Fishery Data Series No. 04-30

Inriver Abundance of Chinook Salmon in the Kuskokwim River, 2003

by

Lisa Stuby

December 2004

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 REPORT NO. 04-30

INRIVER ABUNDANCE OF CHINOOK SALMON IN THE KUSKOKWIM RIVER, 2003

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The Division of Sport Fish Fishery Data Series was established in 1987 for the publication of technically oriented results for a single project or group of closely related projects. Since 2004, the Division of Commercial Fisheries has also used the Fishery Data Series. Fishery Data Series reports are intended for fishery and other technical professionals. Fishery Data Series reports are available through the Alaska State Library and on the Internet: http://www.sf.adfg.state.ak.us/statewide/divreports/html/intersearch.cfm This publication has undergone editorial and peer review.

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ABSTRACT

A two-sample mark-recapture experiment was conducted for Chinook salmon *Oncorhynchus tshawytscha* in the Kuskokwim River and associated tributaries using radiotelemetry techniques from June to August, 2003. An attempt was made to distribute radio tags over the entire run such that the radio-tagged fish would be representative of the entire run with respect to temporal abundance, size and sex composition, and stock composition. Fish were sampled using drift gillnets and fish wheels at various locations between Kalskag and the Aniak River. Chinook salmon that were radio-tagged constituted the marked sample for the first event. For the second event, fish were counted at four weirs on tributaries of the Kuskokwim River. Radio-tagged Chinook salmon that swam past the weirs and were recorded by stationary tracking stations constituted the recaptured portion. Three hundred sixty-five fish were marked and migrated above the Aniak River, 13,646 salmon ≥450 mm MEF were estimated to pass through the four weirs, and 55 radio-tagged fish passed through the weirs when they were operational. The estimate of abundance for Chinook salmon ≥450 mm MEF for the Kuskokwim River upstream of the Aniak River was 103,161 fish (SE = 18,720). The majority of radio-tagged Chinook salmon entered the Holitna and Aniak rivers. Chinook salmon were captured from 2 June-30 July, and 50% of the run had passed the tagging site by 26 June. Run-timing at the capture site was similar for the various Kuskokwim River Chinook salmon stocks in 2003.

Key words: aerial survey Aniak River, abundance estimate, Chinook salmon, Holitna River, king salmon, Kuskokwim River, mark-recapture, *Oncorhynchus tshawytscha*, radiotelemetry, tracking stations

INTRODUCTION

The Kuskokwim River drains a remote basin of about 130,000 km^2 along its 1,130-km course from the interior of Alaska to the Bering Sea. The Kuskokwim River supports five species of Pacific salmon, one of the largest subsistence fisheries in the state, commercial fisheries, and a growing sport fishery. Kuskokwim River subsistence users accounted for about a third (34%) of the total salmon harvest throughout the Kuskokwim River area in 2000 and a majority of the Chinook salmon harvest (Burkey et al. 2001). The 10-year average subsistence harvest (1992 - 2001) of 79,459 Chinook salmon far exceeded the average incidental commercial harvest of 14,312 fish (Ward et al. 2003). The directed commercial Chinook salmon *Oncorhynchus tshawytscha* fishery in the mainstem Kuskokwim River was discontinued in 1987 to ensure that subsistence needs would be met. The incidental catch of Chinook salmon in the commercial fishery currently ranks fourth overall behind sockeye *O. nerka*, chum *O. keta,* and coho *O. kisutch* salmon in terms of total harvest and value to the commercial fishers.

The total sport catch, effort, and harvest of Chinook salmon in the upper and middle Kuskokwim River area has been relatively low compared to other portions of the state, and annual harvests have typically represented less than 1% of the total harvest of Chinook salmon in the Kuskokwim River drainage (Table 1). The largest sport fisheries for Chinook salmon occur in the Kisaralik, Kwethluk, Aniak, and Holitna rivers. The 2002 estimated sport harvest of Chinook salmon in the Kuskokwim River drainage including and above the Aniak River was 243 Chinook salmon (Table 1).

Salmon runs in the Kuskokwim River area are managed for sustained yields under policies set forth by the Alaska Board of Fisheries (BOF) with subsistence use receiving the highest priority. Current information is inadequate to manage these salmon runs for maximum sustained yield.

Table 1.–Estimated sport, commercial, and subsistence harvests of Chinook salmon in the Kuskokwim River drainage, 1985 – 2003.

	Sport Harvest[a]								
Year	Aniak River	Holitna River	Upper Kuskokwim River[b]	Lower Kuskokwim River[c]	Total Sport	Commercial[d]	Subsistence[d]	Total Harvest	% Sport Harvest
1985				43	43	37,889	43,874	81,806	0.05%
1986				24	24	19,414	51,019	70,457	0.03%
1987				178	178	36,179	67,325	103,682	0.17%
1988				264	264	55,716	70,943	126,923	0.21%
1989	738			978	978	43,217	81,176	125,371	0.78%
1990	285			340	340	53,504	85,979	139,823	0.24%
1991	214			308	308	37,778	85,554	123,640	0.25%
1992	172	23	55	274	329	46,872	64,795	111,996	0.29%
1993	300	68	85	444	529	8,735	87,512	96,776	0.55%
1994	437	40	108	842	950	16,211	93,242	110,403	0.86%
1995	279	19	169	321	490	30,846	96,436	127,772	0.38%
1996	592	256	288	782	1,070	7,419	78,063	86,552	1.24%
1997	795	166	279	942	1,221	10,441	81,577	93,239	1.31%
1998	1,058	54	174	1,183	1,357	17,359	81,265	99,981	1.36%
1999	134	25	36	243	279	4,705	73,194	78,178	0.36%
2000	10	22	55	40	95	444	64,893	65,432	0.15%
2001	12	73	85	16	101	90	73,610	73,801	0.14%
2002	135	53	108	211	319	72	70,219	75,169	0.42%
2003	NA[e]	NA[e]	NA[e]	NA[e]	NA[e]	150	78,941	NA[e]	NA[e]

[a] Sport fish harvest estimates from Mills (1986-1994), Howe et al. (1995-1996, 2001a-d), Walker et al. (2003), and Jennings et al. (*In prep a-b*).

[b] Upper Kuskokwim River sport harvest estimates are upriver from the Aniak River, but do not include the Aniak River.

[c] Lower Kuskokwim river sport harvest estimates are downriver from the Aniak River and include the Aniak River.

[d] Commercial and subsistence harvest estimates from Burkey et al. (2002), Ward et al. (2003), and Whitmore and Bergstrom (2003).

[e] Sport harvest estimates not available.

Management and assessment of the commercial and subsistence fisheries is conducted both in season and post-season. Inseason management relies on run-strength indices from commercial catch data, test fisheries, and reports from subsistence fishers. The effectiveness of inseason management has been evaluated with aerial surveys and ground-based projects. However, the size, remoteness, and geographic diversity of the Kuskokwim River have presented challenges to monitoring salmon escapements and assessing run strength. Ground-based projects such as weirs, counting towers, and sonar have only recently been operated in some locations and provide limited information. Aerial spawning-ground surveys have been the least costly means of monitoring salmon escapements, but their usefulness is limited because of a high degree of variability due to inconsistent weather, water conditions and varying staff experience (Burkey et al. 1999). Moreover, the aerial surveys are primarily conducted in the lower Kuskokwim River because the middle and upper river tributaries are generally tannic-stained or glacially-occluded.

The 2001 Kuskokwim area Chinook salmon subsistence harvest increased over the relatively poor harvest in 2000. However, when compared to the 10-year period of 1990 – 1999, the 2001 Chinook salmon subsistence harvest was 11% below average (Burkey et al. 2002). The 2002 Chinook salmon subsistence harvest was similar to that from 2001 (Ward et al. 2003). In addition to the recent decrease in subsistence harvests, Kuskokwim area Chinook salmon have shown declining escapements. The lowest escapements on record were in 1998, 1999, and 2000 with the 2000 Chinook salmon run having the lowest escapement on record. As a result of the recent low harvests and escapements, federal subsistence funds became available in 2001 to assist in escapement evaluation in the Kuskokwim River (Lafferty 2002). In September 2002, the BOF designated Kuskokwim River Chinook and chum salmon stocks of concern under the regulatory *Policy for the Management of Sustainable Salmon Fisheries* (AAC 2001; Molyneaux 2002).

As a result of persistent low escapements, a long-term research program was proposed to examine changes in salmon productivity and the effects on the people who live and utilize this resource along the Kuskokwim River (Merritt 2001). A congressional appropriation in 1998 for salmon research in the Kuskokwim River (Western Alaska Disaster Funds) proposed long term research to: (1) understand stock productivity; (2) evaluate the appropriateness of current management policies and escapement goals during times of low productivity; (3) implement abundance-based management regimes; and, (4) improve preseason forecasts of abundance for industry planning and establishing quotas. Allocation of these funds was contingent on the evaluation of research needs for the Kuskokwim River through a strategic planning exercise using the Analytic Hierarchy Process (Saaty 1990). The primary results of the strategic planning exercise were recommendations to acquire more information on spawning escapement throughout the Kuskokwim River drainage and examine stock specific run timing and exploitation (Merritt 2001).

The strategic planning exercise and infusion of funds resulted in the design of a three-year project to expand current escapement monitoring activities on the Kogrukluk River by estimating the proportion of Holitna River Chinook, chum, and coho salmon that pass the Kogrukluk River weir and subsequently estimating drainage-wide escapement by proportional expansion of the weir counts (Wuttig and Evenson 2001). The Holitna River is the most utilized tributary for sport fishing in the upper portion of the Kuskokwim River drainage because of the diversity and abundance of Chinook, chum, coho salmon and resident species (Burr 2002).

In addition to the Holitna River salmon enumeration project, weirs were operated on the George, Tatlawiksuk, Takotna, and Kogrukluk rivers to enumerate escapements and to estimate age, sex, and length compositions of migrating salmon. A sonar station on the lower Aniak River provides estimates of total salmon passage but does not differentiate between species. The relative contributions of these tributary escapements to total abundance can not be estimated without a drainage-wide escapement estimate. Therefore in 2002, this Kuskokwim River mainstem mark-recapture project was implemented to estimate the number of Chinook salmon passing upstream of Kalskag (approximately 309 river kilometers (rkm) upriver from the mouth of the Kuskokwim River; Figure 1). This mainstem mark-recapture project is currently funded through 2005. This report summarizes information collected during 2003. The goals of this project are to gain a better understanding of escapements in this portion of the drainage over a period of years so that current escapement monitoring projects can be evaluated, escapement goals can be developed or refined, and the impacts of harvest can be assessed. The Office of Subsistence Management, Anchorage, funded the majority the 2003 mainstem Kuskokwim River and all of the Holitna River salmon radiotelemetry projects.

Since 2002, Kuskokwim River Chinook salmon runs have shown improvement. The 2002 and 2003 Chinook and chum salmon runs were large enough to provide Kuskokwim River subsistence fishers the opportunity to harvest the amounts of fish necessary for subsistence use (Bergstrom and Whitmore 2004). The sustainable escapement goal of 10,000 fish for the Kogrukluk River weir was met in 2002 and exceeded in 2003. However, at the January 2004 BOF meeting, the BOF voted to continue the stock of yield concern classification for Kuskokwim River Chinook salmon. This determination was based on the continued inability, despite the use of specific management measures, to maintain expected yields or harvestable surpluses above a stock's escapement needs for three of the last five years (Bergstrom and Whitmore 2004).

OBJECTIVES

The objectives for this project in 2003 were to:

1. estimate the abundance of Chinook salmon in the Kuskokwim River for all waters upstream of Kalskag; and,
2. estimate age, sex, and length compositions of Chinook salmon in the Kuskokwim River upstream of Kalskag.

METHODS

The abundance of Chinook salmon migrating upstream past capture sites on the Kuskokwim River near Kalskag (Figure 1) was estimated using two-sample mark-recapture techniques. Chinook salmon were captured using drift gillnets and fish wheels throughout the run. Age, sex, and length data were collected from all captured fish. Radio tags were the primary mark and spaghetti tags were the secondary mark. The number of Chinook salmon that retained their radio tags and were detected upstream from the tagging site constituted the first sample. The number of Chinook salmon that passed through weirs on the George, Kogrukluk, Tatlawiksuk, and Takotna rivers became the second sample in the mark-recapture experiment. Radio-tagged fish that migrated through the weirs constituted the recaptured portion of the second sample. Age, length, and sex data collected by ADF&G Commercial Fisheries Division (CFD) staff from a

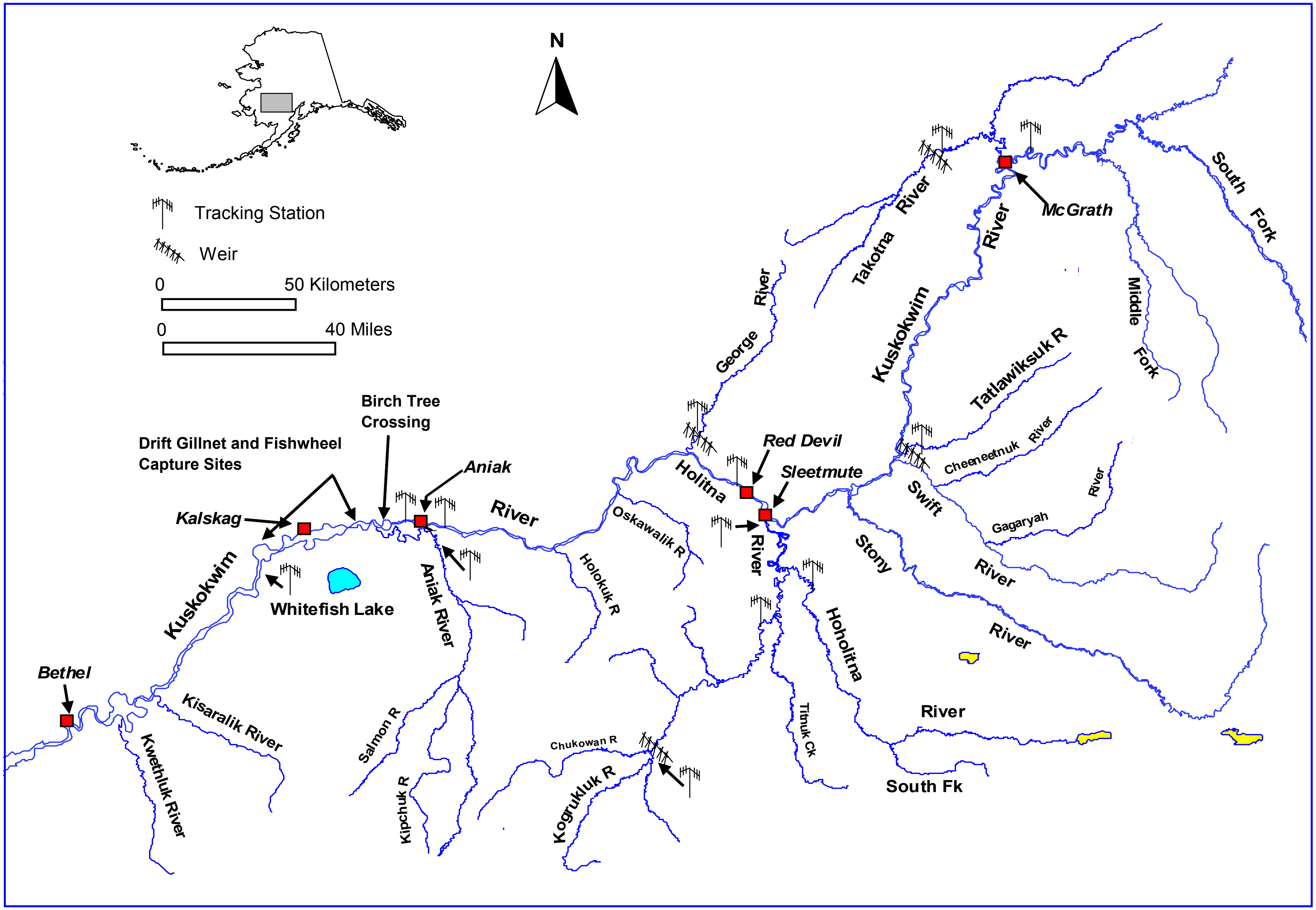


Figure 1.–Map of the Kuskokwim River showing capture sites, weirs, and tracking stations, 2003**.**

sample of the Chinook salmon that passed through each weir were used to test assumptions of equal probabilities of capture.

A lottery for cash prizes was established to encourage the return of tags and assist in determining the fates of all radio-tagged Chinook salmon. All subsistence and/or sport fishers who returned radio and/or spaghetti tags were entered into this lottery. The lottery was operated by the ADF&G CFD in Anchorage. The public was made aware of the study and the lottery through personal contacts and by posting fliers in public places throughout the Kuskokwim area. Each radio tag was labeled with a return mailing address as well as a toll free number to call to provide catch information and enter the lottery. Each spaghetti tag was labeled with that same toll free number.

CAPTURE AND TAGGING

The goal of the first sampling event was to capture Chinook salmon and distribute radio tags over the span of the run in proportion to run strength, size composition, and bank of migration. Fishing was conducted six days per week (Sunday-Friday) from start to end of the run. A tag deployment schedule that attempted to distribute tags proportional to run strength was developed based on Kuskokwim River test net data, which had been collected near Aniak from 1992 to 1995 (Burkey et al. 1997). In addition, weekly tagging goals were determined for small (<650 mm) and large (≥650 mm) Chinook salmon. The number of tags that were deployed in fish of each length category was based on historical length data from the four upriver weirs. These data indicated that on average, approximately 20% of the total Chinook salmon escapement past the weirs were salmon <650 mm. Throughout the Chinook salmon run, the project leader kept in contact with the Bethel test net fishery run by CFD in Bethel and altered the tagging schedule in accordance with what CFD was observing with respect to observed variations in inseason run strength. An attempt was made to radio-tag Chinook salmon in equal proportions along the north and south banks to ensure that all spatial components of the run had a non-zero probability of capture. Chinook salmon were sampled with large mesh drift gillnets and fish wheels, which in combination captured a broad size range of fish.

Sampling efforts in 2002 were conducted in the vicinity of Birch Tree Crossing, located near the outlet of the Aniak River slough (Figure 2). Results from the 2002 study suggested that the south-side fish wheel and nearby drift areas had disproportionately sampled Chinook salmon bound for the Aniak River. Conversely, the north-side fish wheel and nearby drift gillnet sites had captured a much lower proportion of Aniak River bound Chinook salmon compared to the downriver tagging sites. As a result, sampling activities in 2003 were moved downstream, nearer to Kalskag in an attempt to disperse the radio tags more proportional to stock abundance.

Chinook salmon sampling efforts for 2003 commenced on 2 June and continued until 30 July. Drift gillnets were fished by a three-person crew from a riverboat along both the north and south banks of the Kuskokwim River near Kalskag. Sampling was conducted at five locations, and use of a particular site varied with water level and debris accumulation (Figure 2). Fishing efforts alternated between banks every 45-min of soak time and half of the daily effort was expended along each bank. Drift gillnetting typically began each day at 1600 hours and continued until a 3-hour soak time or a 7.5-hour workday was achieved.

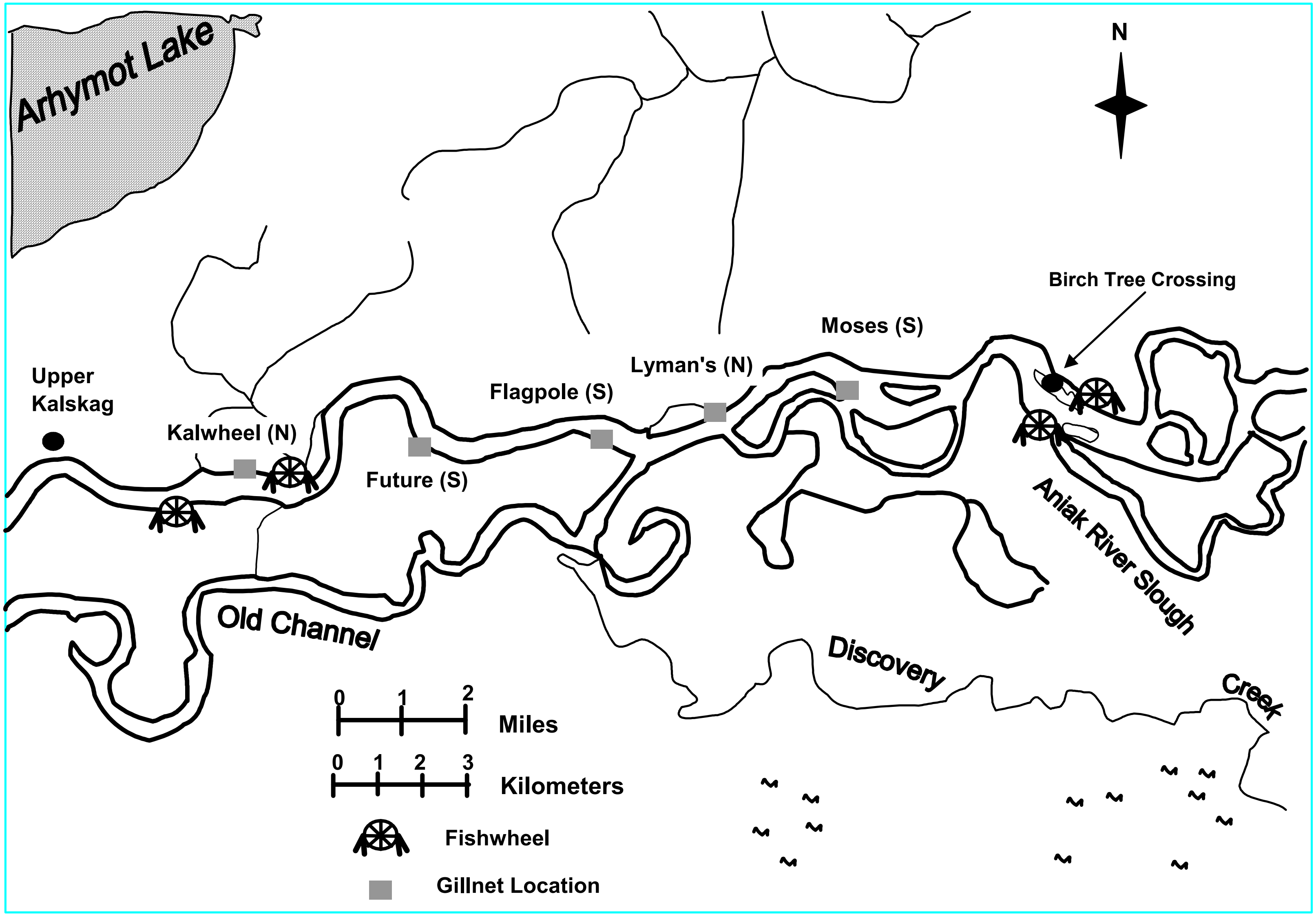


Figure 2.-Map of the drift gillnet and fish wheel tagging locations for Chinook salmon in the Kuskokwim River, 2003. An (S) denotes a south bank and an (N) denotes a north bank location.

In addition to capturing Chinook salmon by drift gillnets, two CFD fish wheels operated 24 hours per day beginning 6 June near Kalskag (Figure 2). The two fish wheels were located along the same stretch of river, but on opposite banks. Each day, CFD personnel sampled salmon out of the fish wheel live boxes between the hours of 0600 - 1430, and 1800 - 0230. A Sport Fish Division (SFD) technician accompanied CFD personnel during each shift in order to radio-tag Chinook salmon.

Drift gillnets were constructed of cable-lay material and were 100 to 150 ft in length. An 8.0 in mesh size net 29 panels deep and/or an 8.25 in mesh size net 45 panels deep was fished each day. The deeper net (45 panel) targeted mid-channel reaches and was used during high water events, whereas the 29 panel net was fished in near-shore reaches. Between, 2 and 6 June, drifts were also conducted with a 5.5 in mesh size net 29 panels deep in an effort to capture and tag smaller size classes to compensate for the CFD fish wheels that were not yet in operation.

When a Chinook salmon was captured in a drift gillnet, the net was immediately retrieved into the boat and the fish was placed into a holding tub. Water in the holding tub was frequently replaced with fresh water, usually after tagging and measuring was completed. All captured fish were measured from mideye to the tail fork (MEF) to the nearest 5 mm and sex was determined from external characteristics. Three scales were removed from the left side of all fish approximately two rows above the lateral line along a diagonal line downward from the posterior insertion of the dorsal fin to the anterior insertion of the anal fin (Welander 1940) and placed on gum cards. Scale impressions were later made on acetate cards and viewed at 100X magnification using equipment similar to that described by Ryan and Christie (1976). Ages were determined from scale patterns as described by Mosher (1969).

The left axillary process was collected from each radio-tagged Chinook salmon using dog toe-nail clippers. Slime and dirt was removed from each axillary process with a towel. Each tissue sample was placed immediately after sampling in a labeled vial and submerged in 100% ethanol. These tissues were collected for later processing by the Anchorage CFD genetics laboratory. The samples will be used to increase their baseline data for tributaries of the Kuskokwim River. The Chinook salmon within the Kuskokwim River drainage can be divided into three genetically distinct groups (B. Templin, Alaska Department of Fish and Game, Genetics Laboratory, Anchorage, personal communication). From baseline allozyme and microsatellite data, the Takotna and Salmon rivers comprise the Upper Kuskokwim Group; Swift, Stony, and Tatlawiksuk compromise the Middle Kuskokwim Group, and the Kogrukluk River and the tributaries downriver to the mouth of the mainstem Kuskokwim comprise the Lower Kuskokwim Group.

Esophageal-implant radio tags were used for the primary mark and their size (14.5 x 49 mm) precluded applying the tags to the smallest size classes encountered in the study. Winter (1983) recommended against using a transmitter that weighed more than 2% of a fish's total weight. John Eiler (National Marine Fisheries Service, Juneau, personal communication) recommended tagging salmon ≥500 mm, which would ensure compliance with the 2% rule. However, during the 2002 Kuskokwim River Chinook salmon radiotelemetry project, five fish between 455 and 480 mm were given radio tags and were later located in a major tributary, proving that they survived the stress of tagging and handling. Similar results were found by Wuttig and Evenson (2002) and Chythlook and Evenson (2003) with coho salmon. Given the objectives and scope of this radiotelemetry project, it was imperative to catch and radio-tag Chinook salmon over as broad of the range of size and age classes as was feasible. Therefore in 2003 Chinook salmon ≥ 450 mm MEF were radio-tagged.

Radio tags were inserted through the esophagus and into the upper stomach of the fish using a 45-cm plastic tube with an inside diameter equal to that of the radio-tags. The radio tag was pushed through the esophagus and into the stomach such that the antenna end was seated 0.5 cm anterior to the base of the pectoral fin. Tagging was performed without the use of anesthesia. All radio-tagged fish were given a secondary mark of a uniquely numbered, fluorescent green spaghetti tag constructed of a 5-cm section of plastic tubing shrunk onto a 38-cm piece of 80-lb monofilament fishing line (Pahlke and Etherton 1999). The monofilament was sewn through the musculature of the fish 1-2 cm ventral to the insertion of the dorsal fin between the third and forth fin rays from the posterior of the dorsal fin. Fish were then released in quiet water out of the main current. Fish that were obviously injured and/or appeared stressed were not radio-tagged.

Radio-Tracking Equipment and Tracking Procedures

Radio tags were Model Five pulse encoded transmitters made by ATS[1]. Each radio tag was distinguishable by a unique frequency and encoded pulse pattern. Twenty frequencies spaced approximately 20 kHz apart in the 149-150 MHz range with 25 encoded pulse patterns per frequency were used for a total of 500 uniquely identifiable tags.

Radio-tagged Chinook salmon were tracked as they migrated up the Kuskokwim River using a network of 12 ground-based tracking stations similar to those described by Eiler (1995). Each station consisted of a steel housing box which contained two 12 V deep cycle batteries charged by a solar array, an ATS Model 5041 Data Collection Computer (DCC II) and ATS Model 4000 receiver (R4000) or a single R4500 Data Collection Computer and receiver combination. Tag signals were received by two, four element Yagi antennas oriented with one facing downstream and one facing upstream so that upstream and downstream movements of fish could be determined. The DCCII/R4000 and R4500 units were programmed to scan through the frequencies at 6-s intervals, and could simultaneously receive from both antennas. When a signal of sufficient strength was detected, the receiver paused for 3-s on each antenna, and then tag frequency, tag code, signal strength, date, time, and antenna number were recorded on the DCCIIs and R4500s. The relatively short cycle period helped minimize the chance that a radio-tagged fish would swim past the station site without being detected. Recorded data were downloaded to a laptop computer every 7–20 days.

A total of 12 tracking stations were used in this study. Five tracking stations were located on the mainstem Kuskokwim River. The furthest downriver station was located downstream of the capture sites at approximately rkm 264 near the abandoned village of Uknavik. In addition, one tracking station each was placed immediately above and below Aniak (50-55 rkm above the capture site), one was placed downstream of the Holitna River near Red Devil, and the fifth was located just above McGrath (Figure 1). One tracking station was placed at each of the four weir sites on the George, Kogrukluk, Tatlawiksuk, and Takotna rivers. Additionally, a tracking station was placed near the ADF&G sonar site on the Aniak River approximately 25 rkm upriver from its junction with the Kuskokwim River. As part of the Holitna River salmon enumeration

[1] Advanced Telemetry Systems, Isanti, Minnesota (Product names used in this report are included for scientific completeness but do not constitute product endorsement).

study, two tracking stations were located on the mainstem Holitna and Hoholitna rivers; these stations were programmed with tag frequencies from the mainstem study in addition to those frequencies used on the Holitna River.

Radio-tagged Chinook salmon were also located by aerial-tracking from small aircraft. Two aerial-tracking surveys were conducted from 17-21 July and 11-16 August. During each survey, fish were tracked along the mainstem Kuskokwim River and major tributaries from the capture site to mainstem tributaries upriver of McGrath, with particular attention paid to the four tributaries with weirs. Aerial tracking surveys were conducted with one aircraft, one person (in addition to the pilot), and utilized one R4500 receiver/scanner. All frequencies were loaded into the receiver/scanner prior to each flight. Dwell time on each frequency was 1-2 seconds. Flight altitude ranged from 100 to 300 m above ground. Two H-antennas equipped with a switching box, one on each wing strut, were mounted such that the antennas detected peak signals perpendicular to the direction of travel. Once a tag was located its frequency, code, and coordinates were recorded. Aerial-surveys were conducted to locate radio-tagged Chinook in the mainstem Kuskokwim River that did not appear to have successfully migrated into a spawning stream (e.g., tag loss or handling mortality), locate tags in spawning tributaries other than those monitored with tracking stations, to locate fish that the tracking stations failed to record, and to validate whether a fish recorded on one of the tracking stations did migrate into that particular stream.

Boat tracking surveys occurred periodically near the capture/release sites to monitor for tags that had been regurgitated. Results from a radiotelemetry study on the Copper River suggested that most fish that expelled tags did so immediately after release (Evenson and Wuttig 2000). During the boat surveys one person monitored a receiver and hand-held H-antenna in the front of a boat and another operated an R4500 receiver/scanner.

ESTIMATION OF ABUNDANCE

Assignment of Fate

For the purposes of mark-recapture abundance estimation, every radio-tagged fish was assigned one of five possible fates:

1. a fish that survived tagging and handling and was harvested above Aniak;
2. a fish that survived tagging and handling, was detected up a tributary that was not monitored with a weir and/or did not pass a weir on the George, Tatlawiksuk, Kogrukluk, or Takotna rivers; but did have a known final destination;
3. a fish that traveled past one of the four tracking stations on the George, Tatlawiksuk, Kogrukluk, or Takotna rivers;
4. a fish that was known to have migrated upstream past the two tracking stations that were located just above and below Aniak, but was not detected in a major tributary; or,
5. a fish that was not located either by the tracking stations near Aniak or by aerial means to have passed upriver of these tracking stations. Fish of this fate included those that were located near or downstream of the capture sites, and fish that were never located.

Fish assigned to Fates #1 through #4 were assumed to have survived tagging and handling and therefore constituted the marked sample. Fish assigned fate #3 constituted recaptured fish. Fates of radio-tagged fish were determined after receiving data from tracking stations, aerial and boat tracking surveys, and from tags returned by fishers. If a fisherman returned a radio and/or spaghetti tag or verbally reported harvesting the fish then it was assigned Fate #1. However, if a fish was harvested near or below Aniak; those fish were censored from the experiment and designated as a Fate #5.

Recapture Sample

The second sample for this mark-recapture experiment was the number of Chinook salmon ≥450 mm migrating through the four weirs, which was estimated from the total count through the weirs adjusted by the proportion of fish sampled that were ≥450 mm. Marked fish in the second sample were fish assigned a Fate #3. Because of the difficulty capturing Chinook salmon in the weir live-traps, only a portion of the Chinook salmon that passed each weir site were handled for age, sex, and length. Chinook salmon age, sex, and length composition data collected from fish handled at each weir were used to test model assumptions of equal capture probabilities.

Conditions for a Consistent Petersen Estimator

For the estimate of abundance from this mark-recapture experiment to be unbiased, certain assumptions needed to have been fulfilled (Seber 1982). The assumptions, expressed in terms of the conditions of this study, respective design considerations, and test procedures are listed below. To produce an unbiased estimate of abundance with the generalized Petersen model, Assumptions I and II and one of the conditions of Assumption III must have been met.

ASSUMPTION I: Marking and handling did not affect the catchability of Chinook salmon in the second event.

There was no explicit test for this assumption because the behavior of unhandled fish could not be observed. However, to minimize the effects of handling, holding and handling time of all captured fish was minimized. In a related study, chum salmon tagged and released in the Yukon River immediately after capture resumed upriver movement faster and traveled farther upriver than fish that had been held prior to release (J. Eiler, National Marine Fisheries Service, Juneau, personal communication). Any obviously stressed or injured fish were not radio-tagged. Radio-tagged fish that were not detected past the two mainstem Kuskokwim River tracking stations near Aniak were removed from the experiment. Travel times for tagged fish to move from the capture site to the tracking stations on the mainstem Kuskokwim River were calculated and inspected to investigate variation in travel time and to make indirect inferences about whether fish were affected by handling.

ASSUMPTION II: Tagged fish did not lose their tags between the tagging site and the weirs.

A combination of stationary tracking stations and aerial and boat tracking surveys were used to identify radio tags that were expelled. In addition, fish inspected at the four weirs were examined for both a spaghetti tag and/or a radio tag. All fish determined to have regurgitated their tags were culled from the analyses.

ASSUMPTION III:

1. **All Chinook salmon had the same probability of being caught in the first sampling event;**

2. **All Chinook salmon had the same probability of being captured in the second sampling event; or,**
3. **Marked fish mixed completely with unmarked fish between sampling events.**

Equal probability of capture was evaluated by size, sex, time, and area. The procedures to evaluate equal probability of capture across sex and size categories are described in Appendix A. Chinook salmon were captured and tagged over the entire span of the run. Radio tags were implanted into Chinook salmon of various sizes and were captured along both banks of the river. Sex, length, date, and time of release were recorded for all tagged fish. Catch sampling at the four weirs also occurred over the span of the run. Age, sex, and length data were collected from a sample of fish passing through each of the four weirs. The George and Takotna rivers drain into the north side of the Kuskokwim River and the Kogrukluk and Tatlawiksuk rivers drain into the south side.

To evaluate the three conditions of Assumption III relative to time of capture, location of capture, and gear type, contingency tables were analyzed as recommended by Seber (1982):

1. Equal probability of capture during the second event was evaluated by comparing ratios of recaptured to not recaptured marked fish from across different tagging periods during the first event;
2. Equal probability of capture during the first event was evaluated by comparing ratios of marked to unmarked fish at each of the four weirs;
3. Independence between bank of capture during the first event and probability of capture during the second event was evaluated by comparing ratios of recaptured to not recaptured marked fish between the two banks of capture during the first event. Independence between bank of mark and bank of recapture was also tested; and,
4. Independence between capture gear used during the first event and probability of capture during the second event was evaluated by comparing ratios of recaptured to not recaptured marked fish between the two gear types.

DATA ANALYSIS

Abundance of Chinook salmon was estimated after stratification by size to minimize bias. For each stratum, abundance was estimated using the Chapman modification to the Petersen estimator (Chapman 1951) and stratum estimates were summed to estimate total abundance:

$$\hat{N} = \sum_{s=1}^{S} \hat{N}_s \text{, and} \tag{1}$$

$$\hat{N}_s = \frac{(\hat{C}_s + 1)(M_s + 1)}{R_s + 1} - 1; \tag{2}$$

where:

$\hat{N}_s$ = estimated abundance of Chinook salmon in the Kuskokwim River upstream from Lower Kalskag in stratum s, $s = 1$ to S;

M_s = the number of radio-tagged Chinook salmon in stratum s known to survive tagging and handling;

R_s = the number of radio-tagged Chinook salmon in stratum s moving past the four weirs; and,

$\hat{C}_s$ = the estimated number of Chinook salmon in stratum s counted past the four weirs.

The estimated number of Chinook salmon in stratum s that passed the four weirs was calculated as the sum of estimates for each weir:

$$\hat{C}_s = \sum_{w=1}^{W} \hat{C}_{sw} \ . \tag{3}$$

At each weir, within stratum passage was estimated:

$$\hat{C}_{sw} = \hat{p}_{sw} C_w \tag{4}$$

where the proportion of salmon in stratum s was estimated from length composition data collected at the weir:

$$\hat{p}_{sw} = n_{Csw} / n_{Cw} \tag{5}$$

and where:

n_{Csw} = number of Chinook salmon in size stratum s observed of those sampled for composition at weir w, w = 1 to W;

n_{Cw} = the total number of Chinook salmon sampled for composition at weir w; and,

C_w = the number of Chinook salmon counted past weir w when the weir was operational.

Variance and 95% credibility interval for the estimator (equation 1) were estimated using empirical Bayesian methods (Carlin and Louis 2000). Using Markov Chain Monte-Carlo techniques, posterior distributions for the $\hat{N}_s$ and $\hat{N}$ were generated by collecting 100,000 simulated values of $\hat{N}_s$ and $\hat{N}$ which were calculated using equations (1-5) from simulated values of equation parameters. Simulated values were modeled from observed data using the following distributions:

observed $n_{C1w},\ldots,n_{CSw}$ ~multinomial $((p_{1w},\ldots,p_{Sw}), n_{Cw})$; and ,

observed R_s ~binomial (q_s, M_s), s = 1 to S;

where q_s is the probability that a radio-tagged salmon from stratum s passed one of the weirs and was treated as a recapture.

At the end of the iterations, the following statistics were calculated:

$$\overline{N} = \frac{\sum_{b=1}^{100{,}000} \hat{N}_{(b)}}{100{,}000} \text{; and,} \tag{6}$$

$$V\hat{a}r(\hat{N}') = \frac{\sum_{b=1}^{100{,}000} (\hat{N}_{(b)} - \overline{N})^2}{100{,}000 - 1} \ . \tag{7}$$

Only actual counts from the weirs were used for the second sample. Those radio-tagged fish that passed through the weir on days when water visibility precluded counting were treated as marks that were not recaptured during the second event.

Age, Sex, and Length Compositions

The numbers of Chinook salmon by ocean-age or sex were estimated first within size strata and then summed across strata. Composition proportions were first estimated at each weir using:

$$\hat{p}_{ksw} = \frac{n_{ksw}}{n_{Cw}} \tag{8}$$

where:

$\hat{p}_{ksw} =$ estimated proportion of Chinook salmon in group *k* (*k* = 1 to *K*), stratum *s* at weir *w*; and,

$n_{ksw} =$ number of sampled Chinook salmon in group *k*, stratum *s*, at weir *w*.

Estimates were then combined across weirs, weighted by estimated total passage at each weir (weights were treated as fixed values, even though varying uncertainty existed about total passage at each weir):

$$\hat{p}_{ks} = \sum_{w=1}^{W} T_w \hat{p}_{ksw} \Big/ \sum_{w=1}^{W} T_w \tag{9}$$

where:

$\hat{p}_{ks} =$ estimated proportion of Chinook salmon in group *k*, stratum *s*; and

$T_w =$ total number of Chinook salmon estimated to have passed weir *w*.

The numbers of Chinook salmon in each group within strata were estimated:

$$\hat{N}_{ks} = \hat{N}_s \hat{p}_{ks} \Big/ \sum_{k=1}^{K} \hat{p}_{ks} \, . \tag{10}$$

These estimates were summed across strata to calculate the estimated number of Chinook salmon in group *k* in the escapement:

$$\hat{N}_k = \sum_{s=1}^{S} \hat{N}_{ks} \, , \tag{11}$$

and the proportion of Chinook salmon in group *k* was estimated:

$$\hat{p}_k = \hat{N}_k \big/ \hat{N} \, . \tag{12}$$

Variance for the estimates of $\hat{N}_k$ and $\hat{p}_k$ were estimated using empirical Bayesian methods (Carlin and Louis 2000). Using Markov Chain Monte-Carlo techniques, posterior distributions for $\hat{N}_k$ and $\hat{p}_k$, which were calculated using equations (1-5) and (8-12) were generated by collecting 100,000 simulated values of $\hat{N}_k$ and $\hat{p}_k$ from simulated values of equation parameters. The simulated values were modeled from observed data using the following distribution:

observed $n_{11w},\ldots,n_{KSw}$ ~multinomial(($p_{11w},\ldots,p_{KSw}$), n_{Cw});

in addition to those distributions described above. Formulae similar to equations (6) and (7) were used to estimate variance.

To estimate mean length within sex and age class, observed lengths were pooled across size strata for each weir for each sex and age class. Without pooling, several strata by sex and age class within each weir category had a sample size of one, precluding estimation of sampling variance within category. As a result of pooling, overall mean length estimates may have been slightly biased because weights used to combine estimates across weir samples were not consistent with stratified estimated abundances as described above. Further, pooling in this instance resulted in poorer precision (larger standard errors) of estimated means than would have been the case if pooling were avoided.

For each weir site, mean lengths and associated sampling variances were calculated for each sex and associated age class k using:

$$\bar{l}_{kw} = \frac{\sum_{i=1}^{n_k} l_{kwi}}{n_{kw}} \text{; and,} \tag{13}$$

$$V\hat{a}r\left[\bar{l}_{kw}\right] = \frac{\sum_{i=1}^{n_{kw}} \left(l_{kwi} - \bar{l}_{kw}\right)^2}{n_{kw}\left(n_{kw} - 1\right)} \tag{14}$$

where:

l_{kwi} = length of salmon i (i = 1 to n_{kw}) at weir w of a given sex and age group k; and,

n_{kw} = number of samples at weir w of a given sex and age group k.

Overall estimates of mean lengths for each age class k were weighted combinations of estimates from each weir:

$$\bar{l}_k = \sum_{w=1}^{W} U_{kw}\bar{l}_{kw} \Big/ \sum_{w=1}^{W} U_{kw} \tag{15}$$

where U_{kw} was an approximate estimate of abundance of total Chinook salmon in class k at weir w.

We calculated:

$$U_{kw} = T_w \hat{p}_{kw} \text{ and } V\hat{a}r(U_{kw}) = T_w^2 V\hat{a}r(\hat{p}_{kw}); \tag{16}$$

where:

$$\hat{p}_{kw} = \frac{n_{kw}}{n_{Cw}} \text{ and } V\hat{a}r(\hat{p}_{kw}) = \frac{\hat{p}_{kw}(1-\hat{p}_{kw})}{n_{Cw}-1}. \tag{17}$$

The variance was approximated by (Mood et al. 1974):

$$\hat{Var}(\bar{l}_k) \cong \sum_{w=1}^{W} \frac{\left(\bar{l}_{kw}\sum_{w=1}^{W}U_{kw} - \sum_{w=1}^{W}U_{kw}\bar{l}_{kw}\right)^2}{\left(\sum_{w=1}^{W}U_{kw}\right)^4} \hat{Var}(U_{kw}) + \sum_{w=1}^{W} \frac{U_{kw}^2}{\left(\sum_{w=1}^{W}U_{kw}\right)^2} \hat{Var}(\bar{l}_{kw}) . \quad (18)$$

RESULTS

The total number of Chinook salmon that were captured and radio-tagged in 2003 was 498. Data regarding fates and mark-recapture analyses were archived as described in Appendix B. The daily number of deployed radio tags closely followed the predetermined sampling schedule. Of the total radio tags deployed, 47% were deployed in fish captured on the north bank and 53% were deployed in fish captured on the south bank. The objectives for tagging fish in the two size classes with respect to bank of capture tracked predetermined objectives and showed similar patterns (Appendices C1 and C2).

Fates were described for the 498 radio-tagged fish (Table 2). Fifty two radio-tagged fish either lost their tags, were harvested below Aniak, or were never located after tagging (Fate #5). Four hundred forty-six radio-tagged fish were known to have retained their tags and migrated upstream of the capture site (Fates #1 - #4). Of the 77 fish that were recorded past the two mainstem Kuskokwim River tracking stations near Aniak but were never located in a tributary (Fate #4), 62 were recorded by the mainstem Kuskokwim tracking station at Red Devil.

In 2003 various high water events limited the number of days that the four Kuskokwim River weirs were operable (Table 3). Forty-eight Chinook salmon swam past the tracking station above the Kogrukluk River weir and became part of the recapture portion. Of the 27 total fish that passed the tracking stations on the George, Tatlawiksuk, and Takotna rivers only 1, 5, and 1 Chinook salmon respectively were added to the recaptured portion due to the long periods when the weirs were inoperable.

The first fish was captured and tagged on 2 June and the last fish was captured and tagged on 30 July. Based on our catches, 50% of the entire Chinook salmon run passed by the tagging site by 26 June. Run timing patterns at the capture site for the major stocks (defined by major drainage) overlapped considerably. Cumulative run timing patterns indicated slight segregation among stocks in run timing past the capture site (Figure 3), but mean dates of passage were fairly similar for all stocks (Figure 4). The genetically distinct Upper Kuskokwim Group arrived slightly earlier than the Middle and Lower populations (Figure 5).

On average, after receiving a radio tag, a Chinook salmon took three days to travel from the tagging sites to the mainstem tracking station below Aniak (355 km), four days to reach the mainstem tracking station above Aniak (375 km), and seven days to reach the mainstem tracking station at Red Devil (520 km; Figure 6). Transit times from point of capture to the tracking stations on the mainstem Kuskokwim River did not significantly vary between Chinook salmon captured with fish wheels compared to those captured with drift gillnets (Figure 7).

Table 2.–Final fates of Chinook salmon that were radio-tagged in the Kuskokwim River, 2003.

Fate #	Fate Description	Number of Radio- tagged Chinook Salmon Assigned This Fate
	Fish that survived tagging and handling	
1	Fish harvested above Aniak.	10
2	Fish detected up a tributary that was not monitored with a weir and/or did not pass a weir on the George, Tatlawiksuk, Kogrukluk, or Takotna rivers.	284
3	Fish that traveled past one of the four tracking stations on the George, Tatlawiksuk, Kogrukluk, and Takotna rivers.	75
4	Fish that were detected upriver from the tracking station above Aniak, but was not detected into a tributary.	77
	Fish that swam past the Red Devil tracking station.	62
	Fish that did not swim past the Red Devil tracking station.	15
	Subtotal	**446**
5	**Fish not detected past the tracking stations near Aniak and therefore its fate could not be determined**	
	Fish harvested below Aniak.	14
	Fish that were not detected by any of the tracking stations and/or by aerial means.	3
	Fish that traveled past downriver station near Uknavik and were never recorded again.	9
	Fish that were detected by the two tracking stations near Aniak and/or by aerial means at or below the two tracking stations near Aniak, but not upriver.	26
	Subtotal	**52**
	Total number of fish that were radio tagged.	**498**

Table 3.–Summary of 2003 weir operations on the George, Tatlawiksuk, Kogrukluk, and Takotna rivers.

Weir	First Day of Operations	Last Day of Operations	Number of Days Weir was not Operational	Number of Chinook Salmon Counted Past the Weir	Number of Radio-tagged Fish that Swam Past Tracking Stations [a]	Comments
George	1 July	19 September	28	975	10	
Tatlawiksuk	20 June	2 July	See Comment	601	15	Was operational for 13 days before becoming inoperable for the remainder of the summer.
Kogrukluk	21 June	20 September	1	11,723	48	Number counted represents total escapement estimate.
Takotna	2 July	20 September	15	354	2	

[a] Includes days when weir was not operational.

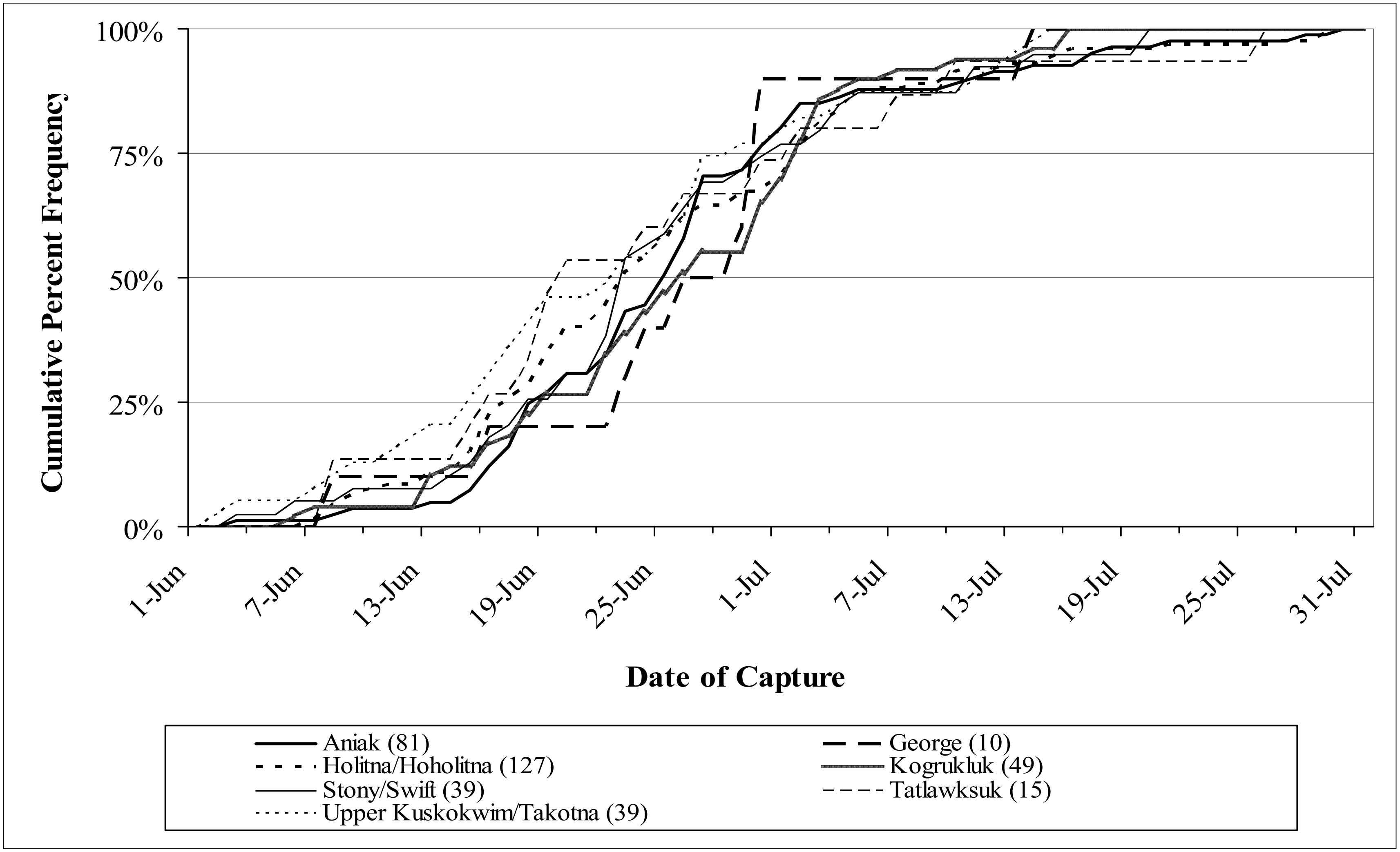


Figure 3.–Cumulative percent frequency of Chinook salmon of known final destinations with their respective dates of initial capture, 2003. The number of fish located in each tributary or combination of tributaries are presented in parenthesis.

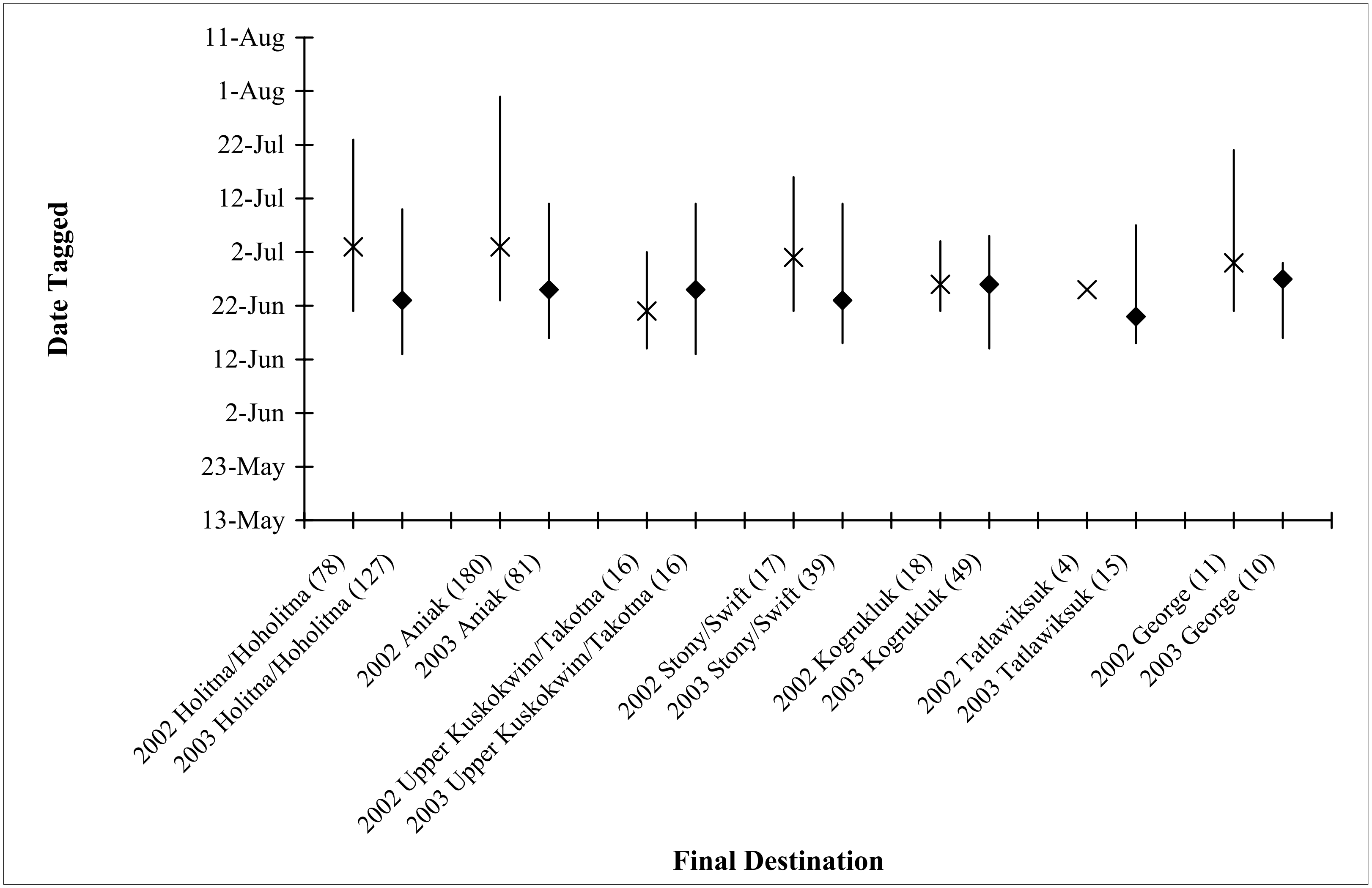


Figure 4.–Median passage date (symbol) and 80% range (vertical lines) of Chinook salmon from the Kuskokwim River of known final destinations with their respective dates of initial capture, 2002-2003. The number of fish located in each tributary are presented in parenthesis.

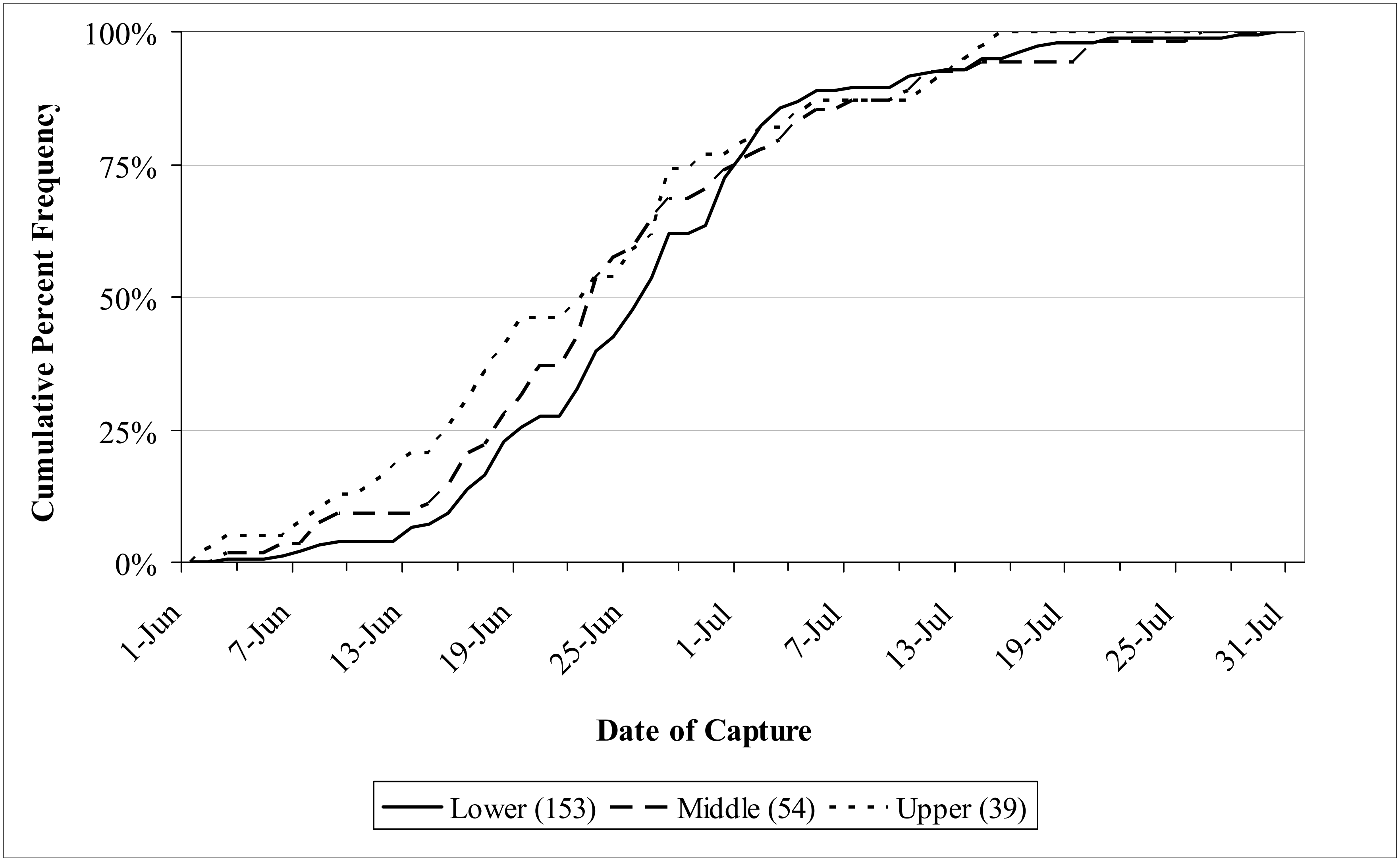


Figure 5.–Cumulative percent frequency of the genetically distinct Upper, Middle, and Lower Kuskokwim Groups with their respective dates of initial capture, 2003. The number of fish in each group is presented in parentheses.

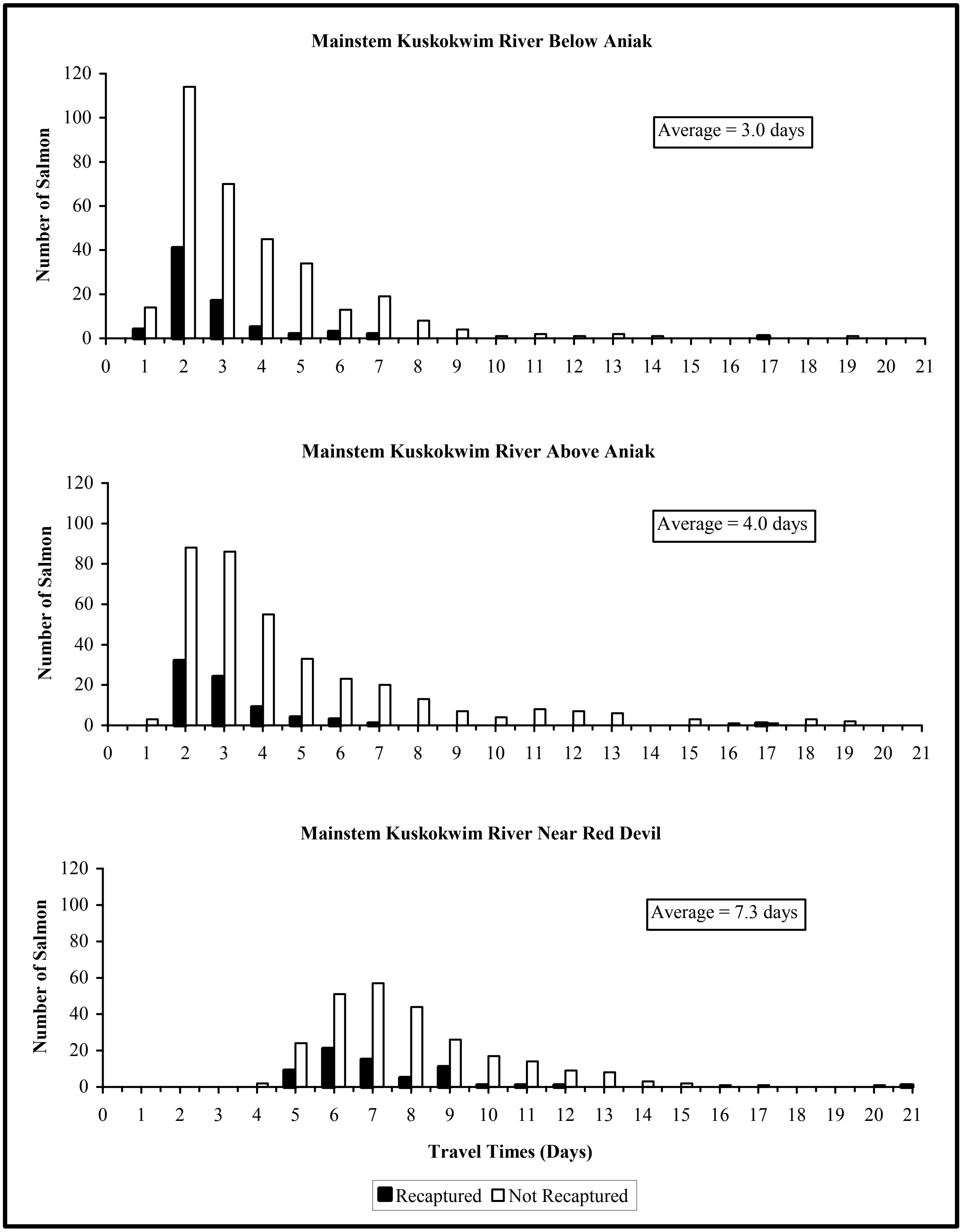


Figure 6.–Travel times from the capture sites to three tracking stations on the mainstem Kuskokwim River for Chinook salmon captured and radio-tagged in 2003.

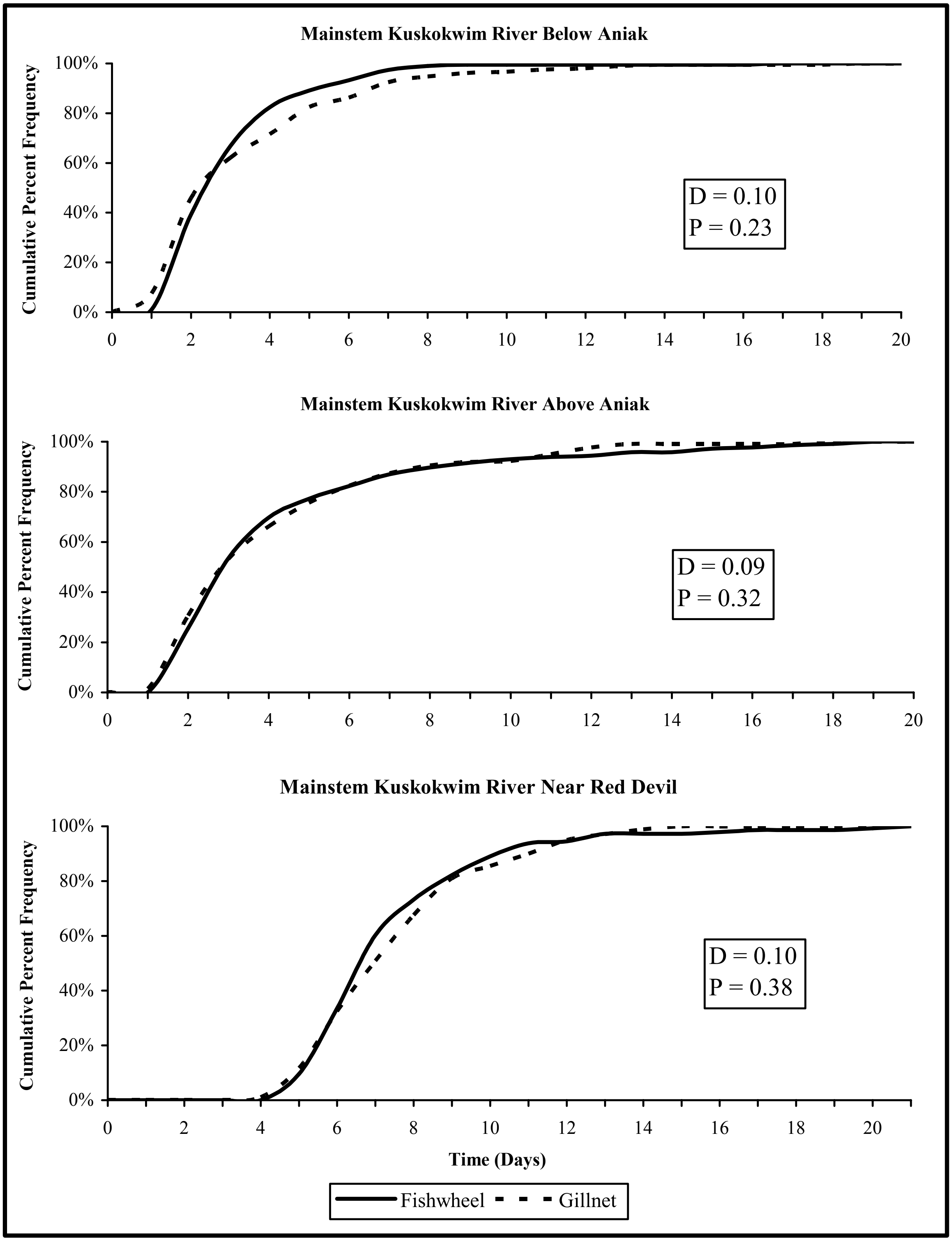


Figure 7.-Travel times from the capture sites to three tracking stations on the mainstem Kuskokwim River for Chinook salmon captured in fish wheels and drift gillnets in 2003.

Thirty-two Chinook salmon swam downriver past the tracking station near Uknavik soon after receiving a radio tag. Nine of these fish were not detected again and therefore censored from the estimate (Fate #5). Twenty fish swam back upriver and were detected in a spawning tributary, one was harvested, and two passed by the tracking station near Red Devil, but were not detected into a tributary.

Mark-Recapture Experiment

The majority of Chinook salmon of known final destinations (Fates #2 and #3) traveled up the Holitna or Aniak river systems (Table 4; Appendices D1 and D2). Even though shifting tagging effort downriver from Birch Tree Crossing to sites near Kalskag appeared to disperse radio tags more proportional to stock abundance, there was evidence that the majority of Aniak River bound Chinook salmon caught near Kalskag were still bank oriented to the south side bank of the Kuskokwim River. One assumption of the tagging effort was that the bank of mark would be independent of the bank of recapture. However, there was concern that including the Aniak River fish could bias the estimate high given that of the 81 Aniak River Chinook salmon, significantly more were captured and tagged from a south bank fish wheel or drift gillnet spot (Table 5; $\chi^2 = 19.38$, df = 1, P $\leq$ 0.01). As a result, the Aniak River bound Chinook salmon were censored from further analyses reducing the marked portion to 365 fish. No lack of independence was detected in the analysis of the 80 Chinook salmon that traveled into the George, Takotna, Kogrukluk, and Tatlawiksuk rivers comparing the bank of mark with their final bank of recapture (Table 6; $\chi^2 = 1.04$, df = 1, P = 0.31).

Because Chinook salmon <450 mm were deemed too small to receive a radio tag, all fish of this size and less were censored from the counts at the weirs. Of the 603 salmon examined at the four weirs for age, sex, and length, one each from the Kogrukluk and Takotna river weirs were <450 mm. There was evidence of size and sex selectivity during both the mark and recapture events. The recapture rates for males (0.20) and females (0.11) were significantly different (Table 7; $\chi^2 = 5.98$, df = 1, P = 0.01). However, these results may be misleading due to the difficulty in accurately assigning sex to small Chinook salmon; Chinook salmon <720 mm are very difficult to sex due to the high incidence of precocious males (jacks) which often exhibit juvenile salmon characteristics. Length distributions of all Chinook salmon marked during the first event and those recaptured during the second event were significantly different (Figure 8; D = 0.20, P = 0.03). Likewise, the length distributions of all marked fish and all fish counted through the four weirs were significantly different (D = 0.10, P = 0.02). These categories were selected based on the results of a battery of contingency table analyses of marked to recaptured ratios with varying size break points. The largest difference between the recapture rates was shown for the smallest size class. For Chinook salmon of the 576-750 mm and >750 mm size classes, recapture rates for males and females showed no significant difference ($\chi^2 = 1.52$, df = 1, *P* = 0.22 and $\chi^2 = 0.15$; df = 1, *P* = 0.70 respectively, Table 7). As a result of these tests, the data were stratified by length categories of 450-575 mm, 576-750 mm, and >750 mm to reduce bias.

A test for independence between time of marking during the first event and probability of recapture during the second event showed equal catchability with respect to time. (Table 8; $\chi^2 = 2.10$, df = 3, P = 0.55). In addition, there was no difference in the marked to unmarked ratios of Chinook salmon counted at the George, Kogrukluk, Tatlawiksuk, and Takotna river weirs (Table 9; $\chi^2 = 5.10$, df = 3, P = 0.16). The probability that a tagged fish was seen at a weir was

Table 4.-Tagging locations and final destinations of Chinook salmon captured and tagged in the Kuskokwim River by gear type and location of tagging, 2003.

Final River Destination	Fish Wheel		Gillnet Sites								
			North			South					
	North	South	Lyman's	Kalwheel	Unknown	Moses	Flagpole	Future	Unknown	Total	% Total
Holitna River	19	15	7	11	0	3	13	13	1	82	18.4%
Hoholitna	16	12	5	4	1	1	4	2	0	45	10.1%
Kogrukluk	12	9	6	7	0	2	3	10	0	49	11.0%
Holitna River Drainage	**47**	**36**	**18**	**22**	**1**	**6**	**20**	**25**	**1**	**176**	**39.5%**
Aniak	7	38	7	4	1	0	9	15	0	81	18.2%
Above McGrath[a]	6	4	4	4	0	3	5	6	0	32	7.2%
Swift	8	5	6	9	0	1	2	1	0	32	7.2%
Tatlawiksuk	8	1	1	1	0	1	1	2	0	15	3.4%
George	3	2	4	0	0	0	1	0	0	10	2.2%
Oskawalik	2	4	0	0	0	0	1	0	0	7	1.6%
Stony	1	2	0	3	0	0	1	0	0	7	1.6%
Takotna	3	1	1	0	0	0	1	0	0	6	1.1%
Holokuk	1	3	0	0	0	1	0	0	0	5	1.3%
Vreeland	0	1	0	0	0	0	0	0	0	1	0.2%
Inriver Harvest[b]	6	1	2	0	0	0	0	0	0	9	2.0%
Unknown Final Destination[b]	16	10	9	9	0	3	12	6	0	65	14.6%
All	108	108	52	52	2	15	53	55	1	446	
% Total	23.1%	26.1%	11.0%	11.6%	0.5%	3.2%	11.0%	13.2%	0.3%		

[a] Above McGrath Chinook salmon includes fish that were not detected into a tributary and one inriver harvest.

[b] Excludes Chinook salmon that were detected by the tracking station near McGrath.

Table 5.–Results of a chi-square test that compared the bank of marking for the recaptured and Aniak River bound Chinook salmon that were radio-tagged in the Kuskokwim River, 2003.

	Final Destinations		
Bank Marked	Recaptures (Kogrukluk, Tatlawiksuk, George, and Takotna rivers)	Aniak River	Total
North	46	19	65
South	34	62	96
Total	80	81	161
	$\chi^2 = 19.38$, df = 1, $P \leq 0.01$		

Table 6.–Results of a chi-square test that examined independence of bank of marking with bank of recapture for Chinook salmon captured and radio-tagged in the Kuskokwim River, 2003.

	Bank Recaptured		
Bank Marked	North (George, Takotna rivers)	South (Kogrukluk, Tatlawiksuk rivers)	Total
North	11	35	46
South	5	29	34
Total	16	64	80
	$\chi^2 = 1.04$, df = 1, $P = 0.31$		

Table 7.–Capture history and contingency table analysis of recapture rates of male and female Chinook salmon sampled during the mark-recapture experiment in the Kuskokwim River, 2003.

Capture History	Male	Female	Total	Pr(M)/ Pr(F)[a]	Test Results
			All Size Classes		
Recaptured	36	19	55		
Not Recaptured	146	161	307	1.87	χ^2 = 5.98, df = 1, *P* = 0.01
Total	182	180	362		
			450-575 mm Size Class		
Recaptured	13	1	14		
Not Recaptured	35	23	58	6.50	Result not informative
Total	48	24	72		
			576-750 mm Size Class		
Recaptured	18	7	25		
Not Recaptured	55	39	94	1.62	χ^2 =1.52 , df = 1, *P* =0.22
Total	73	46	119		
			>750 mm Size Class		
Recaptured	5	11	16		
Not Recaptured	56	99	155	0.82	χ^2 =0.15 , df = 1, *P* =0.70
Total	61	110	171		

[a] Corresponds to the ratio of the recapture rates for males and females.

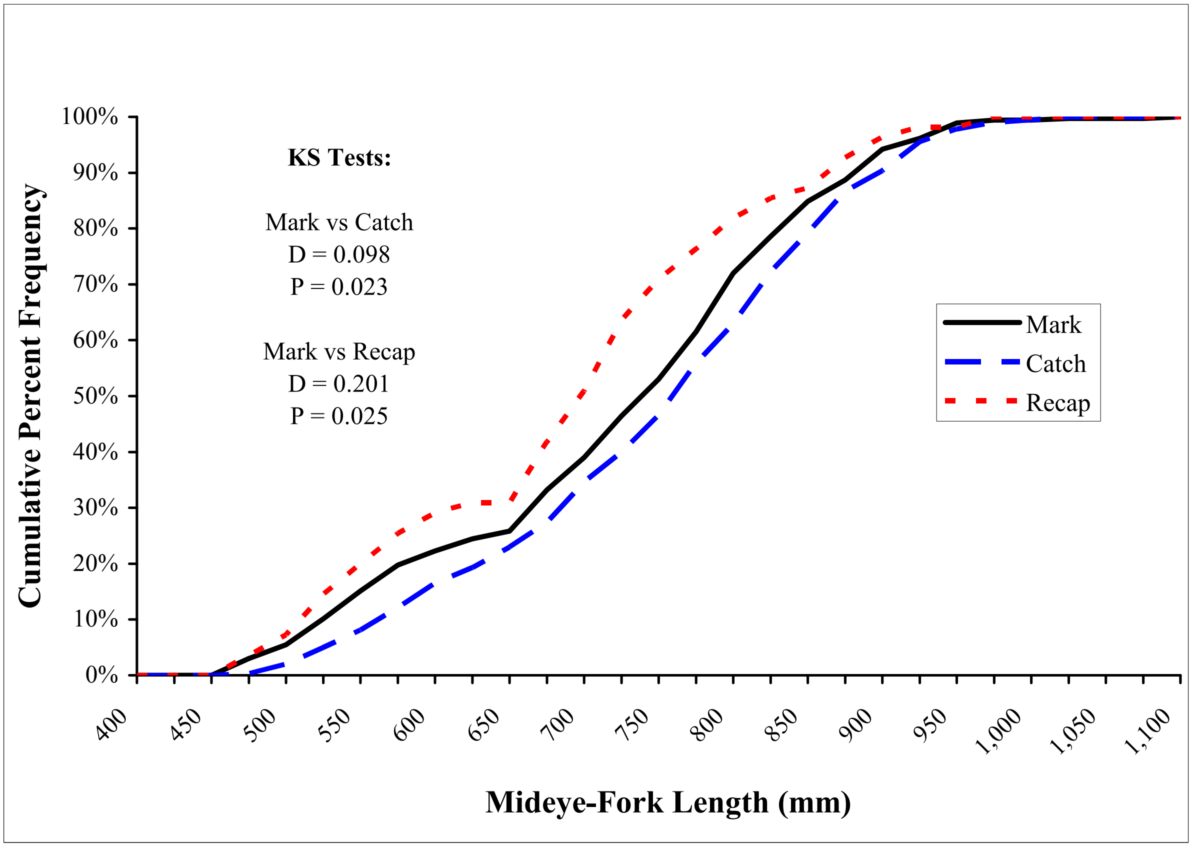


Figure 8.–Cumulative length frequency distributions comparing all Chinook salmon caught during the first (Mark) and second (Catch) events, and all recaptured (Recap) fish caught during the second event from the mark-recapture experiment in the Kuskokwim River, 2003.

Table 8.–Result of a chi-square test for equal catchability by time for Chinook salmon sampled during the mark-recapture experiment in the Kuskokwim River, 2003**.**

Date Tagged	Not Recaptured	Recaptured	Total
6 - 18 June	103	15	118
19 - 25 June	79	13	92
26 June - 1 July	50	13	63
2 - 26 July	78	14	92
Total	310	55	365
	$\chi^2 = 2.10$, df = 3, $P = 0.55$		

Table 9.–Results of a chi-square analysis which compared Chinook salmon that were marked and unmarked. This test was part of the mark-recapture experiment for the Kuskokwim River, 2003.

River	Unmarked[a]	Marked	Total Catch
George	974	1	975
Tatlawiksuk	596	5	601
Kogrukluk	11,723	48	11,771
Takotna	353	1	354
Total	13,646	55	13,701
	$\chi^2 = 5.10$, df = 3, $P = 0.16$		

a George, Tatlawiksuk, and Takotna values represent actual counts only during times weirs were operational. The Kogrukluk river weir was operational throughout the season. Therefore its value represents the total estimate for passage of Chinook salmon.

independent of tagging location (Table 10; $\chi^2 = 0.01$, df = 1, P = 0.91) and gear type (Table 11; $\chi^2 = 1.43$, df = 1, P = 0.23).

After all contingency table analyses were performed and potential sources of bias accounted for, the abundance of Chinook salmon ≥450 mm for the Kuskokwim River upstream of the confluence of the Aniak River was estimated at 103,161 fish (SE = 18,720) with a 95% credibility interval (79,120; 151,800).

One hundred seventy-six Chinook salmon that were radio-tagged in the Kuskokwim River traveled up the Holitna River. These fish were added to the 68 fish that were tagged in the mainstem of the Holitna River and an estimate of 42,013 Chinook salmon (SE = 4,981) was produced for this tributary (Stroka and Brase 2004). Therefore 41% of the total Chinook salmon escapement above the confluence of the Aniak River was estimated to be made up of Holitna River drainage stocks.

Age, Sex and Length Compositions

Diagnostic tests of length selectivity indicated that there was selective sampling in the second event, but the status of selectivity in the first event was unknown (Case IV in Appendix A). Therefore, the age, sex, and length compositions for the population of Chinook salmon in the Kuskokwim River upstream of the confluence of the Aniak River were estimated using Chinook salmon composition estimates at the George, Kogrukluk, Tatlawiksuk, and Takotna river weirs adjusted by summing abundance estimates for each size or age category across strata (Equations 11 and 12; Table 12) .

Ages were determined for 90% of the 603 fish sampled. Composition estimates were 0.57 (SE = 0.04) males and 0.43 (SE = 0.04) females. The dominant age class for males was 1.3 and the dominant age class for females was 1.4 (Table 12). Lengths of males ranged from 430 to 1,020 mm and lengths of females ranged from 600 to 987 mm (Figure 9).

DISCUSSION

This was the second year of a three-year Chinook salmon enumeration project on the Kuskokwim River using mark-recapture and radiotelemetry techniques. As in 2002, the main project objectives were achieved. However, similar to 2002, Aniak River bound Chinook salmon were censored from the analysis due to potential bias associated with bank orientation. In 2003, capture and tagging efforts were relocated further downriver in an attempt to avoid selecting for Aniak River bound Chinook salmon. As a result, the relative proportion of fish bound for this river was much lower and likely more representative of the true population proportion. The number of radio-tagged fish that traveled up the Aniak River suggested that this tributary may represent 20% of the total Chinook salmon population in the mainstem Kuskokwim River drainage above Kalskag. However, south bank orientation was still evident. Because salmon in general have a well-developed homing instinct, their choice of spawning river, tributary, and even riffle appears to be guided by long-term memory of specific odors (Groot and Margolis 1991). The approximate location within the Kuskokwim River drainage where Aniak River bound Chinook salmon begin to detect and respond to their natal water is unknown.

In future years, the Aniak River bound Chinook salmon might be included in the total drainage estimate if radio-tags could be deployed so that no evidence of bank orientation was detectable by robust tests and no other evidence of tagging bias was detected. Ideally, a significant tag

Table 10.-Contingency table analysis comparing rates of recapture with north and south banks of capture for the mark-recapture experiment on Chinook salmon from the Kuskokwim River, 2003.

	Side of River Bank Marked		
	North	South	Total
Recaptured	29	26	55
Not Recaptured	166	144	310
Total	195	170	365
	$\chi^2 = 0.01$, df = 1, $P = 0.91$		

Table 11.-Contingency table analysis comparing sampling gear to Chinook salmon that were recaptured and not recaptured as part of the mark-recapture experiment on the Kuskokwim River, 2003.

	Sampling Gear		
	Gillnet	Fish Wheel	Total
Recaptured	25	30	55
Not recaptured	168	142	310
Total	193	172	365
	$\chi^2 = 1.43$, df = 1, $P = 0.23$		

Table 12.-Estimated proportions, abundance, and mean length by sex and age class for Chinook salmon sampled at the weirs on the George, Tatlawiksuk, Kogrukluk, and Takotna rivers, 2003.

						MEF Length (mm)			
Age[a]	Proportion[b]	SE[b]	Abundance[c]	SE[c]	Sample size[d]	Mean	SE	Min	Max
				Male					
1.2	0.11	0.03	10,856	2,396	87	549	6	430	679
1.3	0.29	0.03	30,330	4,939	196	707	5	514	866
1.4	0.16	0.02	16,325	4,392	66	823	9	666	970
1.5	0.01	0.01	1,527	909	4	977	191	891	1,020
Total[e]	0.57	0.04	59,038	8,881	353				
Total fish[f]	0.57	0.04	58,949	8,827	393	696	6	430	1,020
				Female					
1.3	0.06	0.01	5,685	1,731	27	767	10	600	856
1.4	0.32	0.03	33,510	8,793	145	854	5	700	980
1.5	0.05	0.01	4,928	1,820	17	877	37	796	987
Total[e]	0.43	0.04	44,123	11,190	189				
Total fish[f]	0.43	0.04	44,212	11,170	210	842	5	600	987

[a] Age is represented by the number of annuli formed during river and ocean residence. Therefore, an age of 2.4 represents two annuli formed during river residence and four annuli formed during ocean residence. Because a fish is one year old when the first annulus is formed, an age 2.4 fish is 7 years old.

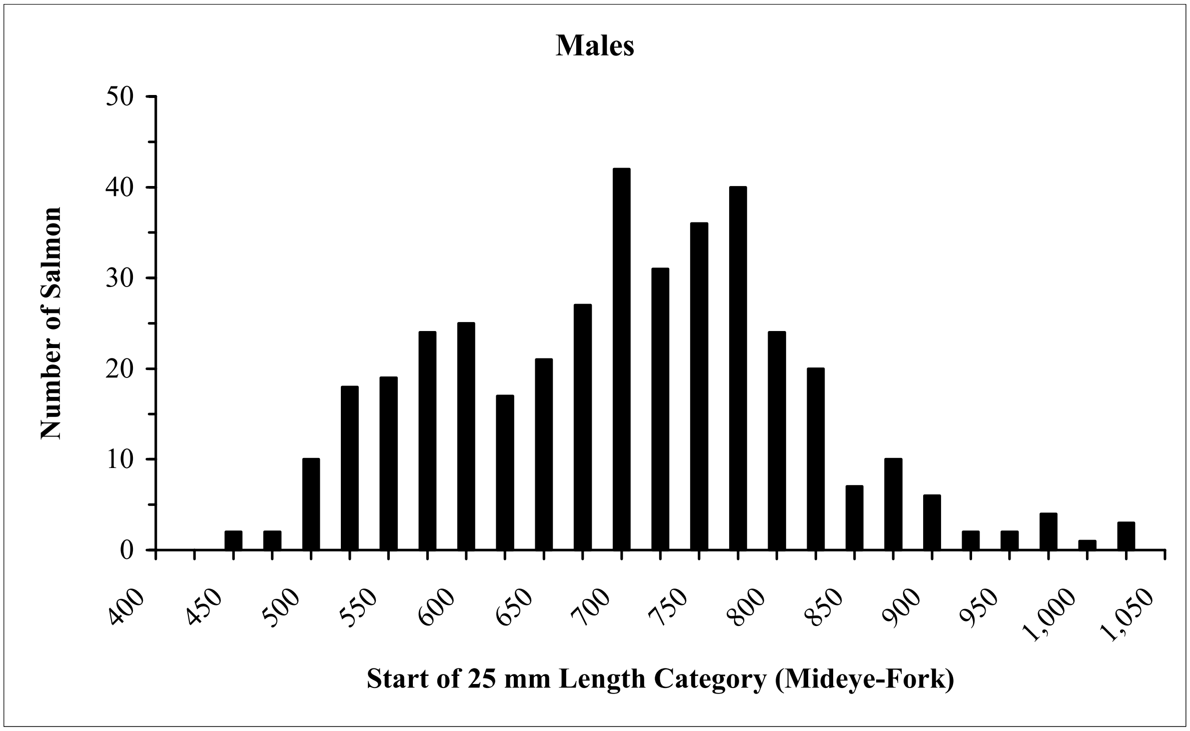
[b] Proportion and SE were based on the age, sex and length data acquired from the Kogrukluk (458), Takotna (71), Tatlawiksuk (45), and George (27) river weirs.

[c] Abundance and associated SE were derived from a Bayesian analysis which were later adjusted to the Chapman estimate of 103,161 (SE = 18,720) Chinook salmon.

[d] Values represent actual fish sampled at the four weirs, including those <450 mm.

[e] Values represent total Chinook salmon for which sex and age could be determined.

[f] Totals include those Chinook salmon for which sex could be determined, including those that could not be aged.



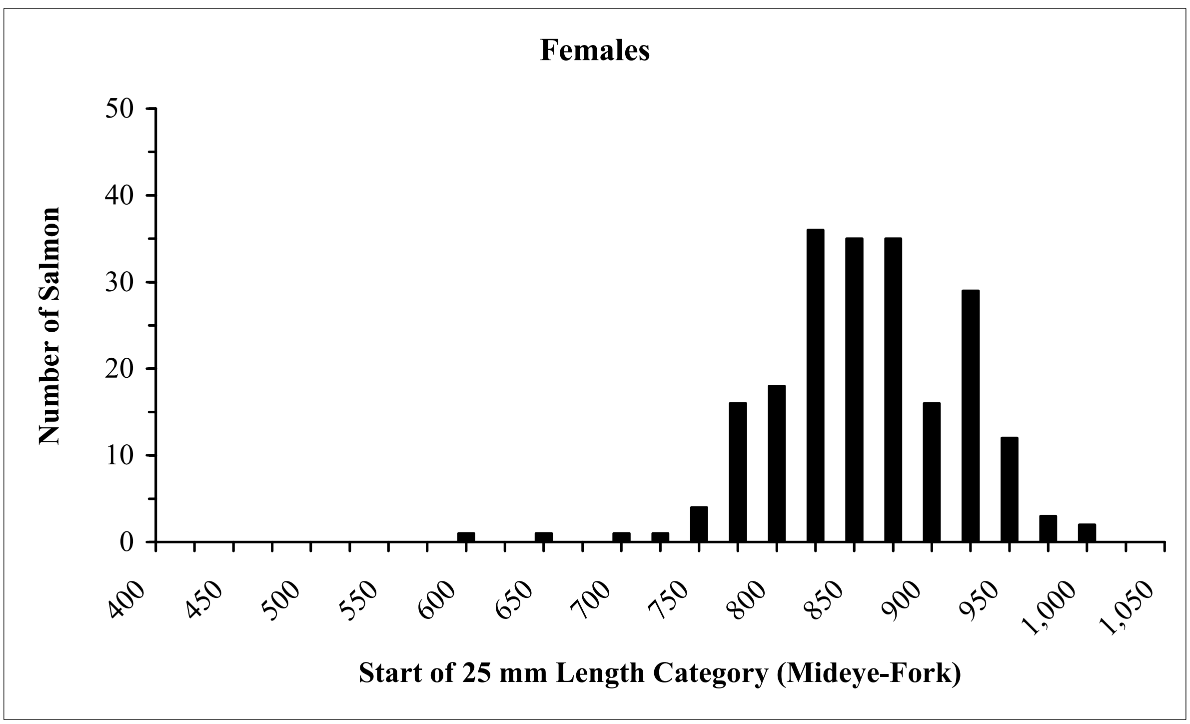


Figure 9.–Length frequency distributions of male and female Chinook salmon sampled at the weirs on the George, Tatlawiksuk, Kogrukluk, and Takotna rivers, 2003.

recovery effort on the Aniak River could provide an estimated marked to unmarked ratio of Chinook salmon in the Aniak River. These data would provide for the evaluation of potential bias due to bank orientation and would potentially allow for adjustments for potential bias. Without an enumeration project on this tributary, such as a weir acquiring a count as well as age, sex, and length composition, an abundance estimate including this drainage may not be possible because incongruities in dispersing radio tags in proportion to stock abundance can not be corrected.

Even though an abundance estimate that included Aniak River stocks was not calculated in 2003, the proportion of radio-tagged fish that traveled up the river provides an indication of the order of magnitude of this run compared to those of the other major tributaries of the Kuskokwim River above Kalskag. The preliminary total aerial survey Chinook salmon estimate for the Aniak, Kipchuk, and Salmon rivers was 6,249 fish for 2003 (C. Whitmore, Commercial Fish Division, Bethel, personal communication). The 2002 aerial survey estimate was 4,707 Chinook salmon. Viewing conditions for the three drainages over the two years were good, except the Aniak River in 2002 was fair to poor. These aerial survey data demonstrate that the 2002 Chinook salmon return to the Aniak River may have been similar or less in magnitude compared to the 2003 return. This supports the theory that the proportion of radio-tagged Chinook salmon migrating up the Aniak River in 2002 was biased high. However it remains unclear as to the extent of the bias (if any) in the proportion of Chinook salmon returning to the Aniak River in 2003.

The mainstem Chinook salmon abundance estimates for 2002 and 2003 could be compared to the Holitna River drainage abundance estimates for these years because of the radiotelemetry project that has been operated concurrently. Using the abundance estimates, the ratio of Chinook salmon in the Holitna River drainage to the Kuskokwim River drainage above the Aniak River for 2003 (43%) was similar to that observed for 2002 (41%). These proportions were similar to the proportions of mainstem radio-tagged Chinook salmon (excluding the Aniak River fish) that entered the Holitna River drainage in 2003 (48%) and 2002 (42%). The Holitna River salmon radiotelemetry project has shown that the Kogrukluk River weir may be a good indicator of Chinook salmon returns for this drainage (Stroka and Brase 2004). However, these estimates are not completely independent, which could explain the similarity in proportions.

If the high water events of 2003 had not precluded acquiring near complete counts of Chinook salmon passing the weirs on the George, Tatlawiksuk, Kogrukluk, and Takotna rivers; then a more precise estimate of all Chinook salmon >450 mm above the Aniak River could have been acquired. There would have been no need to censor tags that had migrated past the weirs when they were inoperable and the catch sample would have been larger. Similarly, larger samples at the weirs for age, sex, and length would also have led to more precise estimates of age, sex, and length compositions. However, even with larger samples it is likely that stratification would still have been required and the same estimation procedures would have been used. Given the size-selectivity associated with gillnet and fish wheel sampling for 2002 and 2003, it is not likely that we will be able to obtain unbiased estimates of age, sex, and size compositions. Those parameters were better estimated from weir data, which provided estimates for escapement and not inriver return.

Compared to 2002, the 2003 run timing curves were more similar for the various spawning stocks and the median dates of passage for the individual stocks were similar ranging from 23 June for the Tatlawiksuk River to 29 June for the George River. In 2003 there were no apparent pattern in run timing curves for upriver stocks (e.g., drainages upriver from McGrath) versus lower-river stocks (e.g., Aniak River). This was in contrast to 2002, where fish that had the farthest to travel were the first to be captured and tagged and those with the shortest distance to travel arrived later in the season. The timing of adult migration and reproduction differs greatly among salmonid populations, but within populations, timing varies only slightly among years (Ricker 1972; Brannon 1987; Groot and Margolis 1991). In 2002, tagging commenced one week later and a disproportionate number of radio-tagged fish were bound for the Aniak River (Stuby 2003). Thus, the discrepancy between 2002 and 2003 may have been a result of earlier sampling efforts, and/or sampling more proportional to stock abundance. However, when spawning aggregations were lumped into the genetically distinct Lower, Middle, and Upper Kuskokwim Groups, the three groups showed fairly distinct run timing patterns despite the disparity in travel distance within each group and geographic proximity of each group. The Lower Kuskokwim Group covers a huge area. So far the Holitna and Hoholitna rivers, have not been assigned a Lower or Middle designation due to a lack of samples. The number of samples sent to the Anchorage genetics lab from this study so far and from 2004 will aid in baseline analysis for these and other tributaries throughout the Kuskokwim River drainage. Although beyond the scope and objectives of this project, it would be interesting to compare run timing patterns of the tributaries between the Aniak River and the mouth of the mainstem Kuskokwim River.

The majority of the 498 radio-tagged Chinook salmon were deemed to have survived tagging and handling. Bernard et al. (1999) provided evidence that adult Chinook salmon captured and handled in rivers during their upstream migration have a tendency, upon release, to pause or move downstream before resuming their upstream migration. In 2003, with the addition of the tracking station near Uknavik, a small number of the radio-tagged fish either traveled past the Uknavik tracking station after being captured and tagged (32) or swam upriver first, then downriver past this tracking station (12). The majority of these fish ended up swimming back upriver and were detected into a spawning location or were located above the tracking station near Red Devil. However, nine of these fish did not return upriver and may have conceivably traveled down and spawned in a lower river location. Three Chinook salmon with bright green spaghetti tags were spotted swimming through the Kwethluk River weir, which is located approximately 240 rkm downstream from the tagging location (K. Harper, US Fish and Wildlife Service, Soldotna, personal communication). Our study was the only known project in the Yukon and Kuskokwim river areas known to be tagging Chinook salmon with bright green spaghetti tags. According to Hinch and Rand (2000), because anadromous salmon migrations are energetically expensive, long-distance migrants they need to be efficient in their use of energy and minimize swimming costs wherever possible. They found that migrating sockeye salmon swim at speeds that minimize energy costs per distance traveled when swimming in slow-current environments. It would seem that the sort of migratory behavior exhibited by some of the radio-tagged Chinook salmon would lead to a higher risk of mortality through depletion of energy reserves. Thus, it was surprising that some of the radio-tagged Chinook salmon were observed traveling approximately 240 rkm out of their way before reaching their spawning tributaries.

In 2003, ADF&G CFD performed a carcass survey on the Aniak River to sample Chinook and chum salmon. The Aniak River drainage was surveyed from Bell Creek on the Salmon River downriver to the mouth of the Aniak River from 11 to 14 August. The primary objectives of this survey were to document locations and densities of Chinook salmon carcasses, gain familiarity with navigating this river and its main tributaries, and evaluate whether it would be possible to collect an adequate number of carcasses for use in future mark-recapture experiments.

According to Heath Sandall, (Alaska Department of Fish and Game, Commercial Fish Division, Fairbanks, personal communication), water clarity was good on the Salmon River beginning approximately 2.5 km upriver from the confluence with the mainstem Aniak River, however, between Bell and Dominion creeks (Figure 10), no Chinook salmon and very few chum salmon were located. At the mouth of the Kipchuk and mainstem Aniak rivers, a few carcasses were found on the gravel bars; however, water clarity was poor. It was concluded that carcass surveys using boats was an ineffective means of acquiring enough Chinook salmon carcasses to determine a marked:unmarked ratio that could be used to describe the population.

PROJECT RECOMMENDATIONS FOR 2004

Sampling procedures in 2003 showed some improvement in dispersing radio tags more proportional to stock abundance compared to 2002. In 2004, CFD is planning on relocating the Kalskag fish wheels approximately 2.5 rkm below Kalskag. The area between Kalskag and the 2004 fish wheel locations is a popular site for drift gillnetting by local fishermen. In order to avoid conflict but still achieve the task of sampling the majority of Chinook salmon further downriver, the SFD crew will continue to sample Chinook salmon from the CFD fish wheels. In addition, they will use drift-gillnets in the lower river area early in the mornings when there are few local fishermen utilizing that area and during the three days per week that the subsistence fishery will be closed per regulation. During the days the subsistence fishery is open, the SFD drift gillnet crew will continue to utilize the 2003 drift gillnet sites.

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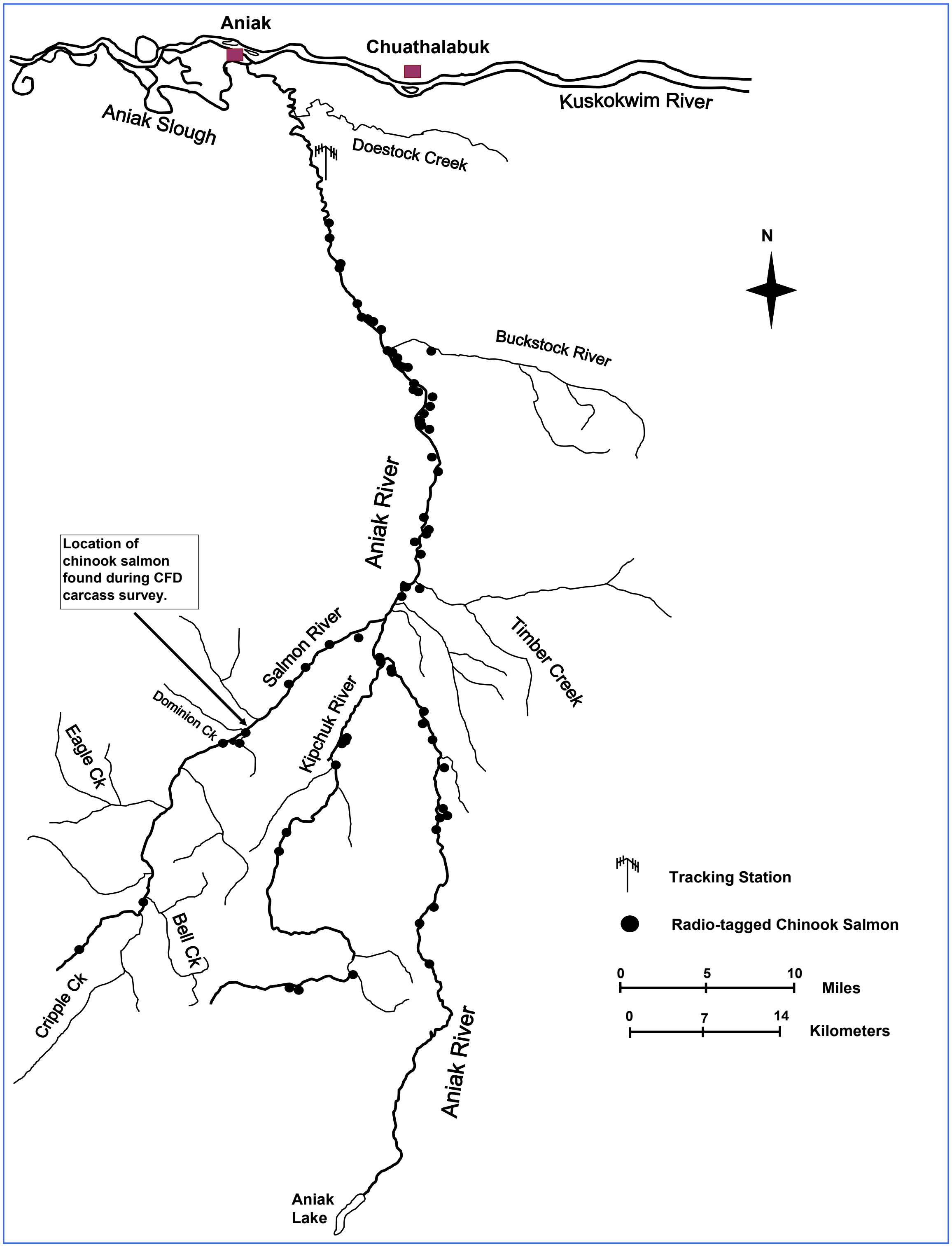

Figure 10.–Map of the Aniak River drainage showing the 70 radio-tagged Chinook salmon that were located during the August aerial survey and the radio-tagged salmon collected during the CFD carcass survey, 2003.

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APPENDIX A

STATISTICAL TESTS FOR ANALYZING DATA FOR SEX AND SIZE BIAS

Appendix A.–Statistical tests for evaluating sex and size bias and the assumptions of a two-event mark-recapture experiment conducted on Chinook salmon in the Kuskokwim River, 2003.

The following statistical tests were used to analyze the data for significant bias due to gear selectivity by sex and length.

A test for significant gear bias by sex was based on a contingency table of the number of males and females that were recaptured and were not recaptured. The chi-square statistic was used to evaluate the bias. If this test indicated a significant bias, then the following tests would be conducted for males and females separately. If this test did not indicate a bias, then males and females would be pooled and the following tests performed on the pooled data.

Tests for significant gear bias by size were based on (A) Kolmogorov-Smirnov two sample tests that compared the sizes of Chinook salmon that constituted the marked sample (First event) and the recaptured sample (Marked fish in the second event); and, (B) Kolmogorov-Smirnov two sample test that compared the distributions of the lengths of fish sampled for age, sex, and length at the four weirs (subsample of the total catch sample) with the recaptured sample. The null hypothesis assumed no difference between the distributions of length for Test A or for Test B. For these two tests there were four possible outcomes.

Case I. Accept both A and B.

There was no size-selectivity during either sampling event.

Case II. Accept A and Reject B.

There was no size-selectivity during the second sampling event but there was size-selectivity during the first.

Case III. Reject A and Accept B.

There was size-selectivity during both sampling events.

Case IV. Reject both A and B.

There was size-selectivity during the second sampling event but the status of size-selectivity during the first was unknown.

-continued-

Depending on the outcome of the tests, the following procedures were used to estimate the abundance of the population:

Case I. One unstratified abundance estimate was calculated and lengths, sexes, and ages from both sampling events were pooled in order to improve precision of the proportions in estimating age, sex, and length composition for the sample.

Case II. One unstratified abundance estimate was calculated and the lengths, sexes, and ages were taken from the second sampling event.

Case III. Both sampling events were completely stratified and abundance was estimated for each stratum. Abundance estimates were summed across strata to get a single estimate for the population. Lengths, ages, and sexes from both sampling events were pooled in order to improve precision of composition proportions and a formula was applied to correct for the size bias in the pooled data.

Case IV. Both sampling events were completely stratified and abundance was estimated for each stratum. Abundance estimates were added across strata to get a single estimate for the population. Also, one unstratified estimate was calculated for the population. Lengths, ages, and sexes from the second sampling event were used to estimate proportions in composition and formulae were applied to correct for size bias to the data from the second event.

Case IVa. If the stratified and unstratified estimates of abundance for the entire population were dissimilar, the unstratified estimate would be discarded. Lengths, ages, and sexes from the second sampling event were used to estimate proportions in composition and a formula was applied to correct for size bias to the data from the second event.

Case IVb. If the stratified and unstratified estimate of abundance for the entire population was similar, the estimate with the larger variance would be discarded. Lengths, ages, and sexes from the first sampling event were used to estimate proportions in compositions and a formula was not applied to correct for the size bias.

APPENDIX B

ARCHIVED DATA FILES

Appendix B.–Data files used to estimate parameters of the Chinook salmon population in the Kuskokwim River, 2003.

Data File	Description
03Geo1.dat[a]	Data file of age, length, and sex data for Chinook salmon sampled at the George River weir, 2003.
03Kog1.dat[a]	Data file of age, length, and sex data for Chinook salmon sampled at the Kogrukluk River weir, 2003.
03Tak1.dat[a]	Data file of age, length, and sex data for Chinook salmon sampled at the Takotna River weir, 2003.
03Tat1.dat[a]	Data file of age, length, and sex data for Chinook salmon sampled at the Tatlawiksuk River weir, 2003.
Kusko River Esc Data-Kogrukluk.xls[a]	Excel spreadsheets with daily and historical counts of Chinook salmon passage through the Kogrukluk River weir, 2003.
Kusko River Esc Data.xls[a]	Excel spreadsheets with daily and historical counts of Chinook salmon passage through the George, Tatlawiksuk, and Takotna River weirs, 2003.
2003 Data.xls[b]	Excel spreadsheets with consolidated capture, aerial, and tracking station data. File also includes determination of fates, final destinations of radio-tagged Chinook salmon, travel times of radio-tagged Chinook salmon to the mainstem tracking stations, run timing of radio-tagged fish into the major tributaries of the Kuskokwim River, and analyses of run timing and survivability differences between fish sampled with drift gillnets vs. fish wheels, 2003.
ASL 2003.xls[c]	Excel spreadsheets with consolidated age, sex, and length data from the George, Tatlawiksuk, Kogrukluk, and Takotna rivers weirs. File also contains results from contingency table analysis testing for sex bias and the KS tests that examined size bias for the mark-recapture experiment.
Tagging schedule for 2003.xls[c]	Excel spreadsheets with daily sampling objectives and actual numbers of Chinook salmon captured and radio-tagged in 2003.
Estimate Analysis.xls[c]	Contingency table analyses to test assumptions for the mark-recapture experiment and stratification breaking points.

[a] Data files have been archived and are available from the Alaska Department of Fish and Game, Commercial Fisheries Division, 333 Raspberry Road, Anchorage, 99518-1599.

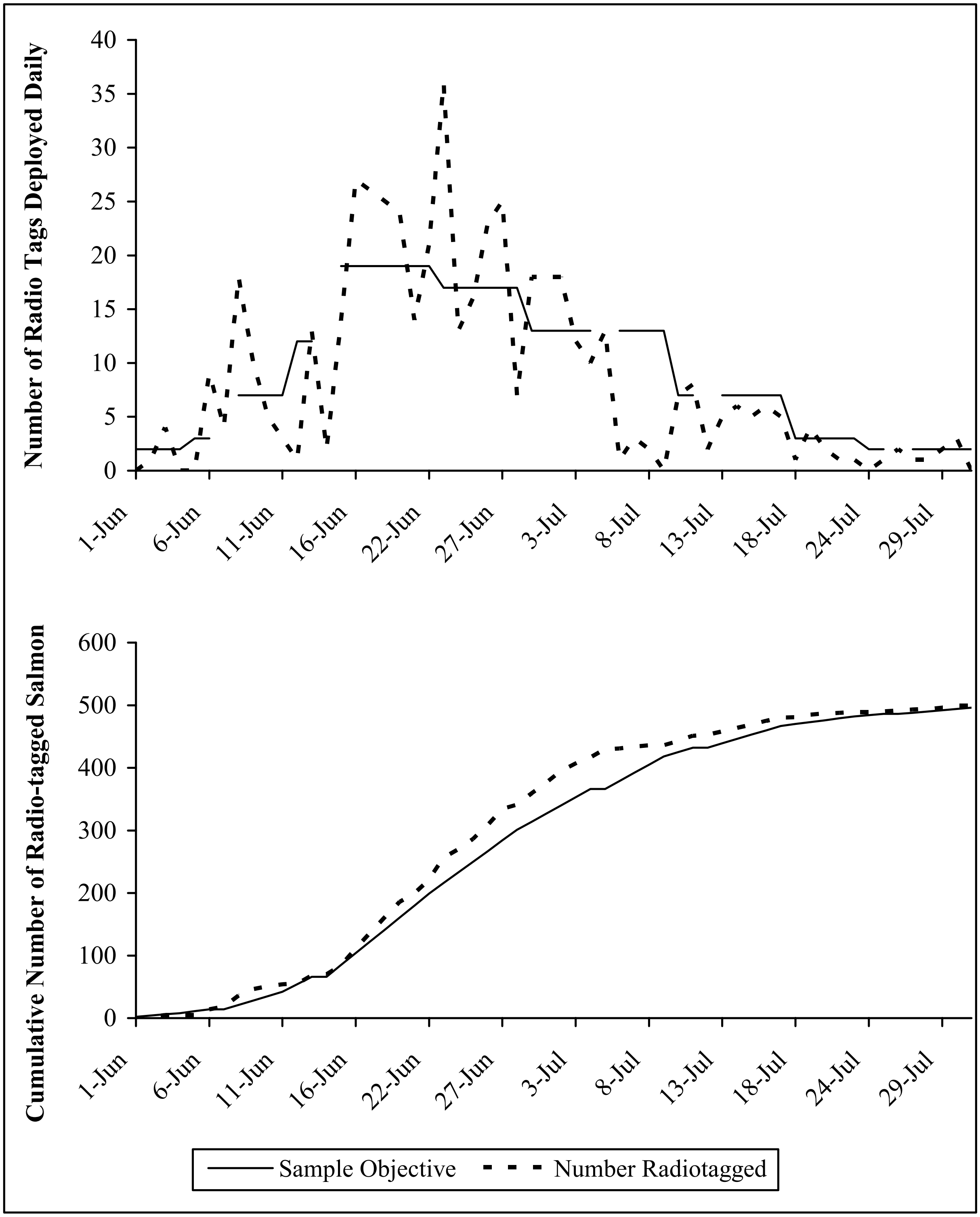
[b] Data files have been archived and are available from the Alaska Department of Fish and Game, Sport Fish Division, Research and Technical Services, 333 Raspberry Road, Anchorage 99518-1599.

[c] Data files have been archived at the Alaska Department of Fish and Game, Division of Sport Fish, 1300 College Road, Fairbanks, Alaska 99701 and are available from the author.

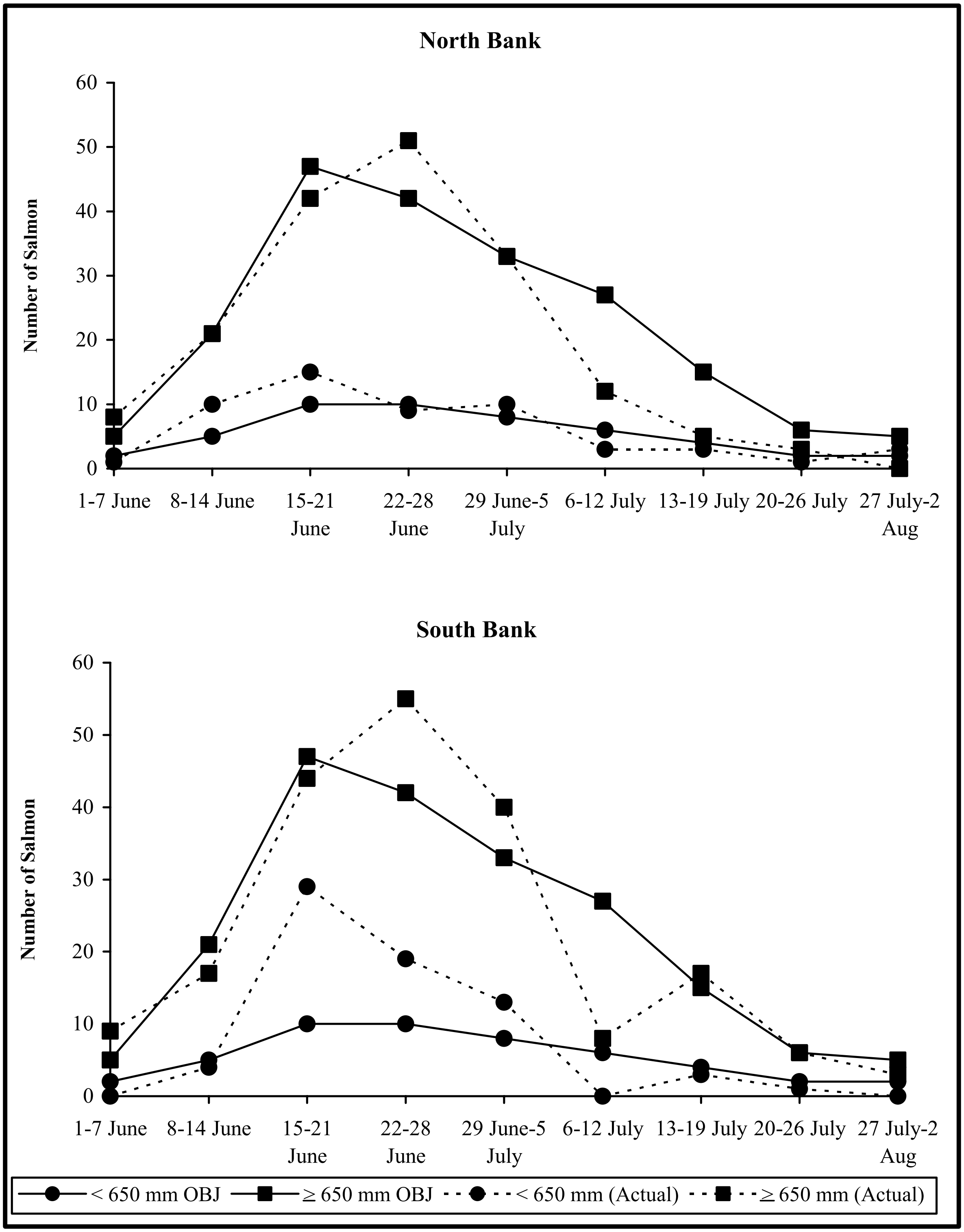
APPENDIX C

SAMPLING OBJECTIVES AND ACTUAL DAILY NUMBER OF CHINOOK SALMON SAMPLED

Appendix C1.–Daily and cumulative number of Chinook salmon that were radio-tagged in the Kuskokwim River versus the sampling objective for 2003.



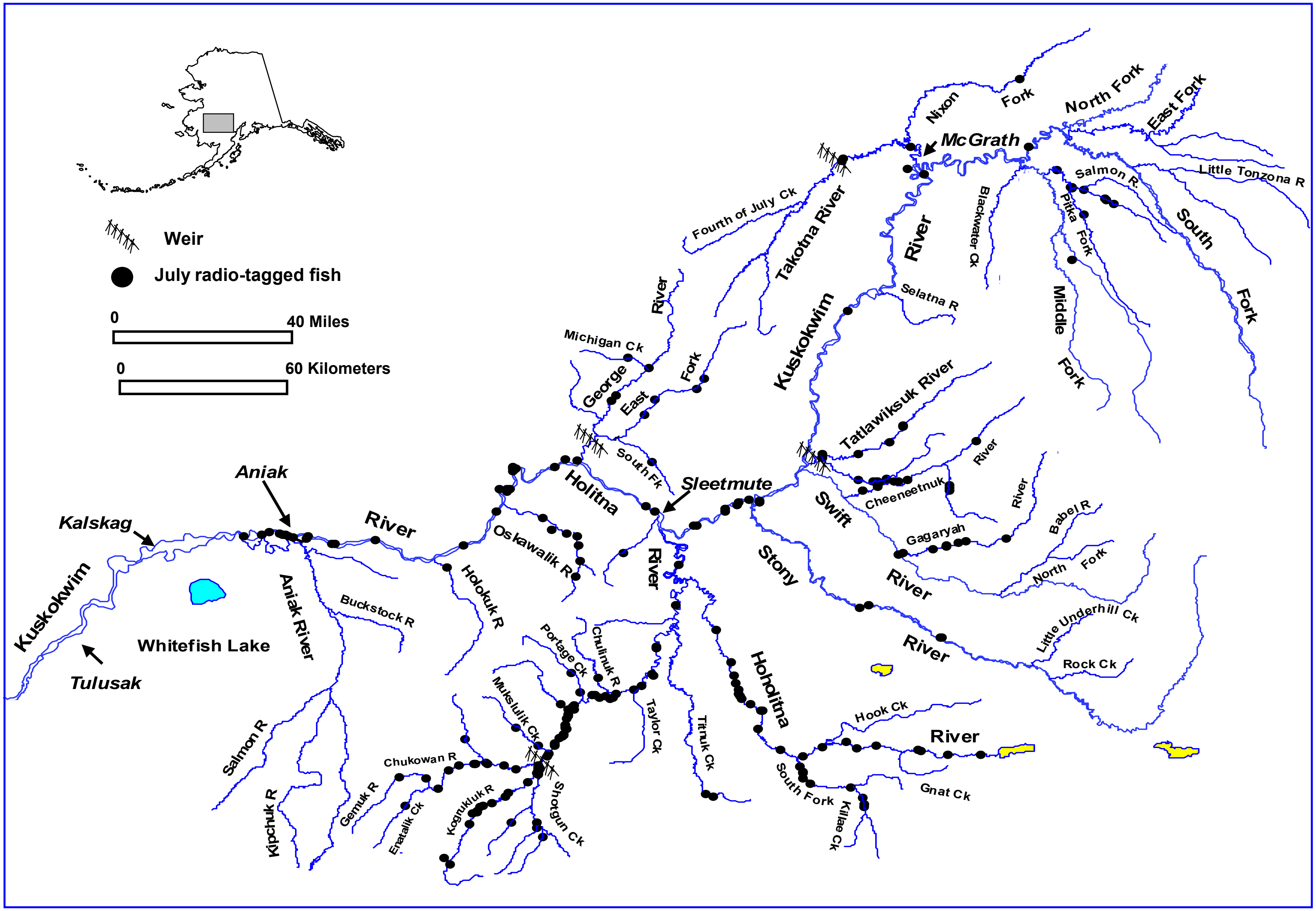
Appendix C2.–Chinook salmon size classes sampled and radio-tagged on the north and south banks of the Kuskokwim River (Actual) versus the pre-season objectives (OBJ).



APPENDIX D

APPROXIMATE LOCATIONS OF CHINOOK SALMON DETECTED DURING THE JULY AND AUGUST AERIAL SURVEYS

Appendix D1.–Map of the Kuskokwim River drainage showing the approximate locations of radio-tagged Chinook salmon that were detected during the July aerial survey flight in 2003.



Appendix D2.–Map of the Kuskokwim River drainage showing the approximate locations of radio-tagged Chinook salmon that were detected during the August aerial survey flight in 2003.