Fishery Data Series No. 14-32

Estimation of Chinook Salmon Abundance and Spawning Distribution in the Unalakleet River, 2009

by

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and

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August 2014

Alaska Department of Fish and Game **Divisions of Sport Fish and Commercial Fisheries**

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Weights and measures (metric)

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

Weights and measures (English)

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

Time and temperature

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

Physics and chemistry

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

General

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

Mathematics, statistics

all standard mathematical signs, symbols and abbreviations	
alternate hypothesis	H_A
base of natural logarithm	*e*
catch per unit effort	CPUE
coefficient of variation	CV
common test statistics	(F, t, 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. 14-32

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ABSTRACT

The Unalakleet River supports the largest and arguably most important Chinook salmon run in Norton Sound. Salmon escapement in the Unalakleet River drainage is monitored by a counting tower located on the North River, which is the largest tributary of the Unalakleet River. Prior radiotelemetry research documented that 37% (1997) and 40% (1998) of drainagewide Chinook salmon escapement migrated up the North River. A stable proportion over time would indicate that the North River counting tower is a reliable indicator of the total Chinook salmon escapement in the Unalakleet River drainage. However, it is unknown how much this proportion varies over several life cycles of Chinook salmon. In 2009, the first year of a 2-year study, radiotelemetry was used to measure the proportion of Unalakleet River escapement that migrated past the North River counting tower, and to estimate drainagewide abundance.

Between June 15 and July 20, 142 Chinook salmon were captured by drift gillnetting in the lower portion of the Unalakleet River and fitted with esophageal radio tags. Final spawning destinations of radiotagged Chinook salmon were determined using 3 stationary receiving stations positioned throughout the drainage, boat tracking surveys, and 3 aerial flights of the entire drainage. Chinook salmon were also sampled for age, sex, and length data above the North River counting tower and in the Unalakleet River above the North River confluence.

Chinook salmon migrated into all tributaries of the drainage except the South River. Chinook salmon that migrated upriver to spawn were concentrated in 2 areas: one in the North River, and one in the mainstem of the Unalakleet River near the mouth of Old Woman River. The proportion of Chinook salmon entering the Unalakleet River drainage that migrated up the North River was estimated to be 34% (SE = 9%) and was not significantly different from the estimates in 1997 and 1998. An estimated 2,355 (SE = 190) Chinook salmon passed the North River counting tower, resulting in a population abundance estimate of 6,888 (SE = 2,422) Chinook salmon for the entire Unalakleet River drainage. Chinook salmon ages ranged from age-1.0 to age-1.4 and -2.3. Most females in both drainages were age-1.4; males in the Unalakleet River were dominated by age-1.2, and males in the North River were dominated by age-1.3.

Key words: Chinook salmon, *Oncorhynchus tshawytscha*, Unalakleet River, Norton Sound, counting tower, North River, escapement, radiotelemetry, spawning distribution, mark-recapture.

INTRODUCTION

The Unalakleet River is a clear, runoff-fed river located north of the Yukon River that drains into Norton Sound (Figure 1). The Unalakleet River drainage is approximately 2,700 square km, flows southwesterly through the Nulato Hills (Sloan et al. 1986), and supports populations of Chinook salmon *Oncorhynchus tshawytscha*, Coho salmon *O. kisutch*, chum salmon *O. keta*, and pink salmon *O. gorbuscha* salmon. The Unalakleet River also supports resident populations of Dolly Varden *Salvelinus malma* and Arctic grayling *Thymallus arcticus*.

The Unalakleet River Chinook salmon stock has been subjected to substantial commercial, subsistence, and sport fisheries in the past. Nearly all commercial and subsistence users are residents of the village of Unalakleet, which is situated at the mouth of the river (Figure 1). Subsistence users fish in the coastal marine waters near the mouth of the river and in the lower parts of the main river. Similarly, the commercial harvest occurs by set gillnet in the coastal marine waters around the mouth. The majority of Chinook salmon caught in marine waters are assumed to be Unalakleet River stock; however, an unknown proportion of the catch is suspected to be Yukon River stock (Estensen and Evenson 2006). Users of the sport fishery include local residents, and fishermen who fly in to take advantage of several of the guide services. The sport fishery occurs in the main river from the mouth up to the Chiroskey River and several kilometers up the North River (Figure 1).

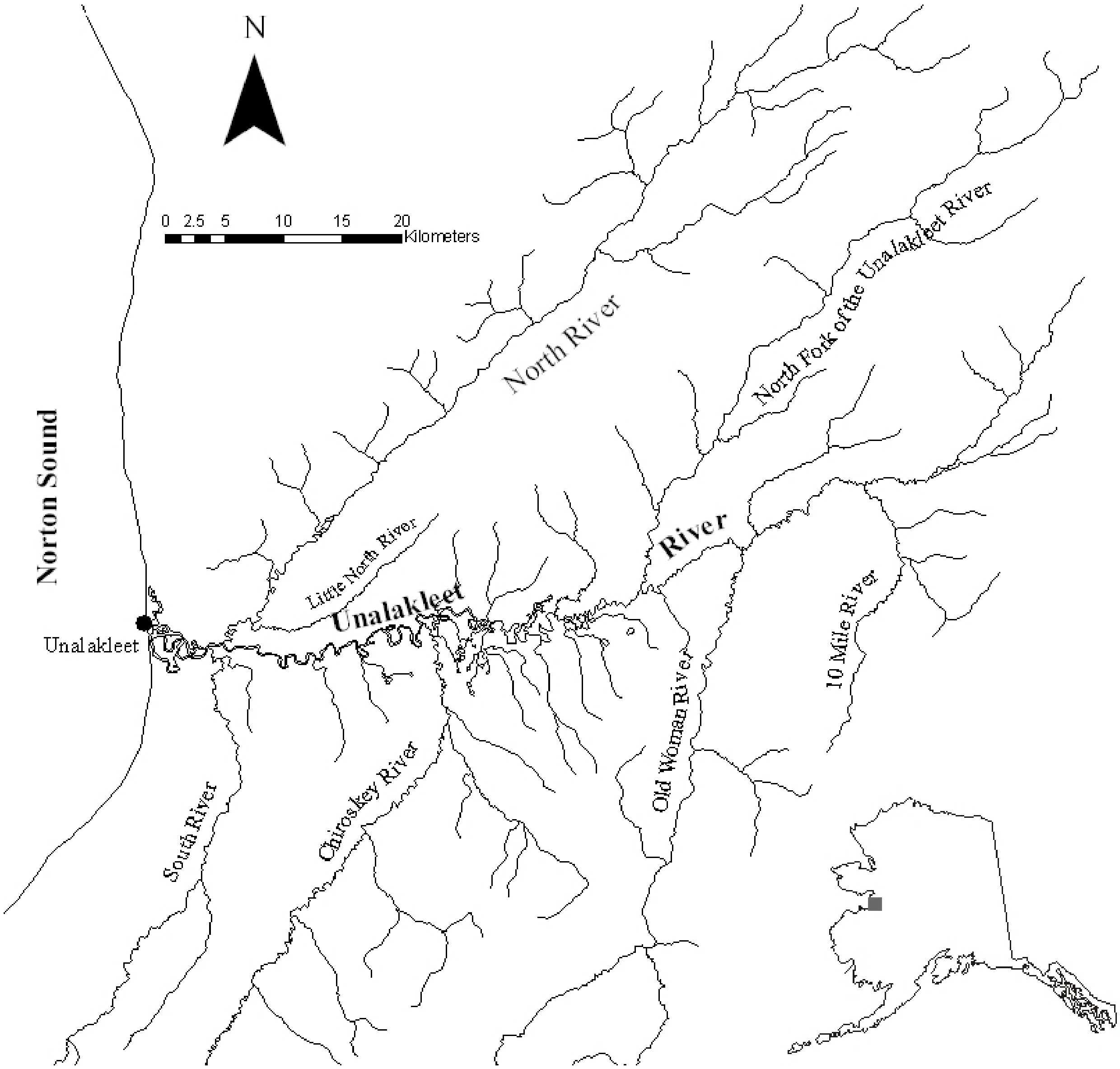

Figure 1.–Map of the Unalakleet River and its tributaries.

Escapement of Unalakleet River Chinook salmon is monitored by a counting tower located on the North River, a set gillnet test fishery (monitored by the Alaska Department of Fish and Game Division of Commercial Fisheries) located 5 km from the mouth, and aerial surveys of index areas in the Unalakleet and Old Woman rivers (Figure 2). The North River is the largest tributary of the Unalakleet River, and its confluence with the mainstem Unalakleet River is 8 km from the mouth (Figure 2). In 2009, the tower was operated by the Alaska Department of Fish and Game (ADF&G) Division of Commercial Fisheries (CF) in conjunction with the Norton Sound Economic Development Corporation (NSEDC). During years when weather and conditions have allowed, aerial surveys were conducted on index areas of the mainstem Unalakleet River and the Old Woman River. Chinook salmon sustainable escapement goals (SEGs) have been established for the Unalakleet River aerial survey index area (550–1,100), and for the North River (1,200–2,600), which is assessed with the counting tower (Brannian et al. 2006).

Run strength of Chinook salmon in the Unalakleet River drainage has varied annually as indicated by past tower counts and by commercial and subsistence harvests. Estimates of escapement past the North River counting tower have varied from 4,185 fish in 1997 to 905 fish in 2008 (Table 1). The Unalakleet River Chinook salmon stock has been listed as a stock of yield concern as a result of poor returns and escapements in recent years (Estensen and Evenson 2006). Since 2003, the lower end of the North River counting tower SEG has been achieved only once in 2007 (Table 1).

Commercial, subsistence, and sport harvests of Chinook salmon have been declining in recent years because of low returns and subsequent management actions. Since 1961, commercial harvests have ranged from 12,621 in 1985 to 4 in 2002. However, since 2001, directed commercial fishing for Chinook salmon has been restricted every year except for 2002 (Table 1, Soong et al. 2008). Over the past 5 years (2004–2008), the commercial harvests of Chinook salmon in the Unalakleet Subdistrict have averaged 43 fish (Table 1). Records of subsistence harvests have ranged from 90 fish in 1966 to 6,325 fish in 1997 (Table 1; Soong et al. 2008). The recent 5-year average subsistence harvest (2004–2008) was 2,003 fish, and the 2008 harvest was estimated at 1,279 Chinook salmon. Restrictive actions were taken in the subsistence fishery in 2003, 2004, and 2006 (Soong et al. 2008). The sport fish harvest over the 5-year period from 2003–2007 has averaged 321 fish, or about 13% of the total Unalakleet River Chinook salmon harvests (Table 1; Scanlon 2009). In 2007, the estimated sport fish harvest of 147 fish was about 9% of the total Chinook salmon harvest. Restrictive actions were taken in the sport fishery in 2003, 2004, 2006, and 2007.

To determine the proportion of the Unalakleet River Chinook salmon escapement that migrated past the North River counting tower, a radiotelemetry study was conducted in 1997 and 1998. The results demonstrated a consistent proportion (37%–40%) of Chinook salmon migrating up the North River and suggested that the North River counting tower may be an appropriate gauge for determining run strength in the entire Unalakleet River drainage (Wuttig 1998, 1999). Additionally, these results suggested that discrepancies between the North River tower counts and aerial surveys of the Old Woman River and Unalakleet River index areas may have been due to inconsistent and unreliable aerial counts (Wuttig 1998, 1999). Nevertheless, 2 sequential years of telemetry data are inadequate for understanding long-term variability in spawning distribution of Chinook salmon under varied environmental conditions. Knowledge of the extent of this variability is important for managers using the North River counting tower as a gauge of overall run strength in the Unalakleet River drainage.

The goal of this project was to determine whether the proportion of Chinook salmon migrating past the North River counting tower was significantly different from that measured by Wuttig (1998, 1999) and to estimate drainagewide abundance of Chinook salmon in the Unalakleet River drainage using 2-event mark–recapture techniques. Escapement of Chinook salmon was interpreted as the abundance estimate minus the sport fish harvest of Chinook salmon in the drainage.

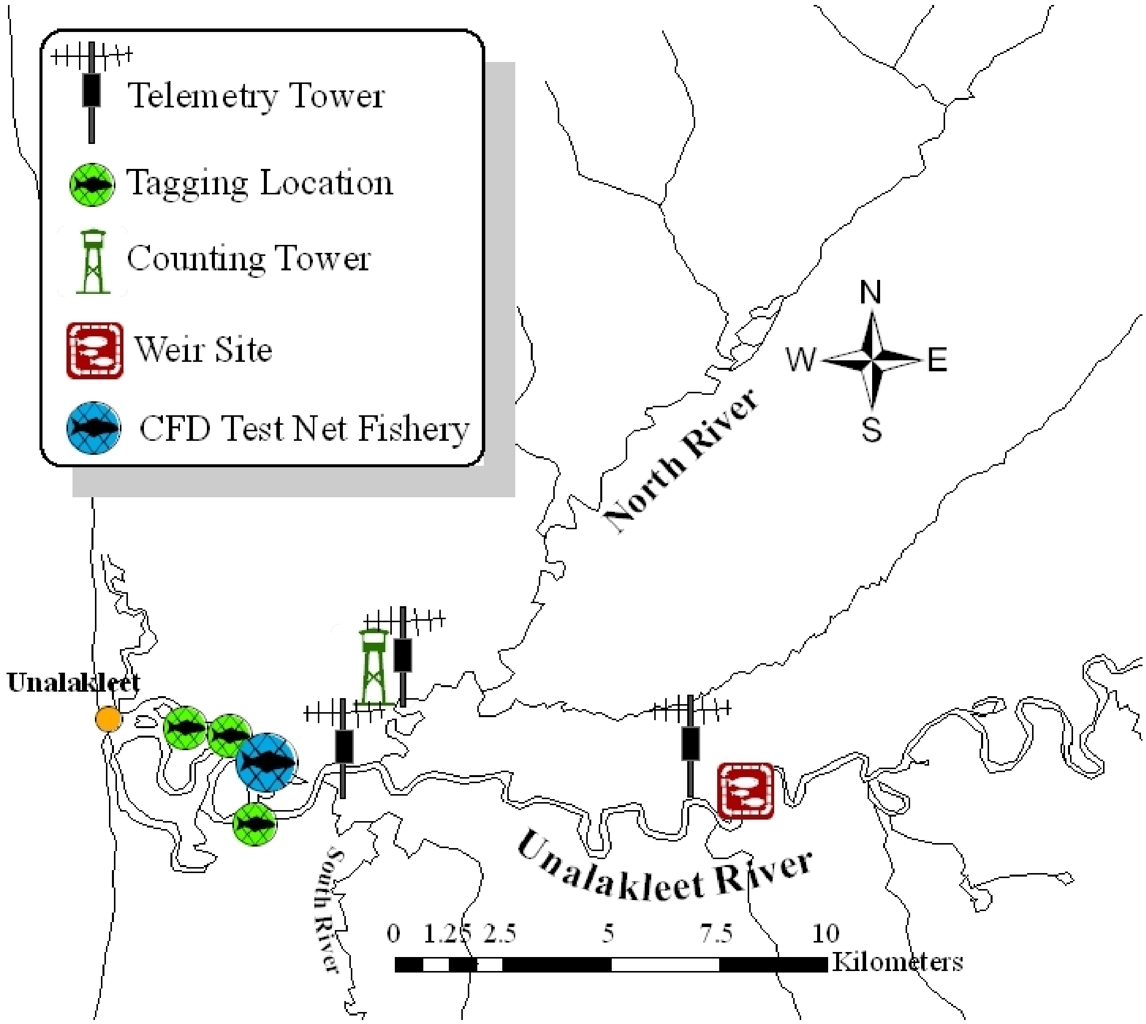

Figure 2.–Chinook salmon tagging locations, tracking station locations, ADF&G-CF test net, North River counting tower, and proposed weir location in the Unalakleet River drainage, 2009.

Table 1.–Unalakleet River Chinook salmon North River tower counts, CFD test fishery catch, District 6 commercial harvest, estimated District 6 subsistence harvest, estimated sport catch, and estimated sport harvest 1985–2008.

Year	North River Tower Counts	CF Test Fishery Catch	District 6 Commercial Harvest	Estimated District 6 Subsistence Harvest	Estimated Unalakleet River Sport Catch	Estimated Unalakleet River Sport Harvest
1985	1,426	193	12,621	1,397		
1986	1,613	52	4,494			
1987		52	3,246			
1988		15	2,218			
1989		50	4,402			
1990		43	5,998	2,476		
1991		36	4,534			
1992		25	3,402		476	117
1993		94	5,944		2,340	382
1994		35	4,400	5,294	517	379
1995		99	7,617	5,049	588	259
1996	1,197	138	3,644	5,324	2,059	384
1997	4,185	202	9,067	6,325	5,144	842
1998	2,100	110	6,228	5,915	1,539	513
1999	2,263	63	1,927	4,504	669	415
2000	1,046	61	582	2,887	1,045	345
2001	1,337	79	116	3,662	542	250
2002	1,484	44	4	3,044	835	544
2003	1,452	25	10	2,585	505	97
2004	1,105	29	22	2,801	1,930	356
2005	1,019	78	101	2,115	431	216
2006	906	79	12	2,155	2,511	394
2007	1,950	96	13	1,665	776	147
2008	905	123	65	1,279	796	580

OBJECTIVES

This was the first year of a 2-year study (2009–2010). The objectives for 2009 were to

1. estimate the proportion of the Chinook salmon escapement migrating past the counting tower on the North River such that the estimate was within 7.5 percentage points of the actual value 90% of the time, to statistically compare this estimate to those documented in 1997 and 1998 (Wuttig 1998, 1999);
2. estimate the abundance of Chinook salmon escaping into the Unalakleet River drainage such that the estimate was within 35% of the actual value 90% of the time;
3. estimate the proportions of the Chinook salmon escapement migrating up the mainstem Unalakleet, Old Woman, Chiroskey, 10 Mile, and North Fork rivers such that the estimates were within 9 percentage points of the actual values 90% of the time;
4. estimate the age, sex, and length composition of the Chinook salmon escapement into the Unalakleet and the North rivers such that all estimated proportions were within 10 percentage points of the true value 95% of the time; and,
5. document the locations of Chinook salmon spawning areas throughout the Unalakleet River drainage.

METHODS

This study used mark–recapture and radiotelemetry techniques to estimate drainagewide abundance and spawning distribution of Chinook salmon. Abundance was estimated using a 2-event mark–recapture experiment for a closed population (Seber 1982). The first event consisted of Chinook salmon being captured and marked using radio tags in the mainstem Unalakleet River below the confluence with the North River. The second event consisted of the total number of Chinook salmon that were counted past the North River counting tower. Radiotagged Chinook salmon that passed the North River tower served as marked fish in the second event. All radiotagged Chinook salmon were sampled for age and length data (sex was indeterminate at the tagging location). To evaluate mark–recapture assumptions of equal probability of capture for all fish, age, sex, and length (ASL) sampling was conducted above the North River tower and in the Unalakleet River upstream from the capture site (referred to in this report as upriver sampling). The spawning distribution of Chinook salmon was estimated by apportioning estimates of passage past the marking site within temporal marking strata, based on the proportions of radiotagged fish migrating to each spawning area within each marking stratum.

CAPTURE AND TAGGING

Chinook salmon were captured with drift gillnets in a stretch of river running from 1.5 km above the Unalakleet River mouth to 3 km below the North River mouth (Figure 2). This tagging location was upstream from the commercial fishery and the majority of the subsistence effort, and downstream from the majority of the sport fishing effort. Net mesh sizes fished over the course of the project measured 6¾, 7¼, and 8 in stretch measure.

The crew began standardized fishing for Chinook salmon on June 15 with 8 in gillnets. Daily shifts began 3–4 hours before high tide and continued until 300 minutes of soak time had been achieved. It became apparent that this amount of effort was insufficient when the CF test net fishery began catching Chinook salmon and the tagging crew was not. On June 23 the crew began fishing in 2 shifts, one around the high tide and the other in the evening from 1800 until approximately 0100. On June 25 the crew began using 6 ¾ in and 7 ¼ in gillnets and eventually settled on 6¾ in nets for the remainder of the season. Fishing continued until catches had diminished to fewer than 1 fish per day for several days. The final day of fishing was July 19.

After capture, Chinook salmon were placed in a large holding tub and received a Model Five pulse encoded radio tag made by ATS[1] along with a numbered Floy™ tag. Each radio tag was distinguishable by its frequency and encoded pulse pattern. Three frequencies spaced approximately 10 kHz apart in the 150–151 MHz range with 50 encoded pulse patterns per frequency were used for a total of 150 uniquely identifiable tags. Transmitters were 5.5 cm long and 1.9 cm in diameter, weighed 24 g in air, and had a 30 cm external whip antenna. These radio tags were inserted through the esophagus and into the upper stomach of the fish using a 45 cm polyvinyl chloride (PVC) tube with a diameter equal to that of the radio tags. The end of the PVC tube was slit lengthwise to allow for the antenna end of the radio transmitter to be seated into the tube and held in place by friction. Radio tags were pushed through the esophagus and seated using a PVC plunger, slightly smaller than the inside diameter of the first tube, such that the antenna end of the radio tag was 0.5 cm beyond the base of the pectoral fin. Salmon were also measured to the nearest 5 mm lengths from mid eye to tail fork (METF). After sampling, Chinook salmon were placed into quiet backwater areas upstream of the capture area for recovery. The entire handling process required approximately 2–3 min per fish.

Both the radio and Floy™ tags were labeled with return information to facilitate identification of the final fates of all fish (i.e., harvested in sport, commercial, or subsistence fisheries). Flyers describing the project and how to return the tags were posted in public locations throughout Unalakleet and with the local sport fish guiding services. To avoid fishers targeting the tagged fish, no lottery or other monetary compensation was awarded for return of the tags.

The Unalakleet River Chinook salmon stock has relatively compressed runs with high interannual variation in timing (Tables 2 and 3). Given these data, a flexible tagging schedule was employed to proportionally radiotag Chinook salmon in relation to their true run timing. The tagging schedule required one or two tags to be deployed per day until either more than two Chinook salmon were gillnetted per hour or the CF test fishery captured at least three Chinook salmon in a single day. Once this trigger was reached, tags were deployed on a schedule such that approximately 90% of the tags would be deployed over the next three weeks.

The North River counting tower was used to gauge the tagging schedule according to the historical difference in the run timing past the counting tower compared to the run timing as recorded at the test fishery. Historically, run timing at the counting tower has consistently lagged behind the test fishery catches such that Chinook salmon do not begin passing the counting tower in significant numbers until approximately 50% of the annual Chinook salmon catch has been recorded in the test fishery (Tables 2 and 4). The date at which the North River counting tower began to record significant Chinook salmon passage was used as a check on the tagging schedule. If less than 40% of the tags had been deployed by this date, the tagging rate would be increased. If more than 65% of the tags had been deployed by this date, the tagging rate would be reduced.

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1. Advanced Telemetry Systems, Isanti, MN. Product names are included for completeness but do not constitute endorsement.

Table 2.–Earliest, latest, and average dates (based on 1996–2007 data) at which the CF test fishery and North River counting tower reached various cumulative percentages of the season's Chinook salmon run.

	CF test fishery			North River counting tower		
Cumulative Percentage	Earliest Date	Average Date	Latest Date	Earliest Date	Average Date	Latest Date
10%	6/7	6/17	7/1	6/26	7/1	7/11
20%	6/9	6/20	7/4	6/28	7/3	7/15
25%	6/9	6/21	7/5	6/28	7/3	7/16
50%	6/13	6/28	7/8	6/30	7/8	7/19
75%	6/24	7/5	7/19	7/5	7/14	7/21
80%	6/25	7/7	7/19	7/9	7/15	7/22
90%	7/1	7/10	7/21	7/14	7/19	7/24

Table 3.–Minimum, maximum, and average number of days that Chinook salmon took to complete the central percentage of their run in the Unalakleet River as recorded in the CF test fishery between 1996 through 2007.

Central Percentage of Run	Min. No. of Days	Max. No. of Days	Average No. of Days	95% C.I.
50%	6	28	15.0	10.9–19.1
60%	7	34	17.2	13.2–21.1
80%	13	42	22.8	18.6–26.9

Table 4.–Minimum, maximum, and average cumulative proportion of the CF test fishery catch corresponding to the point at which the North River counting tower reached 5% and 10% of its recorded run for the years between 1997 and 2007.

Cumulative passage at the North River counting tower	Minimum observed cumulative proportion of CF test fishery catch	Maximum observed cumulative proportion of CF test fishery catch	Average cumulative proportion of CF test fishery catch	95% confidence interval of cumulative proportion of CF test fishery catch
5%	0.31	0.79	0.51	0.42–0.60
10%	0.44	0.84	0.60	0.52–0.68

UPRIVER SAMPLING

Seining was conducted in the Unalakleet River upstream from the North River confluence and in the North River upstream from the counting tower (Figure 2) once fish were counted passing the North River tower. Both rivers were sampled as time allowed. The ADF&G CF performed much of the sampling in the Unalakleet River, and the ADF&G Division of Sport Fish (SF) performed some Unalakleet River sampling and all of the North River sampling. Fish were sampled in any river section that appeared clear of debris and snags and contained Chinook salmon.

Seining was conducted with a small boat and a 150 ft x 8 ft beach seine. Two people anchored one end of the seine on the beach while the boat driver backed out from the beach and encircled Chinook salmon. The crew drifted the seine for as long as river conditions allowed while the motor was used to herd fish upriver into the seine. The boat then pulled the seine into the beach where the crew finished bagging and pulling in the seine. Captured fish were held in the seine while samples were taken.

All Chinook salmon captured were given an adipose fin clip to identify them as being captured upriver. All captured fish were inspected for tags and sampled for length, sex, and age. To determine age, 3 scales were removed from the left side of each 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) and placed on gum cards. In the postseason, scale impressions were 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).

Radiotracking Equipment and Tracking Procedures

Radiotagged Chinook salmon were tracked and spawning destinations were discerned through the use of 3 stationary radiotracking towers, 3 aerial radiotracking surveys, and periodic boat tracking surveys in the lower river. The first tower was located 200 yards up the South River, the second tower was located at the North River counting tower, and the last tower was located on the Unalakleet River several kilometers above the confluence with the North River (Figure 2).

Each tracking tower included one deep-cycle gel cell battery, an 80-watt solar array, an ATS model R4500c receiver, an antenna switching box, a weatherproof metal housing box, and two 4-element Yagi antennas (one aimed upstream and the other downstream). The receiver was programmed to scan through the frequencies at 3-second intervals using both antennas simultaneously. When a radio signal of sufficient strength was encountered the receiver paused for 6 seconds, at which time the data logger recorded the frequency, code, signal strength, date, and time for each antenna. Cycling through all frequencies required 2–15 min depending on the number of active tags in reception range. Data were downloaded weekly onto a portable computer.

The distribution of radiotagged salmon throughout the Unalakleet River drainage was further determined by aerial and boat tracking surveys. Three aerial tracking surveys from fixed-wing aircraft and weekly boat tracking surveys were used to 1) locate tags in areas other than those monitored with tracking towers; 2) locate fish that the tracking stations failed to record; and 3) validate that a fish recorded on one of the data loggers did migrate into a particular stream. Boat tracking surveys were restricted to the mainstem of the Unalakleet River below the Chiroskey River and up the North River to the upriver sampling site. Aerial surveys were performed on July 14, July 27, and August 6, and included all tributaries and tertiary streams.

FATES OF RADIOTAGGED CHINOOK SALMON

To facilitate data analysis, each fish was assigned a final location based on their farthest upriver location. Each radiotagged fish was assigned 1 of 6 possible fates based on information collected from aerial and boat tracking surveys and from stationary data logging stations.

> ***Fate 1)*** *In the North River* – a fish that was determined to have entered the North River, passed the North River tracking tower, and remained above the tracking tower for at least 7 days.
>
> ***Fate 2)*** *In the Unalakleet River and tributaries* – a fish that was determined to have migrated up the mainstem of the Unalakleet River past the North River and either remained in the mainstem or migrated to any of the upriver tributaries including the South River, the Chiroskey River, the North Fork of the Unalakleet River, the 10 Mile River, and the Old Woman River.
>
> ***Fate 3)*** *Dead/regurgitated* – a fish that did not migrate past the confluence of the North and Unalakleet rivers was assumed to have died and/or regurgitated its radio tag.
>
> ***Fate 4)*** *Harvested below tracking stations* – a fish that was determined to have been harvested by a commercial, subsistence, or sport fisherman downstream from the North, Unalakleet, or South river tracking stations, that had not been recorded above a tracking station for at least 7 days.
>
> ***Fate 5)*** *Harvested above tracking stations* – a fish that was determined to have been harvested by a subsistence or sport fisherman upstream from the North, Unalakleet, or South river tracking stations and that had been above the tracking station for at least 7 days.
>
> ***Fate 6)*** *Backed out/unknown* – a fish that was tagged and never recorded at any tracking stations or on any aerial or boat tracking surveys. This fate included fish that were recorded at or below the tracking stations but not upriver of the stations or on any of the boat and aerial tracking surveys. Additionally, fish that migrated past a tracking tower but remained above the tower for less than 7 days before migrating back down and out of the drainage were considered to have backed out of the drainage.

Radiotagged Chinook salmon given fates 1, 2, and 5 were used to estimate abundance; those with fates 1 and 2 were used to describe spawning distribution; and those with fates 3, 4, and 6 were culled from all analyses.

ABUNDANCE ESTIMATION

This experiment was designed so that Chapman's modification to the Petersen estimator (Chapman 1951) could be used to estimate abundance, contingent on the results of diagnostic testing for equal probability of capture (described in the following section), and such that a temporally stratified Darroch (1961) estimate could be performed if diagnostics indicated such a necessity.

Conditions for a Consistent Petersen Estimator

For the estimate of abundance from this mark–recapture experiment to be unbiased, certain assumptions must be met (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, II, and III and one of the conditions of Assumption IV must be satisfied.

Assumption I: The population was closed to births, deaths, immigration, and emigration.

This assumption was violated because harvest of some fish occurred between events. However, we assumed that marked and unmarked fish were harvested at the same rate. Thus, provided there was no immigration of fish between events, the estimate was unbiased with respect to the time and area of the first event (estimate of inriver abundance, not escapement). Sampling in both events encompassed the majority of the run. Any immigration of Chinook salmon past the capture site prior to or after the marking event was assumed to be negligible.

Assumption II: 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 any handling effects, the holding and handling time of all captured fish was minimized. Any obviously stressed or injured fish were not radiotagged. Radiotagged fish that were not detected past either the North River tracking station or the mainstem Unalakleet River tracking station upstream of the confluence with the North River were removed from the experiment. It was assumed that if a fish was able to migrate this distance, then there were no effects from handling and tagging.

Assumption III: Tagged fish did not lose their tags between the tagging site and their spawning destination.

A combination of stationary tracking stations and aerial and boat tracking surveys was used to identify radio tags that were expelled. All fish determined to have regurgitated their tags were culled from the analyses.

Assumption IV:

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.

It was considered likely that tagging rates would vary and possible that fishing effort would vary. If discrete Chinook salmon spawning aggregations in the Unalakleet River entered the river with different run timing schedules, varied tagging rates and fishing effort could result in biased estimates of the proportion of the run that migrated past the North River counting tower and proportion estimates for fish spawning in other areas of the drainage.

Equal probability of capture was evaluated by size and time. Chinook salmon were captured and tagged over the entire span of the run. Radio tags were implanted into Chinook salmon of various sizes. Length, date, and time of release were recorded for all tagged fish. The North River tower counts occurred over the span of the run with only 5 data gaps, none exceeding 2 hours. Counts for the data gaps were estimated using the interpolation method described in Perry-Plake and Antonovich (2009). Age, sex, and length data were collected from the samples of fish past the North River tower and in the mainstem Unalakleet River above the confluence of the North River. The procedures to evaluate equal probability of capture across size categories are described in Appendix A1, as well as corrective measures (stratification), based on diagnostic test results to minimize bias in estimates of abundance and composition. Due to potential errors in correctly identifying the gender of Chinook salmon at the tagging site, sex ratios of tagged fish and fish spawning in the North River were not compared.

To further evaluate the 3 conditions of Assumption IV, contingency table analyses recommended by Seber (1982) were used to detect significant temporal violations of assumptions of equal probability of capture. These diagnostic tests and recommendations for selecting the correct model (Darroch 1961) to calculate an unbiased estimate of abundance are described in Appendix A2.

Temporal strata for both sampling events were identified such that probability of capture was homogeneous within strata and varied between strata. A matrix of fish released and recovered in each stratum was input into the computer program SPAS (Arnason et al. 1996) to calculate the strata ($\hat{N}_s$) and total ($\hat{N} = \sum \hat{N}_s$) estimates of abundance and variance.

SPAWNING DISTRIBUTION

The proportion of Chinook salmon spawning in each major spawning area was estimated using a stepwise process. First, the proportion of marked fish within each stratum that migrated to a particular spawning area was estimated and applied to the stratum estimates of abundance. Then the stratum abundance estimates by spawning area were combined across strata to obtain total estimates of abundance by spawning area. At this point, the total estimates of abundance by area were divided by the estimate of drainagewide abundance to obtain estimates of the spawning distribution.

The proportion of Chinook salmon from marking strata *s* located in spawning area *i* was estimated (Cochran 1977):

$$\hat{p}_{i,s} = n_{i,s} / n_s \qquad (1)$$

$$v\hat{a}r(\hat{p}_{i,s}) = \frac{\hat{p}_{i,s}(1-\hat{p}_{i,s})}{n_s - 1} \qquad (2)$$

where

$n_{i,s}$ = number of Chinook salmon marked during stratum *s* that traveled to spawning area *i*; and

n_s = number of Chinook salmon marked during stratum *s*.

The total abundance of Chinook salmon using spawning area *i* and its sampling variance (Mood et al. 1974) was estimated:

$$\hat{N}_i = \sum_{s=1}^{S} \hat{N}_s \hat{p}_{i,s} \qquad (3)$$

and

$$v\hat{a}r(\hat{N}_i) = \sum_{s=1}^{S} \hat{N}_s^2 \, v\hat{a}r(\hat{p}_{i,s}) + \sum_{s=1}^{S} \hat{p}_{i,s}^2 \, v\hat{a}r(\hat{N}_s) + 2\sum_{s \neq t}^{S} \hat{N}_s \hat{p}_{i,s} \, c\hat{o}v(\hat{N}_s, \hat{N}_t). \qquad (4)$$

where t = temporal period.

Then the proportion of Unalakleet River Chinook salmon using spawning area i and its sampling variance (Mood et al. 1974) was estimated:

$$\hat{p}_{i,} = \hat{N}_i \big/ \hat{N} \tag{5}$$

and

$$v\hat{a}r(\hat{p}_i) = \sum_{s=1}^{S} \frac{\left(\hat{p}_{i,s}\hat{N} - \hat{N}_i\right)^2}{\hat{N}^4} v\hat{a}r\left(\hat{N}_s\right) + \sum_{s=1}^{S} \frac{\hat{N}_s^2}{\hat{N}^2} v\hat{a}r\left(\hat{p}_{i,s}\right) + 2\sum_{s \neq t}^{S} \frac{\left(\hat{p}_{i,s}\hat{N} - \hat{N}_i\right)\left(\hat{p}_{i,t}\hat{N} - \hat{N}_i\right)}{\hat{N}^4} c\hat{o}v\left(\hat{N}_s, \hat{N}_t\right). \tag{6}$$

RUN TIMING

Run timing was calculated for radiotagged Chinook salmon at the tagging location, at the North River tracking station and at the Unalakleet River tracking station. Run timing past the tagging location was described as the number of Chinook salmon radiotagged on each day. For run timing past the tracking stations, the date at which the radiotagged salmon was last recorded at the tracking station was used as the date that each radiotagged salmon passed the respective tracking station, and run timing past the tower was described as the total number of radiotagged Chinook salmon passing the tower on each day. Cumulative run timing at each site was defined as the total number of radiotagged Chinook salmon that had migrated past the tower, up to and including that particular day. Run timing was compared using paired K-S tests.

AGE, SEX, AND LENGTH COMPOSITION

The numbers of Chinook salmon by sex and age were estimated within a major spawning destination (d), where d indicates either North River or mainstem Unalakleet River stocks. These estimates were then combined arithmetically for total length composition by sex and age. Sex of individual fish was accurately determined for virtually all Chinook salmon during upriver sampling, although the proportion of successfully aged fish ranged between 85% and 92% depending on gender and spawning area. So, composition proportions were first estimated by sex g (g = males or females) using:

$$\hat{p}_{g,d} = \frac{n_{g,d}}{n_d} \tag{7}$$

where

$\hat{p}_{g,d}$ = estimated proportion of Chinook salmon of sex g at destination d;

$n_{g,d}$ = number of sampled Chinook salmon of sex g at destination d; and

n_d = total number of Chinook salmon sampled at destination d.

Then, age composition proportions for each sex and destination were estimated using:

$$\hat{p}_{a(g),d} = \frac{n_{a,g,d}}{n_{\bullet,g,d}} \tag{8}$$

where

$\hat{p}_{a(g)d}$ = Estimated proportion of Chinook salmon of age *a* and sex *g* at destination *d*;

$n_{a,g,d}$ = Number of sampled Chinook salmon of age *a* and sex *g* at destination *d*; and

$n_{\bullet,g,d}$ = Total number of Chinook salmon successfully aged for sex *g* at destination *d*.

Sampling variances for the parameter estimates described in equations (7) and (8) were estimated using equation (2), with appropriate substitutions. Estimates of the proportions of salmon age *a* and sex *g* at destination *d* were calculated:

$$\hat{p}_{a,g,d} = \hat{p}_{a(g)d}\,\hat{p}_{g,d} \tag{9}$$

and variance was estimated (Goodman 1960):

$$v\hat{a}r\left(\hat{p}_{a,g,d}\right) = \hat{p}^2_{a(g)d}\,v\hat{a}r\left(\hat{p}_{g,d}\right) + \hat{p}^2_{g,d}\,v\hat{a}r\left(\hat{p}_{a(g)d}\right) - v\hat{a}r\left(\hat{p}_{g,d}\right)v\hat{a}r\left(\hat{p}_{a(g)d}\right) \tag{10}$$

Estimates of total numbers of salmon age *a* and sex *g* at destination *d* were calculated:

$$\hat{N}_{a,g,d} = \hat{N}_d\,\hat{p}_{a,g,d} \tag{11}$$

with variance (Goodman 1960):

$$v\hat{a}r\left(\hat{N}_{a,g,d}\right) = \hat{N}^2_d\,v\hat{a}r\left(\hat{p}_{a,g,d}\right) + \hat{p}^2_{a,g,d}\,v\hat{a}r\left(\hat{N}_d\right) - v\hat{a}r\left(\hat{p}_{a,g,d}\right)v\hat{a}r\left(\hat{N}_d\right) \tag{12}$$

where

$\hat{N}_d$ = N_{NR}, the total North River abundance estimate, where *d* indicates North River, or $\hat{N}_d = \hat{N} - N_{NR}$, where *d* indicates mainstem Unalakleet River.

These estimates were summed across destination to calculate the estimated number of Chinook salmon of age *a* and sex *g* that entered the Unalakleet River drainage:

$$\hat{N}_{a,g} = \sum_{d=1}^{2} \hat{N}_{a,g,d}\ . \tag{13}$$

The variance was approximated assuming statistical independence between the estimates of $\hat{N}_d$, and assuming N_{NR}, the total North River tower count, was known and not estimated:

$$v\hat{a}r\left(\hat{N}_{a,g}\right) = \sum_{d=1}^{2} v\hat{a}r\left(\hat{N}_{a,g,d}\right). \tag{14}$$

The proportion of Chinook salmon age *a* and sex *g* that entered the Unalakleet River drainage was estimated:

$$\hat{p}_{a,g} = \hat{N}_{a,g} \big/ \hat{N} \tag{15}$$

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

$$\hat{var}\left(\hat{p}_{a,g}\right) = \sum_{d=1}^{2} \frac{\left(\hat{p}_{a,g,d}\hat{N} - \hat{N}_{a,g}\right)^2}{\hat{N}^4} \hat{var}\left(\hat{N}_d\right) + \sum_{d=1}^{2} \frac{\hat{N}_d^2}{\hat{N}^2} \hat{var}\left(\hat{p}_{a,g,d}\right). \tag{16}$$

The approximate variance terms in equations (14) and (16) both omit a covariance term, $\hat{cov}\left(\hat{N}_{NR}, \hat{N} - \hat{N}_{NR}\right)$, which is the covariance between the estimates of the number of Chinook salmon passing the North River tower and the estimate of Chinook salmon in the remainder of the Unalakleet River drainage. This covariance term cannot be calculated using analytical methods because when a Darroch (1961) model is used to estimate abundance, the size of the covariance term is unknown, although it is expected to be positive. Computer-intensive techniques such as bootstrapping (Efron and Tibshirani 1993) or empirical Bayesian methods (Carlin and Louis 2000) were employed but were not useful with this data set because of the disproportionally small number of tags deployed very early in the run. If a Chapman (1951) estimator is appropriate for estimating abundance, the covariance term is easily approximated:

$$cov\left(\hat{N}_{NR}, \hat{N} - \hat{N}_{NR}\right) \approx \left(\frac{\hat{N}}{\hat{N}_{NR}} - 1\right) var\left(\hat{N}_{NR}\right). \tag{17}$$

The term $var\left(\hat{N}_{NR}\right)$ was estimated using the methods described by Perry-Plake and Antonovich (2009) for tower counts. When the full Taylor's series expansions (Mood et al. 1974) are used to approximate the variances described in equations (14) and (16), the estimated value of $var\left(\hat{N}_{NR}\right)$ is used, and equation (17) is used to approximate the covariance term. The resulting variance approximations were 1% to 5% smaller than those provided by equations (14) and (16) due to negative coefficients in the Taylor's series for the covariance term. As a result, we felt it was more conservative to use equations (14) and (16) to reduce the risk of the variance estimates being biased low.

Mean length at age within sex and/or spawning destination categories and its sampling variance were estimated using standard sample summary statistics (Cochran 1977). Data used to estimate Chinook salmon abundance, distribution, and ASL compositions in this study were entered into Excel spreadsheets for analysis and archiving (Appendix B).

RESULTS

CAPTURE, TAGGING, AND FATES OF RADIOTAGGED CHINOOK SALMON

Between June 15 and July 20 a total of 142 Chinook salmon were captured and radiotagged at the lower river tagging site. Daily CPUE of Chinook salmon averaged 0.69 (SE = 1.16) and ranged from 0 to 5.1 Chinook salmon/hour of drift time (Figure 3). Captured Chinook salmon ranged in length from 530 to 940 mm METF (Table 5). Of the 142 salmon that were radiotagged, 126 continued upstream migration past the tracking towers on the Unalakleet and North rivers. Seven radiotagged Chinook salmon were harvested (4 in the subsistence fishery and 3 in the sport fishery), 5 radiotagged Chinook salmon either died or regurgitated their radio tag shortly after handling, 3 backed out of the drainage or had tags that failed, and 1 was assigned an unknown fate (Table 6).

SPAWNING DISTRIBUTION

Radiotagged Chinook salmon were detected in all tributaries of the Unalakleet River drainage except the South River (Figure 4; Table 6). Spawning Chinook salmon were concentrated in two geographical clusters: one centered in the North River 20-30 km above the mouth and the other centered in the mainstem of the Unalakleet River around the mouth of Old Woman River (Figures 4 and 5). Of the 126 radiotagged Chinook salmon that passed the tracking stations and were located upriver, 56 migrated past the North River counting tower and 70 migrated up the mainstem of the Unalakleet River. Estimated proportions of Chinook salmon migrating to these various portions of the drainage were 0.34 (SE = 0.09) to the North River, 0.49 (SE = 0.10) to the mainstem of the Unalakleet River, 0.07 (SE = 0.02) to the Chiroskey River, 0.08 (SE = 0.03) to the Old Woman River, and 0.03 (SE = 0.01) to the North Fork of the Unalakleet River (Figure 5).

The estimated proportion of Chinook salmon from the Unalakleet River drainage that migrated up the North River was not significantly different from that measured in 1997 (37%) and 1998 (40%) because both estimates fell within one SE of the 2009 estimated proportion (34%; SE = 9%; Figure 5).

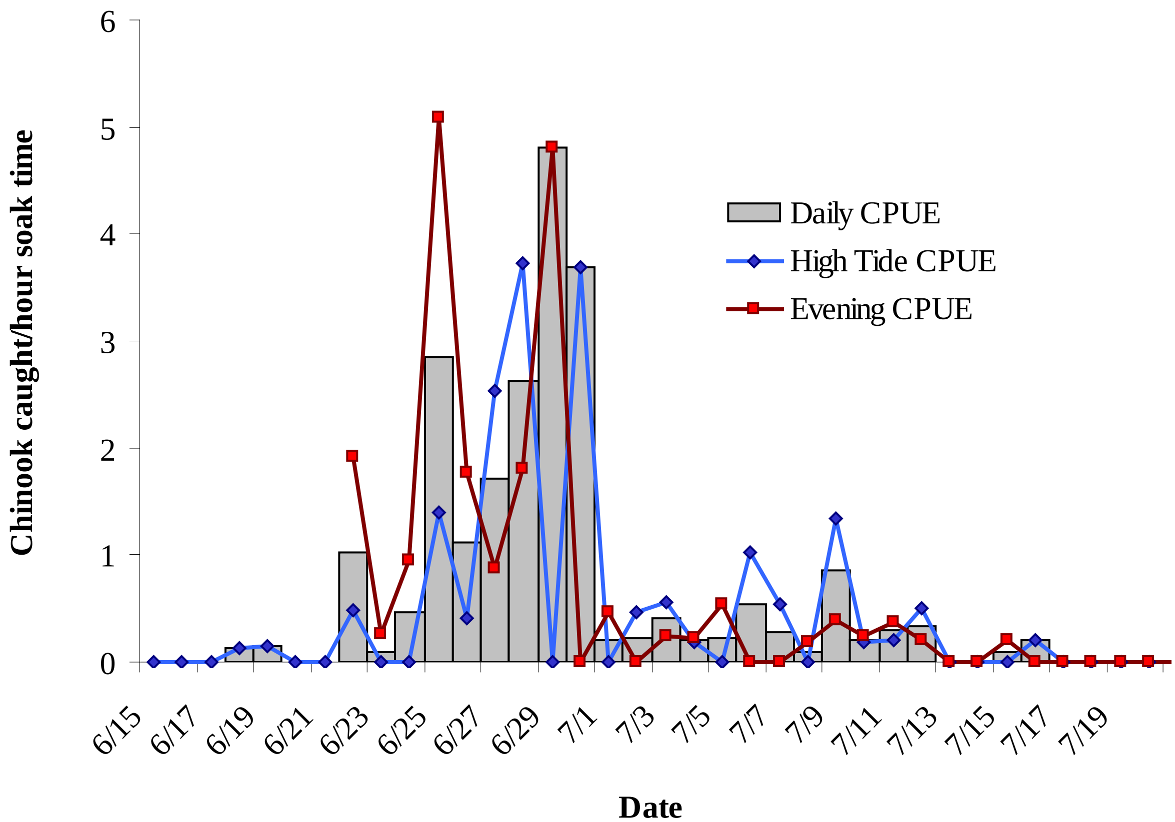

Figure 3.–Catch-per-unit-effort (CPUE) of Chinook salmon at the Unalakleet River tagging site by date for high tide sampling, evening sampling, and total daily sampling.

Table 5.–Catch and length statistics for male and female Chinook salmon sampled at the downriver tagging location and in the North and mainstem Unalakleet rivers, 2009. Standard errors for estimates are in parentheses.

	Downriver Tagging Location	Upriver Sampling	
Statistic	All Fish	Unalakleet River	North River
Number caught			
All	142	200	153
Male	No sex data	116	99
Female	No sex data	99	51
Mean Length (mm)			
All (SD)	788 (101)	710 (152)	724 (140)
Male and Female			
Age 1.1	None		
Age 1.2	598 (46)		
Age 1.3	721 (91)		
Age 1.4	838 (61)		
Male (SD)		630 (133)	673 (125)
Age 1.1		376 (57)	519 (35)
Age 1.2		565 (45)	584 (51)
Age 1.3		670 (57)	716 (77)
Age 1.4		844 (72)	855 (90)
Female (SD)		829 (74)	842 (55)
Age 1.3		749 (87)	808 (46)
Age 1.4		842 (61)	853 (56)
Length Range			
All	530-940	285-965	315-1030
Male		295-965	315-1030
Female		535-960	695-955

Table 6.–Fates of 142 radiotagged Chinook salmon in the Unalakleet River drainage, 2009.

General fate[a]	Number of radio tags	Specific fate	Number of radio tags
North River	56	North River	56
		Little North River	0
		Harvested in North River	0
Unalakleet River	70	Upper Mainstem	46
		South River	0
		Chiroskey River	5
		North Fork Unalakleet	5
		Old Woman River	14
		10 Mile River	0
Harvested above tracking tower on Unalakleet	0		
Total past tracking towers	126		
Dead or regurgitated tags	5		
Harvested below tracking towers	7	Sport fishery	3
		Inriver Test Net (ADF&G CFD)	0
		Subsitence fishery	4
Backed out	3		
Indeterminate fate	1		
Total that never passed tracking towers	16		

[a] A description of each fate is given in the Methods section.

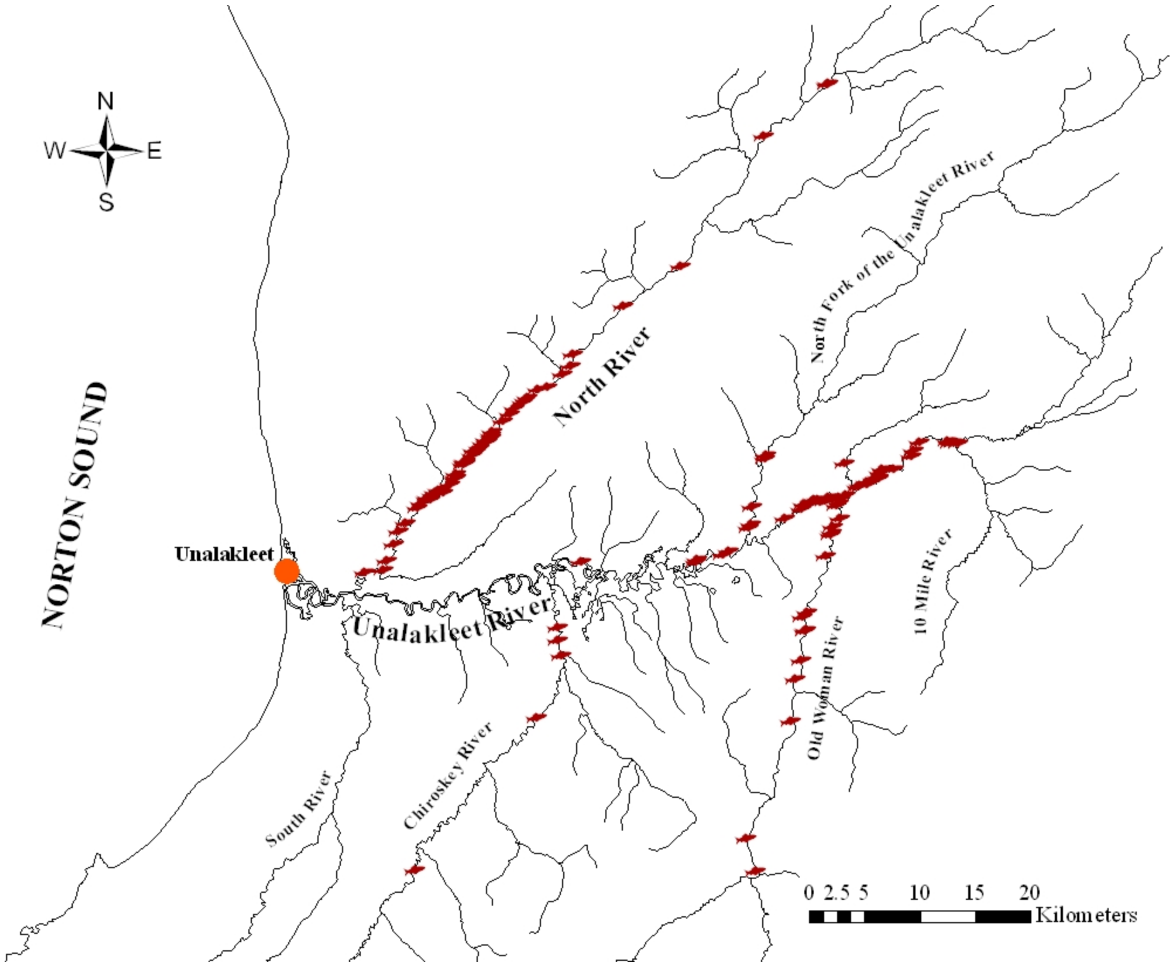

Figure 4.–Map showing the farthest upstream locations of all radiotagged Chinook salmon in the Unalakleet drainage, 2009.

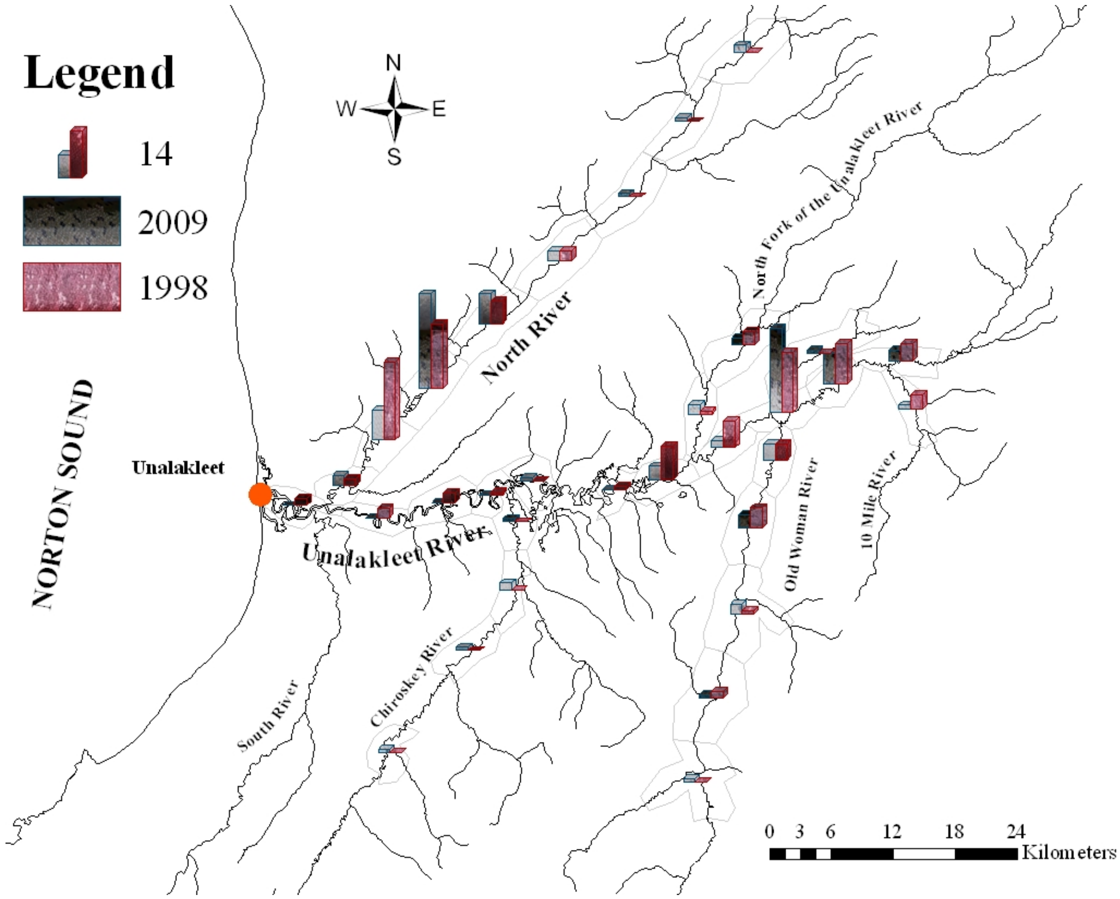

Figure 5.–Number of radiotagged Chinook salmon tracked to 10 km river sections in 2009 (n = 126) and 1998 (n = 149). Legend displays scale of bar heights (bar height in legend is equal to 14 radio tags).

RUN TIMING

Run timing at the tagging location and tracking towers was compressed and passage at the upriver sites lagged behind the tagging site by approximately 2 weeks, reflecting the time it took fish to migrate between the tagging location and the upriver sites (Figure 6). Chinook salmon radiotagged in the lower river took from 3 to 25 days (average = 14.1, SE = 5.0) to pass the tracking towers (Figure 7). The amount of time radiotagged Chinook salmon spent in the lower portion of the river was inversely proportional to the date at which they were captured at the tagging site, with fish tagged later in the season taking less time to migrate upriver (Figure 7). This regression was significant for both Unalakleet River Chinook salmon ($P < 0.01$, Adjusted $R^2 = 0.32$) and North River Chinook salmon ($P < 0.01$, Adjusted $R^2 = 0.29$). Chinook salmon tagged during the first half of the run appeared to make up a disproportionate amount of the fish located in the core spawning areas (North River 20–30 rkm and Unalakleet River 90–100 rkm; Figure 8), although the proportion was not significantly different from non-core areas ($\chi^2 = 1.11$, $P = 0.29$).

At the start of the run there was a considerable difference in the initial capture of Chinook salmon by the radiotagging crew compared to the CF test net fishery (Figure 6). The overall run timing between the tagging site and CF test fishery was significantly different ($D = 0.19$, $P = 0.01$). Despite the difference in captures at the tagging site, the run timing of radiotagged

Chinook salmon that migrated up the North River was similar to that observed at the North River counting tower (D = 0.11, P = 0.51) (Figure 6).

The run-timing of radiotagged North River Chinook salmon was slightly behind that of radio-tagged Unalakleet River Chinook salmon (Figure 6), but there was no significant difference at either the tagging site (D = 0.20, P = 0.14) or the upriver tracking towers (D = 0.20, P =0.14) (Figure 6). There was also no significant difference between the average amount of days between radiotagging and migration past a tracking station for Unalakleet Chinook salmon (average days = 13.7, SE = 4.7) and North River Chinook salmon (average days = 14.6, SE = 5.3; P = 0.35).

ABUNDANCE ESTIMATION

Tests of Sampling Bias

Tests for size-biased sampling (Appendix A1) indicated length selectivity in the first event because there were significant differences in the length distributions of radiotagged Chinook salmon (marks and recaptures) and those sampled above the North River tower (captures) (mark vs. captures D = 0.26, P < 0.01; recaptures vs. captures D = 0.23, P < 0.01; Figure 9). There was, however, no significant difference in radiotagged Chinook salmon that migrated to the North River and the Unalakleet River (marks vs. recaptures D = 0.12, P = 0.47, Figure 8), indicating there was no length selectivity in the second event. These results indicated a case III experiment that precluded the need to stratify the capture data by size (Appendix A1).

Radiotagged Chinook salmon were also significantly older (Tables 5 and 9) than those sampled during upriver sampling. This was because age-1.0 and -1.1 fish were completely absent from the tagging efforts while age-1.2 salmon were underrepresented and age-1.4 fish were overrepresented (Table 9). Small salmon age-1.0 or -1.1 may not have been counted as Chinook salmon at the counting tower because they were hard to differentiate from pink salmon without careful examination. Given the small number of these fish and their exclusion from tower counts, it is unlikely that their presence confounds results so long as Chinook salmon abundance estimates are limited to Chinook salmon age-1.2 and older.

Temporal violations of equal probability of capture during the second event were explored using contingency table analyses (Appendix A2). No significant difference was detected in the probability that a marked fish was recaptured during the second event between the 4 quarters of the run when examining all radiotagged salmon (χ^2 = 5.97, P = 0.11). However, when the last 3 quarters were pooled, significant differences in capture probability were observed between the first 25% of the run and the last 75% of the run (χ^2 = 5.67, P = 0.02; Table 7). This pattern was also evident in first event capture probabilities. No differences were detected when examining the 4 run quarters separately (χ^2 = 3.74, P = 0.29); however, the first 25% of the run demonstrated a significantly lower capture probability than the last 75% of the run (χ^2 = 3.68, P = 0.055; Table 8). These results indicated the need to temporally stratify the estimator around the marking date of June 25 (Darroch 1961).

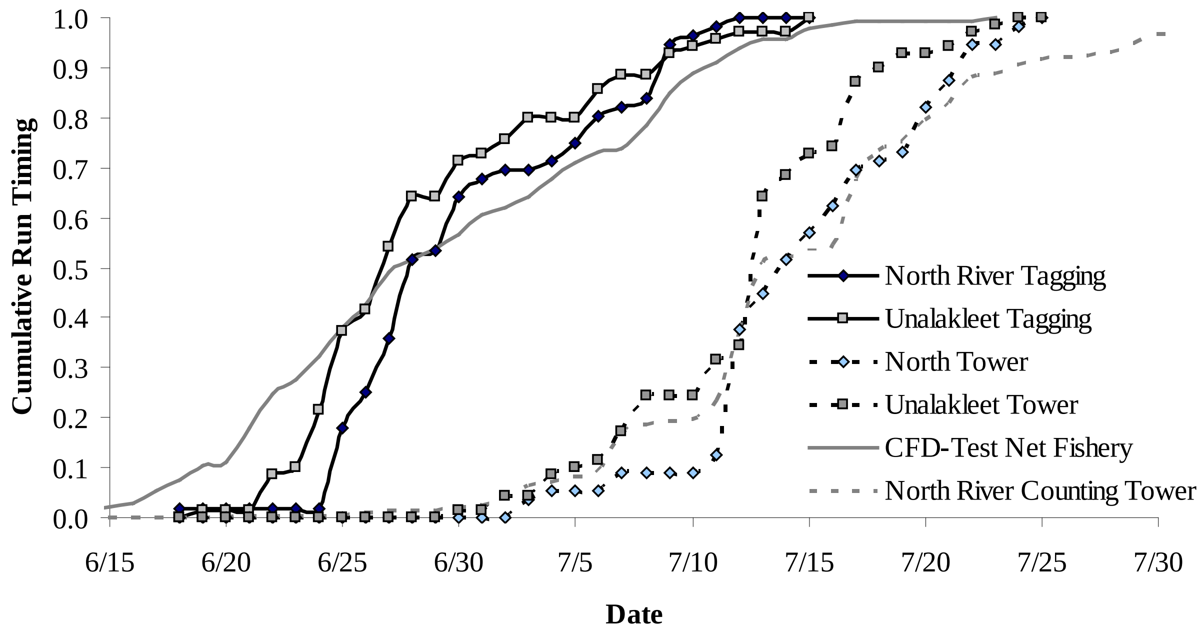

Figure 6.–Cumulative catch at the capture site (solid lines) and passage by upriver tracking stations (dashed lines) for radiotagged Chinook salmon and the cumulative catch of the ADF&G CF test net fishery and the cumulative count at the North River counting tower in 2009.

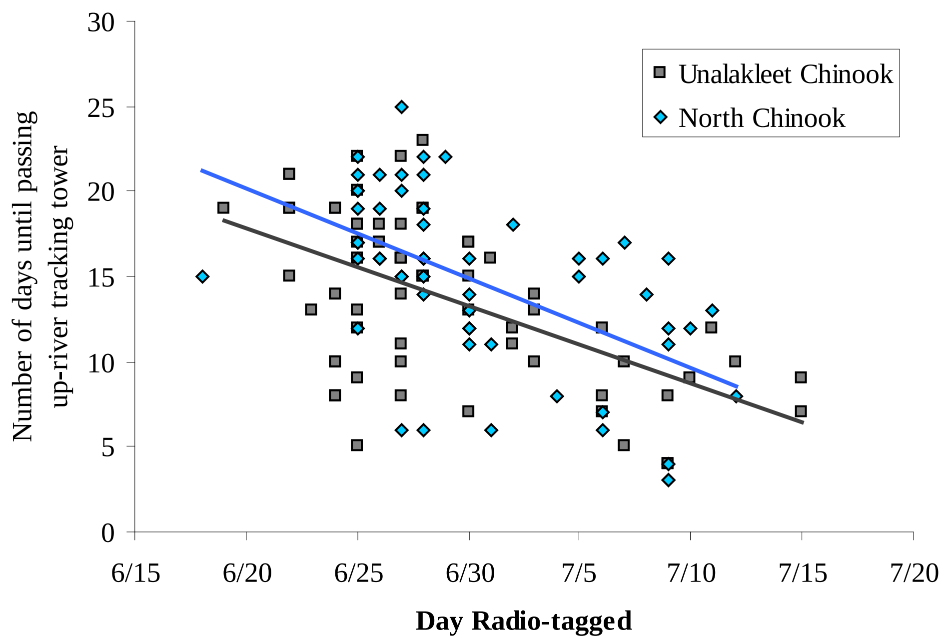

Figure 7.–Number of days between radiotagging Chinook salmon and their passage by either the North or Unalakleet upriver tracking station relative to the day they were captured and radiotagged. Lines represent linear regression for Chinook salmon migrating up either the North (blue) or Unalakleet (grey) rivers.

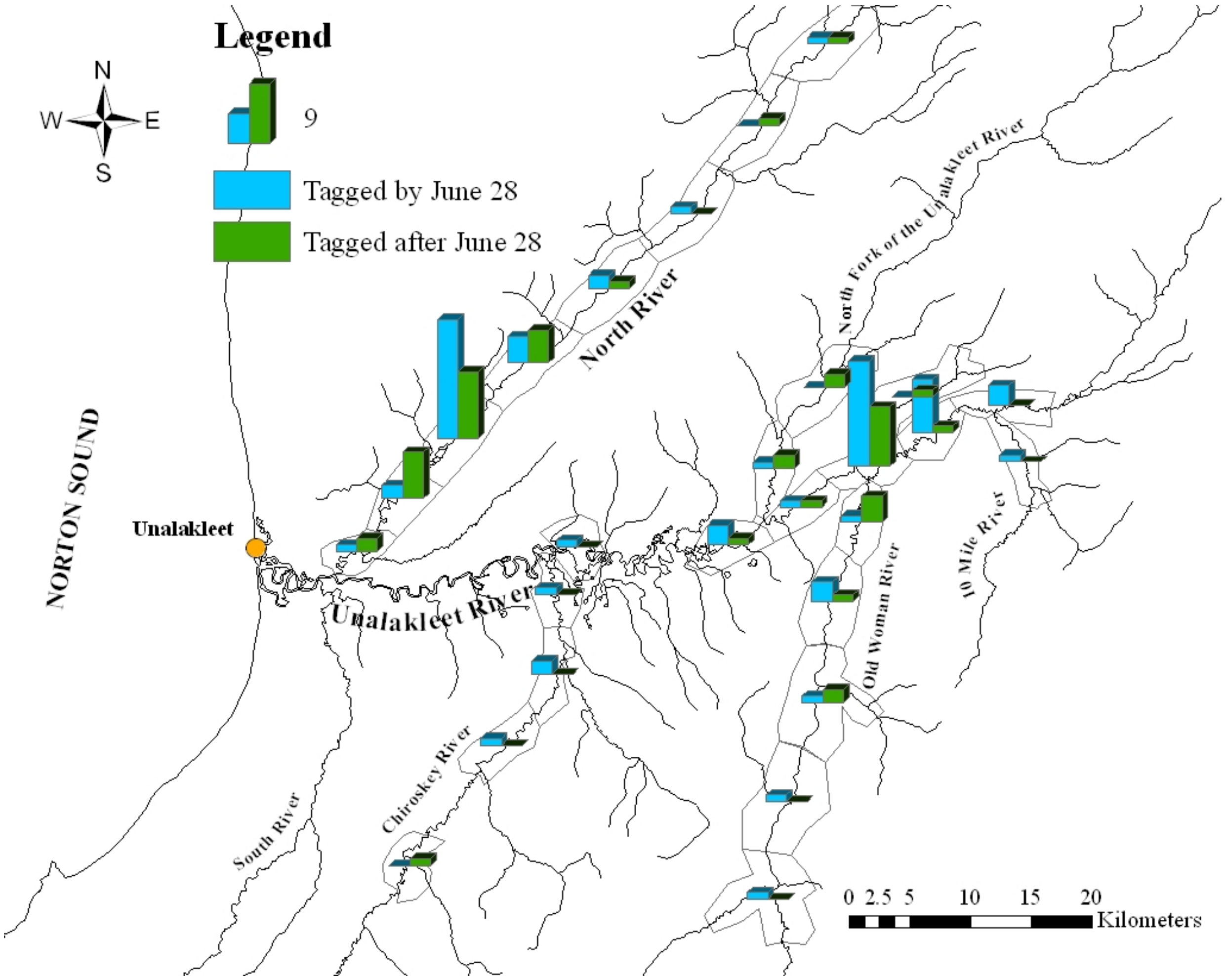

Figure 8.–Map showing the number of radiotagged Chinook salmon tagged in each half of the run that migrated to each 10 km section of river. Legend displays scale of bar heights (bar height in legend is equal to 9 radio tags).

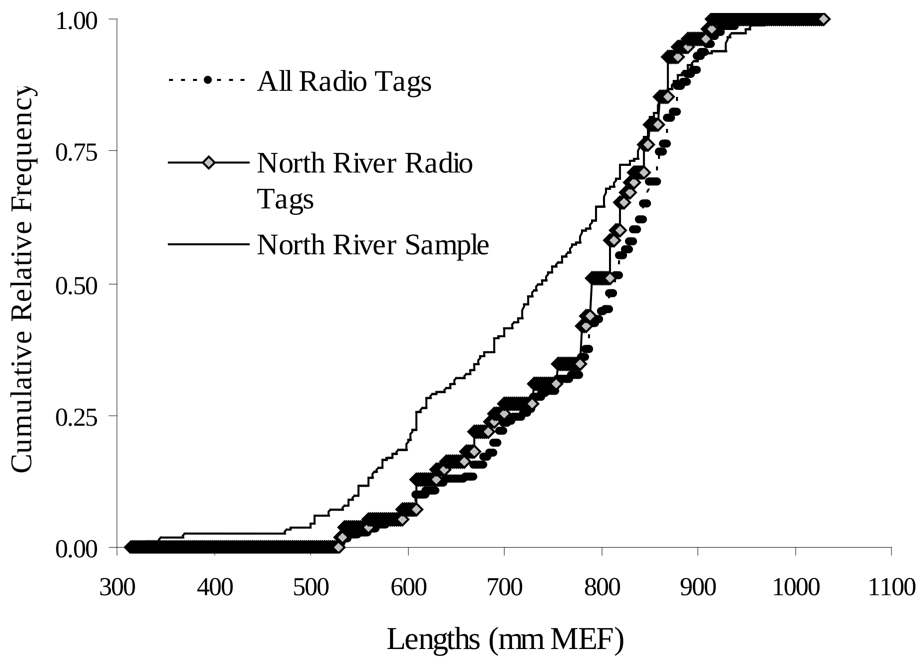

Figure 9.–Cumulative length frequency distributions of all radiotagged fish, all fish sampled above the North River counting tower, and all radiotagged fish migrating above the North River counting tower, 2009.

Table 7.–Data used to test the assumption of equal probability of capture by time during the second event for all fish.

Date	Recaptured	Not Recaptured
June 15–June 25	10	26
June 26–June 28	19	19
June 29–July 2	10	11
July 2–July 29	17	14
June 15–June 25	10	26
June 26–July 29	46	44

Four-part χ^2 test: $\chi^2 = 5.97$
Two-part χ^2 test: $\chi^2 = 5.67$

Table 8.–Data used to test the assumption of equal probability of capture by time during the first event for all Chinook salmon.

	All Chinook Salmon	
Counting period	Marked	North River tower count
June 15 – July 11	7	552
July 12 – July 13	18	648
July 14 – July 19	16	573
July 20 – Aug 15	15	582
June 15 – July 11	7	552
July 12 – Aug 15	49	1,803

Four part χ^2 test: $\chi^2 = 3.74$
Two part χ^2 test: $\chi^2 = 3.68$

Table 9.–Estimated age and sex composition of the Chinook salmon escapement in the Unalakleet River drainage, 2009.

Sex/Age Category	$\hat{p}_k$	SE($\hat{p}_k$)	$\hat{N}_k$	SE($\hat{N}_k$)
Male				
1.0	0.009	0.005	62	36
1.1	0.041	0.012	281	133
1.2	0.236	0.026	1625	650
1.3	0.222	0.031	1531	419
2.2	0.004	0.004	26	26
1.4	0.093	0.017	641	260
2.3	0.006	0.005	44	32
Female				
1.3	0.062	0.014	428	160
1.4	0.327	0.028	2250	882

Abundance Estimate

One hundred twenty-six radiotagged Chinook salmon continued upstream migration past the tracking towers on the Unalakleet and North rivers and served as the first (marked) event. A total estimate of 2,355 (SE = 190) Chinook salmon migrated past the North River counting tower (Kent *In prep*) and served as the second sample. Fifty-six radiotagged Chinook salmon migrated past the North River counting tower and served as recaptures in the second sample. The abundance estimate of Chinook salmon age-1.2 and older that migrated into the Unalakleet River drainage above the capture site was 6,888 fish (SE = 2,422).

AGE, SEX, AND LENGTH COMPOSITION

Age, sex, and length composition estimates of the escapement were from Chinook salmon sampled above the tracking towers on the North and Unalakleet rivers. Chinook salmon were captured by beach seine and ranged in length from 285 to 1030 mm METF. Seining was conducted in the North River between July 14 and July 24 and on the Unalakleet River from June 29 through July 24 (Figure 10).

Examining the length distribution of all Chinook salmon sampled during upriver sampling revealed no significant differences (D = 0.09, P = 0.44; Figure 11) despite a more bimodal appearance in the length distribution of Chinook salmon sampled in the Unalakleet River. Females from both rivers had very similar length distributions (D = 0.13, P = 0.62; Figure 12), whereas males from the Unalakleet River were significantly smaller than those sampled in the North River (D = 0.19, P = 0.04; Figure 12). The proportion of male Chinook salmon in the North River sample was 0.66 (SE = 0.04), and the proportion of male Chinook salmon in the Unalakleet River was 0.59 (SE = 0.04).

Chinook salmon ages ranged from age-1.0 to -1.5 with a single age-2.3 fish and an age-2.4 fish. The predominant ages were age-1.3 and age-1.4 (Table 9). There were significant differences in the age composition of all Chinook salmon sampled in the North and Unalakleet rivers (χ^2=11.25, P = 0.047). Further analysis demonstrated that differences in age composition between the 2 rivers were limited to male Chinook salmon. Females showed no differences in age distribution between rivers (χ^2=0.30, P = 0.86), whereas males demonstrated a pronounced difference (χ^2=14.49, P = 0.01). North River male Chinook salmon were predominantly age-1.3, and the Unalakleet River was dominated by age-1.2 Chinook salmon (Table 9).

The distribution of radiotagged Chinook salmon age-1.2, -1.3, and -1.4 somewhat reflected the results obtained from upriver sampling (Figure 13). The age distribution of radiotagged Chinook salmon that migrated up the North River had a higher proportion of age-1.3 salmon (35% age-1.3 to 55% age-1.4) than those that migrated up the Unalakleet River (19% age-1.3 to 76% age-1.4; χ^2 = 5.94, P = 0.051; Tables 10, 11).

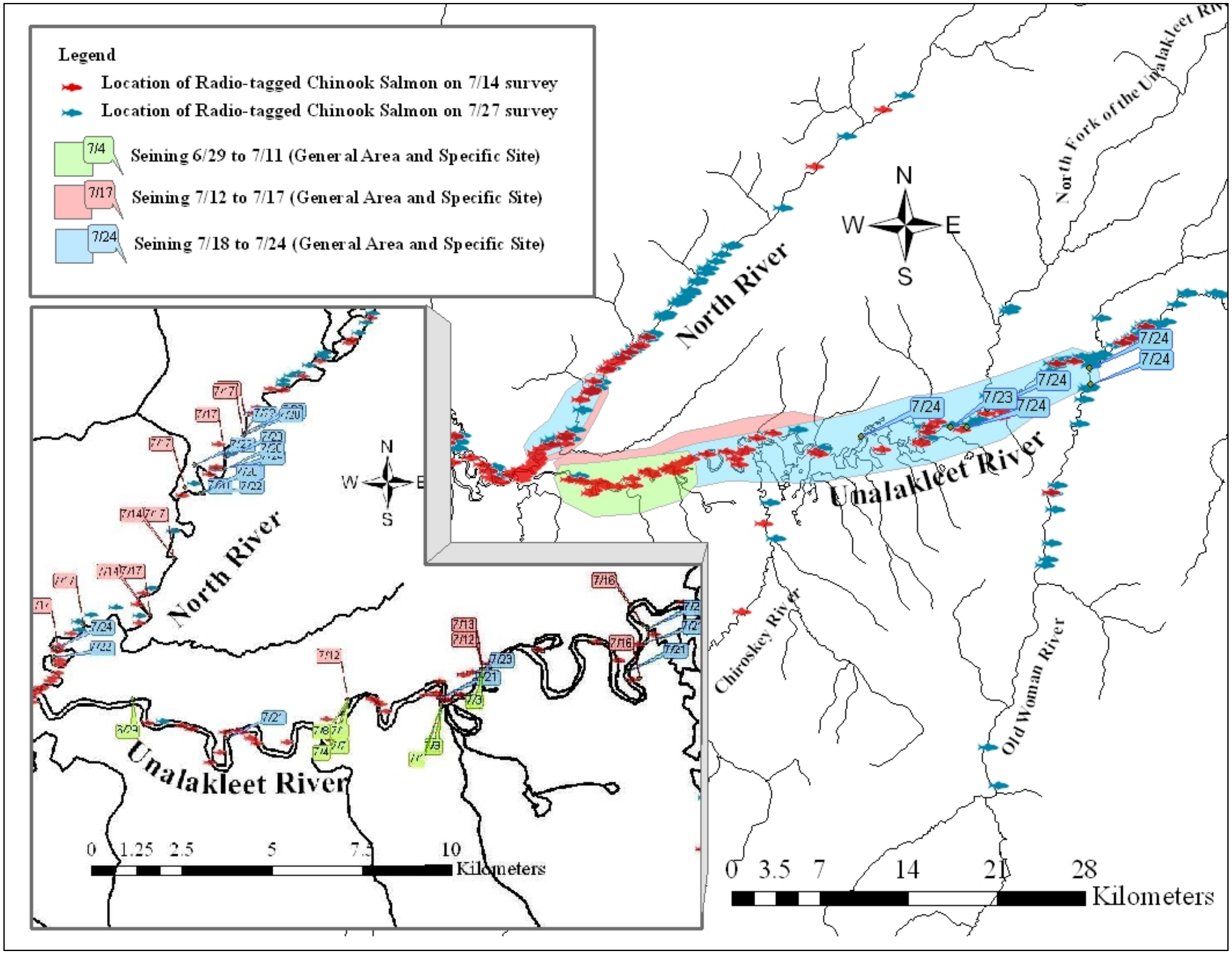

Figure 10.–Location of upriver seining samples by date and the location of radiotagged Chinook salmon in the Unalakleet River drainage on July 14 and 27, 2009.

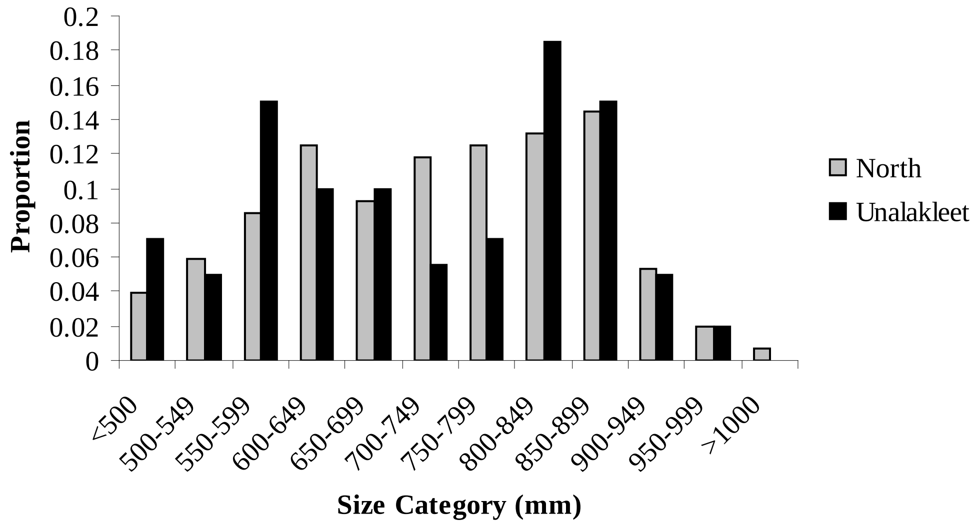

Figure 11.–Size distribution of Chinook salmon sampled in the Unalakleet and North rivers, 2009.

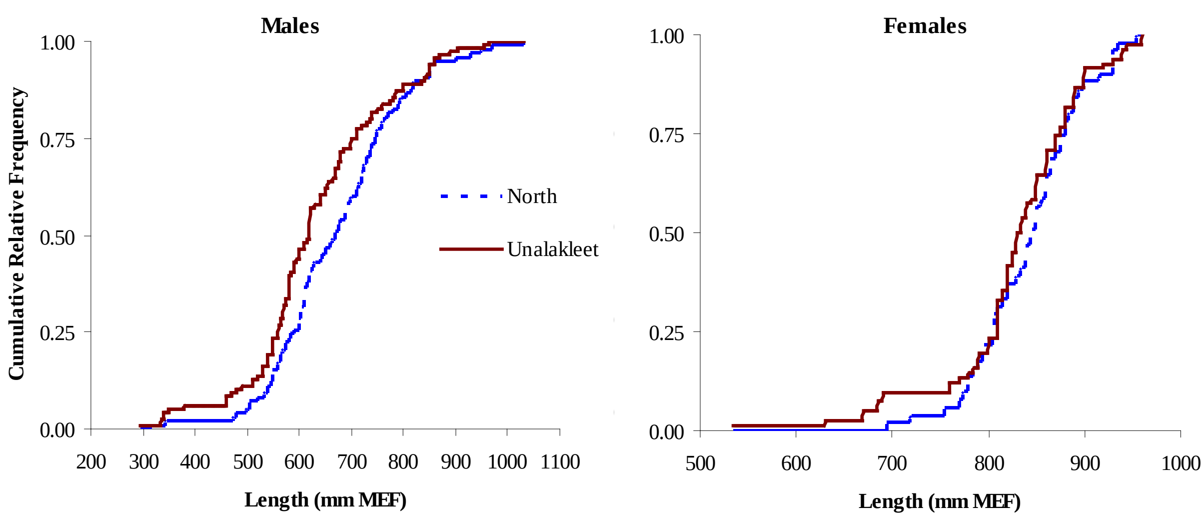

Figure 12.–Cumulative length distribution of male and female Chinook salmon sampled by beach seine in the Unalakleet and North River in 2009.

Table 10.–Proportion of male and female Chinook salmon that migrated up the North and Unalakleet rivers that were age-1.0, -1.1, -1.2, -1.3, and -1.4 in 2009. Standard errors for estimates are in parentheses.

Sex	River	Age-1.0	Age-1.1	Age-1.2	Age-1.3	Age-2.2	Age-1.4	Age-2.3
Male	North River	0.02 (0.02)	0.05 (0.02)	0.28 (0.05)	0.51 (0.05)	0	0.12 (0.04)	0.01 (0.01)
	Unalakleet River	0.01 (0.01)	0.08 (0.03)	0.45 (0.05)	0.28 (0.04)	0.01 (0.01)	0.17 (0.04)	0.01 (0.01)
Female	North River	0	0	0	0.22 (0.06)	0	0.78 (0.06)	0
	Unalakleet River	0	0	0	0.14 (0.04)	0	0.86 (0.04)	0
Male+Female	Tagging	0	0	0.08 (0.02)	0.26 (0.04)		0.66 (0.04)	

Table 11.–Data used to test the assumption that age distribution of radiotagged Chinook salmon that migrated up the North River was not different from those that migrated up the Unalakleet River.

Age	1.2	1.3	1.4
Unalakleet	3	12	47
North	6	19	30

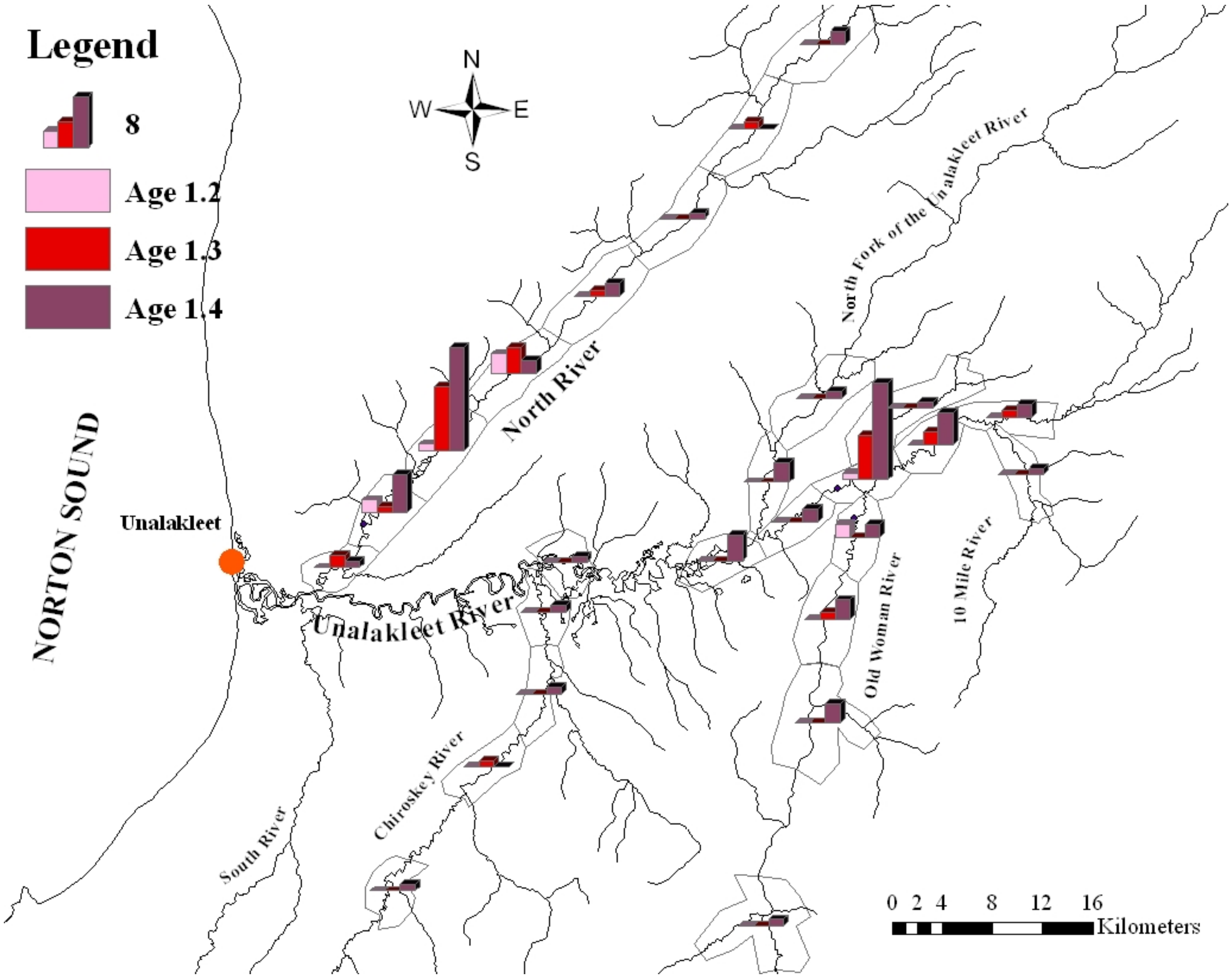

Figure 13.–Map showing the number of radiotagged Chinook salmon from 3 age classes that migrated to each 10 km section of river. Legend displays scale of bar heights (bar height in legend is equal to 8 radio tags).

DISCUSSION

SPAWNING DISTRIBUTION AND RUN TIMING

The spawning distribution of radiotagged Chinook salmon was very similar to that seen in 1997 and 1998 (Wuttig 1998, 1999; Figure 5). Radiotagged Chinook salmon were detected in every major tributary except the South River and were distributed around 2 distinct spawning congregations in the mainstem Unalakleet and North rivers (Figures 4, 5, 8, and 13). The only notable difference in 2009 was the presence of a few radiotagged Chinook salmon in the Chiroskey River, which was not identified as a spawning area in 1997 and 1998 (Wuttig 1998, 1999).

Migration of radiotagged Chinook salmon reflected historical run-timing patterns seen in the test net fishery and the North River counting tower as well as the migration patterns observed in 1997 and 1998 (Tables 2 and 4; Wuttig 1998, 1999). The run timing of Chinook salmon past the counting tower was significantly later than at the radiotagging site despite being only a few kilometers upriver (Figures 2 and 6). Wuttig (1998, 1999) documented radiotagged fish holding for days at the confluence of the North and Unalakleet rivers or "nosing" back and forth between the 2 rivers before eventually migrating to their spawning destination.

ABUNDANCE

The estimate of abundance failed to meet the objective precision criteria because measured relative precision ($\alpha = 0.1$) was ±58% and objective relative precision was ±35%. The failure to meet the precision criteria was probably due to problems at the outset of sampling that resulted in the need for a temporally stratified estimator. Results from diagnostic testing were not surprising based on initial problems with capturing Chinook salmon at the tagging site. Increasing fishing effort (going from one to two shifts) and decreasing mesh size was successful in producing capture rates that resulted in adequate tagging rates and representative sampling for the remainder of the run (Figure 6). The lack of size selectivity in second event sampling (Figure 9) indicated that size bias sampling in the first event would not bias the results as long as the abundance estimate was limited to Chinook salmon age-1.2 and older.

AGE COMPOSITION

The age composition estimates were determined from a sample size that was minimally acceptable for estimating ASL compositions. Given that salmon migrations have demonstrated different timing for males and females as well as large and small fish (Quinn 2005), sampling that omits portions of the run could produce biased results. Ideal sampling would involve sampling at a single location over the course of the entire run; however, the small size of the Unalakleet River Chinook salmon run and the time required to deploy radio tags prevented this from occurring. Unalakleet River samples were taken between June 29 and July 24 and were scattered throughout the drainage from a few kilometers above the North River to the Old Woman River (Figure 10) and allowed for opportunities to sample the entire run. Sampling on the North River, however, did not occur until July 14 by which point 20% of radiotagged North River spawners had migrated past the portion of the river where upriver sampling took place (Figure 10). Differences in male ASL compositions of the two sub-stocks could have resulted from a North River sample that omitted the earliest 20% of the run. Most Chinook salmon studies relating to differential run timing of age and size classes have found that larger and older male fish migrate to the spawning grounds first (Quinn 2005); this suggests that the North River sub-stock is actually older and larger than described, which would accentuate the differences measured here. Further discussion of the ASL composition in 2009 carries the caveat regarding the lack of samples from the earliest portion of the North River escapement.

Discrepancies in the age distributions between gillnet sampling at the tagging location and upriver sampling via beach seining are likely partially the result of both gear selectivity and inefficient fishing during the early portion of the run. The time spent sampling was almost doubled after June 23, while a switch to smaller mesh size (from 8″ to 6 ¾″ and 7 ¼″ mesh) was made on June 25. The absence of 1.0- and 1.1-age fish from the tagging effort is certainly due to the inability to catch these fish with the mesh size gillnets being used for tagging. Similar reasoning probably explains the underrepresented 1.2-age fish and overrepresented 1.4-age fish in the radiotagged sample. The doubling of the time spent fishing probably explains the higher capture probabilities in the last three-quarters of the run.

Differences in the age composition estimates need to be considered when interpreting results. Tagged Chinook salmon were predominately older (age-1.4) than Chinook salmon from upriver sampling (Tables 5 and 9, Figure 9). Further investigation revealed that these differences were due to the absence of young (age-1.0 and -1.1) male Chinook salmon from the tagging efforts and substantial differences between the male age compositions from the two sub-stocks. These results suggest that all males were underrepresented in the radiotagging sample, which would not bias conclusions regarding the distribution of spawning Chinook salmon. More representative sampling across all size classes in the tagging portion of the study in 2010 will minimize the potential for bias.

The relationship between the differing age compositions in the two sub-stocks and the differences in proportional abundance are unclear. Telemetry data in 2009 revealed no significant differences in overall spawning distributions, or the proportion of total Unalakleet Chinook salmon returns to pass the North River counting tower compared to 1997 and 1998 (Wuttig 1998, 1999; Figure 5). However, if North and Unalakleet River sub-stocks truly have differing age structures, it is possible that the proportional relationship will drift over time depending on the strength and weakness of different brood years. Determining how differing age structures in the two sub-stocks could influence their abundance would require considerable modeling and is beyond the scope of this report. Continued efforts should be made to obtain reliable ASL data from both the Unalakleet and North Rivers to monitor these dynamics.

Unfortunately, historical ASL samples of the escapement are lacking and/or biased and are unsuitable for statistical comparisons. ASL compositions derived from the ADF&G-CF test set nets are probably biased due to mesh size (5¾ in), as are samples taken from the subsistence fishery (8 in mesh). ADF&G-CF began upriver seining in the Unalakleet River; however, small and potentially biased samples limited the use of these data. Results from 2007 were completely dominated by age-1.2 males (only 12 of 126 samples were females), whereas the 2008 sample was dominated by age-1.3 fish (97 total samples; Kent 2010). Wuttig (1998, 1999) reported age compositions from carcass sampling as suspect due to the timing and methods of sampling, although he considered the North River samples to be sounder as a result of the easier access to the spawning population in this river. There were no significant differences detected between the two rivers in 1997 and inadequate samples were collected from the Unalakleet River in 1998 to perform any analysis. Males in 1997 were dominated by age-1.2 Chinook salmon, whereas females were dominated by age-1.4 (Wuttig 1998). In 1998, the North River sample was dominated by age-1.3 fish for both males and females.

MANAGEMENT IMPLICATIONS

The primary goal of this study was to determine whether the population assessed at the North River counting tower was reflective (i.e., provided a good index) of the overall Unalakleet River drainage-wide abundance. To evaluate the efficacy of the North River counting tower as an index of the entire population, this project estimated the proportion of the total run enumerated at the tower and compared this proportion to previous estimates of spawning distribution.

The proportion of Chinook salmon entering the Unalakleet River that migrated past the North River tower was 34% in 2009, 40% in 1998 (Wuttig 1999), and 37% in 1997 (Wuttig 1998). These proportions were not significantly different from each other, and the distribution of radiotagged Chinook salmon in each 10 km section of river did not vary significantly (Figure 5). Unalakleet River drainage Chinook salmon in 2009 utilized the same habitat as Chinook salmon in 1997 and 1998. Size distributions and run timing did not vary significantly between the two sub-stocks, although the age composition of male Chinook salmon varied significantly. Data collected in 2009 suggests that the North River counting tower is an adequate indicator of overall run strength in the Unalakleet River drainage.

ADF&G-CF will be installing and operating a weir in the mainstem of the Unalakleet River starting in 2010 to enumerate and sample the Chinook salmon run (Figure 2). In addition to providing an accurate count of the Unalakleet River escapement, it will also provide the opportunity to collect ASL samples over the course of the run. This information can be used to track how ASL compositions change throughout the run as well as provide yearly updates on the proportional relationship between the North and Unalakleet river sub-stocks. It is strongly recommended that representative ASL samples be obtained from the North and Unalakleet river escapements in the coming years to evaluate potential differences in the two sub-stocks and to provide for more accurate brood-year return estimates.

Inseason management of the Chinook salmon fisheries is currently linked to North River escapement goals and tower counts. However, the significant lag time between the test net fishery/subsistence fishery and the counting tower combined with the compressed nature of the runs (Tables 2, 3, and 4; Figures 6 and 7) means that half of the run has migrated through the marine and lower river fisheries before fish have begun to pass the North River counting tower. Inseason management can thus be challenging and frustrating for both ADF&G and fishers alike. Timelier escapement monitoring is not expected from the Unalakleet River weir. Unfortunately, even though the Unalakleet River sub-stock appears to exhibit an earlier run-timing pattern than the North River sub-stock, the actual difference was insignificant for all testable metrics (Figure 6). In other words, the weir project will not provide timelier escapement information because the run-timing patterns between the two sub-stocks are more similar than different.

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APPENDIX A: TESTS TO DETECT VIOLATIONS OF MARK–RECAPTURE ASSUMPTIONS

Appendix A1.–Detection of size- or sex-selective sampling during a 2-sample mark–recapture experiment and its effects on estimation of population size and population composition.

Size-selective sampling: The Kolmogorov-Smirnov 2-sample test (Conover 1980) is used to detect significant evidence that size-selective sampling occurred during the first or second sampling events. The second sampling event is evaluated by comparing the length frequency distribution of all fish marked during the first event (*M*) with that of marked fish recaptured during the second event (*R*), using the null test hypothesis of no difference. The first sampling event is evaluated by comparing the length frequency distribution of all fish inspected for marks during the second event (*C*) with that of R. A third test, comparing M and C, is conducted and used to evaluate the results of the first two tests when sample sizes are small. Guidelines for small sample sizes are < 30 for *R* and < 100 for *M* or *C*.

Sex-selective sampling: Contingency table analysis (Chi^2-test) is generally used to detect significant evidence that sex-selective sampling occurred during the first or second sampling events. The counts of observed males to females are compared between M&R, C&R, and M&C as described above, using the null hypothesis that the probability that a sampled fish is male or female is independent of sample. When the proportions by gender are estimated for a sample (usually *C*), rather than observed for all fish in the sample, contingency table analysis is not appropriate and the proportions of females (or males) are compared between samples using a 2-sample test (e.g., Student's *t*-test).

M vs. R	**C vs. R**	**M vs. C**
Case I:		
Fail to reject H_o	Fail to reject H_o	Fail to reject H_o

There is no size/sex selectivity detected during either sampling event.

Case II:		
Reject H_o	Fail to reject H_o	Reject H_o

There is no size/sex selectivity detected during the first event, but there is during the second event sampling.

Case III:		
Fail to reject H_o	Reject H_o	Reject H_o

There is no size/sex selectivity detected during the second event, but there is during the first event sampling.

Case IV:		
Reject H_o	Reject H_o	Reject H_o

There is size/sex selectivity detected during both the first and second sampling events.

Evaluation Required:		
Fail to reject H_o	Fail to reject H_o	Reject H_o

Sample sizes and powers of tests must be considered:

A. If sample sizes for M vs. R and C vs. R tests are not small and sample sizes for M vs. C test are very large, the M vs. C test is probably detecting small differences that have little potential to result in bias during estimation. *Case I* is appropriate.

B. If a) sample sizes for M vs. R are small, b) the M vs. R *p*-value is not large (~0.20 or less), and c) the C vs. R sample sizes are not small and/or the C vs. R *p*-value is fairly large (~0.30 or more), the rejection of the null in the M vs. C test was probably the result of size/sex selectivity during the second event that the M vs. R test was not powerful enough to detect. *Case I* may be considered but *Case II* is the recommended, conservative interpretation.

-continued-

C. If a) sample sizes for C vs. R are small, b) the C vs. R *p*-value is not large (~0.20 or less), and c) the M vs. R sample sizes are not small and/or the M vs. R *p*-value is fairly large (~0.30 or more), the rejection of the null in the M vs. C test was probably the result of size/sex selectivity during the first event that the C vs. R test was not powerful enough to detect. *Case I* may be considered but *Case III* is the recommended, conservative interpretation.

D. If a) sample sizes for C vs. R and M vs. R are both small, and b) both the C vs. R and M vs. R *p*-values are not large (~0.20 or less), the rejection of the null in the M vs. C test may be the result of size/sex selectivity during both events that the C vs. R and M vs. R tests were not powerful enough to detect. *Cases I, II, or III* may be considered but *Case IV* is the recommended, conservative interpretation.

Case I. Abundance is calculated using a Petersen-type model from the entire data set without stratification. Composition parameters may be estimated after pooling length, sex, and age data from both sampling events.

Case II. Abundance is calculated using a Petersen-type model from the entire data set without stratification. Composition parameters may be estimated using length, sex, and age data from the first sampling event without stratification. If composition is estimated from second event data or after pooling both sampling events, data must first be stratified to eliminate variability in capture probability (detected by the M vs. R test) within strata. Composition parameters are estimated within strata, and abundance for each stratum needs to be estimated using a Petersen-type formula. Overall composition parameters are estimated by combining stratum estimates weighted by estimated stratum abundance according to the formulae below.

Case III. Abundance is calculated using a Petersen-type model from the entire data set without stratification. Composition parameters may be estimated using length, sex, and age data from the second sampling event without stratification. If composition is estimated from first event data or after pooling both sampling events, data must first be stratified to eliminate variability in capture probability (detected by the C vs. R test) within strata. Composition parameters are estimated within strata, and abundance for each stratum needs to be estimated using a Petersen-type formula. Overall composition parameters are estimated by combining stratum estimates weighted by estimated stratum abundance according to the formulae below.

Case IV. Data must be stratified to eliminate variability in capture probability within strata for at least one or both sampling events. Abundance is calculated using a Petersen-type model for each stratum, and estimates are summed across strata to estimate overall abundance. Composition parameters may be estimated within the strata as determined above, but only using data from sampling events where stratification has eliminated variability in capture probabilities within strata. If data from both sampling events are to be used, further stratification may be necessary to meet the condition of capture homogeneity within strata for both events. Overall composition parameters are estimated by combining stratum estimates weighted by estimated stratum abundance.

If stratification by sex or length is necessary prior to estimating composition parameters, an overall composition parameter (p_k) is estimated by combining within stratum composition estimates using:

$$\hat{p}_k = \sum_{i=1}^{j} \frac{\hat{N}_i}{\hat{N}_\Sigma} \hat{p}_{ik} \text{, and} \tag{1}$$

$$\hat{V}[\hat{p}_k] \approx \frac{1}{\hat{N}_\Sigma^2} \left(\sum_{i=1}^{j} \hat{N}_i^2 \hat{V}[\hat{p}_{ik}] + \left(\hat{p}_{ik} - \hat{p}_k \right)^2 \hat{V}[\hat{N}_i] \right) \tag{2}$$

where: j = the number of sex/size strata;

$\hat{p}_{ik}$ = the estimated proportion of fish that were age or size k among fish in stratum i;

$\hat{N}_i$ = the estimated abundance in stratum i; and

$\hat{N}_\Sigma$ = sum of the $\hat{N}_i$ across strata.

Appendix A2.-Tests of consistency for the Petersen estimator (from Seber 1982, page 438).

Tests of consistency for Petersen estimator

Of the following conditions, at least one must be fulfilled to meet assumptions of a Petersen estimator:

1. Marked fish mix completely with unmarked fish between events;
2. Every fish has an equal probability of being captured and marked during event 1; or
3. Every fish has an equal probability of being captured and examined during event 2.

To evaluate these three assumptions, the chi-square statistic will be used to examine the following contingency tables as recommended by Seber (1982). At least one null hypothesis needs to be accepted for assumptions of the Petersen model (Bailey 1951, 1952; Chapman 1951) to be valid. If all three tests are rejected, a temporally or geographically stratified estimator (Darroch 1961) should be used to estimate abundance.

I.–Test for complete mixing[a]

Area/Time	Area/Time Where Recaptured				Not Recaptured
Where Marked	1	2	…	t	(n_1-m_2)
1					
2					
…					
s					

II.–Test for equal probability of capture during the first event[b]

	Area/Time Where Examined			
	1	2	…	t
Marked (m_2)				
Unmarked (n_2-m_2)				

III.–Test for equal probability of capture during the second event[c]

	Area/Time Where Marked			
	1	2	…	s
Recaptured (m_2)				
Not Recaptured (n_1-m_2)				

[a] This tests the hypothesis that movement probabilities (θ) from time or area i (i = 1, 2, ...s) to section j (j = 1, 2, ...t) are the same among sections: H_0: $\theta_{ij} = \theta_j$.

[b] This tests the hypothesis of homogeneity on the columns of the 2-by-t contingency table with respect to the marked to unmarked ratio among time or area designations: H_0: $\Sigma_i a_i\theta_{ij} = kU_j$, where k = total marks released/total unmarked in the population, U_j = total unmarked fish in stratum j at the time of sampling, and a_i = number of marked fish released in stratum i.

[c] This tests the hypothesis of homogeneity on the columns of this 2-by-s contingency table with respect to recapture probabilities among time or area designations: H_0: $\Sigma_j\theta_{ij}p_j = d$, where p_j is the probability of capturing a fish in section j during the second event, and d is a constant.

APPENDIX B: DATA FILES

Appendix B1.–Data files used to estimate parameters of the Chinook salmon abundance and length, age, and sex distributions in the Unalakleet River drainage, 2009.

Data File	Description
Abundance Estimate_UnkChinook2009.xls [a]	Excel spreadsheet with finalized population parameters and estimates.
Chinook_Tracking_09.xls [a]	Excel spreadsheet with consolidated data on all radiotagged Chinook, including calculations used in Chapman estimates.
UnkChinook_masterdata_2009.xls [a]	Excel spreadsheet with raw data on all captured and sampled Chinook in the Unalakleet River drainage in 2009, including data from upriver sampling occasions.

[a] Data files have been archived at the Alaska Department of Fish and Game, Research and Technical Services, Anchorage, Alaska 99518. They are also available from the authors, Division of Sport Fish, 1300 College Road, Fairbanks, AK 99701.