries.

The same procedure was used to determine the proportions of Chinook salmon migrating into each of the nine aerial index streams: the Little Tonsina River, Greyling 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 a particular stream if its radio tag was located there at least once during an aerial tracking flight or was recorded by a tracking station positioned on a tributary.

Conditions for a Consistent Spawning Distribution Estimator

To obtain unbiased estimates of the spawning distribution certain assumptions must have been met:

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

   Test: There was no explicit test for this assumption because we could not observe the behavior of unhandled fish. However, we could compare recapture rates and transit times through the CSDN fishery between groups of fish affected differently by handling. In all 3 years, we compared the recapture rates and transit times through the fishery of fish that migrated from the tagging site to the lower boundary of the CSDN fishery in minimal (less than 11 days), moderate (11-19 days), and substantial (20 or more days) time. Chinook salmon that continued their upstream migration quickly were thought to experience minimal handling affects and would behave similar to untagged fish.

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

Design Considerations: The tagging protocol described was designed to distribute tags over time proportional to passage of salmon past the tagging site.

Test: Marked to unmarked ratios in the second event of the NVE mark-recapture study were compared to evaluate if this condition was met. The NVE data were preferred over recapture data from this study because the recovery event covered a longer and more consistent period than the second event of this study (period of the CSDN fishery) did. If ratios were found to vary and the tag deployment rate and fishing effort were relatively stable during the marking event, each radio-tagged fish was given a numeric weight that took into account estimated differences in the probability that an individual fish was tagged over time during the marking event. Weekly (or some alternate tagging period) salmon abundance past the tagging site was estimated using the methods of Darroch (1961). Weights for each day of tagging were computed and assigned, however weights for each day within a tagging period were computed similarly:

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

where:

$\hat{A}_k$ = estimated abundance of salmon past the tagging site during tagging period *k*; and,

x_k = the number of radio tags deployed during tagging period *k*.

For each day that radio tags were deployed we calculated:

$$R^*_{ij} = R_{ij} * w_i \qquad (3)$$

and substituted for R_{ij} in equation (1).

Precision was estimated by constructing a bootstrap algorithm (Efron and Tibshirani 1993) for the entire experimental process (i.e., for each replicate, new weighting terms were calculated and the new weighted fates of all tags were resampled).

STOCK-SPECIFIC RUN TIMING

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

$$f_j(t) = \frac{R_{tj}}{\sum_{i}^{days} R_{ij}} \qquad (4)$$

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 radio-tagged Chinook salmon bound for tributary *j* that would be caught and tagged during day *t*.

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 was estimated as:

$$\bar{t}_j = \sum_t t\, f_j(t), \tag{5}$$

the variance of the run timing distribution estimated as:

$$Var\left(t_j\right) = \sum_t \left(t - \bar{t}_j\right)^2 f_j(t). \tag{6}$$

To obtain unbiased estimates of stock-specific run timing, the same two assumptions, tests, design considerations, and weighting procedures described for estimating spawning distribution also applied to estimates of run timing.

Inriver Abundance

Inriver abundance of Copper River Chinook salmon was estimated with a combination of radiotelemetry and two-event mark-recapture methods. Chinook salmon were captured and radio-tagged in the mainstem Copper River upstream of Baird Canyon and served as marked fish in the first event. Chinook salmon harvested in the CSDN fishery served as fish examined for marks in the second event. 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.

Conditions for a Consistent Abundance Estimator

To obtain an unbiased estimate of abundance from a mark-recapture experiment, certain conditions must be met (Seber 1982). These conditions, expressed in the circumstances of this study, along with their respective design considerations and test procedures are as follows:

1. *Handling did not make the fish more or less vulnerable to recapture than unhandled fish.*

    Design Considerations: 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 to the lower tracking stations as well as transit times through the CSDN fishery was recorded by the tracking stations.

    Test: There was no explicit test for this assumption because we could not observe the behavior of unhandled fish. However, as with estimates of spawning distribution and run timing, a comparison of recapture rates and transit times through the CSDN fishery between groups of fish affected differently by handling, inferred by different migration times between the capture site and the fishery, was conducted.

2. *Tagged fish were not selected for or against in the CSDN fishery.*

   Design considerations: Selection of tagged Chinook salmon by fishers would result in an estimate of abundance biased low. Selection against tagged Chinook salmon by fishers would result in an estimate of abundance biased high.

   Test: 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 or not selecting it for harvest. Gray tags were less identifiable at time of capture but identifiable while processing the fish.

3. *All tagged fish harvested in the CSDN fishery were accurately reported or known from information recorded on the tracking stations.*

   Design considerations: To ensure accurate reporting, efforts were made to recover as many tags harvested in the CSDN fishery as possible through on-site creel sampling by encouraging fishers to return tags. 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 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 on time and location of capture were posted at the primary access points (e.g., O'Brien Creek). All radio tags were labeled with information to encourage reporting of harvested tags. If only one tag was returned (either the radio tag or spaghetti tag), the CSDN fisher was contacted, if possible, 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. Tagged fish that were harvested in the CSDN fishery but not reported were identified using the two tracking stations located at the lower boundary of the fishery (below Haley Creek), the single station at O'Brien Creek, and the two stations at the upper boundaries of the fishery. Radio tags removed from the water have a pronounced and unquestionable increase in signal strength. Criteria for an unreported harvested fish were: a) a pronounced and prolonged recording of a signal by a data logger at O'Brien or Haley Creek; b) the radio tag was never recorded upstream of the CSDN fishery; and c) no downstream movement of the radio tag was detected after the radio-tagged fish had entered the CSDN fishery.

4. *The number of radio-tagged fish that entered into the CSDN fishery was known and there was no mortality of tagged fish within the fishery other than those that were harvested.*

   Design Considerations: Any tagged fish that was not identified as entering the CSDN fishery by tracking stations and aerial surveys was designated as a "failure".

   Test: We assumed that any tag found only in the area of the CSDN fishery (never found upstream from the fishery) was a fish that was harvested.

5. *Marked fish mixed completely with unmarked fish across the river.*

   Design Considerations: Because sampling with fish wheels and fishing in the CSDN fishery were bank-oriented capture methods, any fish swimming up only the center of the river may not have been included in the estimate. 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 not a center-only segment.

Test: Recapture rates for fish marked on each bank were compared using contingency table analysis. Independence between bank of mark and bank of recapture was also tested.

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

   Design Considerations: Fish wheels were used as a capture gear during the first sample. Sex and length were recorded for each radio-tagged fish. For the second sample, length data were collected from a sample of fish harvested from the CSDN fishery.

   Because length measurements from the second sample were mideye-to-fork (MEF) and measurements from the first sample were fork length (FL; snout to fork of caudal fin), the FL measurements were converted to MEF based on a regression analysis. FL measurements were used by NVE because they found it to be an easier measurement to take from live fish. The 2002 regression analysis demonstrated that FL could be used as an accurate predictor of MEF (Figure 2). Because the slope between males and females was nearly identical, the relationship between FL and MEF for males and females combined was used to calculate MEF length estimates of all fish tagged in the first sample.

   Test: Sex-selective sampling was tested using contingency table analysis to compare ratios of recaptured and not recaptured fish of each gender. If this test indicated a significant bias, Kolmogorov-Smirnov (K-S) tests for equal capture probabilities on the cumulative length distributions were performed for males and females separately: Test (A) all fish radio-tagged during the first sampling 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). If there was no significant bias, males and females were combined and the aforementioned K-S tests performed.

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

   Design Considerations: Equal fishing effort was expended at all times over the summer during the first (marking) event. Radio tags were deployed proportional to daily catch. Date and time of capture for all fish were recorded.

   Test: Marked to unmarked ratios in the second event were compared 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 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.*

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

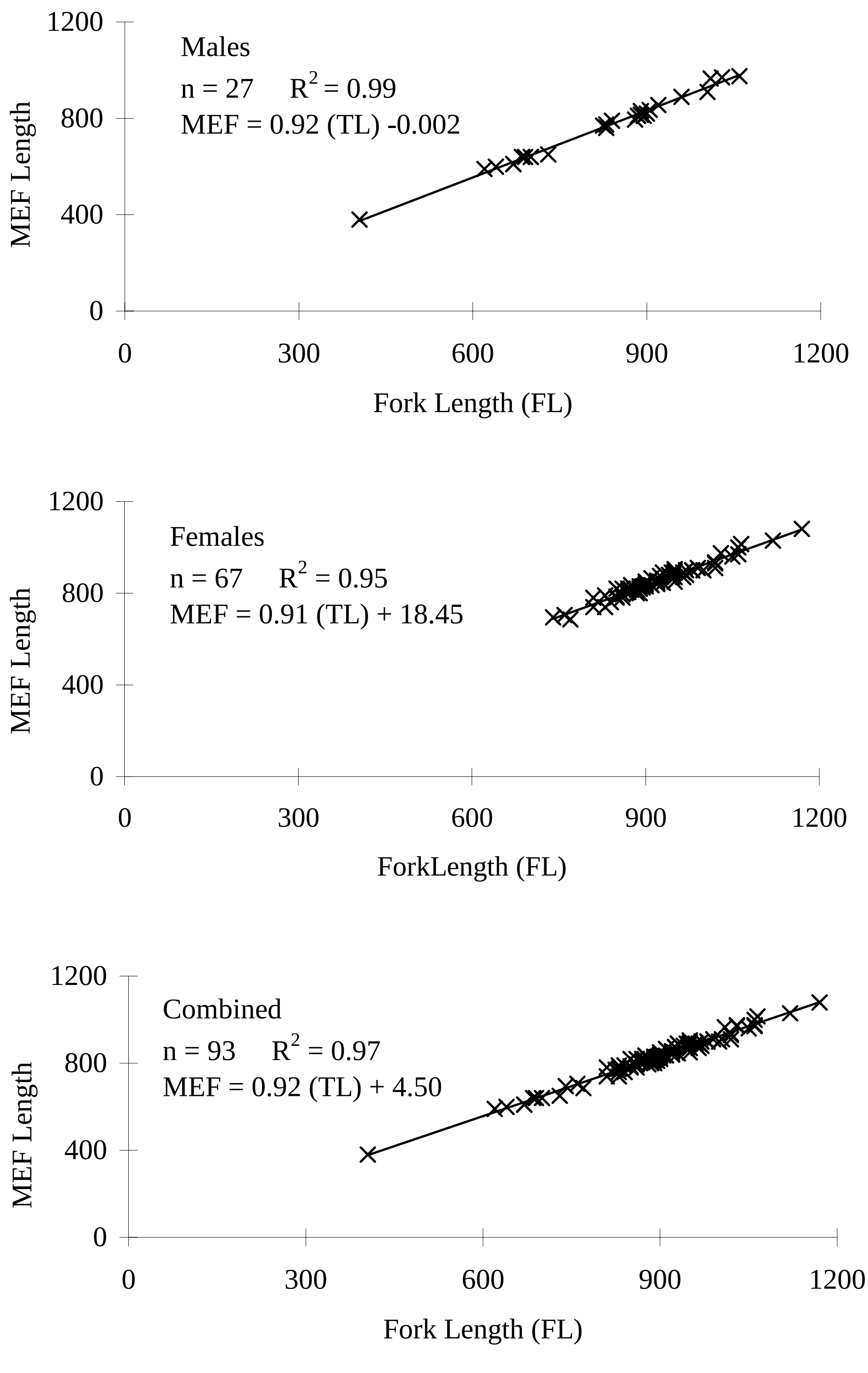

Figure 2.–The relationship between FL and MEF length of males, females, and males and females combined, 2002

Estimator

A two-sample mark-recapture model was used to estimate the inriver abundance of Chinook salmon during the period of the fishery. The appropriate abundance estimator was determined based on the results of the aforementioned tests. In 2002, 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. In 2003 and 2004, temporal stratification was required and the method of Darroch (1961) was used to estimate abundance. The estimates $\hat{N}$ were germane to the point of entry into the CSDN fishery (prior to any inriver harvest). The number of Chinook salmon examined during the second event ($\hat{C}$) was the estimated number of Chinook salmon harvested in the CSDN fishery. The estimated variance of $\hat{N}$ was approximate because $\hat{C}$ was subject to some sampling error due to the estimation of the Chinook salmon harvest from returned CSDN permits. However the estimates of CSDN harvest were very precise (CV<5%). Thus, the sampling error in $\hat{C}$ contributed a negligible amount to the variance of $\hat{N}$.

To estimate the total Chinook salmon run, including those portions of the run that migrated upriver before and after the recovery event (the period when the fishery was open), we divided $\hat{N}$ by the estimated proportion of the run $\hat{P}$ which occurred during the recovery event.

$$\hat{N}' = \hat{N}\hat{P}^{-1} \quad (7)$$

$$\hat{\text{var}}(\hat{N}') = \hat{N}^2\, \hat{\text{var}}(\hat{P}^{-1}) + \hat{P}^{-2}\, \hat{\text{var}}(\hat{N}) - \hat{\text{var}}(\hat{P}^{-1})\, \hat{\text{var}}(\hat{N}) \quad (8)$$

Weekly estimates of abundance in the CSDN fishery from the partially stratified estimator (Darroch 1961) coupled with weekly cumulative catch per unit effort (CPUE) data for the weeks of the fishery were used to model the uncertainty with which CPUE predicted salmon abundance during the CSDN 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 1,000,000 MCMC samples drawn from its posterior distribution:

$$\hat{P}^{-1} = \frac{\sum_{i=1}^{s} \tilde{P}_i^{-1}}{S} \text{ and } \hat{\text{var}}(\hat{P}^{-1}) = \frac{\sum_{i=1}^{S} \left(\tilde{P}_i^{-1} - \hat{P}^{-1}\right)^2}{S} \quad (9)$$

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:

$$\tilde{P}_i^{-1} = \frac{\sum_{j \in B} \tilde{N}_{ij} + \sum_{j \in D} N_j^* + \sum_{j \in A} \tilde{N}_{ij}}{\sum_{j \in D} N_j^*} \tag{10}$$

where:

N_j^* were weekly estimates of numbers of salmon in the recovery area using a time stratified Darroch (1961) estimation procedure with the capture-recapture data; $\tilde{N}_{ij}$ was the projected number of salmon in the recovery area during week *j* in the *i*th simulation; and *B*, *D*, and *A* were 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 $j \in D$,

$$N_j^* = \beta * CPUE_j + \varepsilon_j \text{ where } \varepsilon_j \sim N(0, \mathbf{D}\sigma^2) \tag{11}$$

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

$$\tilde{N}_{ij} = \hat{\beta}_i * CPUE_j \,. \tag{12}$$

RESULTS

CAPTURE AND TAGGING

Chinook salmon were captured in the Baird Canyon fish wheels from 22 May to 12 July, 2002, 15 May to 9 July, 2003 and 22 May to 22 June, 2004. A total 462, 500 and 498 Chinook salmon captured in the fish wheels were radio-tagged and released in 2002, 2003 and 2004, respectively. The daily catch of Chinook salmon ranged from zero fish to 192 fish and the daily radio-tagging rate varied from 3.4%-100% of all captured Chinook salmon (Figure 3).

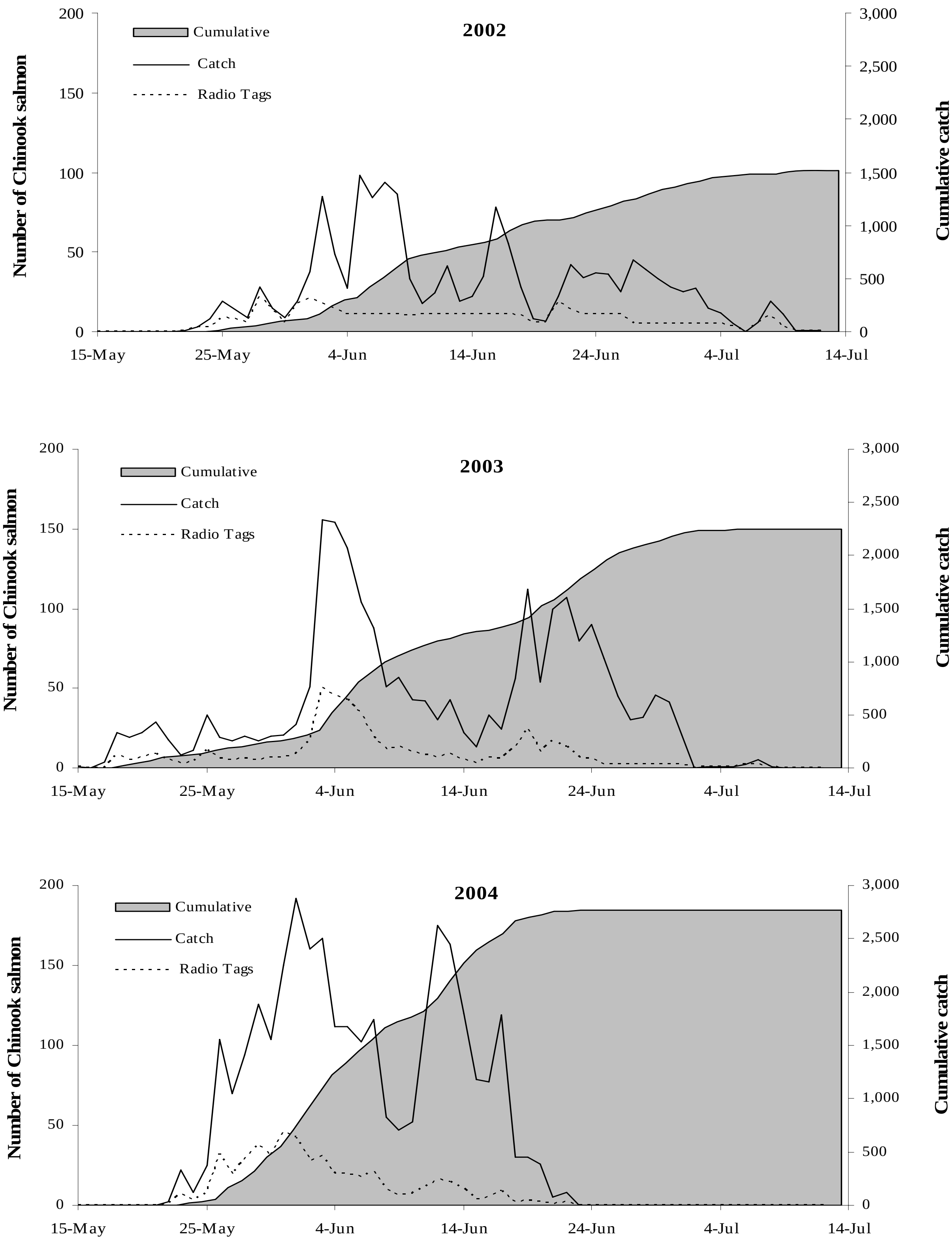

Figure 3.–Catch, cumulative catch and number of radio tags deployed by day for Chinook salmon at the Baird Canyon Copper River fish wheels, 2002–2004.

FATES OF RADIO-TAGGED CHINOOK SALMON

Of the 1,460 radio-tagged Chinook salmon from 2002–2004, 1,356 fish (93%) entered the CSDN fishery and 1,257 (86%) exited the fishery. Ninety-nine radio tagged fish were harvested in the CSDN fishery. One hundred thirty-four radio-tagged fish were never reported as harvested or located in a spawning tributary (upstream migrant fate), 198 fish were known to be harvested in subsistence fish wheels, 75 fish were known to be harvested in sport fisheries, and 910 fish were located in spawning areas (Table 2).

Table 2.–Fates of radio-tagged Chinook salmon in the Copper River, 2002–2004.

	Number of Radio Tags			
Fate[a]	2002	2003	2004	Total
Total Deployed	462	500	498	1,460
Radio Failure	36	32	36	104
Total Entering CSDN Fishery	426	468	462	1,356
CSDN Fishery Recapture Mortality	26	34	39	99
Total Fish Passing Through CSDN Fishery	400	434	423	1,257
Upstream Migrant [b]	41	53	40	134
Subsistence Fishery Mortality	53	73	72	198
Spawner	306	308	296	910
Sport Fishery Mortality	23	32	20	75

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

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

Boat tracking surveys in previous studies (Wuttig and Evenson 2001; Savereide and Evenson 2002) were completed to determine if radio-tagged fish found in the mainstem of the Copper River were mainstem spawners. The surveys found no active Chinook salmon spawning in areas where the radio tags were located. Based on these boat surveys radio-tagged fish found in the mainstem Copper River are assumed to be mortalities or radio tag losses and are not included in the estimates of spawning distribution or run timing.

SPAWNING DISTRIBUTION

From 2002–2004, a total of 426, 468 and 462 Chinook salmon respectively, were recorded entering the CSDN fishery by the Haley Creek tracking stations. In all 3 years of the study, 60-65% of fish recorded between the Baird Canyon and Haley Creek tracking stations reached the CSDN fishery in 12 days or less and 83 (91%) migrated through the CSDN fishery in 5 days or less (Figures 4-6). Recaptured to not recaptured ratios of fish exhibiting minimal (<11 d), moderate (11-19 d), and substantial (>19 d) time to migrate into the fishery after handling implied that radio-tagging Chinook salmon had little influence on their migratory behavior (Table 3). In addition, transit times through the CSDN fishery for fish affected differently by handling were similar (Figure 4-6).

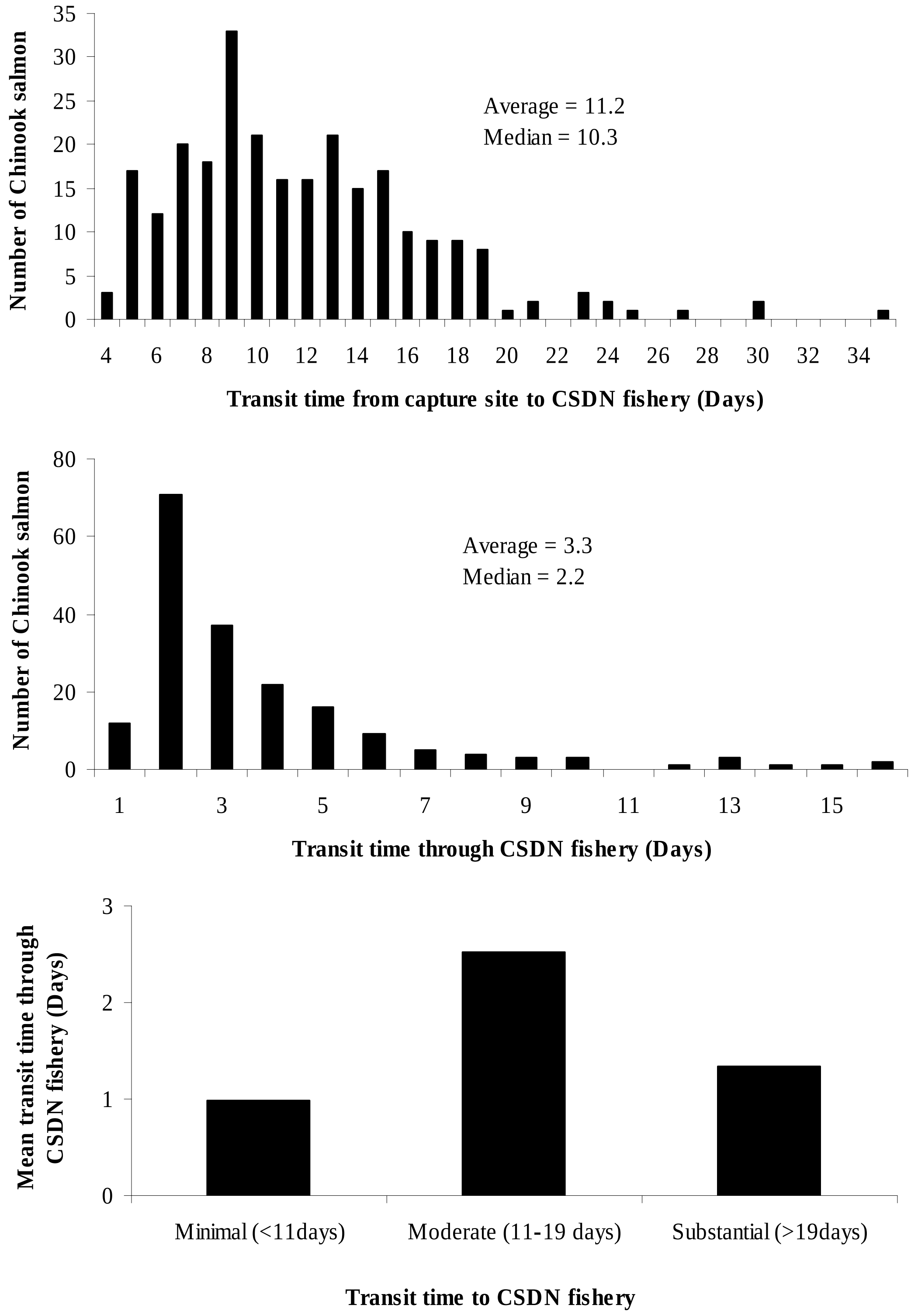

Figure 4.–Migratory times from capture site to the CSDN fishery (top panel), transit times through the CSDN fishery (middle panel), and a comparison of mean transit times through the CSDN fishery of fish that exhibited minimal, moderate, and substantial migratory times (bottom panel) for radio-tagged Chinook salmon in the Copper River, 2002.

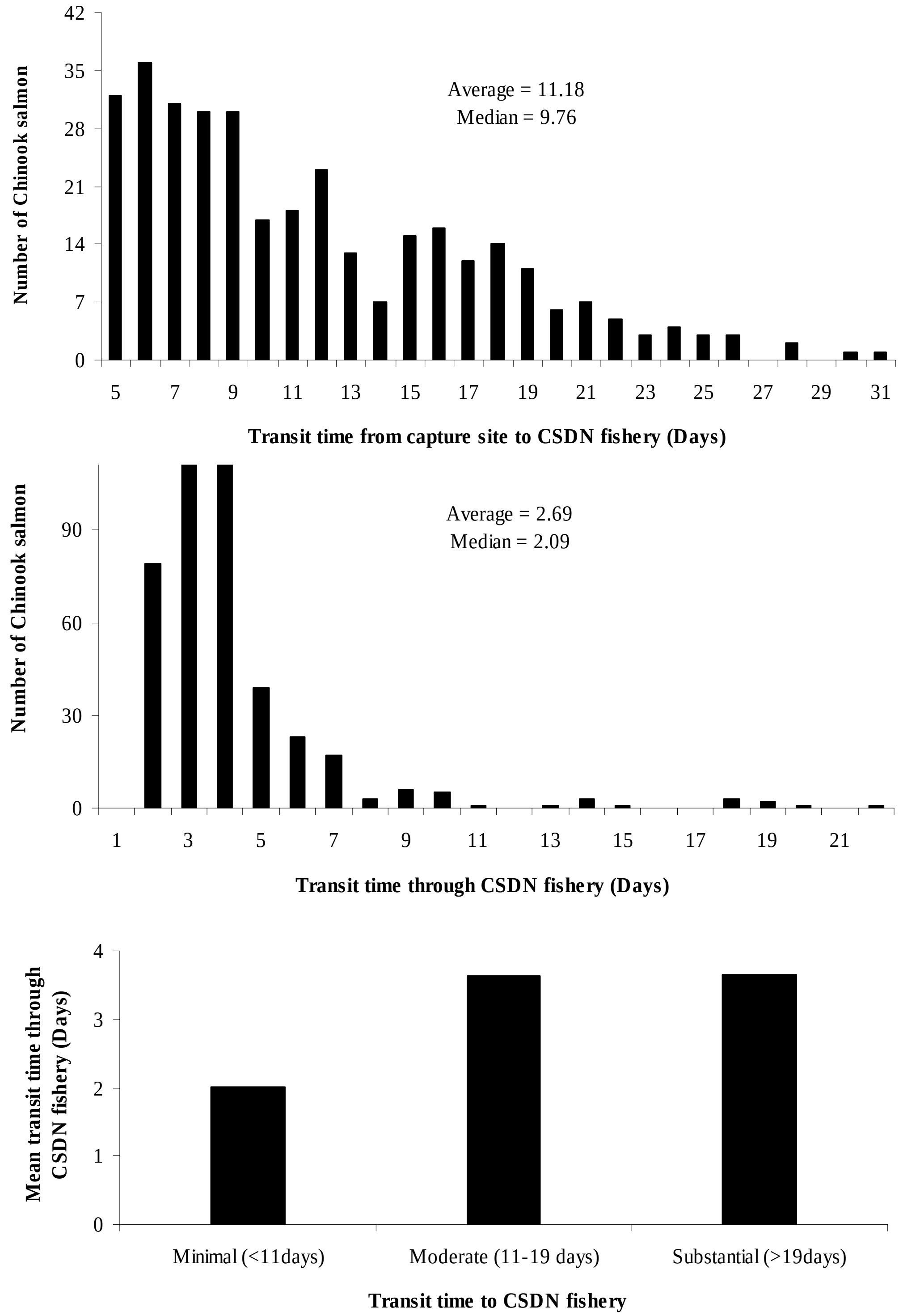

Figure 5.–Migratory times from capture site to the CSDN fishery (top panel), transit times through the CSDN fishery (middle panel), and a comparison of mean transit times through the CSDN fishery of fish that exhibited minimal, moderate, and substantial migratory times (bottom panel) for radio-tagged Chinook salmon in the Copper River, 2003.

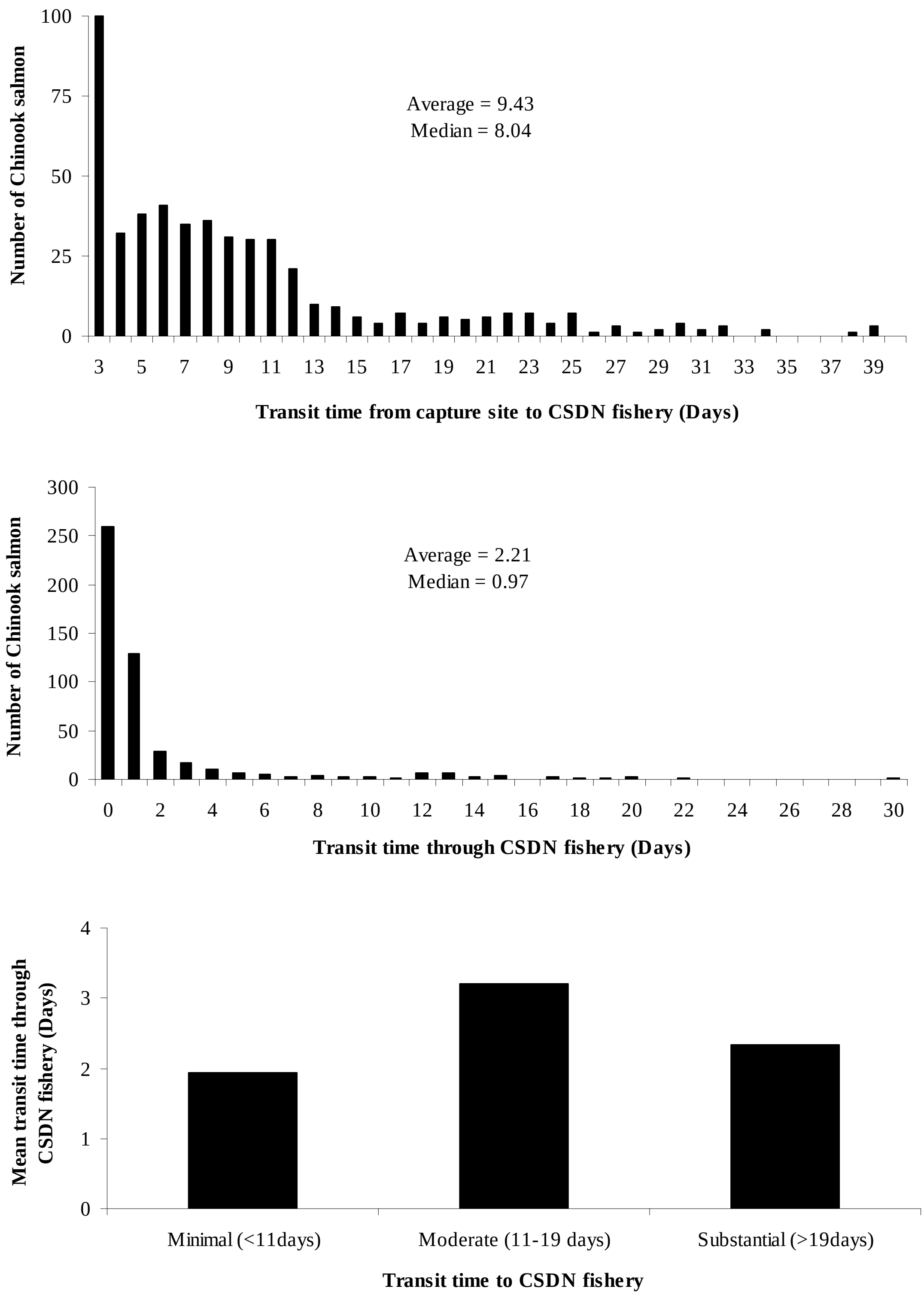

Figure 6.–Migratory times from capture site to the CSDN fishery (top panel), transit times through the CSDN fishery (middle panel), and a comparison of mean transit times through the CSDN fishery of fish that exhibited minimal, moderate, and substantial migratory times (bottom panel) for radio-tagged Chinook salmon in the Copper River, 2004.

Table 3.–Recapture rates for Chinook salmon exhibiting minimal (<11 d), moderate (11-19 d), and substantial (>19 d) time to migrate from capture site into the CSDN fishery after handling, 2002–2004.

	Migratory Time from Capture Site to CSDN Fishery After Handling								
	2002			2003			2004		
Year	< 11 d	11-19 d	> 19 d	< 11 d	11-19 d	> 19 d	< 11 d	11-19 d	> 19 d
Recaptured	**33**	**8**	**3**	**11**	**8**	**3**	**25**	**7**	**7**
Not Recaptured	**311**	**96**	**11**	**183**	**103**	**33**	**318**	**84**	**57**
Total	344	104	14	194	111	36	343	91	64
Recapture Rate[a]	0.11	0.08	0.27	0.06	0.08	0.09	0.08	0.08	0.12

[a] Chi-square tests for heterogeneity in recapture rates for each year were performed for cells with bold numbers (2002: χ^2=2.71; df=2; P=0.26)(2003: χ^2=0.51; df=2; P=0.77)(2004: χ^2=2.01; df=2; P=0.37).

The probability of capture at the Baird Canyon fish wheels varied over time in all years of the study (Table 4). Therefore, equation (2) was used to calculate weights for radio-tagged fish in each period and equation (3) was used to estimate the number of fish tagged on day i with fate j. This estimator provided adjustments based on estimated passage during each period. Estimated passage, rather than CPUE, was preferred for weighting because CPUE may not have varied in proportion to passage due to fluctuations in gear efficiency resulting from changes in river water levels and fish wheel placement.

From 2002–2004, radio-tagged Chinook salmon were located in 32 separate streams within all six major tributaries of the Copper River. The smallest proportion of spawners returned to the Tazlina River and the largest proportion returned to the Chitina River (Figure 7; Table 5).

The proportion of Chinook salmon detected in the nine aerial index streams accounted for 0.46 (SE=0.04) in 2002, 0.34 (SE=0.05) in 2003, and 0.35 (SE=0.04) in 2004 of Chinook salmon in all spawning tributaries (Table 6). The Gulkana River accounted for the largest proportion of spawners in the nine index streams averaging 0.21 from 2002–2004. In addition, mainstem spawners accounted for an average of 0.82 (SE=0.07) of all Chinook salmon in the Tonsina River and 0.55 (SE=0.12) of those in the Klutina River.

RUN TIMING

As with estimates of spawning distribution, weighted observations for individual radio-tagged fish (equations 2 and 3) were used because capture probabilities in the NVE fish wheel study varied significantly by time in each year of the study.

Run-timing patterns at the capture site varied among the individual spawning stocks (Figures 8-10). The mean date of passage at the Baird Canyon fish wheels varied for all Chinook salmon stocks in all 3 years of the study, but individual stocks displayed similar patterns between years (Figures 8-10). In general, migratory timing of Chinook salmon bound for the Gulkana and Upper Copper tributaries arrive earlier than Chinook salmon bound for the Tonsina and Klutina rivers. In addition, Chinook salmon bound for tributaries of the Tonsina and Klutina rivers was earlier than their mainstem spawning counterparts (Tables 7-9).

INRIVER ABUNDANCE

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. From 2002–2004, the majority of radio-tagged fish entering the CSDN fishery migrated through the fishery in less than five days (Figures 4-6). The tracking stations located at the lower end of the CSDN fishery detected approximately 65% of the radio-tagged fish within 12 days of capture and only 13% required 19 days or more (Figures 4-6). Furthermore, recapture rates were independent of the amount of time fish took to migrate upstream (Table 3).

There was no tag loss or natural mortality between the first and second samples. Of the 462-500 radio-tagged Chinook salmon, 36 (2002), 32 (2003), and 36 (2004) were removed from the analysis because they never entered the CSDN fishery. The remaining radio-tagged fish either successfully migrated through, or were harvested in the CSDN fishery (Table 2).

Table 4.–Contingency table analysis comparing marked:unmarked ratios in the second event of the NVE fish wheel mark-recapture study.

	Period of Recapture							
Year	2002		2003		2004			
Period of Marking	26 May – 25 June	26 June – 1 August	15 May – 6 June	7 June – 12 July	28 May – 6 June	7 June – 15 June	16 June – 6 July	7 July – 21 July
2002								
22 May-11 June	1	0						
12 June- 12 July	0	15						
2003								
17 May- 3 June			5	7				
4 June-1 July			1	84				
2004								
22 May–29 May					26	8	2	0
30 May-4 June					5	37	20	2
5 June–11 June					0	14	39	3
12 June-22 June					0	0	17	12
Marked (Total)	**1**	**15**	**6**	**91**	**31**	**59**	**78**	**17**
Unmarked	**305**	**275**	**461**	**1,072**	**1,510**	**646**	**590**	**170**
Marked: Unmarked	<0.01	0.05	0.01	0.08	0.02	0.09	0.13	0.10
Total Examined	306	290	467	1,163	1,541	705	668	187

Note: Chi-square tests for heterogeneity in marked:unmarked ratios were performed for cells with bold numbers for all years (2002: χ^2=16.00; df=1; P<0.01) (2003: χ^2=25.46; df=1; P<0.01), and (2004: χ^2=92.29; df=3; P<0.01).

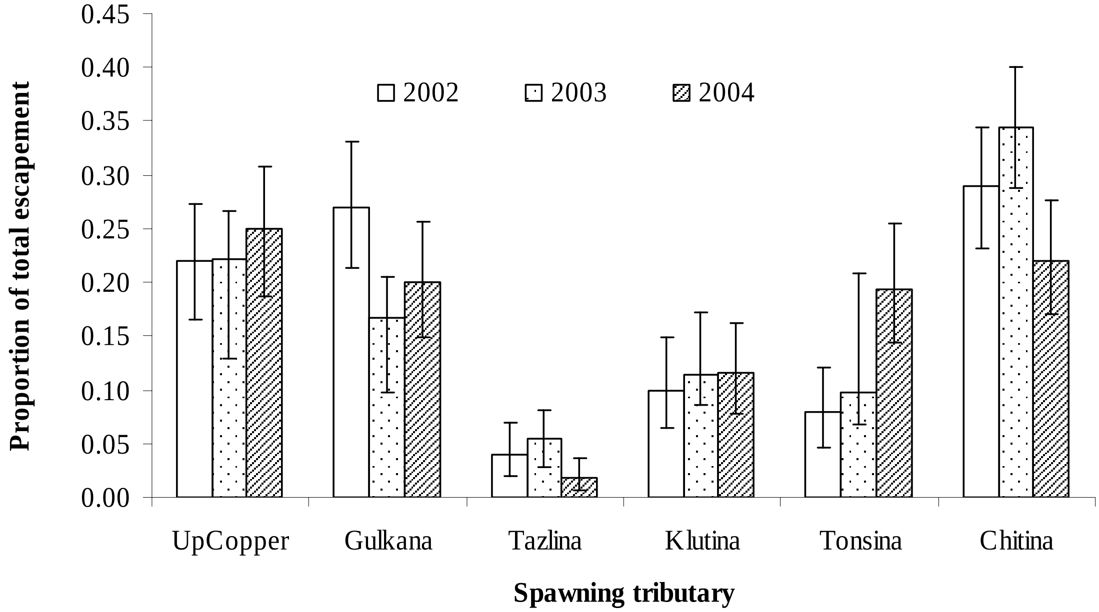

Figure 7.–Spawning distribution and 95% confidence intervals of Copper River Chinook salmon by major drainage, 2002–2004.

Table 5.–Spawning distribution of Copper River Chinook salmon by major drainage, 2002–2004.

	2002		2003		2004	
Spawning Tributary	Proportion	SE	Proportion	SE	Proportion	SE
UpCopper	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 6.–Proportions of Chinook salmon located in nine aerial survey index streams in the Copper River drainage, 2002–2004.

	2002		2003		2004	
Spawning Stream	Proportion	SE	Proportion	SE	Proportion	SE
Gulkana River	0.27	0.04	0.17	0.03	0.20	0.03
E. Fork Chistochina River	0.05	0.02	0.05	0.02	0.06	0.02
Manker Creek	0.05	0.02	0.04	0.02	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	0.03	0.01
Greyling Creek	0.01	0.01	0.00	<0.01	<0.01	<0.01
Indian Creek	0.02	0.01	0.02	0.01	0.01	<0.01
Kiana Creek	0.02	0.01	0.01	0.01	<0.01	<0.01
Mendeltna Creek	0.02	0.01	0.04	0.01	<0.01	<0.01
Total in Index Streams	**0.46**	**0.04**	**0.34**	**0.05**	**0.35**	**0.04**

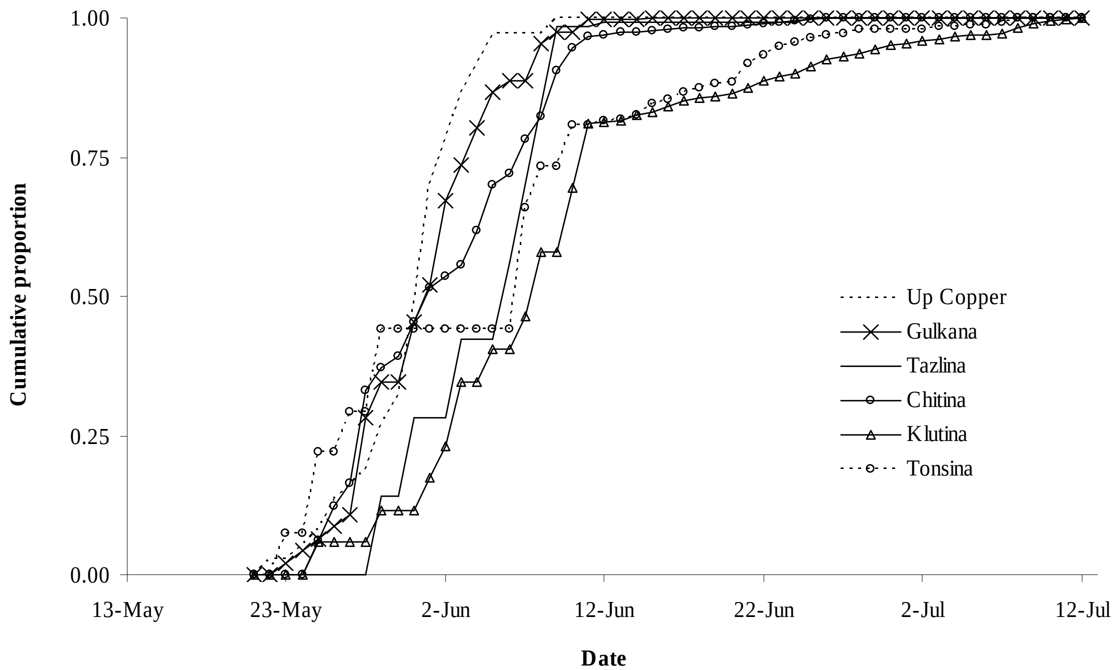

Figure 8.–Run-timing patterns of Chinook salmon at the capture site for the major stocks in the Copper River, 2002.

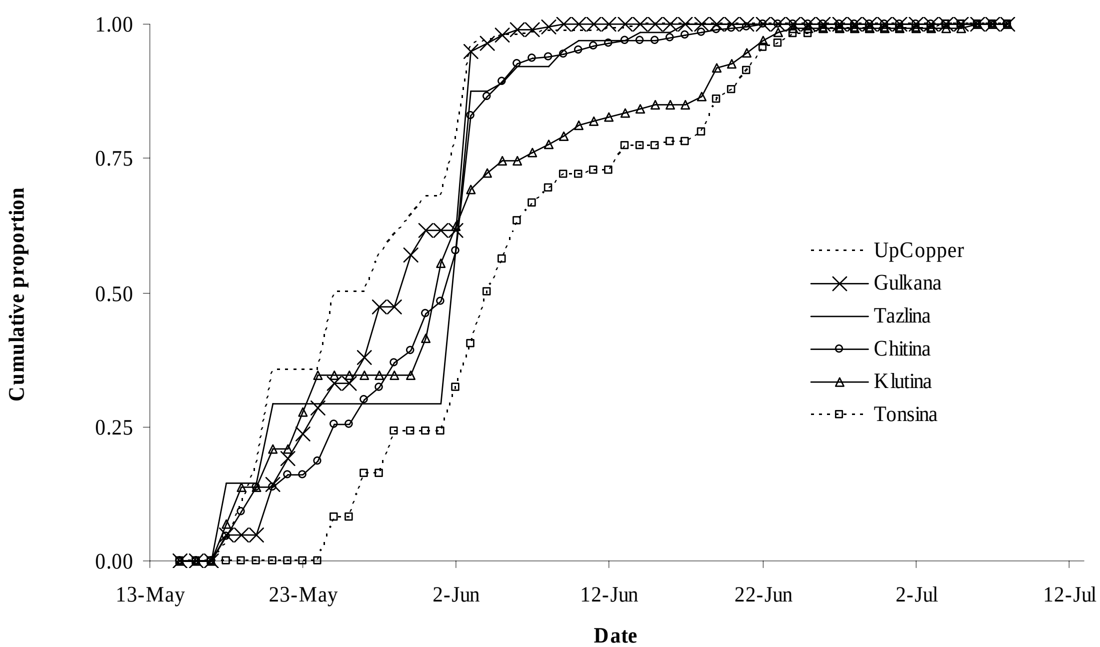

Figure 9.–Run-timing patterns of Chinook salmon at the capture site for the major stocks in the Copper River, 2003.

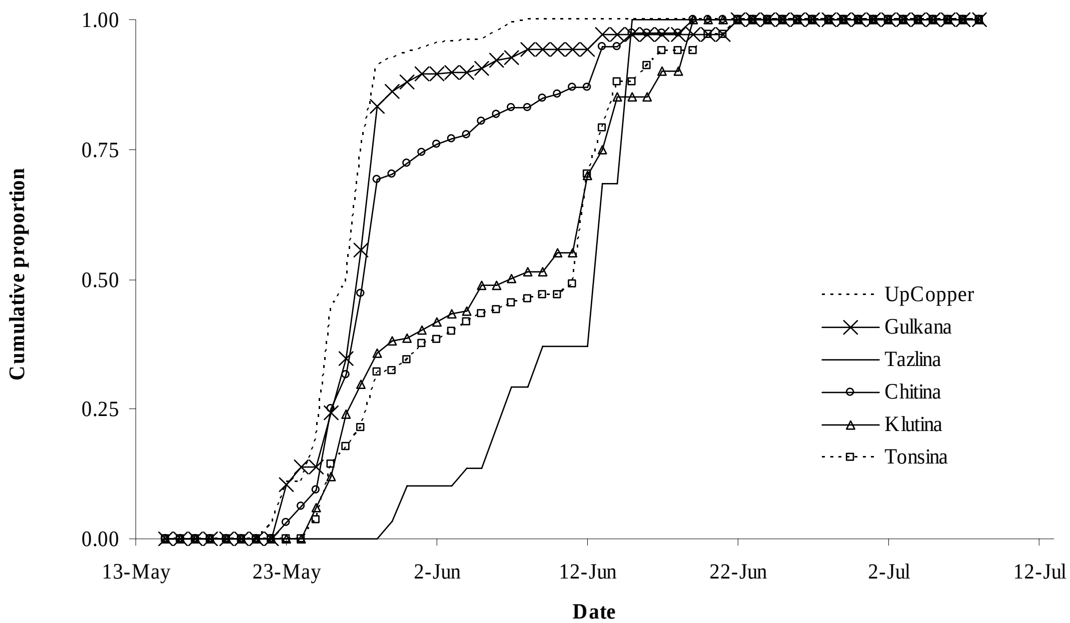

Figure 10.–Run-timing patterns of Chinook salmon at the capture site for the major stocks in the Copper River, 2004.

Table 7.–Statistics regarding the run 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

Table 8.–Statistics regarding the run timing past the capture site in Baird Canyon of the major Chinook salmon spawning stocks in the Copper River, 2003.

Spawning Stock	Duration (No. of Days)	Mean Date of Passage ($\bar{t}$)	SE ($\bar{t}$)
Upper Copper River	5/18-6/14 (27)	5/26	6.1
Gulkana River	5/18-6/09 (22)	5/28	5.5
Chitina River	5/18-6/22 (35)	5/30	6.8
Tazlina River	5/18-6/17 (30)	5/30	7.5
Tonsina River (All)	5/25-7/04 (40)	6/06	9.2
Mainstem	5/25-7/04 (40)	6/09	9.4
Tributaries	5/27-6/08 (12)	5/31	3.6
Klutina River (All)	5/18-7/06 (49)	6/01	10.8
Mainstem	5/23-7/06 (44)	6/06	11.7
Tributaries	5/18-6/10 (23)	5/27	7.0

Table 9.–Statistics regarding the run timing past the capture site in Baird Canyon of the major Chinook salmon spawning stocks in the Copper River, 2004.

Spawning Stock	Duration (No. of Days)	Mean Date of Passage ($\bar{t}$)	SE ($\bar{t}$)
Upper Copper River	5/22-6/08 (17)	5/27	3.02
Gulkana River	5/23-6/22 (30)	5/29	5.75
Chitina River	5/23-6/19 (27)	5/31	6.82
Tazlina River	5/30-6/15 (16)	6/10	4.94
Tonsina River (All)	5/25-6/22 (28)	6/06	8.45
Mainstem	5/25-6/20 (26)	6/08	7.55
Tributaries	5/26-6/22 (27)	6/02	9.11
Klutina River (All)	5/25-6/13 (19)	6/06	8.74
Mainstem	5/27-6/19 (23)	6/10	6.74
Tributaries	5/25-6/05 (11)	5/27	2.62

Movements of radio-tagged fish between banks in the NVE mark-recapture study indicated that marked fish mixed with unmarked fish between sampling events (Smith 2005). The NVE data were used to evaluate this assumption because bank of capture information was generally lacking from fish harvested in the CSDN fishery (recovery event for this experiment). In the NVE study, Chinook salmon were radio-tagged and released from both banks and examined for marks from both banks very near the fishery, so contingency tests comparing recapture rates and movements between the east and west banks could be performed and were appropriate for making inferences for this study.

In all 3 years of the study, the probability of a Chinook salmon being recaptured was not significantly influenced by its gender or size because recapture rates between males and females and small (590-699 mm) and large (700-1150 mm) fish in the CSDN fishery were similar (Table 10). In addition, cumulative length frequency distributions of fish marked during the first event and fish recaptured during the second event in the CSDN fishery were not significantly different (D=0.16; P=0.29 in 2002: D=0.10; P=0.70 in 2003; and D=0.16; P=0.26 in 2004; Figures 11-13). Results of these tests indicated that stratification of the data by size or sex was not warranted and data from both events could be pooled to estimate composition proportions.

Table 10.–Number of radio-tagged Chinook salmon captured in the CSDN fishery by size and gender, 2002–2004.

	Year					
	2002		2003		2004	
Large vs. Small Fish[a]	Small	Large	Small	Large	Small	Large
Recaptured	1	25	0	47	3	36
Not recaptured	37	391	6	400	30	427
Male vs. Female	Male	Female	Male	Female	Male	Female
Recaptured	10	13	17	28	21	18
Not recaptured	104	260	140	255	217	227
P-Value						
Large vs. Small	0.25		0.41		0.79	
Male vs. Female	0.37		0.74		0.55	

[a] Small fish were <570-699 mm and large fish were > 700-1,150 mm.

The probability of a Chinook salmon being captured did not significantly vary over time in 2002 during either event, but did vary over time in at least one event in 2003 and 2004. Marked to unmarked ratios in the recapture event were similar among periods in 2002 (χ^2=6.70; df=7; P=0.46; Table 11) and 2004 (χ^2 =5.71; df=2; P=0.06; Table 13) but were significant in 2003 (χ^2 =8.67; df=3; P=0.03; Table 12). Recapture rates were not significantly different between tagging periods in 2002 (χ^2 =5.82; df=5; P=0.32; Table 11) but were significant in 2003 (χ^2 =11.12; df=3; P=0.01; Table 12) and 2004 (χ^2 =7.24; df=2; P=0.03; Table 13).

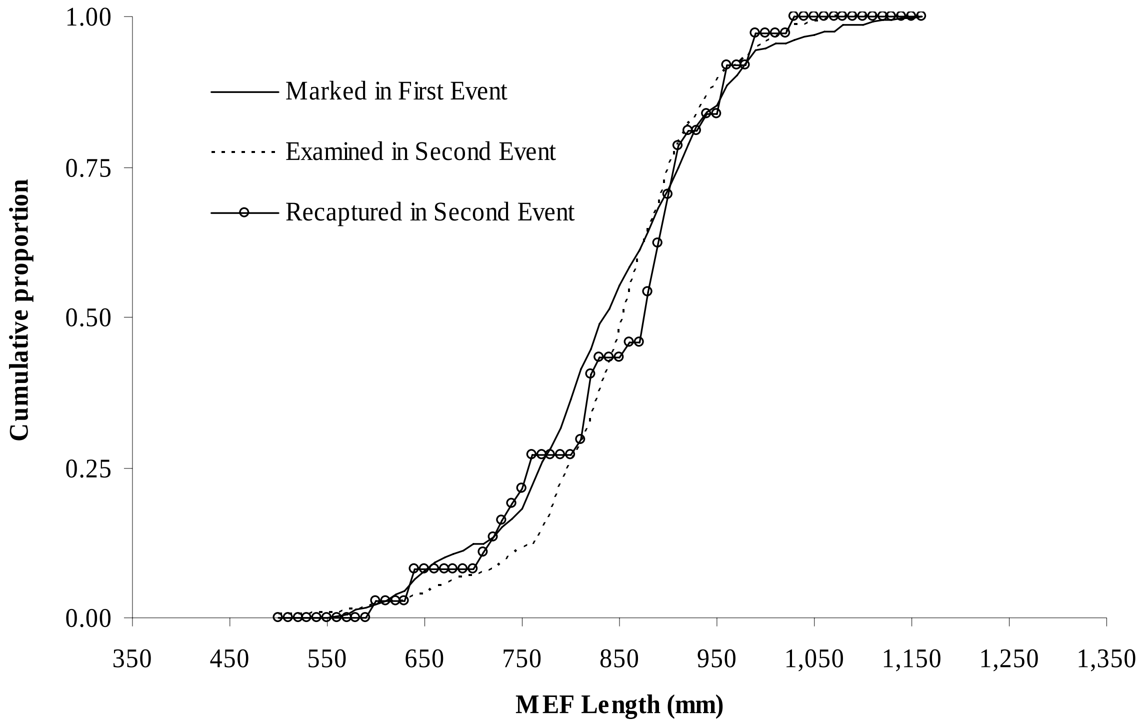

Figure 11.–Cumulative length frequency distributions of all fish marked with radio tags during the first event, all fish examined in the second event, and all radio-tagged fish recaptured during the second event, 2002.

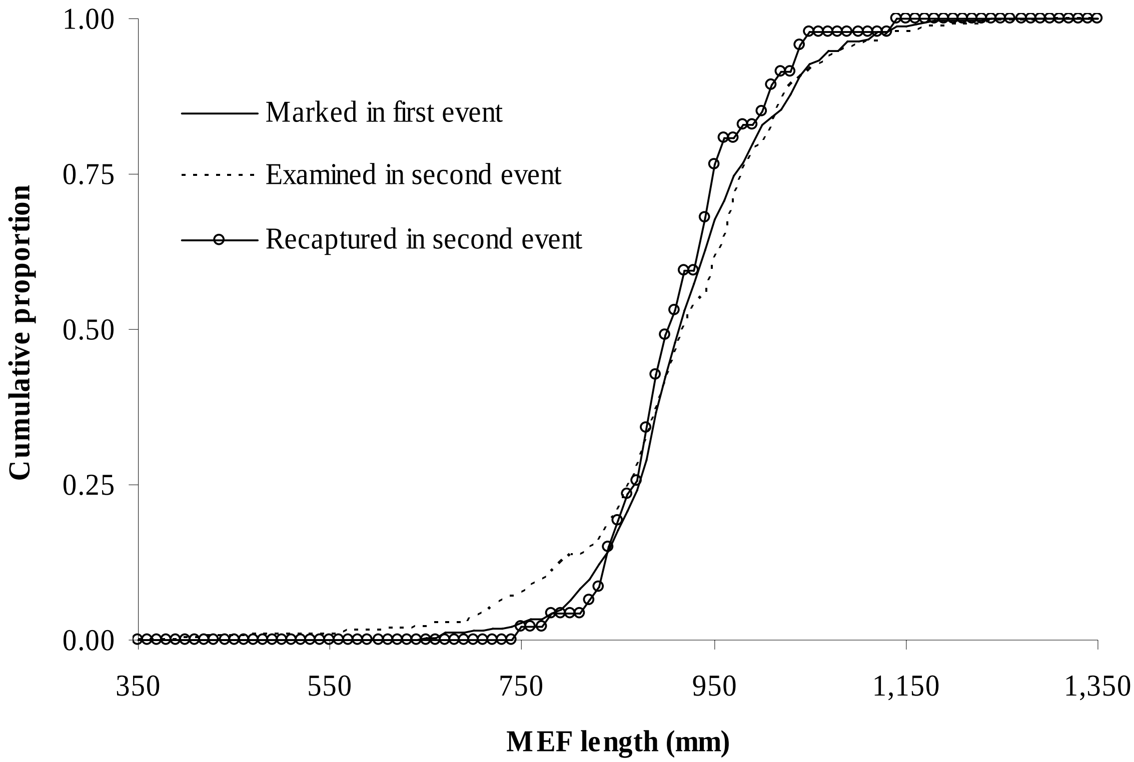

Figure 12.–Cumulative length frequency distributions of all fish marked with radio tags during the first event, all fish examined in the second event, and all radio-tagged fish recaptured during the second event, 2003.

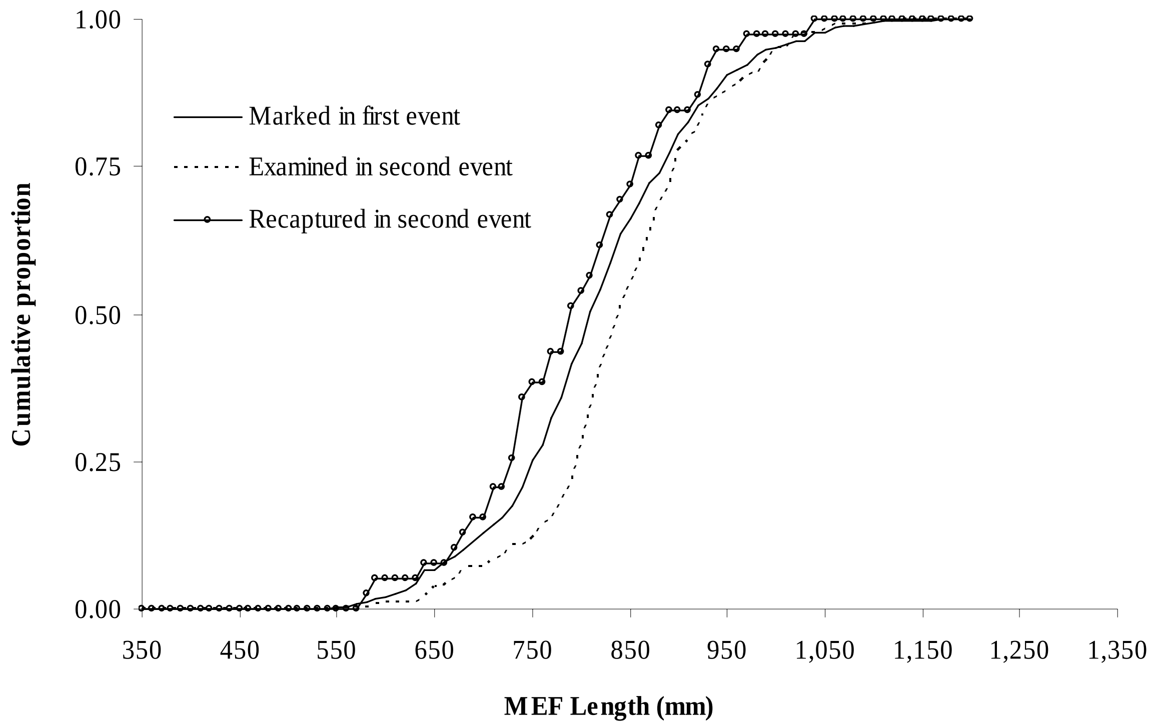

Figure 13.–Cumulative length frequency distributions of all fish marked with radio tags during the first event, all fish examined in the second event, and all radio-tagged fish recaptured during the second event, 2004.

Table 11.–Contingency table analyses comparing marked:unmarked and recaptured:not recaptured ratios for radio-tagged Chinook salmon, 2002.

Test for Equal Marked:Unmarked Proportions in the Second Event

Period	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	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

Table 12.–Contingency table analyses comparing marked:unmarked and recaptured:not recaptured ratios for radio-tagged Chinook salmon, 2003.

Test for Equal Marked: Unmarked Proportions in the Second Event

Period	June 4- June14	June 15- June 21	June 22- July 5	July 6- Sept. 30
Marked	3	13	10	8
Unmarked	340	317	640	572
Marked:Unmarked	0.01	0.04	0.02	0.01

χ^2 =8.67; df=3; P=0.03

Test for Complete Mixing between the First and Second Events

Period	June 4- June14	June 15- June 21	June 22- July 5	July 6- Sept. 30
Recaptured	4	16	9	5
Not Recaptured	90	102	155	40
Recapture Rate	0.04	0.14	0.05	0.11

χ^2 =11.12; df=3; P=0.01

Table 13.–Contingency table analyses comparing marked:unmarked and recaptured:not recaptured ratios for radio-tagged Chinook salmon, 2004.

Test for Equal Marked: Unmarked Proportions in the Second Event

Period	May 30- June 12	June 13- July 10	July 11- Sept. 30
Marked	7	26	6
Unmarked	592	1,172	692
Marked:Unmarked	0.01	0.02	0.01
		χ^2 =5.71; df=2; P=0.06	

Test for Complete Mixing between the First and Second Events

Period	May 30- June 5	June 6- July 10	July 11- Sept. 30
Recaptured	2	32	5
Not Recaptured	77	309	22
Recapture Rate	0.03	0.10	0.23
		χ^2 =7.24; df=2; P=0.03	

Estimator

In 2002, 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 estimated inriver abundance was 30,809 (SE=5,590) Chinook salmon ≥ 620 mm MEF for the period 8 June-30 September. A Bayesian analysis using the relationship between abundance and CPUE during the first sampling event accounted for the proportion of the run that passed prior to the opening of the CSDN fishery on 8 June. 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 30 September was 32,873 (SE=8,863) Chinook salmon ≥ 620 mm MEF.

In 2003, a partially stratified estimator (Darroch 1961) was used to estimate inriver abundance of Chinook salmon because the probability of Chinook salmon being marked and recaptured was dependent on their time of capture and entry into the CSDN fishery. The estimated inriver abundance was 29,662 (SE=7,327) Chinook salmon ≥ 620 mm MEF for the period 4 June-30 September. As in 2002, the 2003 estimate was expanded based on the relationship between abundance and CPUE during the first event. The estimated proportion of the total run that migrated through the fishery from 4 June to 30 September was 0.90 (SE=0.42). Therefore, total estimated abundance entering the CSDN fishery was 33,488 (SE=8,389) Chinook salmon ≥ 620 mm MEF.

In 2004, a partially stratified estimator (Darroch 1961) was also used to estimate inriver abundance of Chinook salmon because the probability of Chinook salmon being recaptured was dependent on their entry into the CSDN fishery. The estimated inriver abundance in 2004 was 33,793 (SE=11,038) Chinook salmon ≥ 620 mm MEF for the period 22 May-30 September. In contrast to the previous years, the abundance estimate was not expanded because effectively the entire run was available to the CSDN fishery.

DISCUSSION

EFFECTS OF CAPTURE AND TAGGING

The parameters in this study were estimated making the assumptions that the population was tagged in a representative manner and that capture and tagging did not alter the fish's behavior. The effects of inserting radio tags into Chinook salmon on survival, migratory behavior, and catchability, however, are not fully understood. The proportion of radio-tagged Chinook salmon that failed to migrate upstream was 8% (n=36) in 2002, 6% (n=32) in 2003, and 7% (n=36) in 2004 (Savereide 2003, 2004). 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 can be explored further. Handling effect was examined in this study by comparing recapture rates and transit times through the CSDN fishery for radio-tagged fish that exhibited varying migration times from the tagging site to the fishery. The assumption was that migration time 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 dip net fishermen and fish wheels. From 2002–2004, similar recapture rates between fish that exhibited minimal, moderate, and substantial time to migrate between the fish wheels and the fishery, coupled with comparable transit times through the CSDN fishery suggested that any handling-induced changes in migratory behavior did not affect their 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 into the posterior stomach instead of just behind the esophageal sphincter in the anterior stomach. The results in this report stem from radio tags that were placed in the anterior stomach of Chinook salmon. On average, only 10% of the radio-tagged fish that migrated through the CSDN fishery from 2002–2004 that were not known to be harvested were never located in a spawning tributary. While some of these fish may have died as a result of handling prior to entering a spawning stream, some may have been harvested and not reported. The results in this report imply that correctly placed internal radio tags do not negatively affect migratory behavior of Chinook salmon. Because only fish that successfully migrated into spawning streams were used to estimate spawning distribution and run timing, it was likely in this study that the probability that a tagged fish successfully migrated to a spawning stream did not vary by spawning stock.

Other Alaskan investigators have cautioned that fish wheel capture of Pacific salmon could impair their migratory fitness (Bromaghin and Underwood 2004). In a similar tagging experiment conducted on the upper Yukon River, the fraction of tagged chum salmon (*O. keta*) precipitously declined with distance from the marking site, in both the mainstem Yukon River and in spawning tributaries. The investigators attributed this result to both the effects of holding fish in a live box after tagging, and the rigors of fish wheel capture. While there are several key dissimilarities between the Copper River and Yukon studies (different species, Copper River Chinook salmon were not held in a live box after tagging); this is a valid concern, especially since the travel distances from the capture site to spawning tributaries is similar between the studies. While the fraction of tagged Chinook salmon was not measured with distance as in the Yukon study, the use of radio tags did provide a direct measure of the survival of tagged fish.(Table 2). Ninety three percent of all tagged fish entered the CSDN fishery, and some of the 7% that did not were due to radio failure. Seventy two percent of all tagged fish that migrated through the CSDN fishery survived to spawning locations. Sport fisheries in the Copper River basin occur in tributary streams near spawning locations, and inclusion of sport-caught tagged Chinook salmon increases the estimate of tagging survival past the CSDN fishery to 78%. Only 134 or 11% of tagged Chinook salmon that migrated through the CSDN fishery were classified as Upstream Migrants, which we assumed were mortalities, unreported harvest, or radio tag losses. Given the rigors of migration up the Copper River and the likelihood of some natural mortality, we concluded that fish wheel capture did not significantly impair the fitness of Copper River Chinook salmon.

SPAWNING DISTRIBUTION

It is important to report that the 2002 spawning distribution estimates presented in Savereide (2003) have changed because the 2003 radio tag weighting procedure described in equations (1) and (2) was applied to data from 2002. The diagnostic tests from 2002 indicated that there were no significant differences in the marked to unmarked ratios of Chinook salmon in the second event (Savereide 2003). However, these tests used temporal harvest information from the CSDN fishery, which were determined from the voluntary return of harvest permits that in many instances did not provide date of capture information. The NVE mark-recapture data (Smith 2004; FIS01-020) provided more accurate and precise estimates of capture probabilities over time and indicated that a weighting scheme based on relative passage was appropriate. In addition, information from a Chinook salmon counting tower on the Gulkana River in 2002 suggested the proportion estimate for the Gulkana River may have been biased low. In 2003, the new weighting procedure was developed incorporating information from the second event of the NVE fish wheel study. When fishing effort and the tagging rate are relatively stable this weighting procedure provides a better representation of the spawning distribution because it incorporates the variable catchability of migrating fish. The only caveat is that the period estimates of salmon abundance past the tagging site in 2002 were based on sporadic recapture information. This problem was remedied in 2003 with the addition of a second recapture fish wheel.

The distribution of spawning Chinook salmon was similar in all 3 years of the project (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 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 Klutina River, which exhibits both early and late runs of Chinook salmon, was also consistent with very little annual variation. In contrast, the Tonsina River, which also displays early and late runs of Chinook salmon, along with the Chitina and Gulkana rivers exhibited 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.

The spawning distribution of Chinook salmon in the Copper River drainage from 2002 –2004 indicated that the nine spawning streams that are aerial surveyed annually for an index of escapement represent a sizeable proportion of the total drainage-wide escapement. Previous studies have determined the estimated proportion to be as high as 40% in 1999 (Evenson and Wuttig 2000) and low as 26% in 2000 (Wuttig and Evenson 2001). Chinook salmon located in the nine index streams accounted for 46% (2002), 34% (2003), and 35% (2004) of all spawning fish in the Copper River drainage. The largest contributor to the aerial index count was the Gulkana River, which accounted for 59% of the escapement in the nine index streams in 2002, 48% in 2003, and 58% in 2004. However, escapement in the Gulkana River represented only 27%, 17%, and 20% respectively, of the total 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.

RUN TIMING

In all 3 years of the project, 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 the river first 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.

One characteristic shared by the Chinook salmon stocks in the Tonsina and Klutina rivers was the different run timings of mainstem and tributary spawners. In all 3 years, tributary spawners were the first to arrive inriver at the capture site and mainstem spawners arrived a measurable time later (Tables 7-9). In addition, mainstem spawners accounted for 59% in 2002, 69% in 2003, and 79% in 2004 of all spawning Chinook salmon in both rivers. These run-timing patterns were also noted in all previous year's of this study and are analogous to the early and late-run Chinook salmon stocks of the Kenai River. Burger et al. (1985) suggested that Kenai and Skilak lakes contribute to increased 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.

ABUNDANCE

In 2002, Chapman's modified Petersen two-sample model (Seber 1982) was used to estimate Chinook salmon inriver abundance at the point of entry into the CSDN fishery. In contrast, a partially stratified mark-recapture model (Darroch 1961) was used in 2003 and 2004 to estimate the abundance of Chinook salmon. 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 in all 3 years of the study (approximately 84%) suggested that the unreported harvest was negligible.

Illegal harvest in the CSDN fishery, defined as harvest without a permit or harvest of more than one Chinook salmon per 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.

Failure to detect radio-tagged Chinook salmon (legally) 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 at O'Brien Creek were able to detect 99% in 2003 and 97% in 2004 of the radio-tagged fish that entered and exited the fishery. In 2002, a problem with the radiotelemetry software limited our ability to detect radio-tagged fish entering and exiting the fishery but this was resolved when the software was replaced.

CSDN fishers that selected for radio-tagged Chinook salmon or removed and returned 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 in the harvest would be larger than the marked to unmarked ratio in the population. Selection for radio-tagged Chinook salmon was assumed negligible because there was no reward offered for returned tags and gray-colored spaghetti tags were used that were difficult to detect while dip-netting fish. 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.

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 CSDN fishery cannot open before 1 June), a portion of the early run typically had already migrated through the study area.

In addition to the potential sources of bias previously discussed, the results of the NVE fish wheel study (FIS01-020) suggest that this study's inriver abundance estimate could be biased low. Smith (2004) reported a 2003 inriver abundance estimate of 44,764 Chinook salmon (SE=12,385) and the 2003 abundance estimate generated in this report was 33,488 (SE=8,389). Even though these estimates are not statistically different (due to overlapping confidence intervals), the results of the NVE study (Smith 2004) and it's design suggest the abundance estimates in this report are biased low. The NVE study design eliminated any bias caused from illegal harvest, misreported harvest, unreported harvest, and/or tag selection by conducting their own second capture event. In addition, Smith (2004) found that the probability of a Chinook salmon being captured and tagged in late May and early June (the period prior to the opening of the fishery) was substantially less than later on during the run. This implies that using the relationship between CPUE and abundance during the period of the fishery to expand for the portion of the run prior to the fishery yields an expanded abundance estimate that is biased low because the relationship changed as the run progressed. The rising water levels during break-up may explain this change in catchability because fish wheel catches tend to be stronger during periods of stable or dropping water levels.

In 2002 and 2003, the CSDN fishery opened on 8 June and 4 June respectively. To estimate abundance for the period prior to the fishery opening, the mark-recapture estimate of abundance for the period during the fishery was expanded by the proportion of the total run it represented. Therefore, the CSDN harvest was used to estimate abundance for an estimated 94% (2002) and 90% (2003) of the total run. The relationship between periodic estimates of CPUE in the marking event and their corresponding estimates of abundance were used to estimate the proportion of the total run represented by the abundance estimate.

In 2004, the CSDN fishery opened on 1 June and continued with relatively few closures thereafter. In contrast to previous years, the estimate of abundance was not expanded based on the relationship between abundance and CPUE. An important assumption in two-event mark-recapture experiments is that all fish must have an equal probability of being marked and recaptured. In 2002 and 2003, this assumption was grossly violated and the abundance estimate only applied to the portion of the run that was available for recapture, which coincided with when the CSDN fishery was open. In 2004, not all of the 79 Chinook salmon that were radio-tagged before the CSDN fishery opened (22 May to 30 May) remained in the CSDN fishery long enough to be vulnerable for recapture. However, with the exception of one fish radio-tagged on 22 May that made it through the CSDN fishery prior to opening, at least 50% of the fish radio-tagged on each day from 23 May to 27 May and all of the fish tagged from 28 May to 30 May were available for recapture in the CSDN fishery.

Diagnostic tests on this group of 79 Chinook salmon were used to determine if there was a difference in the probability of recapture between fish radio-tagged early (22 May-27 May) and late (28 May-30 May). Out of 49 Chinook salmon radio-tagged during 22 May and 27 May, 2 were recaptured, 31 were vulnerable to recapture, and 18 migrated through the CSDN fishery before it opened. All 30 Chinook salmon radio-tagged during 28 May and 30 May were available for recapture but none were recaptured. The probability of recapture for these two groups was not significantly different ($\chi^2 = 1.26$; df=1; P=0.26). Because the data used in the Darroch estimator isolates all of the Chinook salmon radio-tagged before the CSDN fishery opened into their own marking temporal strata, there is little potential for biologically significant bias in the estimate of abundance. Furthermore, because at least 50% of the Chinook salmon radio-tagged had some probability of recapture during the second event, after discounting the one fish tagged on 22 May, there is no substantial evidence to establish a clear line by date of capture between Chinook salmon with significant non-zero probabilities of recapture and those with virtually zero probability of recapture.

CONCLUSIONS

This project was successful in meeting all project objectives from 2002–2004.

Estimates of stock-specific run-timing patterns over the span of this study (2002–2004) have indicated that although there is considerable overlap in run timing among stocks, there has been a consistent pattern of passage through Baird Canyon where upriver stocks tend to pass early and lower stocks tend to pass late.

Estimates of spawning distribution have shown that proportions of the total drainage escapement spawning in the six major drainages have remained relatively consistent over the span of the study with the Gulkana, Tonsina, and Chitina stocks showing the most variability. The variability in spawning proportions may, in part, be explained by varying levels of exploitation in the commercial and inriver fisheries.

The modification of the procedure for estimating spawning distribution and run timing by weighting radio tags based on estimated probabilities of capture by time from the NVE mark-recapture study provided improved estimates.

Evidence suggests the estimates of total inriver abundance for 2002 and 2003 may be biased low as a result of the expansion of the mark-recapture estimate to account for the fraction of the run that passed prior to the opening of the fishery. The expansion was based on the assumption that catchability remained constant throughout the run. However, data from the NVE mark-recapture study suggested that catchability during the early part of the run was lower than during the period of the mark-recapture study.

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; and,
2. Studies that estimate the exploitation rates of the major spawning stocks.

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